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Teaching & Researching Big History: Exploring a New Scholarly Field

Leonid E Grinin, David Baker, Esther Quaedackers, Andrey Korotayev

To cite this version:

Leonid E Grinin, David Baker, Esther Quaedackers, Andrey Korotayev (Dir.). Teaching & Researching Big History: Exploring a New Scholarly Field. Uchitel, pp.368, 2014, Grinin, Leonid, 978-5-7057-4027-7. hprints-01861224

HAL Id: hprints-01861224

https://hal-hprints.archives-ouvertes.fr/hprints-01861224

Submitted on 24 Aug 2018

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Teaching & Researching BIG HISTORY:

EXPLORING A NEW SCHOLARLY FIELD

INTERNATIONAL BIG HISTORY ASSOCIATION

RUSSIAN ACADEMY OF SCIENCES
INSTITUTE OF ORIENTAL STUDIES
The Eurasian Center for Big History and System Forecasting

TEACHING & RESEARCHING BIG HISTORY:
EXPLORING A NEW SCHOLARLY FIELD

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'Uchitel'
Publishing House
Volgograd

ББК 28.02 87.21

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Teaching & Researching Big History: Exploring a New Scholarly Field / Edited by Leonid E. Grinin, David Baker, Esther Quaedackers, and Andrey V. Korotayev. – Volgograd: 'Uchitel' Publishing House, 2014. – 368 pp.

According to the working definition of the International Big History Association, 'Big History seeks to understand the integrated history of the Cosmos, Earth, Life and Humanity, using the best available empirical evidence and scholarly methods'. In recent years Big History has been developing very fast indeed. Big History courses are taught in the schools and universities of several dozen countries. Hundreds of researchers are involved in studying and teaching Big History. The unique approach of Big History, the interdisciplinary genre of history that deals with the grand narrative of 13.8 billion years, has opened up a vast amount of research agendas. Big History brings together constantly updated information from the scientific disciplines and merges it with the contemplative realms of philosophy and the humanities. It also provides a connection between the past, present, and future. Big History is a colossal and extremely heterogeneous field of research encompassing all the forms of existence and all timescales. Unsurprisingly, Big History may be presented in very different aspects and facets. In this volume the Big History is presented and discussed in three different ways. In its first part, Big History is explored in terms of methodology, theories of knowledge, as well as showcasing the personal approach of scholars to Big History. The second section comprises such articles that could clarify Big History's main trends and laws. The third part of this book explores the nature of teaching Big History as well as profiling a number of educational methods.

This volume will be useful both for those who study interdisciplinary macroproblems and for specialists working in focused directions, as well as for those who are interested in evolutionary issues of Astrophysics, Geology, Biology, History, Anthropology, Linguistics and other areas of study.

'Uchitel' Publishing House
143 Kirova St.,
400079 Volgograd,
Russia

ISBN 978-5-7057-4027-7

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Introduction

Big History's Big Potential

Leonid E. Grinin, David Baker,
Esther Quaedackers, and Andrey V. Korotayev

Big History has been developing very fast indeed. We are currently observing a 'Cambrian explosion' in terms of its popularity and diffusion. Big History courses are taught in the schools and universities of several dozen countries, including China, Korea, the Netherlands, the USA, India, Russia, Japan, Australia, Great Britain, Germany, and many more. The International Big History Association (IBHA) is gaining momentum in its projects and membership. Conferences are beginning to be held regularly (this edited volume has been prepared on the basis of the proceedings of the International Big History Association Inaugural Conference [see below for details]). Hundreds of researchers are involved in studying and teaching Big History.

What is Big History? And why is it becoming so popular? According to the working definition of the IBHA, 'Big History seeks to understand the integrated history of the Cosmos, Earth, Life and Humanity, using the best available empirical evidence and scholarly methods'.

The need to see this process of development holistically, in its origins and growing complexity, is fundamental to what drives not only science but also the human imagination. This shared vision of the grand narrative is one of the most effective ways to conceptualize and integrate our growing knowledge of the Universe, society, and human thought. Moreover, without using 'mega-paradigms' like Big History, scientists working in different fields may run the risk of losing sight of how each other's tireless work connects and contributes to their own.

Scientific specialization and the immense amounts of information contained in the various 'silos' of academia can hinder our capacity for inclusiveness, but, paradoxically, it also amplifies the need for it. Many scientists would like a more integrated vision that sees beyond their meticulous and complicated fields of specialization. One can see the growth of such interest in the framework of individual disciplines, as well as in interdisciplinary research. Yet, while interdisciplinarity is not

a new idea, many disciplines can run the disappointing tendency of only paying lip-service to it. This is not possible in Big History. In a discipline that *starts* by weaving together all the disciplines into a single narrative, interdisciplinary work is not only possible, it is essential. A unification of disciplines, a deep symbiosis of academic cells, will open up research areas that are vital to the development of the twenty-first century thought and culture. As has been mentioned on a number of occasions, the rapidly globalizing world needs global knowledge that explains a unified global system (see Grinin, Korotayev, Carneiro, and Spier 2011; Grinin and Korotayev 2009). Indeed, globalization itself becomes a vehicle for Big History. The very existence of the International Big History Association is proof of that.

Big History ideas did not appear out of nowhere. They have deep roots in human spirituality, philosophy, and science. In the nineteenth and twentieth centuries, there was an explosive growth of scientific knowledge accompanied by a deep differentiation of disciplines. This made borders between scholars and scientists much more rigid, while research specialization grew by an order of magnitude. As Erwin Schrödinger justly noted: '[I]t has become next to impossible for a single mind fully to command more than a small specialized portion of it'. However, he continued, there is 'no other escape from this dilemma (lest our true aim be lost forever) than that some of us should venture to embark on a synthesis of facts and theories' (Schrödinger 1944: 1). As disintegration peaked in the twentieth century, such undertakings were not mentioned as often as they ought to have been. When an interdisciplinary synthesis was mentioned at all, it was seen as a lofty goal, the barest whisper of a dream, rather than an approachable reality.

A very different picture appears if we look further back in the history of human thought. From the very moment of their emergence, grand unified theories of existence tended to become global. Even the Abrahamic theological tradition, that was dominant in the western half of the Afroeurasian world-system in the Late Ancient and Medieval periods, contains a sort of proto-Big History. It presents a unified vision of the Universe's origin, development, and future. In that grand narrative, the Universe has a single point of creation and it develops according to a divine plan. Similarly, classical Indian religious philosophy loosely resembles the principle of the unity of the world through the idea of reincarnation, in a Hindu approximation of the First Law of Thermodynamics. Even the delusions of astrologers and alchemists contained the idea of universal interconnectedness (stars and planets affect human

fates; everything can be transformed into everything else). This is only a fragment of the pre-modern ideas that contained elements of Big History thinking. Many interesting insights on the properties of the Universe can be found in pre-scientific worldviews generated by various human civilizations.

Ancient philosophy even aspired to find the single principle cause for everything that exists.[1] This was done in a very insightful way in the works of the ancient Greeks, who were especially interested in the origins and nature of the Universe. Note that even while Greek (and, more generally, classical) philosophy concentrated on ethical or aesthetic issues, it was still dominated by the idea of the single law of *Logos* that governed the whole Universe, with many different interpretations of it provided by various thinkers. This was reinforced by the concept of a 'cosmic circulation' that also influenced human society. Medieval philosophy inherited the Greek tradition 'to comprehend the universe on the basis of archetypal principles … as well as the inclination to detect clarifying universals in the chaos of the life' (Tarnas 1991: 3–5).

The transition from the geocentric (Ptolemaic) to the heliocentric (Copernican) perspective took many centuries notwithstanding all the brilliant conjectures of Giordano Bruno (1548–1600). Discoveries by Johannes Kepler (1571–1630), Galileo Galilei (1564–1642), and Isaac Newton (1643–1727) produced a majestic vision of the Universe. For the first time in history, a more advanced form of Big History thinking was produced – not by the speculations of philosophers or theologians but on the basis of corroborated facts and mathematically formulated laws of Nature. 'Mechanicism' became the dominant paradigm in the western scientific thought (including the social sciences). Thus the formation of a unified scientific worldview was consolidated. 'Natural philosophy', the precursor term for science, investigated everything from the highly cosmological to the deeply sociological and continued to preserve its dominant position in the eighteenth century: the age of the Enlightenment (see Barg 1987; Grinin 2012 for more details).

However, new ideas stressing historical variability soon emerged. Those ideas and discoveries led to a crisis of the dominant scientific paradigm. In geology, Georges-Louis Leclerc, Comte de Buffon, systematized all the known empirical data and analyzed a number of important theo-

[1] In particular, in the classical Indian philosophy one finds the belief in the 'eternal moral order' of the Universe as well as ideas of the collossality of the world space and time, infinity of the Universe comprising millions of such worlds as our Earth (see, *e.g.*, Chatterjee and Datta 1954).

retical issues of the development of the Earth and its surface. He also produced a few insights that turned out to be important for the development of the theory of biological evolution. The hypothesis of the emergence of the Solar System from a gas nebula was first spelled out by philosopher Immanuel Kant and later by mathematician and astronomer Pierre-Simon Laplace in one of the notes to his multivolume *Mécanique Céleste* (1799–1825).

Some of the philosophical roots of evolutionary ideas are very old indeed, and scientifically based evolutionary ideas first emerged in the seventeenth and eighteenth centuries. But the idea of universal evolution only became really influential in the nineteenth century. The first major evolutionary theory in biology was produced by Jean-Baptiste Lamarck (1744–1829), who advocated change via acquired traits. Another no less evolutionary theory was formulated in geology by Charles Lyell (1797–1875) who, in his *Principles of Geology* (1830–1833), refuted the theory of catastrophism.

It is no coincidence that the first narratives beginning to resemble modern Big Histories first emerged around that time. The first real concerted and conscious attempt to unify the story of the physical processes of the Universe to the dynamics of human society was made by Alexander von Humboldt (1769–1859), a Prussian natural philosopher, who set out to write *Kosmos* (1845–1859), but died before he could complete it. Also, Robert Chambers anonymously published the *Vestiges of the Natural History of Creation* in 1844. His book began with the inception of the Universe in a fiery mist and ended with a history of humanity.

In the second half of the nineteenth century, the concept of evolution by natural selection as pioneered by Charles Darwin (1859) and Alfred Russel Wallace (1858) merged with the idea of social progress espoused by Herbert Spencer (1857, 1862, 1896) and became a major influence on western thought. The idea of evolution/progress as a transition from less to more complex systems dramatically transformed the human worldview.[2] It became known that stars and planets, including the Sun and the Earth, are objects that have their origin, history, and end. There was a great deal of indication that revolutionary changes in astronomy were forthcoming.

Two discoveries produced the most important contribution to the emergence of Big History. First, the interpretation of the redshift by

[2] Note that although Spencer paid more attention to biological and social evolution, he treated evolution as a universal process taking place at all possible levels – from microorganisms to galaxies.

Edwin Hubble in the 1920s demonstrated that the Universe is not static and eternal, but is in a general state of expansion, as if it began with a primordial 'explosion'. By the 1940s, interacting teams of physicists and astronomers from around the world speculated on the existence of left-over radiation from this event – cosmic microwave background radiation. This radiation was detected in 1964 by Arno Penzias and Robert Wilson and provides the most convincing observational evidence for the explosive beginning of our Universe, which in the late 1940s George Gamow and Fred Hoyle called the 'Big Bang'. The simple epithet became useful for the theory's supporters. Moreover, the emergence of *historical* evidence for a point of origin of the Universe established a sense of chronology and transformed astrophysics into a historical science. The door firmly swung open for scholars of all shades to produce a universal history, called, to use our own simple epithet, 'Big History'.

By the last decades of the twentieth century, it became clear that the natural sciences contained a clear narrative from the Big Bang to modern day and this unity began to find expression in an increasing number of written works. For the first time it was actually possible for the mainstream to grasp the entire chronology.[3] This began the process of thinking about both natural and human history as part of the unified whole. In 1980, astrophysicist Eric Jantsch wrote *The Self-Organizing Universe* (Jantsch 1980), now sadly out of print, which tied together all universal entities into a collection of processes. It constitutes the first modern unifying Big History. Jantsch did a credible job of examining human history as an extension of cosmic evolution and as just one of many structures operating beyond thermodynamic equilibrium. Jantsch's work constitutes the first attempt to find a common strand or dynamic that streamlines, unites, and underwrites the entire grand narrative. It is thus possible to explore history from the Big Bang to modern day without being weighed down by the scale of the chronology.

Around the same time American-based astrophysicists, geologists, and biologists such as Preston Cloud, Siegfried Kutter, George Field, and Eric Chaisson began writing and teaching courses about the cosmic story. Then, at the end of the 1980s, history and psychology professors like David Christian in Sydney, John Mears in Dallas, and Akop Nazaretyan in Moscow[4] began to craft grand narratives that incorporated

[3] A phenomenon best discussed in David Christian's 'The Evolutionary Epic and the Chronometric Revolution' (2009).

[4] For more details on the Russian Big History tradition see Nazaretyan 2011.

the human story more seamlessly into a larger universal narrative. Fred Spier did the same at Amsterdam and Eindhoven. From here, a Cambrian-style explosion of courses and works has occurred.[5]

Eric Chaisson's *Cosmic Evolution* (2001) defines the unifying theme of Big History as the rise of complexity. Chaisson even proposed a way of objectively measuring this trend. Free energy rate density is the energy per second that flows through an amount of mass. In this way Chaisson empirically established that complexity has been rising in the Universe for 13.8 billion years. The theme of rising complexity was incorporated into David Christian's *Maps of Time* (2004) which further employed it in the human tale. The book also coincided with John and William McNeill's *The Human Web* (2003) and went back further to the beginning of time, for which William McNeill (somewhat superlatively and, one hopes, humorously) compared himself to John the Baptist and David Christian to Jesus of Nazareth for historicizing the natural sciences. Fred Spier, most recently in his book, *Big History and the Future of Humanity* (2010), has emphasized the Goldilocks principle, and how the rise of complexity occurs when conditions like temperature, pressure, and radiation are 'just right' for the rise of complexity to occur. Spier asserts that the rise of complexity combined with energy flows and the Goldilocks principle form the beginnings of an overarching theory of Big History.

The unique approach of Big History, the interdisciplinary genre of history that deals with the grand narrative of 13.8 billion years, has opened up vast research agendas. Or, to engage an evolutionary metaphor, it has triggered a scholarly speciation event where hundreds of new niches have opened up waiting to be filled. The ecological terrain is vast and the numbers that currently populate it are few. The research comes in a variety of forms. We, big historians, must collaborate very closely to pursue this vibrant new field. Our world is immensely diverse and unlimited in its manifestations. However, fundamentally it is one world – that is why it is so important to study those fundamentals.

Hence the International Big History Association was formed on 20 August 2010, at the Geological Observatory at Coldigioco in Italy.

[5] For recent survey of size and of the field see Rodrigue, Stasko 2009; and the canon of seminal works includes but is not confined to Fred Spier's *The Structure of Big History: From the Big Bang until Today* (1996), David Christian's *Maps of Time: An Introduction to Big History* (2004), Eric Chaisson's *Epic of Evolution: Seven Ages of the Cosmos* (2006), Cynthia Stokes Brown's *Big History: From the Big Bang to the Present* (2007), and *Evolution: A Big History Perspective* (Grinin, Korotayev, and Rodrigue 2011).

Subsequently, there was some tireless work involved in arranging the first conference in Grand Rapids, Michigan, in August 2012. Anyone who attended the first conference could not help but feel a little encouraged. We established a fraternity of researchers and educators from every corner of the globe. Numerous presentations were given on a diverse range of projects and we were given demonstrations of Chronozoom and the Big History Project. There is, however, a long road ahead of us as a discipline. One of the most important tasks of big historians in the coming years is to prove that Big History can sustain a wide number of empirically rigorous and truly interdisciplinary research projects. These conference proceedings are a sample made by the IBHA Publications Committee of the excellent work done on the many dynamics of the grand narrative and the best methods of teaching it.

STRUCTURE AND SECTIONS

Big History brings together constantly updated information from the scientific disciplines and merges it with the contemplative realms of philosophy and the humanities. It also provides a connection between the past, present, and future. Big History is a colossal and extremely heterogeneous field of research encompassing all the forms of existence and all timescales. Unsurprisingly, Big History may be presented in very different aspects and facets. One way of dividing it is 1) methodology and the theory of knowledge, 2) ontological aspects, and 3) pedagogy. This volume is consequently structured in the following way:

– **Section 1. Understanding and Explaining Big History** in which Big History is explored in terms of methodology, theories of knowledge, as well as showcasing the personal approach of scholars to Big History.

– **Section 2. Big History's Phases, Regularities, and Dimensions** is connected with ontological aspects. A mental dissection of the whole into its parts is one of the most important tools of scientific cognition.

– **Section 3. Teaching Big History** explores the nature of teaching Big History as well as profiling a number of educational methods.

The first section of the volume stresses the unity of Big History. The second section comprises the articles that could clarify Big History's main trends and laws. The third section shows how that scholarly knowledge is transformed to the benefit of future generations. Naturally, in a field as interwoven as Big History, there is some overlap in the ideas and arguments contained in all three of these sections.

1. Understanding and Explaining Big History

David Christian's *Swimming Upstream: Universal Darwinism and Human History* shows how the patterns in cosmic, quantum, and biological evolution are connected to cultural evolution, especially in relation to his concept of Collective Learning. David Baker's *Standing on the Shoulders of Giants: Collective Learning as a Key Concept in Big History* presents research on the evolutionary history of Collective Learning in hominines, its role in the history of agrarian civilizations, and explains how this form of Universal Darwinism is deeply connected to the wider rise of complexity in the Universe. Lowell Gustafson's highly entertaining *From Particles to Politics* bestows a new perspective on the entire grand narrative through the lens of a political scientist and with the use of political metaphors for a variety of physical processes, showing the 'body politic' of everything from atoms to apes. Esther Quaedackers' *To See the World in a Building: A Little Big History of Tiananmen* explores how the history of one single thing can reflect back the many physical processes of Big History and how Little Big Histories can be used as a fertile research agenda for scholars of any discipline. Esther Quaedackers invented Little Big Histories in 2007 and the concept has since been adopted by the Big History Project and also forms the basis for each episode of H2's *Big History* series. Sun Yue's *Chinese Traditions and Big History* outlines some of the challenges for Big History in the world's most populous nation and also compares some of the key features of cosmic evolution to strikingly similar ones found in traditional Chinese philosophy. Ken Gilbert's *The Universal Breakthroughs of Big History: Developing an Unified Theory* explores how the concept of 'thresholds', as seen through a Gouldian framework, could potentially lead to an overarching theory of Big History that unites cosmology, biology, and human history. Ekaterina Sazhienko's *Future of Global Civilization: Commentary of Big Historians* compiles data from interviews with various people connected to Big History about the prospects for humanity and the future of complexity. The work touches on opinions of big historians about many areas of the grand narrative and uses them to take on the brave, if idealistic, task of figuring out what should be done to address the most crippling problems of the twenty-first century.

2. Big History's Phases, Regularities, and Dimensions

Leonid Grinin's *The Star-Galaxy Era of Big History in the Light of Universal Evolutionary Principles* is an in-depth view of how Universal Darwinism operates in the stelliferous section of the grand narrative. A startling

number of similarities occur at this level, resembling both biological and cultural evolution and governing the life and death of stars – without which further evolutionary processes and the rise of complexity would be impossible. Andrey Korotayev and Alexander Markov's *Mathematical Modeling of Biological and Social Phases of Big History* explores how macropatterns of evolution are similar at both the biological and social phases, and goes even further to explain how these processes can be charted and effectively described by mathematical models. Ken Baskin's *The Dynamics of Evolution: What Complexity Theory Suggests for Big History's Approach to Biological and Cultural Evolution* examines complexity dynamics through the lens of cultural evolution and punctuated equilibrium. Abel Alves' *The Animals of the Spanish Empire: Humans and Other Animals in Big History* is a historian's take on the similarities between animal and human behavior, contrasting the realms of biology and human history, that also tests the hypothesis that humans are 'chimpanzees who would be ants'. It is a remarkable take on conventionally human history and a fresh insight into our relationship with nature. Craig Benjamin's *Big History, Collective Learning and the Silk Roads* explores how in the era of agrarian civilizations human societies across Afroeurasia did not live in isolation. From the rise of the first states to the age of exploration, collective learning operated along the silk roads, spurring along human innovations and connecting the continents of Africa, Europe, and Asia into the largest of the 'world systems'. Barry Rodrigue's *Retrofitting the Future* takes an archaeological look at how technologies devised by humans in the earliest agrarian villages and states can inform our own technological development today. Joseph Voros' brilliant *Galactic-Scale Macro-engineering: Looking for Signs of Other Intelligent Species, as an Exercise in Hope for Our Own* deals with the most daunting of all Big History periods: the future. A respected physicist and futurist, the author looks at possible avenues for the further rise of culturally-generated complexity, how civilizations could harness the power of stars and even galaxies, and the telltale signs that such large scale complexity would exhibit in the night's sky.

3. Teaching Big History

Michael and D'Neil Duffy's *Big History and Elementary Education* discusses methods on how Big History can be extended from university and high school curricula to be taught to elementary students, particularly in a Montessori framework. They have devised a course progression through which young minds can travel through all the thresholds of the grand narrative. Tracy Sullivan's *Big History and the Secondary Classroom:*

A Twenty-First Century Approach to Interdisciplinarity? involves the experience the author has had teaching Big History to high school students and also developing the Big History Project. She uses her knowledge to explore pedagogical questions about how modern educators all over the world will define and improve their curricula in the rest of this century. Cynthia Stokes Brown's *Constructing a Survey Big History Course* takes her experiences in teaching Big History at a university level and gives some careful and direct advice to university lecturers who are considering setting up a course of their own. John Fowler's *Cosmology, Mythology, and the Timeline of Light* explores how to best capture the imaginations of 11 and 12 year old elementary students to impart on them an all-encompassing knowledge of the long story of existence from the Big Bang to modern day. Lastly, Jonathon Cleland Host's *Big History Beads: A Flexible Pedagogical Method* demonstrates a fun way that students of many ages can further reinforce their education of Big History by some simple but clever mnemonic devices.

THE FUTURE OF THE IBHA

Big History has already come a long way, and these proceedings are but a small sliver of proof that this new field already has minds churning with a thousand different ideas about how we understand and interpret the Universe. It is our hope that further work will be done in the near future, on a mounting scale, with an ever-widening network of collaborators. As a young discipline, we have enjoyed advantages in our early years that other young disciplines do not. The historical study of the Universe has a highly interdisciplinary and mind-blowing quality to its founding principles that embraces and inspires scholars from every background. Scientists, historians, philosophers, and more, can find a place in our ranks. And many who have heard of Big History have eagerly jumped at the chance to do so. We also benefit from the wholehearted support of prestigious and well-respected public figures like Bill Gates and Walter Alvarez.

We also enjoy the advantage of timing. At no point was a discipline that explored the connections between the natural and social sciences more relevant than now. At no time was a discipline that told the inhabitants of all nations across the globe their common story more important than in an age when travel is swift and communications are instantaneous. And never before in human history have we been so conscious of our potential in the cosmic story of rising complexity and so conscious of the perils threatening to reduce that potential to ruins and

ashes. The timing is not a coincidence. We are currently in the middle of a cultural revolution unprecedented in the times of all our forbearers. We should not be surprised that people from many different backgrounds and nations should at once have risen up and called for a grand historical epic that unites us all.

But each member of the IBHA needs to get the word out about Big History. Too few people have yet heard of this genre, much less the full story of humanity, life, and the Universe. We need to foster a network of researchers from the sciences and humanities. Physicists, geologists, biologists, historians, philosophers, and more, need to be encouraged to pursue interdisciplinary research projects in Big History. We need support, positions, and funding for graduate students who will be the researchers and educators of Big History in the future. We need to establish an academic journal to provide incentive for more scientists and scholars to spend their time doing Big History research. We need to create large, funded, research hubs in America, Europe, Australia, and anywhere else that a university will take us, to bring together people from various disciplines to work jointly on the questions of cosmic evolution. Much depends on the reader of this volume to do his or her part in these early days, so that the words 'Big History' will one day immediately leap to mind when people talk of the cultural legacy of the twenty-first century.

Acknowledgements

The editors would like to express the deep gratitude to Elena Emanova and Kseniya Ukhova for their invaluable assistance in the process of preparation of this volume.

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I. UNDERSTANDING AND EXPLAINING BIG HISTORY

1
Swimming Upstream: Universal Darwinism and Human History*

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Abstract

This essay discusses Universal Darwinism: the idea that Darwinian mechanisms can explain interesting evolutionary change in many different domains, in both the Humanities and the Natural Sciences. The idea should appeal to big historians because it links research into evolutionary change at many different scales. But the detailed workings of Universal Darwinism vary as it drives different vehicles, just as internal combustion engines differ in chain-saws, motor cycles and airplane engines. To extend Darwin's ideas beyond the biological realm, we must disentangle the biological version of the Darwinian mechanism from several other forms. I will focus particularly on Universal Darwinism as a form of learning, a way of accumulating information. This will make it easier to make the adjustments needed to explore Darwinian mechanisms in human history.

Keywords: *Universal Darwinism, collective learning, information, Big History.*

> Countlessness of livestories have netherfallen by this plage, flick as flowflakes, litters from aloft, like a waast wizard all of whirlworlds. Now are all tombed to the mound, isges to isges, erde from erde.
>
> *Finnegans Wake*, Ch. 1

James Joyce's strange masterpiece, *Finnegans Wake,* is fractal. You can read it at many different scales, but you always have the eerie feeling that you are hearing a story you have already heard somewhere else. A mathematician might say the stories are 'self-similar'. You may think

* My thanks to David Baker, Billy Grassie, Nick Doumanis, Ji-Hyung Cho, and Seohyung Kim for reading suggestions and comments on earlier versions of this paper.

you are reading about the wake for a drunken bricklayer who fell to his death from a ladder; but you are actually reading about the fall of humanity and the expulsion from Paradise; and then again the story is *really* about Dublin and the many rises and falls of that city's history, people and landscapes. Something similar happens in the emerging discipline of Big History (see Christian 2004, 2010). Big History surveys the past at the scales of cosmology, physics, geology, biology and human history. Each discipline tells its own story, but as you get to know the stories, they start to overlap, and we begin to see each discipline refracted in the others. Like *Finnegans Wake*, Big History is 'self-similar'. And like *Finnegans Wake,* Big History derives much of its power from the synergies that arise when you glimpse unexpected connections across different scales and domains.

This paper explores one of these fractal phenomena: 'Universal Darwinism'. In biology, the Darwinian paradigm describes a distinctive form of evolutionary change that generates adaptive change through repeated copying of selected variants. Universal Darwinism is the idea that similar mechanisms may also work in many other domains. If so, do they always work as they do in biology? Or can we distinguish between a core machinery and the modifications needed to drive it in different environments?

Universal Darwinism

Richard Dawkins coined the phrase 'Universal Darwinism' in an essay published in 1983. If we find life beyond this earth, he argued, it will surely evolve by 'the principles of Darwinism' (Dawkins 1983: 403). But there will also be differences. For example, the replicators may not be genes. Dawkins suggested that human culture might offer an example in the 'meme', an idea or cultural artifact such as a song or fashion that varies, that replicates through imitation, that travels in sound or images, and colonizes human minds when selected from a population of rival artifacts (on meme theory see Blackmore 1999). More generally, he suggested that, 'Whenever conditions arise in which a new kind of replicator *can* make copies of itself, the new replicators *will* tend to take over, and start a new kind of evolution of their own' (Dawkins 2006: 193–194).

Universal Darwinism treats natural selection as one member of a family of evolutionary machines that generate adaptive change through repetitive, algorithmic processes. Always we see variation, selection and replication. Some variations are selected, then copied and preserved with slight modifications, after which the process repeats again and again.

Here is a description of the basic machinery by a physicist, Lee Smolin,

> To apply natural selection to a population, there must be:
> • a space of parameters for each entity, such as the genes or the phenotypes;
> • a mechanism of reproduction;
> • a mechanism for those parameters to change, but slightly, from parent to child;
> • differentiation, in that reproductive success strongly depends on the parameters (Smolin 2005: 34).

And here, to illustrate slight variations in our understanding of the basic machinery, is a description by a psychologist, Susan Blackmore:

> Darwin's argument requires three main features: variation, selection and retention (or heredity). That is, first there must be variation so that not all creatures are identical. Second, there must be an environment in which not all the creatures can survive and some varieties do better than others. Third, there must be some process by which offspring inherit characteristics from their parents. If all these three are in place then any characteristics that are positively useful for survival in that environment must tend to increase (Blackmore 1999: 10–11).

Repeated many times, these simple rules yield interesting evolutionary change. Variation creates diversity, but by selecting some variations over others you steer diversification in a particular direction. You ensure that surviving variations will fit the environment that selected them, so they will be 'adapted'. In this way, the Darwinian machinery steers change away from the random mush ordained by entropy and the second law of thermodynamics. And if by chance some selected variants are slightly more complex than others, then we have, in Universal Darwinism, a way of increasing complexity. Indeed, Lee Smolin argues that natural selection provides the *only* scientific way to explain how complexity can increase against the tide of entropy (Smolin 2005: 34). (As I write this paper, I watch myself selecting some ideas, words and metaphors, and rejecting others; and I know that eventually the paper itself will have to take its chances in a competitive world populated by many other academic papers.)

So powerfully does the Darwinian machinery steer biological change that many find it hard to avoid imagining that there must be a designer. Surely, organs as beautifully designed as wings or brains must

have been, well, designed! Yet natural selection needs no cosmic project manager. This is what Daniel Dennett called 'Darwin's Dangerous Idea': operating without purpose, the Darwinian algorithm creates the appearance of purposefulness (Dennett 1995). From camels to chameleons, species fit their environments so precisely that they seem to transcend the laws of entropy. Yet they need no teleology and no driver. Darwin's ideas threatened theism because they explained the appearance of direction without needing a divine director (*Ibid.*).

Even in Darwin's time, some wondered if the same machinery could work outside the domain of biology. In a section on language in Chapter 3 of *The Descent of Man,* Darwin wondered if languages evolved like living organisms. After all, he noted, languages vary, they are reproduced, and their components – words, grammatical forms and even particular languages – are subject to selection for their 'inherent virtue'. Darwin concluded that, 'The survival or preservation of certain favoured words in the struggle for existence is natural selection' (Darwin 1989: 95). Darwin's friend, Thomas H. Huxley, suggested that there might be evolutionary competition between different bodily organs, while William James extended the idea of evolution to learning in general (Plotkin 1994: 61–64).

But it was in biology that Darwin's ideas really triumphed. In the 1930s and 1940s, several lines of research converged in the 'neo-Darwinian synthesis', which fixed several weaknesses in Darwin's original theory. For example, Darwin assumed that inheritance was blended, an idea that threatened to eliminate successful variations by driving all variation towards a mean; Darwin also feared that natural selection worked too slowly to generate today's biodiversity, particularly on a planet he believed to be less than 100 million years old. The neo-Darwinian synthesis used the work of Gregor Mendel to show that inheritance works not by blending but by copying discrete alleles. August Weismann showed the importance of distinguishing between phenotype and genotype, between characteristics acquired during an organism's lifetime, and those inherited through the germ line, which ruled out intentional or 'Lamarckian' forms of evolution; and this suggested that genetic mutations had to be random rather than purposeful. Finally, population geneticists such as Ronald A. Fisher and John B. S. Haldane proved mathematically that successful genes could spread fast enough to generate all the variety we see today, and geologists showed that the earth was almost 50 times older than Darwin had supposed (Mesoudi 2011: 40–51). Just as James Watt's modified steam engine made it industry's standard prime mover, so the neo-Darwinian synthesis turned Darwinism

into biology's standard explanation for biological change. The discovery of DNA and the evolution of genetic research consolidated Darwinism's paradigm role within biology.

Paradoxically, the success of the neo-Darwinian synthesis inhibited its use in other fields by creating the impression that all Darwinian machines had to be neo-Darwinian. Replicators had to be particulate; they had to be distinct from the entities in which they were tested (phenotypes or bodies); and variation had to arise randomly. Outside of biology, the neo-Darwinian model worked much less well than it did within biology. Historians and social scientists resisted Darwinian models for another reason: applied carelessly or too rigidly, they seemed to encourage Social Darwinism. The idea of Social Darwinism attracted scholarly attention after the publication of Richard Hofstadter's, *Social Darwinism in American Thought,* in 1944 (Hofstadter 1944). For Hofstadter, Social Darwinism's primary meaning was 'biologically derived social speculation'; but others associated it more closely with racist theories, though even Hofstadter had warned that '[Darwinism] was a neutral instrument, capable of supporting opposite ideologies' (Leonard 2009: 41–48). These fears helped preserve the gulf between the humanities and the natural sciences that Charles P. Snow bemoaned more than 50 years ago (Snow 1959).

In the late twentieth century, scholars in several fields returned to modified Darwinian models of change. They found them at work in immunology, in economics, in the history of science and technology, and even in cosmology, where Lee Smolin has proposed a theory of 'cosmological natural selection' (Smolin 1998; Nelson 2006; Campbell 2011). In Smolin's model, new universes are born in black holes. Information about how to construct universes resides in basic physical parameters, such as the power of gravity. Reproduction generates variation because daughter universes may inherit slightly different parameters. Variations are 'selected' and preserved because they will survive only if they generate universes complex enough to form black holes and reproduce. So cosmological natural selection does not generate a random mix of universes, but only those universes with just the parameters needed to create complexity. Our own existence proves that some universes will be complex enough to yield planetary systems, and life and creatures like us. Here we have a Darwinian explanation for the existence of a universe such as ours whose parameters seem exquisitely tuned for complexity.

Wojciech Zurek and his colleagues at the Los Alamos National Laboratory have even detected Darwinian mechanisms in quantum physics (Campbell 2011: 89ff.). When a quantum system interacts with an-

other system, perhaps by being measured in a lab, just one of its many possible outcomes is selected and launched into the world, in the process known as 'decoherence'. We have variability of the initial possibilities, a selection from those possibilities, and a copying of the selected possibilities from the quantum to the non-quantum domain. 'This Darwinian process allows a quantum system to probe its environment searching for and selecting the optimal low entropy states from all those available, thus allowing greater complexity to be discovered and survive' (*Ibid.:* 154). (The author of this paper makes no claim to understand these processes except in the most superficial way. The point is that Darwinian mechanisms may be at work even at the quantum level.)

Darwinian ideas have also returned to the humanities and social sciences, attracting the attention of anthropologists, linguists, psychologists, game theorists and some economists, political scientists and historians of technology (see Mesoudi 2011 on cultural evolution; Fitch 2010 on language origins and Nelson 2007: 74 on Darwinian models in other fields). Such explorations may get easier because the neo-Darwinian synthesis is loosening its grip within the core territory of biology. When the human genome was deciphered in 2003, it turned out that humans have far fewer genes for the manufacture of proteins than had been expected, little more than 20,000, fewer than in the rice genome. This discovery reminded biologists and geneticists that DNA is not a lone autocrat; it rules through a huge biochemical bureaucracy, whose agents often manage their ruler, as civil servants manage politicians. Mechanisms within cells control how and when the information in DNA is expressed, and occasionally they even alter DNA itself, if only to repair it. Even more striking, some of these changes seem to be hereditable. Through this modest backdoor, Lamarckian inheritance is creeping back into biological thought. In a recent survey of these changes, Jablonka and Lamb write that 'there is more to heredity than genes; some hereditary variations are nonrandom in origin; some acquired information is inherited; evolutionary change can result from instruction as well as selection' (Jablonka and Lamb 2005: 1).

These debates within biology may help us stand back from the biological form of the Darwinian machinery and see how different variants work in other realms, including human history.

Information and Universal Darwinism

Darwinian machines run on information: they replicate patterns, and that means replicating *information* about those patterns. So to under-

stand their general properties, we need the idea of information. But information is a mysterious and ghostly substance that sometimes appears to float above reality, so we must define it carefully (accessible surveys include Floridi 2010; Gleick 2011; Lloyd 2007; Seife 2007).

The idea of information presupposes the existence of differences that matter. To an antelope it matters if the animal behind the tree is a tiger or another antelope. Information reduces uncertainty by selecting one of several possible realities. This is why Donald MacKay described information as 'a distinction that makes a difference' (Floridi 2010: 23). A difference matters if other entities can detect and react to it. They may be able to detect it directly; but if not, they can often detect it indirectly, by secondary differences that correlate with the initial difference. This is where information steps in. When two differences are correlated, the second can carry a message from the first to any receiver able to interpret the message. In this way, causal chains carry potential information, whether or not there is a mind at the end of the chain. An antelope may detect a nearby lion by its shadow, and that should remove uncertainty about the danger. Run! But an electron can also be said to detect and react to a proton through its electric charge. Inserting a conscious entity into the chain simply adds one more link. It may add uncertainty, but all links do that. In this way information can travel along causal chains because we infer differences that are hard to detect from others that are easier to detect. Information is embedded in chains of cause and effect. '[It] is not a disembodied abstract entity; it is always tied to a physical representation. It is represented by an engraving on a stone tablet, a spin, a charge, a hole in a punched card, a mark on paper, or some other equivalent' (Rolf Landauer, cited in Seife 2007: 86).

When information travels through long causal chains, it can lose precision. The second, and third and fourth differences are not, after all, the same as the first. So we can judge a message by how well it represents the original difference. Faulty genes trick cells into making cancer cells, and an antelope can take a trick of the light for a tiger's shadow. But some chains transmit information more efficiently than others. As a general rule, digital or particulate information carriers detect differences better than continuous or analogue carriers, because they *have* to discriminate. That is why DNA employs genes, languages use words, and computers prefer on/off switches. Effective transmission systems can partition the smoothest of changes.

We can also judge a transmission system by the amount of information it carries. Claude Shannon, the founder of 'Information theory', showed that information increases precision by reducing uncertainty (Floridi 2010: 37ff.). You can measure the amount of information in

a message by the number of alternative realities it excludes. 'There is a tiger behind the bush' is helpful advice; it reduces uncertainty. But if a friend adds that the tiger is hungry and in a bad mood, that should eliminate any doubts you had about running away. If, from all the possible things that might have happened, a message selects a tiny, not-easily-predicted sub-set, then it eliminates a vast number of other possibilities and a huge amount of uncertainty. Each rung on a molecule of DNA can exclude three out of four possible futures; so the entire molecule, with billions of rungs, can exclude a near infinity of possible creatures. It tells you how to build just one, say, an armadillo. Not an amoeba, or an archaeopteryx, but an armadillo. In information theory, 'the amount of information conveyed by [a] message increases as the amount of uncertainty as to what message actually will be produced becomes greater' (Pierce 1980, Kindle edition, location 461).

We have seen that information does not need minds. However, words like 'meaning' make sense only when the causal chain *does* include a mind. Only then can we describe information as *semantic*. And when the information is complex it makes sense to call it knowledge. Luciano Floridi writes,

> Knowledge and information are members of the same conceptual family. What the former enjoys and the latter lacks … is the web of mutual relations that allow one part of it to account for another. Shatter that, and you are left with a pile of truths or a random list of bits of information that cannot help to make sense of the reality they seek to address. Build or reconstruct that network of relations, and information starts providing that overall view of the world which we associate with the best of our epistemic efforts (Floridi 2010: 51).

We needed this digression on information because Universal Darwinism builds complexity by accumulating, storing and disseminating information about how to make things that work. Darwinian machines generate unexpected outcomes, like armadillos or human brains, because they accumulate information that is *not* entropic mush. So wherever they are at work, unexpected things happen – whether in the immune system or in DNA, or in human history or entire universes (Blackmore 1999: 15). Darwinian machines learn (a classic summary is Campbell 1960: 380). This is why Karl Popper described the growth of knowledge as: 'the result of a process closely resembling what Darwin called "natural selection", that is, *the natural selection of hypotheses:* our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) fitness by surviving so far in their struggle for existence' (Plotkin 1994: 69).

Three Darwinian Learning Machines

Seeing Darwinian machines as learning machines will help us understand how they may shape human history. On this planet, living organisms learn in three distinct ways. All are Darwinian, but they use different variants of the same basic engine.

Genetic Learning and Natural Selection. The first variant is natural selection. Biologists have studied this engine for a long time and they understand it well. It explains how molecules of DNA accumulate adaptively significant information. DNA codes information about how to manufacture proteins using four nitrogenous 'bases': Adenine, Thymine, Guanine and Cytosine. Differences in the order of the letters really matter. Exchange one A for a T in the code for a protein with 146 different amino acids and you get sickle cell anemia. DNA stores information that is rich because it is specific, impossible to generate randomly, and therefore it is unexpected. Over time, billions of new genetic recipes for building proteins and whole organisms accumulated in the world's stock of DNA to generate the species we see today.

Generation by generation, packets of DNA are sieved as their products enter the world. Mutations, copying errors and recombination during reproduction create random variations in genes and in the organisms they give rise to, so that slight modifications on the original instructions are continually being tested. Only those packages that produce viable organisms will survive and reproduce. Much of the information they contain tells cells how to choose the tiny number of biochemical pathways that resist entropy. For example, it may include recipes for enzymes that steer biochemical reactions along rare but efficient pathways, or that help export entropy outside the organism (Campbell 2011: 102). In each generation, that information can be updated. This explains why living organisms have an uncanny ability to track changing environments.

DNA preserves information because it acts like a ratchet (on the 'ratchet effect' in human history, see Tomasello 1999). Mechanical ratchets allow a gear-wheel to turn in only one direction because the 'pawl' catches on the cogs and prevents the wheel from turning backwards. By only copying information that works, DNA ensures that the gear wheel of evolution normally turns in the direction that accumulates viable variations. Without an information ratchet, the wheel of evolution could turn in either direction, viable variations would survive no better than any others, and biological change would drift with the flow of entropy. That is why it makes sense to suppose that life itself began with DNA or

its predecessor, RNA. Before the evolution of DNA or RNA, parts of the Darwinian machine already existed: there was plenty of variation within pre-biotic chemistry, and variations could be selected for their greater stability. But only after DNA evolved (possibly preceded by RNA) could successful variations be locked in place so that genetic information could accumulate. With DNA preventing any backsliding, life was off and running.

To summarize key features of genetic learning: information accumulates as it is locked into the biochemical structures of DNA molecules. Most variations arise randomly during reproduction. Variations survive only if the DNA molecules they inhabit are copied. Genes are particulate, but when working together, they can create the impression of a 'blending' of characteristics. Because most variation arises during reproduction, genetic learning is non-Lamarckian; it does not preserve 'acquired variations', variations generated during an individual's lifetime. Random variations are tested, one by one, surviving only if they create organisms that fit their environment. These are the rules of the neo-Darwinian synthesis.

Individual Learning. The other two forms of learning have been studied less closely than the genetic machine, and we do not understand them as well.

I will call the second machine 'individual learning'. It works not across species or organisms but within the neurological system of a single individual. It is at work in species as varied as cephalopods, crows and chimpanzees. It works even in simple organisms, which can learn to detect and react to gradients of light or warmth or acidity. But individual learning is most impressive in animals with brains. Imagine our antelope glimpsing a lion near a waterhole. Was that really a lion? Should it make for another waterhole? With no guidance, it might have to choose randomly, as young animals often do. It will soon find out if its gamble succeeded. But intelligent animals also have better ways of choosing. They accumulate memories of past experiences associated with pain, fear, anxiety or with a sense of pleasure and ease. If any of those memories are similar to what is happening right now, they may provide guidance. Trying out possibilities in memory is less dangerous than trying them out in the real world, and the accompanying sensations, installed over time by genetic learning, will provide better than random criteria for repeating or avoiding particular experiences. Alasdair MacIntyre reports that if a young cat catches a shrew, it will eat it as if it were a mouse. It will then become violently ill, which is an unpleasant experience. But it has learnt a difference that matters and from

now on it will avoid shrews (MacIntyre 2001: 37). A memory that should help the cat survive has outcompeted a memory that once caused it misery.

Put more generally, an intelligent organism undergoes experiences that carry information about the outside world, if they can be stored and interpreted. Memory provides an information ratchet as it encodes experiences in neurological networks. It accumulates useful information within an individual's lifetime. Faced with an important choice, the organism can refer to its memory bank and look for experiences that had happy or unhappy outcomes. As it replays memories with their associated experiences of pleasure or pain or fear or comfort, it learns to make better choices. Significant memories are selected by being reinforced (through repetition or association with other strong experiences), while memories that are not reinforced will fade away (Campbell 2011: 119–120). The criteria for selection – repeated reinforcement or strong association with experiences of pain or pleasure – will have been built into the organism by genetic learning, which teaches you to cherish parents and shun predators. Here we have the complete Darwinian cast: varied experiences that are encoded in memories, only some of which are selected for preservation.

So individual learning is a Darwinian machine. But it does not work quite like the machinery of the neo-Darwinian synthesis. Its arena is the individual brain, rather than the outer world. Individual learning preserves useful memories acquired during an individual's lifetime, but those memories can also change; unlike genes, memories are not fixed from the moment of their birth. So individual learning can be Lamarckian. It contains no simple analogue to the neo-Darwinian separation of genotype (which does not change during an individual's lifetime) and phenotype (which can change within a lifetime). Variation arises mainly from the diversity of individual life experiences, though some may arise from mistakes in coding or assessing those experiences. In individual learning, the primary information carriers are neurological networks, and memories, their psychological correlate. Both are more diffuse and variable than genes and subject to constant minor changes as they join or separate from other networks and memories. Selection occurs through reinforcement rather than reproduction, as networks are selected for their strength and connectedness, which depend on the number and strength of the synapses from which they are constructed. Networks that are reinforced strongly because they are repeated often ('*that* waterhole is safe') or are particularly shocking ('nearly got caught that time!'), will survive, while the rest will dwindle and fade. The criteria for selection

do not reside in the outer environment, but are built into the organism by genetic learning. But selection is not purely mechanical. Sometimes it demands a judgment call '*that* waterhole is safe but the water does not taste as good, Hmmm'. At this point we may conclude that animals ponder alternatives before selecting consciously and with intent. Selection is beginning to look purposeful.

So here we have a Darwinian machine that lacks the bells and whistles of the neo-Darwinian synthesis but can still generate new, non-random and significant information. It also sports some glossy new features. It is very fast; it can accumulate new information in seconds, while genetic learning gets to test new variations just once in a lifetime. Individual learning is also specific; instead of producing generic adaptive rules for millions of individuals, it tells a particular individual how to live in a particular time and niche. But individual learning is also ephemeral; it cannot survive outside the arena of the individual brain. A lifetime of learning evaporates on the death of each individual, so every generation starts from scratch. Individual learning is Sisyphean; it cannot accumulate information at time scales larger than a lifetime, so it does not lead to a long-term change. That is why it cannot generate what we humans call 'history'; change at scales larger than a single lifetime.

Darwinian Machines in Human History: Collective Learning

Our third Darwinian machine *does* generate long-term change. I call it 'collective learning', and it seems to be unique to our species, *Homo sapiens* (for brief discussions see Christian 2004, 2012).

Collective learning happens when you join individual learning to a sufficiently powerful system of communication. It depends on the ability of individual learners to share what they have learned with others, and to do so in such volume and with such precision that new information accumulates at the level of the community and even the species. As Merlin Donald writes, 'The key to understanding the human intellect is not so much the design of the individual brain as the synergy of many brains' (Donald 2001: xiii).

Collective learning uses a new and more powerful information ratchet. Unlike individual learning, it stores information in many minds over many generations, so that information can outlive the individuals who created it. If a fraction of that information improves how individuals exploit their environments, collective learning will tend to increase the ecological power of whole communities. Like all animals, humans exploit their environments to extract the energy and resources they need to survive; but only humans keep discovering and sharing new ways of

exploiting their environment, so that over time they can extract more and more energy and resources. Our ecological creativity explains why humans are the only species that has a history of long-term changes in behaviours, social structures and ecological adaptations. Like individual learning, collective learning also works much faster than genetic learning. That is why, within just a few hundred thousand years we have become more powerful than any single species in the 3.8 billion year history of life on earth, so powerful that some geologists argue we have entered a new geological epoch, the 'Anthropocene' (see Steffen *et al.* 2007).

By sharing ideas, information, gossip and beliefs, collective learning creates human 'culture', which Mesoudi defines broadly as 'information that is acquired from other individuals via social transmission mechanisms such as imitation, teaching, or language' (Mesoudi 2011: 2–3; for a similar definition see Distin 2011: 11). Of course, humans are not alone in having 'culture' in this sense. Songbirds, chimps and whales all share information. The difference is in the degree of sharing, but that small difference really matters. Animal languages lack an efficient information ratchet, so in the animal versions of 'telephone', information leaks away within a few exchanges and has to be constantly relearned. This is why knowledge accumulation has little impact on any species except ours, and that is why no other species has a history of long-term change over many generations. Alex Mesoudi sums up a broad consensus among those who study animal culture:

> Although numerous species exhibit one-to-one social learning and regional cultural traditions, no species other than humans appears to exhibit cumulative culture, where increasingly effective modifications are gradually accumulated over successive generations. This might therefore be described as the defining characteristic of human culture (Mesoudi 2011: 203).

There is a narrow but critical threshold between individual and collective learning. To appreciate its significance, imagine pouring water into a bathtub with no plug. A trickle of water will deposit a thin film at the bottom of the bathtub. But the level will not rise because water leaks away as fast as it pours in. Increase the flow and the water level will rise and settle at a new level. (We see something like this in species such as *Homo erectus,* or in some species of primates.) Increase the flow just a bit more and suddenly the level starts rising and keeps rising as water enters faster than it leaves. You have crossed a critical threshold beyond which there appears a new type of change because now the water level will keep rising without limit (until it overflows the bathtub).

How did our ancestors cross the threshold to collective learning? We do not really know, though we have plenty of suggestions. Many changes led our ancestors towards the threshold of collective learning (for recent discussions, see Tattersall 2012; and Fitch 2010). They included larger brains; insight into the thinking of others (a 'theory of mind'); some ability to cooperate; the ability to control vocalizations and interpret the vocalizations of others; the use of fire to cook and predigest food, which, as Richard Wrangham points out, gave access to the high quality foodstuffs needed to grow brains. Many other species share some of these qualities and abilities (Tomasello 1999, 2009; Wrangham 2009; MacIntyre 2001: chs 3, 4). So, as Richerson and Boyd put it, we can imagine several species gathering at the barrier before collective learning, until eventually one broke through (Richerson and Boyd 2005: 139). Our own history suggests that the lucky species would then deny passage to its rivals: 'humans were the first species to chance on some devious path around this constraint [the difficulty that culture works only within a community of skilled social learners], and then we have preempted most of the niches requiring culture, inhibiting the evolution of any competitors' (Boyd and Richerson 2005: 16). Since humans broke through, our closest hominine relatives, from Neanderthals to Denisovans, have perished and our closest surviving relatives, the chimps and gorillas are approaching extinction. Even if several related species arrived almost simultaneously at the barrier to collective learning, there was apparently room for only one species to sneak past it.

But the speed of the change – we, humans, began our climb to world domination less than 500,000 years ago, a mere second in paleontological time – suggests that a single push shoved us through. Perhaps, it was a glitzy new neurological gadget, some form of Chomsky's 'grammar' module, or a new form of the FOXP2 gene that pushed us through. Or perhaps, as Terrence Deacon has argued, it was symbolic language (Deacon 1998). Some have argued for a slower transition. But, as a recent article argues, even if human language evolved 500,000 years ago, in evolutionary terms, that is a 'flash in the pan', implying that 'language abilities were relatively rapidly cobbled together from preadapted cognitive and neurophysiological structures' (Dediu and Levinson 2013: 10). Whatever the explanation, we should expect to find a single, critical change, because it defies reason to suppose that all the necessary pre-adaptations could have converged simultaneously on a single point in paleontological time. As Michael Tomasello writes: 'This scenario [of a single switch] solves our time problem because it posits one and only one biological adaptation – which could have happened at any time in human evolution, including quite recently' (Tomasello 1999: 7).

Suddenly, humans began to communicate not just in semantic fragments ('Tiger!'), but in organized and contextualized strings of information ('Yup, it's got the same markings as the one that got Fred, and it's behind the same bush!'). They began to use large, coherent packets of symbolic information, words like 'family' or 'gods' that compressed a world of experience into a few sounds, and linked those sounds into precise relationships using grammar (Deacon 1998). Human language locked up cultural information as tightly as DNA molecules locked up genetic information. As Tomasello puts it, 'The process of cumulative cultural evolution requires … faithful social transmission that can work as a ratchet to prevent slippage backward – so that the newly invented artefact or practice preserves its new and improved form at least somewhat faithfully until a further modification or improvement comes along' (Tomasello 1999: 5). That is why some anthropologists describe cultural accumulation as 'cultural ratcheting' (Pringle 2013).

Once the switch for collective learning was thrown, our ancestors could start building new knowledge, community by community, accumulating local knowledge stores that steered each group in different directions to generate the astonishing cultural variety unique to humans. At the same time, our inner world was transformed as ideas washed from mind to mind. We do not just learn collectively; we *experience* collectively. The anthropologist, Clifford Geertz, descried this realm as, 'that intersubjective world of common understandings into which all human individuals are born, in which they pursue their separate careers, and which they leave persisting behind them after they die' (Geertz 2000: 92). A simple thought experiment illustrates the power of this mental sharing. Look inside your head and do a quick census of everything that is there. (It takes just a few seconds.) Then ask the question: how much of that stuff would be there if you had never had a conversation with another human? Most will agree that the correct answer is: 'Very little'. And that 'very little', mostly produced by individual learning, hints at the inner world of chimps. While chimps learn alone or in ones and twos, humans learn within teams of millions that include the living and the dead.

When did our ancestors cross the threshold to collective learning? In paleontological time, the crossing took an instant, but in human time it was probably smeared out over tens of thousands of years (a paradox captured in the title of McBrearty and Brooks 2000, 'The Revolution that Wasn't'). And even when the engine of collective learning spluttered into action, it took time to pick up speed. So we cannot easily judge when human history began. But we do know what to look for. We should look for sustained evidence of humans adding ideas to ideas to form

new ideas. We should look for sustained innovation and ever-increasing cultural diversity. We should look for new and more diverse tools, and signs that humans were exploiting many new niches. And if, as Terrence Deacon and others have suggested, the breakthrough was the acquisition of symbolic language, then we should also look for evidence of symbolic thinking in art, body painting or signing (Deacon 1998).

The first speakers of a fully human language may not have belonged to groups normally classified within our own species, though they were surely very similar to us (Dediu and Levinson 2013). If they did belong to our species, we can date human history to at least 200,000 years ago, because that is the date of the oldest skull generally assigned to *Homo sapiens*. It was found in Omo, in Ethiopia in the 1960s (Tattersall 2012: 186).

But what we really need is evidence of new behaviours. In a comprehensive survey of African evidence from the Middle Stone Age, published in 2000, Sally McBrearty and Alison Brooks found hints of collective learning from as early as 250,000 years ago (McBrearty and Brooks 2000; and for a brief update see Pringle 2013). The Acheulian stone technologies associated with *Homo ergaster* were replaced by new, more delicate and more varied stone tools, some of which may have been hafted. The new tools are associated with species that few anthropologists would classify as *Homo sapiens,* so the technological speed up may have preceded our own species. By 150,000 years ago, when members of our species were surely around, McBrearty and Brooks find hints that some groups were using shellfish and exchanging resources over long distances. We also see evidence of regional cultural variations. Ecological migrations are important because they show a species with enough technological creativity to move further and further from its evolutionary niche. Early in our history, new knowledge counted most at the edge of a population's range, where people faced the dangers and opportunities of testing new plants or animals. Before 100,000 BCE, we have tantalizing hints that some humans had entered deserts and forests (McBrearty and Brooks 2000: 493–494). After 60,000 such evidence multiplies; humans appear in Europe, in Australia and then in Ice-Age Siberia and, by at least 15,000 years ago, in the Americas.

Language leaves no direct traces, but archaeologists have found many hints of symbolic thinking. More than 260,000 years ago, early humans near Twin Rivers in modern Zambia used hematite (red iron oxide), possibly to paint their bodies (Stringer 2012: 129). Later evidence is less equivocal (for a good survey see Pettit 2005; on Blombos cave see Henshilwood *et al.* 2011). At Pinnacle Point in South Africa, in sites dated to about 160,000 years ago, we find the earliest evidence for the use of shellfish, along with signs of composite tools and lots of hematite, of

a particularly brilliant red, which points to symbolic uses (Stringer 2012: 129). By 115,000 years ago, similar evidence turns up in modern Israel, where, in Skhul cave, archaeologists have found evidence of symbolic burials. But the best evidence of all for rich symbolic activity comes from the marvellous South African site of Blombos cave, whose remains date from almost 100,000 years ago. Here, Chris Henshilwood and his team have found delicate stone tools, seashell beads, and lumps of ochre carved with wavy lines that could almost be an early form of writing (*Ibid.*: 129–130).

Evidence for early signs of collective learning will surely come into sharper focus, but in the meantime, these hints suggest that if human history began with collective learning then something had cranked up the motor certainly by 100,000 years ago, perhaps, as early as 250,000 years ago and possibly 500,000 years ago (Dediu and Levinson 2013).

Collective Learning as a form of Universal Darwinism

Collective learning launched and sustained our species on its astonishing journey towards planetary domination. If this argument is right, it seems that some form of Universal Darwinism has driven human history. We see *variation* in the ideas and information of different human societies, from their technologies to their religious rituals, from their art and clothing to their cuisine and entertainment. Individuals and whole societies *select* some variants and reject others. And selected variations are *preserved* as they flow between minds.

But in detail, collective learning works differently from genetic learning and individual learning, and any Darwinian accounts of human history must take these differences into account. As Alex Mesoudi writes,

> …many of the details of biological evolution that have been worked out by biologists since [*The Origin of the Species*], such as particulate inheritance (the existence of discrete particles of inheritance, genes), blind variation (new genetic variation is not generated to solve a specific adaptive problem), or Weismann's barrier (the separation of genotypes and phenotypes such that changes acquired in an organism's lifetime are not directly transmitted to offspring), may not apply to cultural evolution (Mesoudi 2011: x).

Why does collective learning work so much faster than genetic learning? In part because it builds on the machinery of individual learning, which works with neurological impulses rather than entire organisms. A genetic mutation must wait a generation before it effects change; a suddenly triggered memory can have you swerving in a sec-

ond. Collective learning also copies fast. It can transmit new ideas on the fly, as they evolve, and can broadcast them to many brains at once because it works with sound waves (in speech) or light waves (in signalling and imitation). Like genetic learning, collective learning is auto-catalytic, so it has generated better ways of storing and transmitting information, from writing to printing to the telegraph and internet. Auto-catalysis explains why collective learning generates not just change, but *accelerating* change. Finally, collective learning, like individual learning, builds on acquired as well as inherited variations. While genetic learning gropes randomly in the dark, collective learning can probe more purposefully.

How do variation, selection and reproduction work in collective learning?

In collective learning, as in genetic learning, some variation is blind, arising from mutation and drift; but these variations arise from misunderstandings or simple blurring of meaning rather than from biochemical glitches. Much more important is another source of variation: deliberate innovation. Richerson and Boyd call this 'guided variation' (see the taxonomy of cultural evolutionary forces in Richerson and Boyd 2005: 69). Individuals deliberately add what they have learnt to the common pool of knowledge, or tweak and modify existing ideas. A little more salt in the soup, or tautness in the bowstring, or even a separate boiler for the steam engine. Moment by moment, and often with a sense of purpose, individual learning adds new information to a shared pool of knowledge, whereas genetic learning receives its variations at random.

Selection, too, can be conscious and purposeful in collective learning. Richerson and Boyd describe purposeful selection as 'biased transmission'. We select using 'content-based' biases when we choose an idea or cultural variant on its merits, for its beauty or precision, perhaps. Other forms of selection are deliberate but less thoughtful. In a conformist or lazy mood, we often choose the most accessible idea or behaviour, or we choose ideas or behaviours associated with admired role-models. In the taxonomy of Richerson and Boyd these are called 'frequency-based biases' or 'model-based biases'. Either way, selection is trickier in collective learning because cultural variations are fuzzier than genes, though often, when we choose one word or another or vote for one political party rather than another, we chop up the cultural flow.

Reproduction is fuzzier and more complex than in genetic learning. Ideas have many parents. They can also replicate in their thousands at religious festivals or political rallies or through mass media. Most important of all, in collective learning reproduction is less tightly bound to the reproductive success of particular individuals than in genetic learning. This is why humans often select variations that are *not* adaptive

under the rules of genetic learning. For example, they may choose to have fewer children than possible, thereby reducing their reproductive success (Richerson and Boyd 2005: ch. 5). This makes no sense under the rules of genetic evolution, which measure success by the number of genes passed on to the next generation. Even worse, humans sometimes risk their lives for others who are not even close kin. Genetic reproduction can just make sense of sacrifices on behalf of close kin (who do, after all, share genes with you). But it cannot explain sacrifices on behalf of strangers or people you may never have met. Collective learning can explain such behaviour, because collective learners live within shared flows of ideas, information and motivation that create a sense of shared meaning and purpose, and magnify the importance of reciprocity. We inherit ideas and values from dead strangers and living teachers as well as from parents and grandparents, and we cannot always distinguish clearly between the two types of inheritance. So collective learning allows behaviours that, from the perspective of genetic learning, seem like errors, such as the choice of a group of ducklings to treat Konrad Lorenz as their mother. Symbolic thinking blurs the line between genetic and imagined kinship. And where meanings are shared so, too, are their emotional charges. Flags and national anthems can motivate us as powerfully as family, particularly if cultural differences sharpen our sense of shared community. Richerson and Boyd have shown that in such environments models predict the rapid spread of altruistic behaviours. This is particularly true where cultural selection is 'conformist', where people choose values because they are normal within their community (*Ibid*.: ch. 6).

In short, a sense of shared meaning blurs the distinction between individual and group success. In collective learning, the viability of ideas (and sometimes of the humans who carry them) depends as much on the reproductive success of entire groups as on that of individuals. So where collective learning is at work, group selection may be as important as individual selection, because with the flourishing of human culture, genes are no longer the primary shapers of behavioural change. Group mechanisms including shared cultural norms and social structures clearly play a profound role in explaining human behaviour. So we should not be surprised to find that humans collaborate so effectively in bands, tribes and nations as well as in families. Though the idea of group selection is fiercely contested at present (for two different positions see Pinker 2013 and Wilson 2007), something like group selection is surely at work in the evolution of human culture.

Finally, and most mysteriously, collective learning generates an entirely new form of change, cultural change. Like information, cultural change often seems to inhabit a limbo between the physical and mental

worlds. John Searle, who has spent much of his career trying to explain cultural phenomena, argues that the cultural realm arises from 'shared intentionality', or the shared sense of meaning created by collective learning (not his term) (Searle 2010: 3–8 and passim). 'Shared intentionality' explains why only humans can assign conventional meanings or functions to people and objects. It matters if they agree to call a piece of paper a twenty-dollar bill. The agreement creates rights, obligations and possibilities; it motivates behaviours that go well beyond our sense of individual wants or needs. Searle argues that such agreements are the foundation of all social relations and institutions. They are what make human societies different.

Conclusion: Different Versions of the Darwinian Machine

Wherever we see change swimming against the flow of entropy, we should suspect that a Darwinian machine is at work. Human history represents a spectacular example of this kind of change, so we should expect to find a Darwinian machine lurking somewhere within the discipline. Most historians have rejected this possibility, partly from fear of Social Darwinism, partly because the neo-Darwinian synthesis fit human history so poorly. But as we have seen, Darwinian machines come in different versions. A clearer appreciation of these differences may encourage historians, too, to explore the possibility that Darwinian mechanisms of some kind can help us explain the remarkable trajectory of human history. But they may also help us see human history itself as part of a much larger story of increasing complexity, most of which (perhaps all of which) was driven by Darwinian mechanisms of some kind.

'*Mutt. – Ore you astoneaged, jute you?*
Jute. – Oye am thonthorstrok, thing mud' (Finnegans Wake, Ch. 1).

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2
Standing on the Shoulders of Giants: Collective Learning as a Key Concept in Big History

David Baker

Abstract

One of the key concepts for the human part of the grand narrative is known as 'collective learning'. It is a very prominent broad trend that sweeps across all human history. Collective learning to a certain degree distinguishes us as a species; it got us out of Africa and the foraging lifestyle of the Palaeolithic, and underpinned demographic cycles and human progress for over 250,000 years. The present article looks at collective learning as a concept, its evolution within hominine species, as well as its role in human demography and the two great revolutions in human history: agriculture and industry. The paper then goes on to explain the connection of collective learning to Jared Diamond's 'Tasmanian Effect'. Collective learning also played a key role in the two 'Great Divergences' of the past two thousand years. One is industry and the rise of the West, described to great effect by Kenneth Pommeranz, the other is the less well known: the burst of demography and innovation in Song China at the turn of the second millennium AD. Finally, the paper concludes with insights into how collective learning forges a strong connection between human history and cosmology, geology, and biology, through what is widely recognized as one of the 'unifying themes' of Big History – the rise of complexity in the Universe.

Keywords: *complexity, collective learning, demographic cycles, evolution, accumulation.*

When I arrived in Sydney in 2010 to start my PhD in Big History, my original topic was long-term patterns in Malthusian cycles. However, it was only a few weeks before I noticed the strong connection between population dynamics, the rise of complexity that is central to Big History's grand narrative, and a concept known as cultural evolution, which is the transmission of cultural ideas, beliefs, and attitudes through an algorithm of variation and selection very similar to the evolution of genes in biology. Cultural ideas evolve and adapt far faster than genetics and this permits a much more rapid increase in complexity. Cultural evolution is, of course, one of many manifestations of the

'Darwinian algorithm' that is observed in cosmology, geology, biology, and even quantum physics, that seems to play a role in rising complexity (Baker 2011a, 2013, 2014; Christian in this volume). My dissertation has explored the Darwinian connection among these differing physical processes and I have explored them in a few other articles, but in this article I would like to focus on an aspect of cultural evolution that is crucial to human progress and the upper end of the immense complexity the Universe has generated so far.

Collective learning is an ability to accumulate more innovation with each passing generation than is lost by the next. It has allowed humans to exploit our ecological niches with increasing efficiency and allowed us to largely harness the energy flows of the planet and the Sun. Through foraging, agriculture, and heavy industry collective learning has raised the carrying capacity of the population, allowing for more potential innovators, who in turn raise the carrying capacity, thus creating even more innovation. Gradually, over 250,000 years of humanity, the population has risen and we have generated increasingly complex societies and have developed the capacity to harness an enormous amount of energy. In terms of the wider rise of complexity and in processes of Universal Darwinism, collective learning is the summit of the process, and I say the next two words with emphasis, *thus far*.

The historian's view of all human history is no longer vague or boundless with a chaotic tangle of periods and research areas. Collective learning gives a clear and definite shape to the whole picture as well as an underlying theme. This is revolutionary not only for Big History, but for areas of conventional human history as well. The idea has its uses within archaeology, agrarian history, and within the study of the industrial era – not to mention our anxiety-fraught examination of the looming trials of the twenty-first century. For the concept of collective learning we are deeply indebted to David Christian for expounding it in his own works, and also anthropologists like Peter Richerson, Robert Bettinger, Michelle Kline, and Robert Boyd, for developing it mathematically and, in one case of a recent paper to the Royal Society, with a strong degree of empiricism (Christian 2005: 146–148; Richerson, Boyd, and Bettinger 2009: 211–235; Kline and Boyd 2010: 2559–2564).

In natural ecology, all organisms are slaves to some form of *S*-curve that restricts the amount of resources available to an individual and a species, enabling them to survive and reproduce. When the carrying capacity of a biological population is reached, the population undergoes

strain, decline, and recovery. While potentially destructive to life-forms, it does have the merit of spurring along evolution by natural selection. Thomas Malthus' *Essay on the Principle of Population* (1798) illustrated how the human population growth always tended to exceed the resources capable of supporting its burgeoning numbers. Darwin read it in 1838 and extrapolated it to other organisms whereby species overbreed, compete, and change over time to possess the traits that are best able to extract resources from their environment and perpetuate their survival. It was an epiphany for him. At last, he said, 'I have finally got a theory with which to work' (Darwin 1887: 82). It also applies to human history. In his recent book, big historian Fred Spier identifies the unifying theme of our long story:

> If we want to prevent our bodily complexity as well as all the complexity that we have created from descending into chaos, we must keep harvesting matter and energy flows on a regular basis. *This is the bottom line of human history*. I will therefore argue that during most, if not all, of human history, the quest for sufficient matter and energy to survive and reproduce... has been the overriding theme (Spier 2010: 116; emphasis added).

Until a few million years ago there was nothing on Earth to indicate that anything else besides the *mêlée* of genetic evolution, with its constant generation and annihilation of diversity, would arise. It appeared the short, ignorant, and terrifying existence of beasts of the field was the highest level of complexity of which the planet was capable. Biology seemed like the finest manifestation of the Darwinian algorithm that gradually produced more and more complexity, with the annihilation of useful DNA mutations and the selection of useful ones. However, like stellar evolution builds on quantum Darwinism, like mineral evolution is an extension of stellar evolution, biological evolution soon spawned another Darwinian process. There emerged the groundswell of collective learning, the concept that a species' learning accumulates in ways over several generations that enhances their ability for survival. If harvesting energy to maintain our complexity is the bottom line of human history, then collective learning and its ability to raise the carrying capacity is without question the shape. That shape looks something like this.

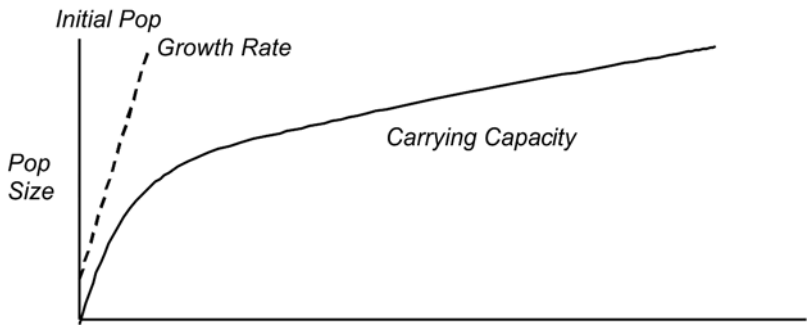

Fig. 1.

Source: Richerson *et al.* 2009: 219.

I. Collective Learning in the Palaeolithic

What precise ability enables collective learning? How did it evolve? What selection pressures made it spring into being? This engages with a much larger and much older debate over the nature of human uniqueness – something to which a refined version of collective learning can contribute. These ideas are universal grammar *à la* Noam Chomsky *vs.* symbolic reference *à la* Terrence Deacon, the emergent thought *vs.* the computational model of the mind, the role of imitation and mimicry in the evolution of language, and the debate over group selection in humans that raged over a recent book by Edward O. Wilson and the counterblast of Steven Pinker (Wilson 2012; Pinker 2012). While the importance of collective learning and technological accumulation to human history has been clearly identified, it is much less clear what trait or a set of traits enabled it in the first place. A number of theories exist and they all seem to revolve around the gradual and the sudden. Chomsky argues against gradualism and considers universal grammar an all or nothing proposition that somehow flickered into being (Chomsky 2002: 80). Pinker argues for a more gradual evolution of a computational model of the mind similar to the evolution of the eyes (Pinker 1997: 21). Deacon argues for the appearance of symbolic reference as a sudden occurrence (Deacon 1997: 328–355). Dunbar claims that enhanced communication abilities and technological accumulation were the gradual result of selection pressures on complex interaction and coordination due to increasing group size and inter-group connectivity (Dunbar 1996: 3–17, 56–58, 62–64, 77; 2004: 28–29, 71–72, 125–126; 2010: 22–33). Finally, Corballis places gesticulation as the fundamental form of social learning with speech being the ultimate form – thus being a change of degree and not of kind (Cor-

ballis 2002: 41–65). Whatever the skill that allowed humans to accumulate more innovation with one generation than was lost by the next, it needs to have a clear explanation about how it evolved in real terms without recourse to metaphor and with identifiable selection pressures – whether sudden or gradual.

These questions tie into the next issue: the threshold after which collective learning became possible. Where is it drawn? Is it the result of a gradual evolution over several species or a sudden jump? If we knew what ability, origin, and selection pressures caused collective learning, we might be able to better answer that question. For now it is a big blank spot on the map. Do we draw the line at humans? And if so, how do we treat the nascent elements of collective learning in our evolutionary family? David Christian often gives the example of the Pumphouse Gang baboons, where a skilled hunter dies and information eventually degrades, vanishes, and the range of the species does not expand. He also gives a nod to what he calls the 'sporadic learning' in apes and in *Homo habilis* and *Homo ergaster/erectus* (Christian 2005: 146). But if we place the threshold where more knowledge is accumulated with each generation than is lost by the next, we are confronted with questions about the significance of situations where knowledge neither degrades nor accumulates – it is simply preserved. For example, termite fishing, rock hammers, leaf sponges, branch levers, and banana leaf umbrellas are passed on by social learning, not instinct, and not sporadically, in certain populations of chimpanzees, and are withheld from others outside that cultural network (Pinker 1997: 198–199). They are sustained and passed on, usually from mother to offspring, and are not reinvented every generation. Here is a tremendous ability, however weak, probably possessed by our last common ancestor. This ought to tell us something about the nascent elements of collective learning. But, on the other hand, if this learning does not accumulate, but is only preserved, perhaps, it can conceivably be dismissed, if we wish to maintain a sudden threshold with humanity and not a gradualist account.

Similarly, the stagnant nature of stone tools 2.6–1.8 million years ago may potentially be dismissed as a 'sporadic learning', simply preserving knowledge but not accumulating it. Around 1.8 million years ago, however, the assertion grows more tenuous. Stone tool manufacture is less haphazard, with deliberate shapes being constructed that are passed on culturally. *Homo ergaster/erectus* also migrated into different environments in Asia, no mean feat, and there is evidence of a demographic boom in Africa that may have driven the migration. A demographic boom also indicates an enhanced ability to exploit niches in the ecosystem. There is also

evidence of increased brain size and sociality (Stringer 2011: 25–26; Tattersall 2012: 123–124). All of these things are staple arguments for collective learning in *Homo sapiens* and the profound impact they had on the Palaeolithic world. There is no reason why the same arguments could not apply to *Homo ergaster/erectus*, albeit on a lesser scale. But this is a difference of scale, not a difference of kind.

Nevertheless, the jury is still out on whether there was any technological accumulation. When *Homo ergaster/erectus* first arrived on the scene 1.8 million years ago, they were making tools that had not changed significantly since *Homo habilis*. However, 1.78 million years ago we begin to observe rare and crude new forms of teardrop hand-axes in Kenya (Tattersall 2012: 105). But for about 200,000 years we see, for the most part, no major widespread improvements in the stone tools of *Homo ergaster/erectus*. This remained the case in most migratory regions. The tools were functional. The object was to get a flake edge. No aesthetics were involved. But in Africa 1.5 million years ago, where *Homo ergaster* populations were at their densest, the hand-axes first made 1.78 million years ago rapidly became common. What is more, they improve in quality, shaped with a flat edge into multipurpose picks, cleavers, and other kinds of implements (Tattersall 2008: 125–127). This has been considered by some archaeologists as the first clear sign of tinkering, accumulation, and improvement of technology, if only a much weaker form of collective learning among *Homo ergaster/erectus* than *Homo sapiens*, who are the real champions at it.

Still, the assertion that *Homo ergaster/erectus* had crossed the threshold into mild collective learning can still be reasonably disputed and dismissed if the case is only based on such limited evidence. This argument is less feasible for the hominines of the last million years. *Homo antecessor*, *Homo heidelbergensis*, and the Neanderthals presided over the systematised and regular use of fire in hearths (790,000 years ago), the earliest wooden spears (400,000 years ago), the earliest use of composite tools (400,000 years ago), the first evidence of intricately constructed shelters (350–400,000 years ago), and the first prepared core tools (300,000 years ago) all before *Homo sapiens* was ever heard of (Goren-Inbar *et al.* 2004: 725–727; Tattersall 2008: 125). *Homo heidelbergensis* became the first pan-Old World hominine (600,000 years ago), showing signs of technological improvement, with the earliest specimens using simpler tools than later ones, and even evidence of pigments at Terra Amata, a site in Europe 350,000 years ago (Oakley 1981: 205–211). The Neanderthals adapted to climes that made clothing and other cultural innovations necessary for insulation and warmth. There is also limited evidence for use of pigments (Stringer 2011: 163–165). They used complex tool manufacture,

with prepared stone cores, producing a variety of implements, sharp points, scrapers, teardrop hand-axes, wood handles, with deliberate use of good stone materials, and an endless supply of variations and signs of improvement over time (Tattersall 2012: 166–173; 2008: 150–158).

Now, bearing in mind that *Homo sapiens*, without question, is by far the most talented at collective learning, there is very little doubt that these hominine innovations accumulated over several generations, did not fade away, improved in quality down the chronology, and yielded a certain degree of ecological success and extensification into new environments. Interestingly enough this happened in several hominine species for which there has yet to be found clear evidence of symbolic thought and complex language, two things that are sometimes (and probably incorrectly) attributed as the *cause* of collective learning rather than more efficient vehicles for it. All this raises severe questions about the threshold that must be addressed. It also bleeds into questions about human uniqueness and why it is so important for some people to draw an iron-clad boundary between us and our evolutionary family that distinguishes us in essential kind. This sort of essentialism is alien to many forms of evolution. It would be a rash statement indeed to say that if *Homo sapiens* had never existed and had never out-competed other hominines, that these same hominines would not have possessed collective learning or attained some degree of cultural complexity. Much more work, at any rate, would be required before one could make such a statement. As it is, it appears a more gradual evolution of collective learning occurred over several hominine species.

The question of a 'Palaeolithic revolution' is another point of contention. Did *Homo sapiens* undergo a biological change *c.* 50,000 years ago and does this explain the explosion of technological complexity that appears in the fossil record? Or did collective learning and population density achieve a point of saturation allowing for a faster pace of learning? Or did this complexity arrive in Africa prior to 100,000 years ago as McBrearty and Brooks have suggested (McBrearty and Brooks 2000: 453–563)? If the latter, it is probably the result of collective learning maintaining a faster rate of accumulation in denser African populations than disparate migrant ones. Collective learning may have also played a role in the Out-of-Africa migrations themselves. Recent DNA studies have shown exponential human population growth in Africa preceded our most successful migration out of that continent *c.* 60,000 years ago (Atkinson, Gray, and Drummond 2009: 367–373). This coincides with evidence of an increase in the complexity of technology around the same time (Mellars 2006: 9381–9386). It is possible that there is a correlation between migration and population growth that may be ex-

plained by the gradual rise of collective learning. If such a connection exists for the ecological success of humans, it might also be applied to the prior migrations of *Homo ergaster/erectus*, *Homo heidelbergensis*, and the Neanderthals. The human correlation is also reinforced by genetic studies by Powell, Thomas, and Shennan that show population density in Africa may have reached a critical mass to allow more consistent technological accumulation without as many periods of loss (Powell, Shennan, and Thomas 2009: 1298–1301).

Decline in population and collective learning can also lead to a Tasmanian Effect, where technology disappears or undergoes simplification. Jared Diamond coined the term for the extreme disappearance of technology in Tasmania (Diamond 1978: 185–186). Kline and Boyd recently established a similar case in Oceania, where technology declined in groups that were isolated or lost density (Kline and Boyd 2010: 2559–2564). My own work has unearthed a similar occurrence of technological disappearance and simplification in the extreme and sustained population decline of isolated parts of post-Roman Western Europe in the fifth and sixth centuries (Baker 2011b: 217–251). Finally, Zenobia Jacobs, Bert Roberts, Hilary Deacon, and Lyn Wadley established two Palaeolithic Tasmanian Effects in Africa, at Still Bay 72,000 years ago and Howieson's Poort 64,000 years ago (Jacobs *et al.* 2008: 733–735; Wadley *et al.* 2009: 9590–9594). All are cases where technology disappears or is simplified in areas that suffered isolation and population decline – a phenomenon deemed more likely in the Palaeolithic due to lower populations and lower connectivity. It might explain why collective learning took tens of thousands of years to get off the ground, relatively speaking, before the explosion of agriculture.

II. Accumulation of Innovations from Foraging to Agriculture

Culture evolves through an accumulation of small variations. Those ideas that are successful or useful, in whatever way, are selected and spread throughout a society. Every invention of technology or breakthrough in practice, like in agriculture, comes from a series of small improvements contributed by a long dynasty of innovators. The single innovation of a genius might be of revolutionary magnitude and repercussions, but would have been impossible without the hundreds of tiny innovations made by the hundreds of generations that came before it. Newton said he stood on the shoulders of giants. It might be fairer to say that every ordinary person stands on the shoulders of other ordinary people – some with more than ordinary perceptiveness and absolutely extraordinary timing. Our technologies, our institutions, our languages are far too elaborate for even the most gifted of geniuses to cre-

ate from scratch. Human beings have a tremendous capacity for language. We can share information with great precision, accumulating a pool of knowledge that all people may use. The knowledge an individual contributes to that pool can long survive his death. If our populations are large and well-connected enough, more information is acquired by each passing generation than is lost by the next. It can be accessed and improved by countless generations.

From the origins of collective learning in the Palaeolithic, it is clear that from the rising carrying capacity and increase in cultural variants and innovations, that collective learning has great bearing on the historical narratives. Nowhere is this more relevant than the discussion of population cycles. The inception of the current arc of complexity is easily spotted. Around 74,000 years ago there was a catastrophic eruption at mount Toba, on the island of Sumatra, part of what is now Indonesia. It was worse than anything in recorded history. The eruption drastically lowered temperatures on Earth for several years (Rampino and Self 1992: 50–52). Genetic studies show that the resultant decline in flora and fauna upon which humans could predate had reduced the population to near extinction. It is likely that in the aftermath of a period of starvation, on the entire face of the Earth there were scarcely more than 10,000 (and perhaps as few as 1000) human souls, which, as an aside, is what makes our long history of racism so abhorrent and absurd, particularly those ideological impulses inspired by Darwinism (Williams *et al.* 2009: 295–314; Rampino and Ambrose 2000: 78–80; Ambrose 1998: 623–651). Here is a low watermark for the current trend of human population dynamics. Evidently the starvation did not last long. In approximately the same amount of time that separates us from the dawn of agriculture, the human species had recovered and *c.* 60,000 years ago migrated out of Africa across the world. By 30,000 years ago, the foraging human population had risen to half a million. By 10,000 years ago, the innovation of hunter-gatherer bands had allowed them access to almost every environment on Earth, from Eurasia to Australia to the Americas. We must remember that the carrying capacity for a foraging band is quite low and they need a vast area to supply relatively small numbers. Nevertheless, by the dawn of agriculture the ranks of our species had swelled to six million people, approaching the full capacity for supporting hunter-gatherers of which the entire surface of the Earth is capable (Livi-Bacci 1992: 31). Innovations began to mount up. The earliest recorded evidence for herding goats and sheep in Southwest Asia is from 11–12,000 years ago, and one thousand years later, we have evidence for the farming of wheat, barley, emmer, lentils, and pigs. By 8,000 years ago, East Asia had be-

gun using millets and gourds, and the Americas had domesticated llamas and maize. By 6,000 years ago, Southwest Asia had domesticated dates and the grapevine, while East Asia had domesticated water chestnuts, mulberries, water buffalo, and that mainstay of all Asian crops – rice (Roberts 1998: 136). All of a sudden, much larger numbers could be supported over a much smaller land area. The agrarian civilizations brought about a greater degree of connectivity, faster population growth, and a new rapid pace for innovation. Suddenly there were a lot more minds to generate ideas and a lot less space between those minds in order to conference. Agricultural efficiency gradually improved and practices slowly spread to new regions. From the upper limits of the carrying capacity for foragers, the population increased nearly tenfold by 3000 BC to 50 million people, and it took only another 2000 years to increase this number to 120 million (Biraben 1979: 13–25). But there was a problem. The tinkering of ideas in cultural evolution is random, after all. For nearly 10,000 years, the growth in the carrying capacity of agriculture was sluggish while population growth was exponential, and so there was a series of miniature waves of population collapse and recovery throughout the period of agrarian civilizations. From there came the advent of industry which has raised the carrying capacity and enhanced collective learning by leaps and bounds.

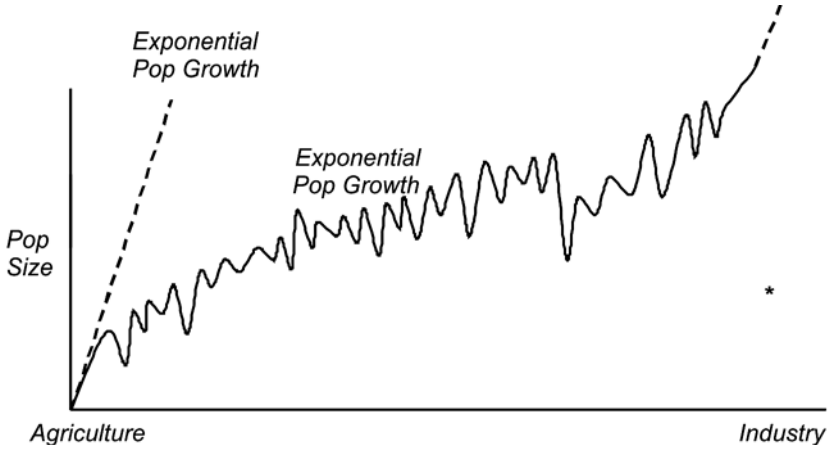

Fig. 2. The asterisk (*) marks a period of severe population decline where collective learning is lost

Bear in mind that each innocuous-looking downturn on the graph represents a period of intense starvation, suffering, and death. Every few centuries an agrarian civilization overshot its carrying capacity and count-

less famines, instability, poverty, and plagues ravaging a malnourished landscape, resulted. Each droop of the line represents the death of millions. Sometimes population loss would be so significant that it adversely affected the onward march of collective learning, as the asterisk simulates. If collective learning is lost, the carrying capacity falls, and the smaller group of innovators has to make up lost ground. This reversal of the process is known as the Tasmanian Effect.

III. Collective Learning Undermined and Overthrown

When a catastrophe strikes and a population is reduced and isolated, the accumulation of knowledge slows down and a population's ability to retain information is weakened. The most extreme example of this is from Tasmania, which possessed many technologies shared by their Australian relatives to the north, but whose skills and technologies gradually disappeared after Tasmania was cut off from Australia *c.* 10,000 years ago. Jared Diamond famously observed that when the Europeans first visited Tasmania in the seventeenth century, the native population was small, isolated, and lacked many of the tools and methods that the aboriginal Australians on the mainland possessed. The Tasmanians could not produce fire in hearths, they did not have boomerangs, shields, spears, no bone tools, no specialized stone tools, no compound tools like an axe head mounted on a handle, no woodworking, no sewing of clothes despite Tasmania's cold weather, and even though they lived on the sea coast, they had no technology for catching and eating fish (Diamond 1978: 185–186). Diamond hypothesized that this was caused by the loss of the land bridge between Australia and Tasmania *c.* 10,000 years ago. A subsequent recent study of Tasmania's archaeological and ethnohistorical evidence has borne out the same result (Henrich 2004: 197–218). The Tasmanians upon European contact had lost a great deal of technology that was enjoyed not only by their neighbours across the Bass Strait but also by most groups of *Homo sapiens* in the Palaeolithic. Humans probably arrived in Tasmania from Australia 34,000 years ago, across a land bridge, and were indeed cut off 12,000–10,000 years ago by the rising sea (Jones 1995: 423–446). The archaeological evidence shows that at the time of migration, the Tasmanians were producing bone tools, cold-weather clothing, fishhooks, hafted tools, fishing spears, barbed spears, fish/eel traps, nets, and boomerangs, and continued to do so even after the island was cut off by the rising seas. These tools gradually declined in frequency, variety, and quality between 8,000 and 3,000 years ago before completely disappearing from the archaeological record (Henrich 2004: 198). Thereafter, to hunt and fight, the Tasmani-

ans used one-piece spears, rocks, and throwing clubs, and their entire toolkit consisted of 24 items, as opposed to the hundreds of tools possess by the Australians to the north (Ryan 1981). Bone tools are on the Tasmanian record from at least 18,000 years ago, just as they were in Australian records and also enjoyed by Palaeolithic man in Africa from 89,000 years ago (Webb and Allen 1990: 75–78). The archaeological record also shows that from 8,000–5,000 years ago, the Tasmanians relied heavily on fishing, second in their diet only to seal hunting, and much more than hunting wallabies. By 3,800 years ago, fish bones disappear from archaeological sites and it was not part of the Tasmanian diet when Europeans arrived (Henrich 2004: 199). All told, Jared Diamond's hypothesis forty years ago about a loss of knowledge due to connectivity and a shrinking population has been largely borne out by subsequent research.

It is not the only case where such a phenomenon has occurred, though it is undoubtedly one of the most extreme. Other Pacific groups have a history of losing canoe, pottery, and bow technology (Rivers 1926). The Inuit were decimated by a plague and lost knowledge to construct kayaks, bows and arrows, and the leister, until it was reintroduced by migrants from Baffin Island (Rasmussen 1908; Golden 2006). Michelle Kline and Robert Boyd detected a similar trend in Oceania (Kline and Boyd 2010: 2559–2564). The ecological similarity between these environments allowed Kline and Boyd to focus on fishing technology, preventing geographical differences from distorting the results. The groups also had a common cultural descent. The finding was that the number of tools and the complexity of them are higher in larger well-connected populations. Zenobia Jacobs, Bert Roberts, Hilary Deacon, and Lyn Wadley have determined that there was a Tasmanian Effect at Still Bay 72,000 years ago and Howieson's Poort 64,000 years ago (Jacobs *et al.* 2008: 733–735; Wadley *et al.* 2009: 9590–9594). At Still Bay, humans created highly complex flake technology, including finely shaped, bifactually worked spearheads. At Howieson's Poort, humans created composite weapons and stone artifacts, both of which were hafted. These two sites were more innovative than much else in Middle Stone Age Africa, and an increasingly complex social organization is implied by the use of bone tools, symbols, and personal ornaments. The strange thing is that these two industrious cultures are separated by several thousand years of stagnation and total disappearance of their technologies. And the differences between the way the technologies of Still Bay and Howieson's Poort are constructed implies that when Still Bay disappeared, the innovators of Howieson's Poort started from scratch.

Both cultures intriguingly fall within the genetic bottleneck that occurred 80–60,000 years ago (Jacobs *et al.* 2008: 733). It would appear a relatively low carrying capacity for hunter-gatherers ranging across a territory, the small size of their groups, and their vulnerability to ecological changes and disasters made the disappearance of knowledge more common in the Palaeolithic. The Tasmanian Effect is not just confined to hunter-gatherer societies, however, though due to the low connectivity and small populations of those societies it may be more common. The Tasmanian Effect can also occur in agrarian civilizations. It occurred in the post-Roman West in the fourth, fifth and sixth centuries AD. We must make clear, however, that this trend was not mirrored in the Roman-Byzantine East, which underwent a different population trend, including growth through the fourth, fifth, and into the sixth centuries AD. The extreme settlement abandonment of the Roman West, started in 350, intensified by the Germanic invasions, and then further exacerbated by the bubonic plague of Justinian, reduced the already sparse and illiterate population to low levels. The loss of technology and expertise is reflected in the decline of various artisanal practices, pottery methods, military equipment and architectural knowledge (Murray-Driel 2001: 56–64; Pugsley 2001: 112–115; Ward-Perkins 1999: 227–232; Arthur 2007: 181; Mannoni 2007: xlv-xlvii; Knight 2007: 100; Rossiter 2007: 115; Bishop and Coulston 1993: 122–149; Coulston 2002: 23; Williams 2002: 45–49; Murray 1986: 31–32; King 2001: 26–28). It remained to subsequent generations to rediscover classical learning and devise new methods to make up for this shortfall and raise the carrying capacity once again. The process of recovery from the Tasmanian Effect took Western Europe more than 700 years.

IV. Song China and Industrial Britain: The Two 'Great Divergences'

In the past two millennia, certain key innovations in Song China and Industrial Britain have prompted an explosion of growth in collective learning, bringing humanity ever closer to industrialization. There were other periods in human history which arguably could be deemed as 'explosions' of collective learning (the Axial Age, the Renaissance, the Enlightenment, the Scientific Revolution, *etc.*) but what is notable about Song China and Industrial Britain is that they were explosions in collective learning that prompted one world zone to tear ahead of their contemporaries in that time period. Hence, scholars often use the phrase 'great divergence' as popularised by Ken Pomeranz (2000). This term has so far applied to the industrial divergence that separated 'West from

rest', but taken within the context of collective learning it can also apply to an earlier period.

The first great divergence was in Song China in the ninth and tenth centuries AD which led to something staggeringly similar to the rates of innovation and production seen in the Industrial Revolution. In the sixth century BC, the carrying capacity of China was already ahead of ancient Europe. China was already growing crops in rows, paying attention to weeding, and frequently employing iron ploughs. All of these innovations would not be employed in Europe for centuries. The Chinese also used horse harnesses by the third century BC, avoiding the risk of strangulation by a horse and permitting them to carry ploughs and heavy equipment. The seed drill came into use by the second century BC. In the first-second century BC, the types of mouldboard ploughs that only became available in Europe after Charlemagne were already in use in China (Temple 1986: 15–20). At the time, the majority of the Chinese population concentrated in the north in the Yellow River valley where they farmed millet and wheat – not rice (Ponting 1991: 93). Even before the explosion of wet rice agriculture in China, these innovations served to create a higher agricultural output and carrying capacity compared with Roman Europe centred on the Mediterranean Sea, both in the East and especially the sparsely populated backwater that was the Roman West.

Until the first millennium AD, both world zones had supported themselves mainly on grain products, with the Chinese sustaining a higher carrying capacity than Europe due to better agricultural practices. Even further divergence happened between 500 and 1000 AD with the spread of wet rice production in China, which has a much higher yield than grain. Per hectare, traditional varieties of rice support around 5.63 people compared to 3.67 people on a hectare of wheat (Fernandez-Armesto 2001: 105). Dry rice farming came first. However, it has a carrying capacity that is not much higher than wheat. The problem is that dry rice farming requires constant weeding (Woods and Woods 2000: 50). It was also ill-suited to the climate of northern China. In the north, millet farming in the Yellow River valley began in 6,000 BC (Higman 2012: 23). By 200 BC, the Han north was sustained by the farming of millet and wheat in an inefficient two-crop rotation. The inhospitable soils and temperatures of the Yellow River valley in the north usually permitted only one crop a year. From AD 1, wheat was immediately planted after millet or soy to increase crop frequency. In order to avoid too much loss of nutrients from repeated planting, the crop was often planted in alternating furrows, with new furrows being planted in between the old ones. The Han

plough had limited depth of ploughing. Over-seeding was sometimes used to save labour at the expense of the yield (Hsu 1980: 112–114).

Meanwhile, in southern China, rice was domesticated in 7,000 BC along the Yangtze River and by 3,000 BC, a large-scale wet rice farming was present (Chi and Hung 2010: 11–25; Zheng *et al.* 2009: 2609–2616). For several thousand years, the yield was still relatively low because farmers did not employ terracing and paddy systems. Instead, wet rice was grown beside streams and in small irrigated plots (Simmons 1996: 99). This is the reason why northern China held the bulk of the population despite a long history of wet rice farming in the south. Nevertheless, wet rice farming even without terracing and paddies was fairly productive. In the third century BC, the Qin Emperor Shi Huangdi constructed a 20-mile canal to facilitate transport of wet rice from southern China to the populous north (Headrick 2009: 43). Slowly but surely the carrying capacity was being raised. Finally, labour intensive methods of terracing and paddies caught on in southern China in AD 200 (Chang 2003: 16). The employment of a crop with much higher yields than grain and that can sustain higher population densities, might go some way to explaining the higher rate of collective learning and innovation that set these civilizations ahead of other zones in Eurasia in terms of population and cultural complexity.

At the fall of the Han dynasty, the barbarian attacks forced more Chinese south to the Yangtze River basin. The reunification under the Sui in AD 589 made the region more stable, and rice expansion and the migration of the northern population to the south continued in earnest (Ponting 1991: 93). Gradually, migration between AD 500 and 1300 transformed the agricultural output and population distributions of China, particularly intensifying in the Song dynasty (AD 960–1276). The Song government initiated a set of policies to shift agricultural production from the northern millet and wheat regions to the wet rice producing south. In 1012, the Song introduced a strain of rice from Vietnam that allowed for multiple harvests per year, or the alternation of rice in summer and wheat in winter. The government appointed 'master farmers' from local communities, who were to disseminate new farming techniques and knowledge of new tools, fertilizers, and irrigation methods. The Song also introduced tax breaks on newly reclaimed land and low-interest loans for farmers to invest in new agricultural equipment and crops (Bray 1986: 203). The Song encouraged terracing, created fields that were evenly flooded and trapped fertile silts from being washed away. In 1273, the Chinese government distributed 3,000 copies of *Essentials of Agriculture and Sericulture* to landowners in order to improve crop yields. Wet rice farming by this method produced two-three crops a year com-

pared to the meagre one-crop harvest of the millet-producing north (Headrick 2009: 51–52, 85).

The adoption of wet rice farming and the migration of many people to the south had a profound impact on collective learning in Song China. In AD 1, the population of China was around 50–60 million and did not exceed that number level until the tenth century (Faser and Rimas 2010: 118). During the 900s and 1000s under the Song dynasty, migration to the Yangzi river valley to farm rice raised the carrying capacity of China from 50–60 million to 110–120 million, with record high population densities of 5 million people farming an area of 40×50 miles (Korotayev, Malkov, and Khaltourina 2005: 186–188). By 1100, this constituted 30–40 per cent of the population of the globe, compared to all Europe's 10–12 per cent as it just entered its 'Great Leap Forward' (Biraben 1979: 16). The population was raised, so was the density, and so the number and connectivity between potential innovators was increased. This really constitutes the first 'Great Divergence' between East and West, when Chinese collective learning advanced by leaps and bounds by a much higher carrying capacity. It is no coincidence that the Song dynasty was one of the most technologically advanced and industrially prodigious societies in pre-modern history, almost to the point that the late Song dynasty could conceivably have had an Industrial Revolution of their own. For instance, the annual minting and use of coin currency was increased greatly under the Song (Hansen 2000: 264). Farming techniques improved: the use of manure became more frequent, new strains of seed were developed, hydraulic and irrigation techniques improved, and farms shifted to crop specialization (Elvin 1973: 88). Coal was used to manufacture iron and iron production increased from 19,000 metric tons per year under the Tang (AD 618–907) to 113,000 metric tons under the Song (Hansen 2000: 264). The Song dynasty was the first to invent and harness the power of gunpowder. Textile production showed the first ever signs of mechanization (Pacey 1990: 47). Some surprisingly modern innovations in Song China did not arise in conjunction with an increased population, but the eleventh and twelth century innovations followed after the initial rise of the Chinese carrying capacity between AD 500 and 1000. The adoption of wet rice farming and the migration of the Chinese farmers from the northern grain producing region to the Yangzi River valley triggered a rise in the number of potential innovators and a Great Divergence that placed China as one of the largest, densest, and most productive regions of the globe from AD 900 to 1700 – at the very least.

The second explosion of collective learning was the Industrial Revolution itself. It was born out of a collection of small innovations that were selected and spread, combining into a feedback effect that significantly increased the carrying capacity of the human species. In 1709, Abraham Darby used coke to manufacture iron, inefficiently, until tinkering made the practice efficient enough in the 1760s to be selected and spread across Britain. Henry Cort invented a process in 1784 to create bars of iron without use of coke, further increasing efficiency (McClellan and Dorn 1999: 279–281). In seventeenth century France, Denis Papin revived an invention that was known to the Romans, the Chinese, and many other cultures using atmospheric pressure, later worked on by Englishman Thomas Savery, and eventually producing Thomas Newcomen's steam engine in 1712. More tinkering and the harnessing of a steam engine to power a blast furnace for iron production in 1742 also raised production. From there James Watt tinkered with the steam engine in the 1760s making it even more efficient (*Ibid*.: 282). In textiles, the Dutch innovations using waterwheels and the Italian factory plans were brought into England and further innovated into textile production in the 1730s. Three more innovations in the 1780s – the waterframe, the spinning jenny, and the spinning mule, all built on these innovations – transformed cotton to a common commodity rather than a luxury good (Mokyr 1990: 96–98, 111). Once the steam engine was brought into these innovations, the production efficiency advanced even more. From here the steam engine was also brought in to enhance locomotion. The nineteenth century saw this advanced capacity for production and innovation spread into almost every industry and across Europe and the globe. Much of the initial practices that led to the spark of industry were familiar in medieval China, but it was these cultural variations that came together at the right time in the right place to raise the carrying capacity and produce a Cambrian explosion of further innovation (Pacey 1990: 113; Mokyr 1990: 84–85; Needham 1970: 202). In many ways, it was a matter of chance. The occurrence of variation and selection is the key to the advance of collective learning. Conditions have to be just right, there has to be an available niche, and certain cultural variations have to be able to combine to produce material breakthroughs.

V. Collective Learning and the Rise of Complexity

From here collective learning has delivered us to the increased amount of energy, production, and almost instantaneous connectivity that we enjoy today. We have split the atom, revealing for the first time a microcosm of the massive amounts of energy that have radiated for billions of

years out from the heart of the sun. We have established highly efficient forms of mass transportation, by sea, land, and air. We have seen the birth and expansion of the Internet, which ties the entire globe of potential innovators together into one community of lightening fast communication. The world's population has just passed seven billion, providing us with an increasing number of potential innovators. Provided we do not exhaust the resources of the planet in the same way that agrarian civilizations occasionally exhausted the resources of the field, we may be facing another explosion of innovation quite soon that shall look as different from the technologies of the industrial and post-industrial eras as factories and assembly lines differ from the implements of early agriculture. Collective learning not only defines our past and present, but our future as well. From this source radiates greater and greater amounts of complexity.

It is important to look at how collective learning ties into the broader Big History themes developed by Eric Chaisson and Fred Spier: the rise of complexity in the Universe and energy flows. It would appear that collective learning plays a direct mechanistic role in increasing the level of free energy rate density and also the number of available cultural variations and technological innovations. This raises the level of complexity in the Universe, just as solar, chemical, and biological evolution do.

Collective learning and rising complexity also ties into Universal Darwinism, an algorithm of random variation and non-random selection, which I have explored in other works (Baker 2011a, 2013, 2014). Variations emerge from collective learning on an unprecedented scale. By comparison, few variations emerge from the chaos of the quantum realm to the Newtonian physical realm, only about a hundred elements emerge from stellar evolution, a few thousand variations emerge from chemical/mineral evolution, millions of variations emerge in the biological realm, and in cultural evolution and collective learning the many variations of innovation are increased further still.

At each stage the free energy rate density increases, as does the magnitude of energy that can be harnessed. And it would appear that the number of possible outcomes is relative to the complexity of the process under discussion. When we arrive at something as complex as culture and modern human society, with a free energy rate density that is many times higher than the average product of genetic evolution and four million times higher than a galaxy, there are a mind-boggling number of cultural and technological combinations. Essentially, if you were to take a human brain and a brain sized chunk of a star, there is no question that the former would have a much higher density of free en-

ergy at any given time. The rate of complexity seems to increase with the number of viable selection paths.

Table 1. Amount of free energy running through a gram per second, and the australopithecine and human free energy rate density is determined from the average energy consumption of an individual (Chaisson 2010: 28, 36)

Generic Structure	Average Free Energy Rate Density (erg/s/g)
Galaxies	0.5
Stars	2
Planets	75
Plants	900
Animals (*i.e.* human body)	20,000
Australopithecines	22,000
Hunter-Gatherers (*i.e.* 250,000–10,000 years ago)	40,000
Agriculturalists (*i.e.* 10,000–250 years ago)	100,000
Industrialists (*i.e.* 1800–1950)	500,000
Technologists (*i.e.* present)	2,000,000

It would appear, for the time being, that collective learning and the complexity it bestows is the highest point in this process of which we are yet aware. There are two tiers of human evolution. The first is genetics, which operates in the same way as for other organisms. Those genes gave humans a large capacity for imitation and communication. Those two things enabled the second tier. Culture operates under similar laws, but on a much faster scale. Cultural variations are subject to selection and the most beneficial variations are chosen. Unlike genes, these variations can be transmitted between populations of the same generation and can be modified numerous times *within* that generation. Like a highway overpass looming over older roads, collective learning can blaze along at a much faster rate of speed.

We do not yet know where this tremendous capacity for collective learning will lead. It is likely to reveal even higher levels of complexity in the future, if we do not wipe ourselves out. When it comes to the broader trend in the Universe, it is fairly clear that the next rise of complexity will be down to animate rather than inanimate physical processes. As stars burn down, as planetesimals tumble through cold space, it may be that species like us, with a tremendous ability for collective learning and harnessing energy flows, will reveal even more remarkable phases of cosmic evolution. In that sense, collective learning tells us not only about human history, but about the overwhelming thrust of human

destiny in a rising crescendo of complexity. That is, if we do not go extinct beforehand. An asteroid collision, a volcanic super-eruption, or a nuclear war could wipe the slate clean. Eventually the Sun will destroy the Earth. Even in the short term, as the twenty-first century appears to deepen further into crisis, the entire arc of collective learning could come very abruptly to an end. We shall then never know where collective learning might have led us or what we might have achieved as a population of billions of increasingly educated and well connected innovators. Mankind's great task in the twenty-first century is to survive it.

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3
From Particles to Politics

Lowell Gustafson

Abstract

In this paper we investigate the gradual and uneven development in the complexity of polity, or the sustained, structured relationships that incorporate earlier ones and go on to be subsumed by subsequent relationships. This takes us from the very early and long-lasting relationships among two types of quarks to the emergence of human polity, with annihilations, extinctions, and wars as part of the often unpredictable development. Can the study of this process add to the likelihood that it will move more thoroughly through the latest transition toward the greatest known complexity in polity, or will it face the temporary or even permanent effects of entropy?

Keywords: *Big Politics, polity and natural science, Big History and politics, politics and science, Political Science.*

Big Politics is the process of emergent complexity of sustained, structured relations that began with the Big Bang and has continued in stages through today, as it may continue to do in the future. The natural sciences explain how the simplest forms of sustained, structured relationships emerged and how they gradually, unevenly, and increasingly became more complex over time (Christian 2004, 2011; Chaisson 2006; Brown 2007; Spier 2010; Shubin 2013). Relationships have become progressively complex between sub-atomic particles, atoms, molecules, cells, morphology, animals, human families, villages and cities, nations, regions and empires. Each less complex and older set of relationships is incorporated within newer and more complex ones.

From the beginning, each new combination of units exhibits new properties. One significant new property was the emergence of consciousness and self-consciousness. Exactly how matter comes to be able to reflect on itself is still not fully understood, but the ability emerged out of pre-reflective matter. With this new property, conscious beings have played a greater role in choosing among alternative, imagined futures in ways that can create or inhibit further growth in complexity.

Politics among humans are certainly different from, but also emergent from, earlier types that vastly precede the relatively brief human period. Pre-written and pre-human politics are not mere analogies for human politics nor inevitable causes of it, but its necessary antecedents.

It is not possible to study the formation of atoms 300,000 years after the Big Bang and predict from that the writing of Plato's *Republic*. It is also a misperception that there is a great divide between human and pre-human politics. Human politics, much less politics before writing, did not emerge fully blown and without antecedents. The field of political science still needs to incorporate the story that the natural sciences permit us to tell, and not to begin its study with the ancient world of a few thousand years ago or even 200,000 years ago in political anthropology. As familiar as ancient political thought is to students of political philosophy and contemporary politics to those who use such methodologies as survey analysis, the study of political science can now vastly predate those periods. The study of light, rocks, bones, and blood as well as written texts, surveys, and electoral results, tell a story of the entire past from which human politics has emerged and remains embedded.

In one way, examining the relationship of politics and nature is nothing new. The famous ancient Greek philosopher, Aristotle, wrote books such as one on *Physics* and another on *Politics*. In the latter, he wrote that humans are by nature political animals. In the European medieval period, Thomas Aquinas developed Aristotelian thought on natural law; he argued that humans were created within a politically constituted community. By the seventeenth and eighteenth centuries, such State of Nature political philosophers as Thomas Hobbes, John Locke, and Jean-Jacques Rousseau postulated human politics before or without such institutions as the state. They wanted to determine how to construct states so that they helped resolve the basic problems of human nature. The authors of the U.S. Constitution saw their political construct as consistent with nature (Kammen 2006). For all of their differences, they all saw human politics as rooted in nature. None of them had the same understanding of nature as has developed since Darwin, Einstein, Hubble, and others in recent centuries.

The emergent complexity of sustained, structured relationships that incorporate earlier ones in new combinations and with new properties is possible due to access within pockets to high quality energy. The second law of thermodynamics would lead us to expect entropy, or transitions from greater to lesser order rather than emergent complexity, which is possible in energy rich pockets. From the origins of polity until today, we can observe in certain places a process of increased complexity due to the existence in certain locations of access to energy. If we can resolve our current energy crisis in a sustainable way, and if we have the imagination, this process may continue. However, there was no uniformity in emergent complexity in the past and there is no guarantee it

will continue in the near future. In the distant future, we are virtually certain to face entropy. A narrative of humanity's common origin in Africa, life's origin from LUCA, and the Universe's origin from a singularity, may help foster greater complexity in politics among humans and between humans and our environment.

The major sub-fields of political science are often presented to students with discussions of their origins, structure, and emergent complexity. The origins of these sub-fields occurred centuries or even millennia ago. But our question here is not about the origins and development of American Politics, International Politics, Comparative Politics, or Theoretical Politics; it is about Politics. How has it developed greater complexity and become the human politics that we know today? What instruction might this provide for the future? Politics does not begin with the U.S. Constitution, the Treaty of Westphalia, or Plato's *Republic*. It began long before 1787, 1648, or 2,500 years ago. It cannot be studied only by public opinion polls since it began before any living person. It cannot be studied only by reading primary sources since it began before writing. It is not structured now just by written constitutions or by common law. Politics began long before in ways that continue to make us what we are today. Just as the past did not begin with writing or even with humans, so politics also did not begin with them. Our present and our politics emerge from much earlier antecedents that still includes them. Our well-being in the future may depend on our understanding this and acting on it. In the period since the origin of consciousness and culture, or collective learning, the persuasive narratives we tell ourselves and how we frame our stories become part of the evolution of emergent complexity.

Baryonic Matter

Sustained, structured relationships emerged quickly after the Big Bang, according to the standard view (Carroll 2012). The many complex properties that would characterize human politics were not inevitable from the sustained structure that began to develop 13.82 billion years ago (Planck 2013 Results Papers).

Perhaps, branes bounced or an infinitely hot and dense point without mass began expanding and cooling 13.82 billion years ago. It may be that nothing is always pulsating and is regularly turning into a variety of forms of something. Perhaps, we live in a multiverse with an infinite number of Big Bangs occurring all the time in ways we cannot detect or imagine. Other universes may be sharing our space or off in other locales. Or maybe our own universe has an infinite set of cycles of trillions of years (Singh 2004; Lederman and Teresi 2006; Greene 2011; Lederman

and Hill 2011; Steinhardt and Turok 2007). We used to think there was only one galaxy. Then we wondered if there were other inhabitable planets. We now know there are great numbers of both. Why should ours be the only universe? However, for now we will restrict our attention to our own universe and to the development of polity.

At the earliest moment in our universe's known history, there was little discernible structure. If there was a singularity, it is hard to see how there was any structure in a point without mass. Ordered relations among parts did not begin until almost immediately after the Big Bang. If America was one nation formed by 13 former colonies and could adopt the Latin motto, *e pluribus unum* (from many one), the universe might adopt the opposite of from one many (*multa ex uno*). Incredible variation would emerge after the radiation period immediately after the Big Bang. Increasingly complex relationships between a relative few of these varied parts began very quickly.

All but immediately after our own universe's Big Bang, when energy first congealed into normal or baryonic matter, six types of quarks appeared. Four of these quarks led extraordinarily brief lives before returning to energy; they did not go on to form more complex forms of matter. However, two of them – the up and down quarks – did form relationships as they appeared. This will be a pattern. Some things go on to participate in emergent complexity. Many do not.

At least those quarks that survived formed relationships. For a billion and one bits of matter that appeared, a billion bits of anti-matter with opposite spin did as well. When they come into contact, matter and anti-matter annihilate each other. This is a rather good thing from our point of view, since if all the matter that appeared survived, the universe would have been just too crowded to ever have developed into us. Enough matter remained after the great annihilation to eventually make a hundred billion galaxies each with an average of a hundred billion stars all have been formed by the leftovers of the great annihilation. Destruction can be very creative.

The surviving quarks did not exist in isolation; they always exist in threesomes. Their relationship is structured by the strong force that is mediated by the exchange of the charmingly named gluons. Two up quarks and a down one form a positively charged proton; two downs and an up form a neutron. Why is the strong force exactly as strong as it is and not weaker or stronger? Is it different in other universes? It is simply not known. But if it differed at all, we would not be here and neither would anything else that we know of.

Quarks do not merge into one undifferentiated blob. Each proton and neutron is constituted by two different types of quarks. They relate to

each other through the strong force, but they keep their distance as well. Relative to their own size, quarks have a rather pronounced need for personal space. Both relationship and distinct identity are part of Big Politics.

The protons and neutrons that were formed quickly after the Big Bang are with us still after almost 14 billion years. In fact, they are us, and everything else that we can see or feel. The structured relationships among individual quarks have been remarkably sustained. As inventive and creative as nature is, it also keeps certain things around for a long time. Something seems to have come from nothing at the Big Bang. That is change. Quarks can maintain their relationships for tens of billions of years. You cannot get much more of a status quo than that. We see in the epic of evolution the combination of long periods of stasis connected by periods of transition to greater levels of complex relationships. Both the status quo and periods of significant development are part of Big Politics.

About three hundred thousand years after the Big Bang, when the universe had expanded enough to cool sufficiently, the electromagnetic force mediated by the exchange of photons could structure a sustained relationship between protons and electrons. Atoms appeared. Hydrogen, with one proton and one electron, appeared in the greatest numbers. If you add up their mass, about three quarters of all atoms in the universe are still hydrogen. If you count atoms by number, they constitute about 90 per cent of all atoms. They also constitute 63 per cent of the number of atoms in your body (ten per cent by mass). As has been said, hydrogen is an odorless, colorless gas which, given enough time, turns into us (Harrison 1981).

Helium, with two protons and two electrons each, formed about a quarter of all atoms' mass that then existed (nine per cent by number). There was also a small amount of deuterium, or heavy hydrogen (one proton, one neutron, and an electron), helium isotopes, and lithium (three protons and electrons). Vast primal clouds of hydrogen and helium atoms, millions of light years across, still majestically float in certain areas of space nearly 14 billion years later. Some have gone on to form greater complexity; many have not.

Once formed, and left on their own, positively charged protons kept their distance from each other. While the strong force bound quarks together and protons and neutrons together within atoms, these atoms did not fuse. They might approach each other as they moved about, but usually swerved off, avoiding connections with each other.

We sometimes hear about an 'atomistic society'. For example, political philosopher Russell Kirk wrote that 'Individualism is social atomism; conservatism is community of spirit' (Kirk 1960). Social atomism refers to a rather asocial condition in which individuals have little to do

with each other. The analogy might be a billiard table, with hard billiard balls usually sitting by themselves, but occasionally knocking into each other, sending each other off in various directions. Atoms may be the basic building blocks; in our experience, blocks usually just sit there by themselves. We are each made of about $6.7*10^{27}$ atoms. What are we then like at our most constitutive level? Are we like the individuals discussed by Hobbes in Leviathan? Do we live our lives largely isolated from others? By nature, are we as asocial as the universe's vast majority of unaffiliated atoms? If we seek to form relationships, do we need to find ways to overcome our natural proclivity for individualism? And since we are built from atoms, is that what we are really like, all niceties aside?

But what if the story is one of emergent relationship as well as distinct identity? Recall that even the simplest of atoms – those that have only one or two protons and are still the most abundant in the universe – are each a set of sustained, structured relationships. Quarks which just moments before had not existed, started to be related through the exchange of gluons mediating a strong force. Atoms, which had not existed before the Big Bang plus 300,000 years, added a relationship between protons and electrons. Atoms are sets of sustained, structured relationships. They are the simplest of polities. At our most constitutive core, we are built more from relationships than from building blocks. Quarks and electrons are more fuzzy than blocky. Their 'hardness' comes from forces defining their relationships. What exists between things is as real as the things themselves.

Stars

But what about positively charged protons naturally avoiding each other? Two hydrogen atoms (H_2) might combine on their own by sharing electrons, but they do not fuse into helium as they float in enormous clouds. Helium did not combine with anything. One and two proton atoms by themselves would never on their own have led to us. To form larger, more massive atoms, a new set of relationships was required.

When they did form, atoms were not perfectly distributed, if 'perfect' means absolute equality. They were slightly more densely distributed here, a little less there. This asymmetry, unequal distribution, or imperfection was another very fortunate occurrence. Gravity has no force at the relatively small distances between quarks. However, the space between atoms can be just enough to let it start operating. A clump of atoms here can exert gravitational attraction on a smaller clump there. If all atoms had been equally distributed, their gravitational attraction on each other would have canceled it all out, and they would never have been drawn to each other. However, with the asym-

metry, the denser regions could start drawing in the slightly less densely packed atoms. Gravity kept pulling them together, increasing their density and heat. As they were pulled closer together, they began to spin faster like a figure skater drawing in her arms. Once sufficient density and heat developed, with atoms moving about more and more quickly, the atoms overcame their preference to stay away from each other. Hydrogen began fusing. They not only ran into each other, hydrogen nuclei could stick to each other, forming helium, with its two protons and two neutrons, all held together by the strong force.

The newly joined atoms were less than the sum of their parts. Each new helium atom weighed slightly less than the hydrogen atoms which had combined to form it. The missing matter had turned into energy. The fusion caused energy to burst out. Gravity kept trying to draw the atoms in. The equilibrium between these two forces resulted in the formation of stars.

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

Gravitational attraction between stars and dark matter formed galaxies or groupings of stars in distinct patterns. Galaxies formed relationships due to gravity in local groups and even larger patterns. The theoretical work of Fr. Georges Lemaître, confirmed by the evidence collected by Edwin Hubble, demonstrated that not only were there more galaxies than our own Milky Way, but that once they got to be further away from each other than those in the local group, they are racing away from each other. It may be that dark energy or anti-gravity is causing the galaxies to keep 'falling out' with space and the universe expanding at ever faster speeds the further from each other they are. In the long run, this may lead to the final disassociation of the universe and the end of polity. The continued development of polity within pockets of available energy is a medium-term possibility. In the long run, we and the universe may both finally succumb to entropy.

When the largest of the stars began to make iron with its 26 protons, energy was consumed rather than released. The equilibrium between

gravity and fusion was broken. Almost immediately, the star exploded in a supernova. The sudden increase in temperatures during the explosion permitted the almost instantaneous formation of all the elements with more than 26 protons per atom, all sent streaming into space at incredible speeds, often mixing with pre-existing clouds of hydrogen and helium that had been floating since the Big Bang.

Molecules

Atoms form in such a way that electrons orbit protons in shells. The innermost shell is full with two electrons, the second with eight, the third with 18, the fourth with 32, the fifth with 50. Hydrogen, with its one electron, has a vacancy sign out in its only electron shell. That shell seems to want one more electron to form a full house. Oxygen, with its eight electrons, has two in its first shell and six in its second. This leaves two vacancies in its second shell. This is a match made in the heavens. If two hydrogen atoms hook up with an oxygen atom, each sharing their electrons, each hydrogen atom can have two electrons in its only shell and oxygen can have eight in its second shell. A new relationship between atoms is formed: H_2O – water. This molecule has a new property. At the right temperature, it has the property of wetness, which did not exist before. Water, which is abundant throughout space, is not the only molecule that forms. Dozens of molecules with 2, 3, 4, 5, or more atoms evolve naturally. Many atoms due to the way electron shells work lead to the formation of these new relationships called molecules.

Not all atoms are anxious to form molecules. Helium has two electrons in its only shell and has a No Vacancy sign well lit. It is called a noble gas. Having all they need, nobility does not require additional relationships with the lesser types that are needy. Relationship added to relationship is not much part of helium's story. While hydrogen becomes us, helium often just goes floating off into space. Not everything is social. Not everything forms polity, or sustained, ordered relationships. We saw that same aloofness with four of the six quarks. A subatomic particle formed in nuclear fusion, neutrinos, are much the same. Like photons, they go shooting from stars off into space, but almost never interact with anything. They can sail through twenty miles of lead and never hit anything. It has taken extraordinary measures to detect them at all. History and polity are not built on the backs of two thirds of quarks, neutrinos, helium, or other asocial phenomena. They are indeed the rugged individualists of the universe. The story of emergent complexity in our universe is not uniform and it may not be eternal.

Earth and the Emergence of Life

After a nearby supernova shot its star dust out into neighboring space, disturbing pre-existing clouds of hydrogen and helium, gravity again began pulling together the mixture of elements and molecules. A second generation star with mostly hydrogen and helium but also with traces of heavier elements in it – including oxygen, carbon, neon and iron – eventually began shining as our Sun 4.6 billion years ago. It is not big enough to permit gravity to create densities high enough to fuse elements heavier than helium. This is good for us, since huge stars live fast and die young. Our Sun fuses 600 million tons of hydrogen each second, turning it into 596 million tons of helium and more energy than mankind has ever produced in our species' entire history.

The Sun's rate of consuming its stock of hydrogen will permit it to continue shining for a total of about, meaning it is at mid-life now. Its 4.6 billion year history has provided energy and the time for Earth to develop. Although the Sun will likely increase its output of radiation enough within two billion years to kill most or all life on Earth, it will be five billion before it turns into a red giant, evaporates the oceans and engulfs the Earth.

While gravity drew together 99.86 per cent of the total mass of the Solar System to make the Sun, the left over debris went to good use. On the outskirts of the spinning disk that eventually ignited as the Sun, these leftovers from part of the supernova started accreting through the power of gravity. Chunks of iron, nickel, silicon, and bits or gold, silver, uranium and other elements and molecules bumped into each other and stuck together. All this knocking together that created kinetic energy, as well as the radioactive decay of uranium and other such elements, made for a molten, hot planet even on its surface. As its outer layer cooled, Earth formed its own structure from thousands of molecules and the minerals they produced. Heavier iron and nickel sunk into a dense core that is still as hot as the surface of the sun. Silicon and other lighter elements rose to the top. Eventually, a thin layer made of the frothy basalt and granite could cool enough to permit land to form. Lighter and cooler outer layers spinning around denser iron and nickel produced a magnetic shield around the planet that protected it from solar winds that might otherwise blow away Earth's atmosphere.

The process of chemical evolution that had begun in space continued on Earth (Hazen 2005, 2012; Hoffmann 2012; Pross 2012). The most common elements on the surface of the earth continued to combine in many ways. Hydrogen, carbon, nitrogen, oxygen, sodium, magnesium, phosphorus, sulfur, chlorine, potassium, calcium, iron, and other elements on Earth interacted to form over 4,700 minerals. Around black

smokers at the bottom of the oceans where tectonic plates separated and mineral rich heated waters bellowed up, or on sun soaked pools of water on rocky beaches, the process of chemical evolution continued. Lipids that created films formed, eventually forming membranes. Carbon, with its four electrons in its second orbit and a total of six overall, was able to combine with many other elements, and was central to the Krebs cycle which spins off amino acids. These molecules continued to combine until they integrated membranes, metabolism or access to energy, and RNA and DNA that permitted reproduction with variation in response to environmental changes. The Last Common Universal Ancestor – LUCA – was combined in the most complex relationship in universal history to date – that we know of. The first prokaryote cells were earthlings, formed of the commonly available chemicals and elements on earth. They were also children of the universe, with elements forged in stars that had died long before. We can look to the skies where one or more enormous stars exploded billions of years ago – and to the green scum covering the local pond – to see the equivalents of our ancestors. This might bring us a sense of both pride and humility. It also may elicit a sense of intimate relationship with all of nature.

Biological Evolution

It has been said that the dream of every bacteria, the simplest of cells, is to become two bacteria. Reproduction has to be important for any species that plans on surviving, since the death of any given individual is part of the way life works. Sustained relationship is not eternal relationship. The nice thing about being a bacterium is that your dreams can come true about every twenty minutes. Reproduction with variation in response to environmental changes is a skill perfected by prokaryote cells. You just cannot argue with success. They live in virtually any setting, however extreme the condition on earth can be. From deep underground to thermal waters, prokaryotes are there. There are more bacterial cells in and on your body than there are cells that constitute your body. They help you digest food. And when you die, they will digest you. These types of cells have survived for almost four billion years. They will be on earth long after humans have vanished. Many prokaryote cells follow a plan that is not broken and does not need fixing, although they do keep adjusting to new conditions such as antibiotics. They evolve quickly, but as a group, they have not become fundamentally more complex.

However, after a couple billion years of happily reproducing at their same level of complexity, some did become more complex (Dawkins 2004, 2010; Lane 2009). About two billion years ago, eukaryote cells de-

veloped with a membrane covered kernel inside the cell in which more complex DNA was kept. It also maintained a relationship with a mitochondrial cell rather than having digested it. This provided an ability to burn carbohydrates and permits us to enjoy eating donuts.

A more complex set of relationships within the cell led to more complex relationships among cells. Films of bacteria on the surface of the ocean or accretions of them in rock like formations of stromatolites in tidal pools were steps towards multicellular life forms. Another step in multicellular cooperation came with creatures like the sponges. These are formed by the same type of cells that could still specialize in serving different functions. Some cells drew in nutrient rich water, others expelled nutrient drained water. Same type of cells; different tasks. Push these cells through a sieve so that they are separated as they fall to the bottom of a tank, and they scoot back together to form another new sponge. These are cooperative cells, not hardy individualists.

Relationships among increasingly complex body structures formed by different types of cells are seen in such examples as cnidarians, or jelly fish, first seen about 800 million years ago. They have little harpoons that can inject prey with poison, have such structures as a mouth / anus, and have two layers of tissue. Their nervous system is pretty uniformly spread out throughout the animal. Jelly fish are still around and doing fine. They have existed 4,000 times longer than *Homo sapiens* have. They see no reason to develop more complexity.

Still, there were additional mutations that worked out in the environment of the time. Flatworms introduced a body plan about 590 million years ago with a right and a left side, an up and down, and a front and a back. Sense organs were put up front, along with ganglia of nerve cells to interpret the incoming data. Chordates like the currently existing hagfish put a cord along its back to protect the flow of information from the ganglia to the rest of the body, as well as putting the mouth up front and an anus in the rear. About 525 million years ago, vertebrates started breaking that cord into bony segments, offering better protection and definition. The first animals to venture out from the seas onto land, such as Tiktalik, had wrists to help scoot on land and a neck to help look around. About 360 million years ago, the first amniotes could recreate the watery world in which reproduction had originally taken place, and start producing eggs with a protective shell and watery interior. About 360 million years ago, mammals first appeared, which had, among other things, a more complex auditory system with more parts that helped them hear better. The story of evolution is in part a story of increasing complexity of body structures, with more complex relationships among greater numbers of parts.

It is worth recalling a few things. First, part of the reason for this development was in response to the bitter competition between and among species. An arms race of those seeking to eat others and those seeking not to be eaten was good to select which individuals would survive to reproduce the next generation. Increasingly complex relationship was spurred in part by sustained relationships that were harshly competition. Conflict, even deadly conflict, can spur greater complexity. Secondly, there was no steady rise from simplicity to complexity. Five major extinction periods between 450 mya and 65 mya caused huge interruptions. This is only part of the reason why over 99 per cent of the species that have ever existed are now extinct. We may be going through a sixth (self-induced) extinction period that we hope does not conclude with our own species' disappearance. However, virtually all species, including the human one, have gone or will go extinct as the evolution of life continues.

Relations among Animals and Plants

Relationships among quarks, protons and electrons, atoms, molecules, cells, and body parts were followed by increasingly complex relations among and between species. Edward O. Wilson's *The Social Conquest of the Earth* offers a brilliant discussion of this phenomenon (Wilson 2012). From quorum sensing of bacteria to schools of fish, bee hives, ant colonies, flocks of birds, herds of bison, troops of chimpanzees, and many other examples, animals often live in groups and groups often form ecosystems.

Not all animals live in groups. Many seem to exist in splendid isolation for most of their lives, coming together just long enough for reproduction without any care for offspring after birth. Mother guppies and sharks would just as soon eat their babies. Sea turtles lay their eggs on the beach, return to the sea, and likely do not think about them after that. Crocodiles help their offspring out of their eggshell and out of the nest; after that, the offspring are usually on their own. Childcare is, of course, more of an issue for various lengths of time for many species. From weeks of care to a couple years is common. Mothers, fathers, and others are involved in different ways, depending on the species.

By the time we get to hominids, our ancestors' survival strategy and increasing sociability went hand in hand (Tattersall 2012). *Australopithecus* and its ancestors were likely more often the hunted than the hunters. They may have scavenged, eating bone marrow of leftover carcasses, but gathering fruits, nuts, tubers, and leaves likely provided a mainstay of their diet. Other than that, they tried to stay out of the way of predators. They had few natural weapons. Their teeth were no

match for those of lions. Their speed was no match for cheetahs. They had no shells for defense or wings for flight. No wonder that there do not seem to have been huge numbers of hominids, that most species went extinct, and that our own ancestors came close to extinction (Sarmiento, Sawyer *et al.* 2007). They just did not have that much going for them.

Bipedalism, for whatever reason it was adopted, did permit more use of the arms, hands, and opposable thumbs. A parent could hold a child and pick fruit all at once. But it also altered the skeleton, restricting the birth canal, making child birth that much more dangerous. This became a greater problem once the hominids' greatest weapon did finally start to develop. Brain size from *Australopithecus* to Homo sapiens tripled, with Neanderthals winning the brain size competition. (Brain size for *Australopithecus* averaged between 375 and 550 cm^3, *Homo habilis* from 500 to 800, *Homo erectus* 750 to 1225, *Homo sapiens* 1200–1750, and Neanderthals 900–1880.) It is not just brain size that is important, but how the structure of the brain develops and its size relative to body size. Hominids' enormous cerebral cortex permits the development of memory, attention, perceptual awareness, thought, language, and self-consciousness. With its development, polity emerges into politics. Hominids could not outfight competing species, but they could start to outthink them. Brains rather than brawn would eventually win the day.

But big brains come at a cost. Even with only partial brain development and soft skulls at birth, delivering children had become highly risky. To permit time for the brain to develop to maturity, grow a bony skull, and learn all that they required to survive, childhood for hominids took years. Breastfeeding and childcare-giving mothers developed close relations with offspring over long childhoods.

Child mortality was still likely high. For a handful of children to reach sexual maturity, birth would need to be given to a number more. For a species with relatively few members, the group had a strong interest in reproduction. Especially with life-spans in the 30s or so for adults who got through childhood, this meant that most or all of a female's adult life was involved with pregnancy and childcare. Working mothers were the norm. They likely provided the bulk of the calories through gathering and carried out many other important tasks. Still, they would have needed support as they did the primarily important work of getting children to adulthood so the species and the kinship group could survive. Long term relations between mothers and children and between child care-taking females and males were necessary for the large skulled hominids to survive.

It is one thing to get together briefly to copulate. That is all sharks need to do since childcare is not a problem. It is a wholly other set of problems to stay together for many years to raise children, a problem that hominids did have to figure out if they were to survive. Resolving the issues of food, shelter, and other necessities for a kinship group over years takes problem solving and relationships to a whole different level. The increased demands of a long childhood and the long term adult relations it required selected for an increased ability to figure out how to live together for many years at a time. The gender relations made necessary by being a big brained bipedal species is a root of hominid polity. Sexual politics has changed markedly recently with longer life spans and lower mortality rates. Mothers no longer spend their entire adult lives dealing with pregnancy and childcare, and have the time and energy to do much else.

As Michael Duffy, who writes within the Montessori tradition, notes that as we go through evolution,

> organisms produce fewer and fewer offspring and require longer and longer periods of care, leading to more important and deeper relationships. Fish produce thousands of eggs and rarely care for their young, reptiles produce hundreds of eggs and have only limited contact with their offspring, most mammals produce only a litter of a half dozen young and care for them for a long time through nursing, and humans have one or maybe two babies at a time and produce the most parent dependent creatures on Earth! (Duffy personal communication, May 13, 2013)

Many species have long developed their own ways of developing and maintaining relationships. Baboons groom each other, checking for parasites in the fur. Frans de Waal discusses how bonobos use sex for much the same purposes. Social primates, who were not genetically identical like ants within a colony are, developed a 'theory of mind'; they could understand each other's reactions. They could even sometimes 'feel for each other', or empathize. The law of the jungle, as de Waal argues, includes the social practices and understandings that would later be self-consciously developed into ethics (Waal 1989, 2005, 2007; Waal, Macedo *et al*. 2006).

Picking lice out of children's hair and having sexual relations has forever been part of hominid mothers' lives as well (Wade 2006). Hominids' survival strategy led to developed abilities to relate to each other. For their relations to develop, they would need to exchange a lot more than just gluons and photons. If you thought physics was hard to grasp, just try politics.

Memory, Imagination, Symbolic Thinking, and Exchange

Virtually all species remember, although in very different ways. The long childhoods in which each person remembers their period of dependency creates long term memories of caretakers. Hominid adults still remember their own childhoods and their caretakers. They remember how these important experiences were carried out by those who are now old or dead. What was so important is now gone, but remains important in memory. Memories of what is no longer may be pondered while going about present tasks.

Being able to remember what no longer is – and imagine what is not yet – is facilitated by symbolic thinking and language. Vervet monkeys will make one call for threats from above such as an eagle, another for threats in trees such as snakes, or those on the ground such as big cats (Johanson and Edgar 2006; Kenneally 2007; Bickerton 2009). When a monkey makes such a call, others in the troop look in the right direction. A screech signifying eagle causes other monkeys to look up. A sound and an expressed/perceived meaning are linked correctly, helping the group's survival. However, the monkey does not make the sound in the absence of the threat. They do not intellectually manipulate or exchange symbols.

The development of syntax or grammar and vocabulary went along with that of symbolic thought. Being able to consider words and meaning in the absence of immediately present referents, adjust them, move them around and think of alternative arrangements, was facilitated by language. Being able to communicate these ideas in novel yet understandable ways meant that new meanings could be created. With language, communication could nurture more complex forms of politics. Remembering and imagining in the absence of the referent is a source of symbolic thinking, planning, and realizing possibilities.

An important step in the road from the communication of monkeys to the symbolic thinking of hominids may have been tool-making. By over two and a half million years ago at the Gona River in Ethiopia, *Australopithecus* or *Homo habilis* was making stone tools. Other species use tools as well. Crows, wolves, chimps and others will use stones and sticks to achieve various purposes. However, the Gona River chipped tools were fashioned by toolmakers. Tool-making was added to older tool-using skills when symbolic thinking and imagination was possible due to eye-hand and brain development (Nowell and Davidson 2010; Shea 2013). Those who had emerged from nature now began to adjust what they found in nature. Hominids could begin to select what helped them survive and live better. Evolution could begin to be not only in response to environment, but determinative of it. Nature became partially self-selecting in hominids.

By the Oldowan period from about 2.6 to 1.7 million years ago, *Australopithecus* and/or *Homo habilis* had developed more sophisticated tools. By the Acheulean period about 1,650,000 to 100,000 years ago, tools had become bifacial, larger, and more varied. The oval or pear shaped tools were not only functional, they also have shapes that are pleasing to us and, perhaps, to their makers. Natural emergence had become hominids' creativity.

Adjusting nature was done in various ways. Eating meat and tough tubers was hard on the digestive track of early hominids. Cooking them made them easier to digest and taste better. Exactly when this began is not certain, although it seems to have started between 1,500,000 and 790,000 years ago with the fire altered stones at Gesherbenot-Ya'aqov in Israel. The transition from scavenging to hunting had been made at least by a half million years ago, as indicated by spear points and skeletal wounds in prey found at Boxgrove, England and Kathu Pan 1 in South Africa.

Burials indicate a new level of relationship. Other species such as elephants will clearly mourn dead members of the group. But the careful burial of the dead is a human activity. Again, exactly when this began is not clear, but there are burials from 80,000 to 120,000 years ago in Qafzeh, Israel. Here, we have living members of the group remembering the people who had died and imagining they have an obligation to them even after they die. Burial is a relationship with the dead, requiring memory of what is no longer. What is real in the present is only part of what matters. Memories of the past – kept in the electrical/chemical relationships among neurons – can be more important than the hard stuff that one can touch now in the present.

Hunters had long understood the difference between life and death. Causing an animal to bleed from wounds transformed the beast from one running through the woods to one lying on the ground. Did the hunters begin to think symbolically about the 'life' being in the blood that sank into the ground? Does the life of the body go into the earth looking for a new form to inhabit? Is the spirit of the dead animal believed to be angry at the hunter, planning to return to the surface world to make trouble if proper steps of propitiation are not taken by the hunter?

Once grave goods become included in the burials, we seem to also have imagination of the future added to memory of the past. Burial goods suggest that people thought they could indeed take it with them. Everything had a spirit: people, mountains, rivers, pots, weapons, *etc.* The life or spirit of the dead person will need the spirits of various tools or weapons in the next life. Members of the group were socially close to those now dead. They remembered them and valued these memories. They wanted to imagine that their beloved would live on, and that

proper actions by the living could help the dead live well. Ancestor worship may be one origin of religion. This seems to indicate the powerful social attachments our ancestors had with each other.

The discoveries at Blombos cave in South Africa from about 75,000 years ago include an etched, rectangular rock. A net or diamond-like design is scratched, with diagonal and parallel sets of lines. This is not just aimless doodling. This is done by a person interested in perceiving and creating patterns. What other patterns were being perceived and analyzed? Seasons? Plant growth? Movements of animals? Behaviors of fellow members of the group? Did the patterned lines have symbolic meaning of some sort in a way that etched crosses, six pointed stars, or crescents often have for us?

Shells with drilled holes were also found at Blombos. The cave is near the coast, and a diet of sea food sustained them. Did they wear the shells as a way to offer the spirits of the dead animals a place to live after their bodies had been ingested? Did they wear necklaces of shells out of a sense of beauty made possible by using or improving on what nature offers? What do these artifacts indicate about their symbolic thinking?

By perhaps 48,000 years ago, at the El Castillo Cave in Spain, an artist painted animals and designs from dots and lines on the walls. This was the case later as well at Chauvet, Lascaux, and elsewhere. The animals that were painted were not modeling for them. The artists worked from memory. What purposes did they have in painting these animals and designs underground? What were the artists thinking about the animals and designs they painted? It is hard not to speculate. Was the cave where the spirits of dead animals went to live after their blood drained from their bodies? Were these spirits looking for new bodies to inhabit? What was the meaning of the paintings for those who drew or first viewed them?

The importance of reproduction and fertility is made explicit by the so-called Venus figures found at Hohle Fels in Germany from the Upper Paleolithic period, the Woman of Willendorf from about 24,000 years ago, the Woman of Laussel from about 20,000 years ago and many others. These palm size statuettes of women with exaggerated breasts and hips may have offered comfort to mothers going through pregnancy or delivery, or had any number of other possible meanings. Whoever made the statues did so while thinking about fertility and sexuality rather than engaging in sex. These statues demonstrate symbolic thinking about sex in the immediate absence of sexual behavior (Bahn 1998; Lewis-Williams 2002; Clottes 2003, 2008; White 2003; Curtis 2007; Whitley 2009).

The evolution of music is noteworthy. The hardware necessary to transforming the waves through a medium such as air into perceived sounds in the brain began with early land dwellers feeling vibrations in their bones. Sight is great, but you cannot see around the bend or over the hill. Sound provides crucially important information. The patterns and tones of sound provide important information about the environment. Many species produce sounds as well as perceive them. Some birds will sing to announce territorial claims or attract mates. Whales and others too will sing to communicate over long distances. Sounds can convey information to others.

With the malleus, incus, and stapes as part of their auditory system, mammals became able to hear in ways that reptiles cannot. Listening to the sound waves caused by ocean waves, lion roars, chirping crickets, and howling winds all had important meanings for hominids. Hearing and responding to a dependent babies cry, parting the lips and calling 'Ma' with various inflections of tone elicited powerful responses among caretakers (Bernstein n.d.). Different sounds would have elicited other profound emotional responses, such as fear or sexual desire. Rhythmic music and drumming would have enhanced group identity during kinship groups' dances. Eventually, fife and drums communicated information and bolstered courage during battle. Campaign theme songs would identify candidates. National anthems would stir patriotism. Perceiving and making music has a long history of the relationships between animals and their environments, and animals such as humans with each other.

Symbolic thinking and imagination made combination beyond natural referents possible. A wonderful example of this is the Löwenmesch or Lion Man from Germany from about 30,000 years ago. A bipedal man's body with a lion's head was not something the artist had ever seen. This was work not from memory alone but from imagination and combination. This indicates the ability to manipulate symbols separate from natural perception. It also indicates a crucially important political ability of combining what had not yet been combined in nature.

Nature had combined much in the past through increasingly complex relationships. Quarks, atoms, molecules, minerals, cells, body parts, animal groups, and ecosystems all kept putting things together in larger and novel combinations. Now, humans could do this at a faster pace and self-consciously.

Placing value on symbols for their own sake was exhibited by early artists as well. For example, there is a beautiful ivory horse sculpture from Vogelherd, Germany from about 32,000 years ago. The artist did not try to include all the musculature of a real horse. Instead, it is an

idealized shape with a series of flowing curves. This is not so much a representation of a physical horse as an ideal one expressing a sense of beauty. The artist took delight in abstraction.

Relationships through the exchange of words, music, and symbols developed human relationships. Exchange of goods did too. This also has a long history, going back to sharing food to enhance group relations. Specialized tool production *Homo habilis* sites relatively far from sources of rock that were used indicate trade as much as two million years ago. Trading routes become increasingly extensive and established, until by 14,000 years ago the obsidian trade in the Near East and then the famous Silk Road established what some see as a central core political system.

Political Development

Kinship

The growth of symbolic thinking and exchange of goods, words, glances, gestures, musical sounds, and artistic images facilitated political development. We have discussed the importance of kinship groups. Long term bonding of childcare givers required sophisticated relationships demanding lots of exchanges. Kinship groups within a scavenger-gatherer and then hunter-gatherer economy likely became complex, but were still limited in size to perhaps fifty or a hundred persons. Larger trading routes would have permitted development of complexity of relationship. Family groups needed to exchange offspring for mating in the next generation. This led over generations to complex sets of inter-kinship relations.

In kinship relationships, lineage is important. Loyalties are to caretakers and common ancestors. Family and kinship remains important in our own day. The powerful resonances are indicated by larger groups attempting to appropriate kinship relations. Nationalists sometimes have referred to their country as a Motherland. In the United States, George Washington is referred to as the 'Father of the Country'. Larger, non-lineage groups often seek to call upon the powerful forces of kinship. One of the values of Big Politics is its scientific story of the real lineage of all persons, going back to a small group in Africa about 200,000 years ago; of all life to LUCA, and the Universe to a single point. It turns out that we really do all have a common background. Big Politics is the scientific story for a period of Human Politics.

Agriculture and Villages

One of the major thresholds of Big History is the Agricultural Revolution. The transition from hunting and gathering to growing crops and raising certain animals is of crucial importance. It also entails a stage of

political development (Wenke and Olszewski 2007). Hunting-gathering went along with kinship polities. With agriculture came the emergence of chiefdoms and settled villages of increasing size, beginning to include different kinship lines. This presented the village with an enormous political problem: how to establish a sustained, structured set of relationships beyond kinship.

One way to do this was to create dynasties; village lineages that all could be persuaded or forced to adopt. Lineage now became a symbolic political category rather than a biological one. In many regions of the world, mounds and other monumental burial sites enshrined the lineage of the village. Those within one lineage might still have the right to rule, but all needed to exchange the symbols that helped nurture loyalty to it.

The political leaders of these settlements or villages during the early agricultural era were sometimes those who had access and control over the best growing areas. We start to see increased social stratification and inequalities in wealth as the agricultural era proceeded. Some residences and some graves are noticeably grander than others. Hierarchy in the hunter-gatherer era was more likely based on strength, size, or cunning. In each period, leadership could also be exercised by those whom we call shamans, or those who could impress their fellows with their special insights and relationships. When some went through fasting, whether by choice or necessity, carried out rhythmic dancing while listening to repetitive rhythmic music, added various hallucinogens, and perhaps inflicted self-flagellation, they likely could report any number of special insights and experiences. Shapes would have shifted, experienced as traveling in other realms. These were similar to dream-like states. Dreams while sleeping and trances while awake offered symbolic connections with what was beyond normal referents. Imagined relationships with abstract designs, ancestors, and the supernormal by some could have impressed others and established a claim to leadership.

Village identity could be developed and expressed through styles of clothing, certain verbal expressions, or other identifiers. Stories about the village could be told at gatherings. It took enormous effort and creativity to incorporate loyalty to the family within loyalty to the village.

Cities and Empires

Monumental, ceremonial architecture reinforced the claim by some of symbolic leadership that legitimized claims to leadership. Leaders may have preferred subjects to stand in awe not directly of the universe, but of the leaders' special connections with it. From Watson Brake in Ouachita Parish in Louisiana from about 5,400 years ago to Imhotep's Saqarra in Egypt about 4,700 years ago, grand burial sites began to announce

the emergence of full time leading families. Large, stylized burial mounds called attention if not of the gods, at least of the humbled onlookers who stood before them during ceremonies. Equivalents in modern America are the tall, stiff obelisk in honor to the Father of the Country, or the Jefferson or Lincoln Memorials in which political pilgrims can stand reverently in front of larger than life leaders who have mythical meaning and personify the presidential succession that leads to the current national leader.

Large, monumental architecture also announces the emergence of new political units of cities with larger populations and relations of cities within regional associations and nations or empires. The great ancient cities represent a transition to larger, more complex political units. Sometimes these became the hubs of empires; sometimes they were combined with other cities within empires. The modern European empires were transformative through their incorporation of the Industrial Revolution. The British, French, Dutch, German, and Japanese empires were built from steel, oil powered ships, railroads, and gasoline powered vehicles. The Russian and American empires combined these in the Information Age with nuclear power and nuclear weapons.

Empires have survived for various lengths of time, sometimes lasting for a number of centuries. Imperial overstretch often exhausted them. This happened most recently with the Soviet empire, which broke up as many of its satellite states gained independence. It may be happening now with the American empire, with a state that is quickly becoming hopelessly indebted. Hundreds of US military bases add to a military budget that is equivalent to those of the next twenty states combined – and to US budget deficits that, along with entitlements and the interest on previous borrowing, add to the skyrocketing of American borrowing.

The struggles for power within empires and between some of them are the stuff of traditional history. The endless lists of battles and army flanks can make for a depressing account of the human past. Homer's account of the Trojan War is heroic enough, but it is also just another deadly battle scene. And things do not seem to have improved much. We started the twentieth century with a war to end all wars, followed by a horrific Second World War twenty years later. Since the end of WWII, there have been about 250 wars with over 50 million people killed, tens of millions more wounded, and countless made homeless.

Big Politics?

What will replace America's unipolar moment after the end of its empire? Will it be replaced by another empire? A return to a multipolar world such as existed in Europe in the nineteenth century? Are we with-

in a transition to a new level of complexity which incorporates relationships among quarks, atoms, molecules, cells, body structures, families, villages, cities, nations within a more closely related humanity within our common environment?

Some find hopeful evidence for such a transition occurring. The research into missiles starting in the Second World War and continuing through the Cold War is responsible for much of the technology that produced the Earth Rise photo, a banner for globalism ever since it was first taken by astronaut William Anders in 1968 during the Apollo 8 mission. Steven Pinker argues in *Our Better Angels* that we have experienced a promising trend of decreasing use of force. Humans are indeed capable, he argues, of exercising their self-control, empathy, morality, and reason. We have seen the emergence of government claiming a monopoly on force and violence. Many regions of the world have robust trading and financial relations. We have seen increased literacy, urbanization, mobility, and access to mass media. These have led to greater familiarity among cultures. There has been some increase in the rule of various forms of democracy. As bad as the many wars since 1945 have been, there has been no civilizational ending nuclear war. Twenty years separated WWI and WWII; we have gone 68 years since WWII without any WWIII. There is no reason for complacency yet, of course. It was a century between the Napoleonic Wars and WWI; so we have yet to equal the successes of the nineteenth century. Still, there maybe come collective learning about how to keep the peace.

The threat of environmental degradation, pollution, and climate change may have become more pressing that the threat of war. Decreasing reserves of fossil fuels and the carbon emissions from the use of those we have combine in an energy crisis. If this crisis cannot be solved in a sustainable way, the consequences could be negatively transformative. On the other hand, within the past generation, environmental concerns have gone from marginal to central for great numbers of people.

The hopes of those who established the United Nations frequently seem illusory, given that body's actual performance since the Second World War. Yet, the nations of the world continue to belong to it and even make productive use of it at times. We are very long way from a world government, but also a long way from international anarchy.

Where are We Going?

What can we conclude from our 13.82 billion year journey so far in this Universe? The access to high quality energy in certain pockets has permitted increased complexity in relationships between quarks, atoms, molecules, cells, animals, and humans within families, cities, nations,

empires, and the world. Each of the earlier relationships continues to be part of our current ones, although often in transformed ways. You and I are the beneficiaries of the relationships that have been developed. We are made from the relationships among quarks, atoms, molecules, cells, and many intricately related body parts. We live within kinship groups, nations, and empires. Many of us are connected with others around the world through the almost instantaneous exchange of digital information. We have evidence for a common origin of all of us and indeed everything in the universe. All of us on earth have a common origin and we may perish together in a species wide extinction; all of life on earth will quite certainly come to an end together as the Sun becomes a Red Giant.

Will we continue to have access to high quality energy and remain as the pockets which continue to develop the most complex relationships of which we are aware in the universe? Can we use this energy without polluting our world and making it uninhabitable? Even if the energy crisis is resolved in a sustainable way, do we have the imagination to combine national, ethnic, and other types of groups within new and meaningful relationships? Can we be as creative as nature was earlier when it first combined protons and electrons, atoms in molecules, molecules in cells, cells in plants and animals, and animals in various groupings? Can we be as imaginative as the artist who carved the Löwenmesch, imagining the combination of lions and people? Or the shaman who imagined how to combine kinship groups in the village? Can the study of Big History be formative enough to teach us how to combine families, ethnic groups, cities, nations, empires, humans, and our environment in ways that protect all of them? Can this be done even while there are many in less complex relationships who show little or no interest in participating in Big Politics, who are satisfied with staying at their level of complexity? Can enough people make the transition to the next level of complexity? Can we fashion a more complex sustainable, structured set of relationships? A new Big Politics?

Or will entropy overtake us before it needs to?

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4
To See the World in a Building: A Little Big History of Tiananmen

Esther Quaedackers

Abstract

This article is about Big History. Yet it is also about something that is, at least as seen from a Big History perspective, very small. It is about one single building, which is now called Tiananmen. It is tiny when compared to many of the other structures Big History deals with, and it has been around for only a fraction of the time that has passed since the Big Bang. Big History will be combined with an analysis of this specific building by linking Tiananmen to aspects of three major phases in Big History: inanimate history, the history of life, and human history. These kinds of combinations have become known as Little Big Histories. Although Little Big Histories can seem a bit odd at first – after all, what could for instance the history of our universe possibly tell us about Tiananmen and vice versa? – Little Big Histories can help us understand both Big History and the small-scale subjects they deal with in new and unexpected ways.

Keywords: *Little Big History, Tiananmen, architecture, animal building.*

Little Big Histories can enrich our understanding of small-scale subjects and also the grand narrative in two ways. One, it connects the rather small to larger processes that have shaped cosmological, biological and human history. Two, it enables us to comprehend how even the seemingly most mundane subjects have been influenced by far-reaching historical processes and in some cases have influenced those very processes. In the words of the English poet William Blake, this can help us 'see a world in a grain of sand, and heaven in wild flower' (Blake 2004 [1803]: 15). It can lead to a different kind of appreciation for the small-scale subject that is being analyzed. For instance, in many cases our appreciation for a grain of sand changes after realizing how the sand grains constituents were cooked in the centers of stars, how its minerals travelled through the Earth's mantle, over its surface and perhaps even through the guts of earthworms before being described by a human being in a poem (Zalasiewics 2010: chs 1–3 and Hansell 2007: 32). The sand grain stops being 'just' a sand grain, and becomes something that inspires awe and triggers curiosity. This is one way in which Little Big Histories can change our understanding of the particular subjects they study and of Big History in general.

A second way in which Little Big Histories can change our understanding of both Big History and the small-scale subjects they deal with is best explained with the aid of a short history of the Little Big History approach. I first developed Little Big Histories in 2007 as an assignment for students in the Big History courses I have been teaching for the past years together with my colleague Fred Spier.[1, 2] I asked students to link a subject that interested them to an aspect of each lecture in their Big History course.[3] As a consequence, students started to write about the connections between their chosen subjects (*e.g.*, beer, quantum computing, or the Mona Lisa) and the lectures (*e.g.*, the Solar System, the origin of life, or human evolution). Once they are past the initial confusion ('are you serious you want us to do that?') most students have a lot of fun. Moreover, the ability to recognize abstract Big History concepts in subjects that students cared about helped many of them to understand these concepts better. And, perhaps most importantly, because students were able to see all kinds of connections they had not realized existed, they started to see how rich and remarkable their subjects really were. As a result, they started to ask more and more questions about them. Some students even started to ask questions that few people had ever asked before. In a way this was not surprising, because students were looking at their subjects in ways few people had ever done before. This made it easy for them to discover questions that had been previously overlooked by other scientists and scholars and made it exciting to look for corresponding answers.

This is not only the case for students. Little Big Histories allow anybody to explore the uncharted territories of the sciences and the humanities with greater ease. For this reason, the Little Big History approach cannot only be used as a stimulating pedagogical tool, but also as a fruitful research method that can reveal new things about small-scale subjects and Big History, and therefore change our understanding of both.

Perhaps partly for this reason, over the past years a handful of scientists and scholars have begun to use something quite similar to the

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[1] Fred has been tremendously helpful during these past years, while I was trying to figure out how to teach and research Big History in my own way. This article has also been greatly influenced by his book on Big History (Spier 2010).

[2] Although I first came up with the idea for the Little Big History approach, Fred later coined the term 'Little Big History'.

[3] A somewhat similar approach was developed around the same time by Jonathan Markley for his Californian students. At the 2010 conference, Jonathan told me he was asking his students in a history of food class to trace back one food product as far as they could in time. As a result, his students were also trying to link a subject of their choice to several major phases in Big History, albeit in a slightly different way.

Little Big History approach, often without calling their work a Little Big History. For instance, in 2002, astrophysicist Lawrence Krauss published a book called *Atom: A Single Oxygen Atom's Journey from the Big Bang to Life on Earth... and Beyond*, a title that speaks more or less for itself (Krauss 2002). More recently paleobiologist Jan Zalasiewicz published *The Planet in a Pebble: A Journey into Earth's Deep History*, a book that describes how different characteristics of a pebble have been shaped by billions of years of history (Zalasiewicz 2010). And my Big History colleague Jonathan Markley is currently working on a book on grasses as seen from the perspective of Big History, based on his 2009 article 'A Child said: "What is the grass?": Reflections on the Big History of the *Poaceae*' (Markley 2009). In this article he describes how different orders of grasses have rivaled each other for world dominance and shaped human history while doing so. These studies are wonderful eyewitness accounts that provide a fresh perspective on atoms, pebbles, and grasses and on the history of everything.

The existence of such studies indicates that in a sense, Little Big Histories are not new. Yet so far, they have not been used for in-depth studies of subjects that, unlike atoms, pebbles and even grasses, have not been around for a significant portion of Big History. They have not been used for in-depth studies of subjects like Tiananmen, which has been around for only six centuries or so (Zhu 2004: ch. 2).[4] For such a subject, the eyewitness approach that has been used in the previously mentioned publications will not work. Surely, it would be possible to write a fascinating novel by having a subject like the gate tell us what it saw, heard and felt over the past centuries, but because its experience would only cover the final fractions of Big History, its account would not really be a Little Big History. To study a subject like Tiananmen, a different approach that links the building to periods in time in which nothing like human buildings or even building behavior in general existed is necessary. Over the years, such an approach has been tested by hundreds of students, but it has not been used to write a more extensive research article yet. This article on Tiananmen is therefore a bit of an experiment, that aims at testing the limits of the Little Big History approach by tracing to roots of the gate all the way back to the beginnings of Big History – the Big Bang.

[4] When the gate in the Beijing's southern imperial city wall that is now called Tiananmen was first built six centuries ago, it was actually called Chengtianmen and looked rather different than Tiananmen as we know it today.

Fig. 1. Tiananmen, photographed in 2009. *Source:* Wikimedia Commons

Tiananmen and the History of the Cosmos, the Solar System and our Planet[5]

During the first fraction of a second after the Big Bang, the fundamental forces emerged. These forces split off from one grand unified force that had existed right after the Big Bang. Gravity went its own way first. The strong nuclear force split off a bit later. And the weak nuclear force and electromagnetism split up last (Chaisson 2005: ch. 1). Gravity and electromagnetism are particularly relevant for this story about Tiananmen. In fact, any building, including Tiananmen, can be seen as a precarious balancing act between these two forces.

Gravity makes sure that masses attract each other. The strength of attraction between masses is dependent on the amount of mass involved in the attraction. As a result, gravity works on large scales and is responsible for creating stars and planets and for keeping them together, amongst other things. Electromagnetism is much stronger than gravity. It makes sure that opposite electrical charges attract each other and that similar electrical charges repel each other. Yet despite its higher strength, electromagnetism works on much smaller scales than gravity, because electromagnetism leads to a rather homogenous distribution of charges that cancel each other out. The electromagnetic force is responsible for creating and keeping atoms, molecules, and groups of molecules together (Trefil and Hazen 2010: 282).

[5] While trying to connect Tiananmen to the history of non-living things, to the history of life and to human history, I have not focused on all the important processes that have taken place during the 13.8 billion years that have passed since our universe first emerged. Instead, I have been selective and have only discussed things that seem most important for my subject. I think this is a necessary strategy for people writing a Little Big History; after all, not all things are equally interesting for every subject.

Buildings are smaller than the scales on which gravity exerts its greatest influence, and bigger than the scales on which electromagnetism generally works. It is not possible to build without both of these forces. But if the influence of gravity becomes either too great or too small compared to the influence of electromagnetism, building becomes difficult as well.

It is probably quite obvious that both gravity and electromagnetism were required for building Tiananmen. Without gravity, the elements from which Tiananmen is built, like the silicon and oxygen on the planet, bricks, plaster, and tiles and the carbon and oxygen in wood would not have been concentrated on Earth. Instead, the predecessors of these elements would still be floating around in space, more or less by themselves, not meeting their fellow elements most of the time.[6, 7] Gravity alone is not enough to build though. Earth would have been a rather boring place had it not been shaped by electromagnetism as well. The electromagnetic force made sure that silicon and oxygen and in many cases some other elements as well combined into silicates, that these silicates formed into minerals like, for instance, feldspars and that people were able to glue these minerals together into bricks and even the plastered brick walls and vaults that characterize the base of Tiananmen (Hazen 2012: ch. 5). Likewise, it ensured that carbon and oxygen combined into carbon dioxide, it enabled life to use this carbon dioxide to synthesize organic molecules like lignin and allowed lignin to bond with other organic molecules like cellulose and hemicellulose to form the complex molecular structures that give the wooden post and beams in Tiananmen's gatehouse their strength (McDonald and Donaldson 2001: 9612–9615). Without electromagnetism, no strange clumps of matter protruding from the Earth's surface like Tiananmen's base, Tiananmen's gatehouse and a whole range of other objects would have formed and the Earth would have remained a rather featureless sphere.

It may be less obvious why the influence of gravity cannot become too great or too small when compared to the influence of electromagnetism in order to be able to build. A thought experiment may help. Imagine trying to build Tiananmen on a planet very similar to Earth, but with a higher mass, like on one of the recently discovered Gliese 667C super-Earths, that circle a nearby star some 22 light years away from us (Science Daily 2013). On such a planet, the effect of gravity would be

[6] The word 'predecessors' is used here, because without gravity, elements like carbon, oxygen and silicon would not have existed, but their predecessors, hydrogen and helium, might have.

[7] After all, on average our universe is rather empty, containing only one proton per four cubic meters (NASA 2013).

stronger, which would allow the gravitational force to break down some crucial electromagnetic bonds and to cause the collapse of large parts of Tiananmen. It would be particularly easy for gravity to overwhelm electromagnetism in places where both forces work in opposite directions. For instance, this is the case with Tiananmen's gatehouse, which consists of an elegant post and beam structure topped with a tiled roof. The higher weight of this structure on one of the Gliese super-Earths would lead to a greater curvature in its beams. This would mean that in the base of the beams, bonds between molecules would be ripped apart by the effect of gravity. If too many of these bonds would fail, the beams would crack and the roof structure would disintegrate.

A way to prevent such a collapse would be to make sure that gravity and electromagnetism work in the same direction. This is what the Chinese builders aimed for when they constructed the vaulted passageways in Tiananmen's base that provided access to the imperial city north of Tiananmen. These builders tried to make sure that the shape of their construction matched the natural distribution of forces within the construction. The result of such a match was a structure dominated by compression stress, or, in other words, a structure in which both gravitational and electromagnetic forces were trying to keep together the materials the structure was made of.[8] Tiananmen's builders partly used this strategy because the base of Tiananmen mainly consists of silicon oxygen minerals, in contrast to, for instance, the wooden gatehouse which mainly consists out of carbon oxygen compounds. Silicon is chemically quite similar to carbon but it is a lot heavier. Therefore, the effects of gravity are stronger within silicon-based structures, which make it easier for gravity to overwhelm electromagnetism if these forces work in opposite directions.

The strategy to align gravitational and electromagnetic forces within constructions in order to prevent collapse was not only used by Tiananmen's builders, but is used by many other animals that build with earth or rocky materials as well. Of course, most of these animals do not build elaborate arches, vaults or domes the way humans do. Instead, they burrow.[9] Burrowing seems to be the default strategy for building with earth or rocks and is used by many arthropods, fish,

[8] For a nice interactive explanation of how forces are distributed within stone arches, see the Nova site Physics of Stone Arches (PBS Learning Media 1996).

[9] It could be argued that animals like mud daubers or certain types of swallows and martins build something resembling domes in a human-like way (Hansell 2000: 64–67). The technique these animals use is a bit different from human dome-building though, because they rely more heavily on sufficiently strong electromagnetic bonds to keep their structure together than on gravity.

birds, and mammals (Hansell 2007). It enables these animals to 'accidentally' create vaults and domes by excavating the space below these arched roofs. Burrowing may be a better option for most animals than actually building vaults or domes because burrowing is technically easier than constructing the arched roofs themselves. The latter task can be quite complex, partly because arch-shaped structures often are not stable until a keystone or similar object is put into place. Only after that is done, the gravitational forces within the structure line up with the shape of the structure, resulting in a structure dominated by compression stress. Before a keystone or something similar is put into place, however, additional support may be required to prevent the incomplete structure from collapsing. This construction process may therefore require an ability to plan ahead that many animals do not seem to possess.[10] They may therefore have few other choices than burrowing when it comes to building with earth or rocks, even though burrowing has important drawback when compared to constructing the vaults and domes themselves. In many cases, burrowing requires the movement of more materials than building vaults or domes does, and therefore, requires more energy, simply because the interior of a vaulted or domed structure is usually more voluminous than its surrounding shell.

Following the examples set by the builders of Tiananmen's base and by burrowing animals, builders on one of the Gliese super-Earths would probably be able to build something. Yet their options would be much more limited than they are on Earth. This raises questions about the possibilities for building on planets where the effects of gravity are less strong than they are on Earth, like on our sibling planet Mars. Would the potential for building on such a planet be greater, leading to the development of buildings our own planet's inhabitants can only dream about?

Perhaps, it would, but there is one catch. When the influence of gravity becomes too small compared to the influence of electromagnetism, building options increase but building incentives may decrease. To understand why, it is necessary to first consider what building actually is. Many dictionaries mention that building involves assembling materials to form a structure, but these definitions miss an important point.[11] Building involves assembling materials to form a structure that

[10] Animals probably do not need large brains to build in general: Mike Hansell has demonstrated in various books and articles that they really do not and can often evolve all kinds of hard-wired complex building behavior. Yet the ability to build arches, vaults and domes in all likelihood does not evolve easily, because the stages leading up to an arch, vault or dome would be useless as they would easily collapse.

[11] For instance, according to the New Oxford American Dictionary app, building is 'the process or business of constructing something'. According to Merriam Webster, build-

its builders can easily leave behind. Such a definition excludes structures like body parts that organisms usually assemble by growing and not by building. One could argue that it also excludes clothing. The definition does include many kinds of webs, nests, tools, roads, dams, bridges and 'regular buildings' that are normally considered to be built by humans and other animals.

So how does this definition relate to the idea that the incentive to build is stronger when the influence of gravity is sufficiently strong? If the effects of gravity are sufficiently strong, it makes more sense to leave a structure behind. After all, even though in such situations a lot of energy is required to assemble a building, even more energy is required to carry it with you all the time. If, in contrast, the effects of gravity are not that strong, carrying a structure around becomes a more sensible option. Carrying a structure around makes it much easier to reach and use the structure when needed. This benefit may outweigh the costs of having to carry a structure around, especially when those costs are fairly limited.

When it comes to building on Red Planet, this may mean that even though hypothetical builders would have the option to build something like Tiananmen, or even a much more fantastical version of the gate, incentives to do so might be lacking. Instead of buildings like Tiananmen, builders might prefer portable structures. Organisms that rely on biological evolution to adapt to their environment would, perhaps, grow such structures instead of building them. After all, that is what many animals on Earth do. They grow furs to protect themselves from harsh climates, instead of building a structure that keeps the cold out. They grow spikes, venom producing organs, or fast legs to defend themselves, instead of building structures that protect them from their enemies. They grow powerful beaks or claws to catch prey instead of building traps. And they grow colorful feathers to impress members of their own species instead of building 'monuments'. For organisms that rely on cultural evolution to adapt to their environment, the situation might be slightly different. Because through cultural evolution, such organisms might be able to build structures faster than growing ones (given that one process happens well within a lifetime and the other over millions of years of evolution), they might actually prefer such built structures and construct the hypothetical Martian equivalent of armor and all kinds of easily transportable tools. Like those theoretical organisms of Mars that

ing is 'the art or business of assembling materials into a structure' (Merriam Webster 2013). And according to Collins English Dictionary, building means 'to make, construct, or form by joining parts or materials' (Collins Dictionaries 2013).

rely on biological evolution though, builders would probably prefer portable structures over buildings like Tiananmen.

Of course, it goes without saying that this thought experiment involving building on a Gliese super-Earth and Mars is rather speculative. Nevertheless, it helps to elucidate some fundamental concepts that have had an enormous influence on why building is the way it is on Earth. A few examples of such Earthly building behavior, like burrowing, have already been mentioned. But there is much more to explore. In order to do so, the history of life on Earth will be discussed next.

Tiananmen and the History of Life

On our own planet, the incentives to build, caused by the sufficiently strong (but not too strong) effects of gravity, are particularly critical in three specific situations.

Protection

First of all, building seems to be particularly useful in some circumstances when protection from enemies is vital. This may be the case because protective structures need to be quite heavy to function properly. For instance, structures that are too light can be easily picked up or cracked by predators and other opponents. Heavier structures are much safer. But they are also much more difficult to move around. It is therefore a big advantage if they can be left behind, for instance, when an animal needs to go on a foraging trip or needs to go out to find a mate. Heavy protective structures that are fixed to an animal's body and cannot be left behind would severely limit such endeavors. Snails and tortoises, for example, seem to be hampered in their movement by the shells and carapaces they carry around. It is, therefore, not surprising that many of these animals are so slow.[12]

This may partly explain why, if animals build something, they usually build protective structures and not much else. Only humans and certain invertebrate species, most notably spiders and certain larvae, build traps (Hansell 2007: 149–150). Hardly any animals, with the exception of humans, chimpanzees, birds like the New Caledonian crow and again certain spiders, build tools.[13] And just two animal species, hu-

[12] The fact that tortoises and snails carry around a carapace or shell may not have caused them to be slow. Instead, a reduced need to move around, slower metabolic rates and carapaces or shells may have evolved together.

[13] There are several more species that use tools, such as gorillas, certain monkeys, dolphins, and several insects. Yet these animals do not really build them; they just use sticks, rocks or other objects the way they find them and do not modify them in any way (Hansell 2007: ch. 7).

mans and bowerbirds, build ornamental structures (Hansell 2007: ch. 8). The fact that most animals do not build such things is often attributed to a general lack of cognitive capacities. Yet that argument may be too simplistic. It cannot account for the fact that many of the most complex traps and tools are built by organisms that do not seem to possess advanced cognitive capabilities. For instance, the complexity of traps built by the tiny sea-squirt *Oikopleura dioica*, that look like mucus houses containing inlet funnels and different kinds of filter nets, seems much greater than tools and traps built by early humans (*Ibid*.: 69). So, perhaps, something else is going on. Perhaps, in many cases only protective structures are sufficiently important for an animal's survival to assemble and leave behind. Many other structures that are important to animals, like traps, tools, and ornaments, can be lighter and therefore carried around all the time. If there is no need to leave such structures behind, in many cases it may be a better option to grow such structures than to build them. After all, through biological evolution animals are able to synthesize better materials for such structures than materials that are available in nature to build with, such as woody or rocky materials. Wood decays easily and must therefore be protected, while rocky materials are heavy and crumble, and therefore often require gluing them together in one way or another. Grown structures often consist of materials that are better adapted to their function. Of course, not all animals are willing to wait until biological evolution provides them with suitable structures that enable them, for example, to catch prey or impress a mate. For animals that can adapt to their environment a lot quicker with the aid of cultural evolution, building traps, tools and ornaments can be a good option. Yet there seem to be few animal species besides our own capable of this type of evolution.

Frequently staying in one place

Building is often worthwhile when animals frequently stay in one place. In such situations, it is not necessary to spend a lot of energy just to reach a building that has been left in a specific place. As a result, using the building is cheaper in terms of expended energy. This consideration may have led to the building behavior in animals that stay in one place while metamorphosing or hibernating. It also may have contributed to the development of building in species that are caring for immobile young or attending to the needs of a eusocial colony. Perhaps, it may even mean that animals that roam large areas to find sufficient food or suitable mates will be less inclined to build. After all, if, due to large territories, animals cannot return to a building frequently enough, what is the use of building in the first place?

Thinking about the way animals use their territories may have implications for ideas about the origin of human building in general, and about human tool building in particular. Evidence indicates that when our Oldowan ancestors first started to build stone tools, they left clusters of them in specific places. It has been suggested that these early humans partly did so because the places where such tools were left served as centers where food could be processed, thus preventing them to have to carry their heavy tools with them all the time (Potts 1991, 1994). This suggestion fits in quite well with the idea described above and may partly explain why our Oldowan ancestors started to build tools whereas very few other animals did so. Unlike other animals, they had come up with a way of using the landscape that maximized tool use potential. Ultimately, this may have enabled them and later members of the genus *Homo*, including ourselves, to use building in a more flexible way than any other animal does, by creating different types of traps, tools, and protective and decorative structures, positioning them in well thought of places and using them when needed without too much hassle. According to paleoanthropologist Richard Potts, such flexibility may well have been one of the reasons why our ancestors survived the rapid climate fluctuations that are characteristic of the Pleistocene, whereas many other animals, including hominin species who probably did not use tools, such as our robust *Paranthropus* cousins, went extinct (Potts 1996: 121).

This tale about human evolution is relevant for Tiananmen in three ways. First of all, obviously, building anything like Tiananmen is impossible without the varied and elaborate set of tools humans eventually developed. Secondly, if the hypothesis about early human building behavior is correct, such behavior may have contributed to types of spatial thinking that have been extremely important during the conception and construction of the gate that would later become known as Tiananmen. After all, Tiananmen is not just a gate, but part of a carefully laid out city plan in which different parts had different functions and symbolic meanings (Zhu 2004: ch. 2). Thirdly and most importantly, the fact that humans started to use their built structures in more and more varied and flexible ways could well be one of the most distinctive features that separates human building behavior from animal building. It may have given human building a unique dynamic that has helped shape Tiananmen in critical ways. This dynamic will be explained in more detail in the part of this article on Tiananmen and human history.

Once animals start to stay in one place more frequently, whether to create and use tools or to metamorphose, hibernate, care for offspring, or attend to the needs of a eusocial colony, protection often becomes

more vital. Such animals may otherwise become easier prey or targets. This also works the other way round – at least when adding building to the mix. If protection is vital, building a protective structure is a good survival option. Once such a structure is in place, animals are likely to stay there more often, especially when animals start to 'store' things in their structures like young or food sources. Staying in one place can make protection more vital, and, alternately, building out of greater need for protection can make animals stay in one place more frequently. In some cases a positive feedback loop may have emerged that may have stimulated evolution (*e.g.*, insect cocoons, birds' nests, rodent burrows and beaver lodes). It may also have helped trigger specialization among members of some social species.[14] After all, it is difficult, and perhaps even impossible, to support individuals that have specialized duties beyond gathering or producing food without having a fixed and protected place where food can be stored or grown for them. Specialization, either in the form of a simple differentiation between reproducing and non-reproducing community members, or in the form of more elaborate distinctions between all kinds of workers, soldiers, and royalty, only seems to have emerged in social animals whose ancestors were in all likelihood already building defensible structures in which they stored, grew, or had direct access to ample amounts of food.[15] Examples of such animals include termites, members of the hymenoptera family like eusocial wasps, bees and ants, certain types of beetles, shrimps and mole rats, and, of course, humans living in sedentary communities. It is interesting to note that such specialization, in turn, seems to have stimulated large-scale building projects. The world's most elaborate building complexes, such as termite mounds that are about twice as high to a termite as the tallest building in the world is to us. Elaborate imperial cities, like the one Tiananmen used to be a part of, are all built by animals that created specialized roles for some members of their communities.[16]

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[14] Specialization based on gender differences is probably the result of very different processes.

[15] For instance: termites seem to descent from type of sub-social roach that lived in and off nests in trees (Korb and Heinze 2008: 162), eusocial hymenoptera in all likelihood descent from groups of primitive hymenoptera that collectively build defensible and valuable nests (Nowak, Tarnita, and Wilson 2010: 1062), *Austroplatypus incompertus* is a member of a family of social beetles that live in nests in trees in which they 'grow' fungi they eat (Choe and Crespi 1997: 181–215), the shrimp *Synalpheus regalis* lives in group nests in sponges it eats (Duffy 1996: 513) and certain mole rats live in group burrows in which they store tubers (Jarvis and Bennett 1993: 253).

[16] This estimate is based on data from Hansell (2007: 93).

Conspicuous consumption

At least in human state societies, specialization has led to a third situation in which building seems to be particularly useful. Building seems to be a good idea when the costs of building, imposed by gravity amongst other things, can be used to affirm certain privileged positions within a society. People in such privileged positions are often able to command large energy flows and in order to show off this ability to the people around them, they sometimes consume parts of these energy flows conspicuously (Veblen 2008). There are several ways to do so, but building can be a very good option, partly because it requires so much effort to lift and move large amounts of often heavy materials. For instance, Ming emperors made sure that the pillars of the most important buildings in Beijing's imperial city were made out of gigantic trunks of precious Sichuanese hardwood, which had to be transported over thousands of kilometers to Beijing (Barmé 2008: 32, 33 and 159). Likewise, the floors of the most important halls and gates in the imperial city were made out of valuable 'gold bricks' that were mainly made in Suzhou, a city located more than 1000 kilometers to the south of Beijing (Lou and Li 2002: 22). Of course there are other reasons to consume conspicuously with the aid of building, besides the wish to demonstrate one's ability to counter gravity. Buildings, especially tall ones, are very visible component of the urban landscape and partly for this reason they are good places to showcase valuable resources. The citizens of Beijing, for example, used to be able to see the gilded sides of the roof of Tiananmen from many locations in the city.

When talking about 'gold bricks' and gilding, it may be interesting to take a few steps back, back to the history of the cosmos. Most precious elements like gold formed a long time ago, in dying stars much heavier than our own Sun. When such stars ran out of fuel, they started to collapse under their own weight. During these collapses, large amounts of energy were created, eventually causing the stars to explode. Only during the brief cosmic fireworks that resulted from such processes was it possible to form elements heavier than iron, like copper, silver and gold (Chaisson 2005: ch. 3). Since the circumstances under which these elements formed were so exceptional, elements heavier than iron are very rare. Things that are very rare are often difficult to acquire, expensive and therefore a good indicator of one's position within a society. It has been suggested by many, including Charles Darwin, that for this reason, humans have evolved an aesthetic appreciation for rare things, including rare elements (Miller 2001: ch. 8). So in a way, dying stars may be responsible for Tiananmen builders' preference for bricks that shine like gold and roof decorations made of the precious

yellow metal. They may even have caused the Chinese to start to see golden-yellow as the most important color, which, during the times when Tiananmen was built, could only be used for imperial purposes.[17] This explains why the tiles on Tiananmen's roof, like those on the roofs of other buildings that were part of the imperial city complex, are golden yellow, whereas the roofs of most other buildings in China were not.[18]

Although humans are the only animals that use conspicuous building with heavy, exotic or rare materials to affirm their own social status, they are not the only animals to consume conspicuously with the aid of building. In rare situations, other animal species do the same, mostly to confirm their biological rather than their social fitness. Examples of such builders are bowerbirds that live in Australia and Papua New Guinea. This bird family features several types of builders, but Vogelkop bowerbirds are perhaps the most enthusiastic ones. Some males of this species build bowers that consist of a moss platform, on which they erect a maypole assembled out of hundreds of twigs. They encase their platform and maypole with a hut that can measure up to 1.8 meters in diameter and can become almost 0.8 meters high (Gould and Grant 2007: 241). As if building such a structure is not impressive enough for a 25 cm creature, the bird then goes on to decorate his bower with large amounts of ornaments. The ornaments, that can range from colorful fruits and flowers to shiny black stones and insect parts, depending on the taste of the particular male, are arranged by type and color, displayed in and around the bower, and replaced when necessary (*Ibid*.: 241–246). Assembling such an enormous and elaborate structure obviously requires a lot of energy. The males seem to spend all this energy to convince female bowerbirds that they are sufficiently fit and therefore a good potential mate. In a way, the bowerbirds' strategy is similar to the strategy followed by the Chinese emperor who ordered the construction of a huge imperial city complex out of rare materials from far away to demonstrate to his people that he was sufficiently powerful and could continue to serve as a good ruler. Of course, there is also a difference. Whereas the bowerbirds are trying to convince females looking for a mate, the Chinese emperor was trying to convince a broader set of followers. Yet both were or are trying to convince others by using restric-

[17] There may be other reasons for this choice as well. Joseph Needham, amongst others, has suggested that the central position of yellow in Chinese culture may have been derived from the color of the loess soils that has dominated the heartland of the Chinese civilization for centuries (Needham 1956: 261).

[18] There were a few exceptions to this pattern. The predecessors of the Qing emperors, for instance, broke with this tradition (Guo 2000: 350).

tions imposed on building by physical forces like gravity and physical processes like the formation of elements in stars to their advantage.

Only bowerbirds and humans seem to have discovered ways to use buildings as a means to consume conspicuously. This raises the question of what sets these animals apart from other animals that are also able to build complex structures, but do so for very different reasons. There may be several answers to this question. One characteristic of bowerbirds that seems particularly intriguing is the fact that they live in an environment where there are relatively few other species competing for the same food and relatively few predators (Diamond 1988: 650). Humans in general, and people in privileged social positions in particular, often live in a very similar environment. Such an environment may have enabled both bowerbirds and humans to spend a lot of energy on conspicuous building behavior. Bowerbirds and humans do not only live in rather similar environments, both species also possess relatively large brains. Birds that build bowers generally have larger brains then birds from the same family that do not, and in birds that build more complex bowers the brain areas associated with learning from observation and experience and with exploring new situations tend to be larger (Hansell 2007: 244). As was mentioned before, such larger brains may not be required for all types of building. Yet they may be necessary to build in the varied and flexible ways necessary to consume conspicuously with the aid of building. As was also mentioned before, humans have become particularly good at building in varied and flexible ways, possibly partly because positioning their tools, traps, and protective structures in strategically fixed locations made it easier for them to reach and use these structures. Humans may have even become too good at this. It seems that at a certain point in history, the human ability to build in more varied and flexible ways than any other creature has created completely novel challenges for human builders, which will be described in the next part of this article.

Tiananmen and Human History

One of the reasons why I think the human ability to build in such varied and flexible ways has caused problems for some human builders is the fact that I have encountered such problems myself as an architect. When presented with a design task, I often found that there were thousands of different ways to tackle such a task. This is the case because over the past few millennia a wide variety of building practices accumulated in humanity's collective memory.[19] As a result, all kind of ancient and

[19] This is, of course, not only due to the fact that reaching and using buildings became easier for humans during their evolution. It is mostly due to the process that has been

modern materials, construction techniques, types of spatial organization, aesthetic effects, symbolic meanings and economic considerations have become available for any builder to use and combine in lots and lots of different ways. All of these options are a testimony to humanity's incredible ingenuity and are wonderful resources for contemporary architects. But how do you, as an architect, know which ones to choose? How do you know which combination yields the best results in a specific situation? Quite often, that question is hard to answer. Nevertheless, it is central to the architectural discipline. It is difficult to come up with a good design without trying to answer the question. Doing so has been difficult for me, but probably also for builders in the past.

From quite early on in human history, ideas about building were retained in the buildings themselves and in stories, figures, images, and manuals that circulated widely and could travel long distances. Admittedly, in the case of China, buildings themselves were and are not always the best source of information, mainly because many of them did not survive that long since they were built out of perishable woods. Other Chinese sources of building information were much more persistent though. Stories about ancient buildings like the legendary palaces of China's first emperors were passed on from generation to generation long before the oldest remaining buildings were built. Elaborate pottery models of various buildings that were created during the Han and sometimes even earlier dynasties also stood the test of time, as did paintings of buildings that survived in the Mogao Caves along the silk road (Guo 2010: 1 and Steinhardt 2004: 228–254). Perhaps most importantly, ideas about building were transmitted from person to person by informal and formal training programs, and by various building manuals. The most famous manual, one that has survived intact until today, is the Yingzao Fashi. It was first published by a government official called Li Jie in 1103 CE and commonly used by builders after that time (Guo 1998: 1). The manual can be seen as a compendium of architectural knowledge, containing 34 chapters composed of information about for example materials, technical details, decorations, and labor organization (*Ibid.*: 4–6). All of this information from the Yingzao Fashi, other manuals and other sources could have easily been combined by Tiananmen's builders into a number of very different versions of Tiananmen. But for some reason, the people who constructed the gate chose one specific design. Why did they do so?

A possible answer to this question involves the emergence of the architectural profession and architectural styles. While more and more

described by David Christian as collective learning, although the former process could have influenced the latter (and vice versa) (Christian 2004: ch. 7; see also in this volume).

ways to build something accumulated in our societies' memory, architects became more important. It is easy to see why. When more options to build became available, it became difficult to master them all and even more difficult to find the most suitable combination of building options in a specific situation. Therefore, at a certain point in history and for certain building projects, specialized architects became necessary to help people make sensible and in some cases also interesting building choices. An overload of options may not only have created greater need for architects, but may also have led to emergence of building styles. Put a bit crudely, applying a certain building style can be seen as largely sticking to something that structurally, socially, aesthetically, symbolically, and economically 'works' while adding relatively small variations. Therefore, applying a certain style usually results in a fairly safe design solution, even though such a solution may not always be the optimal one given a specific situation. Nevertheless, in many cases people seem to prefer such a safe solution to the application of completely new and experimental combinations of building practices that sometimes work out marvelously and sometimes fail miserably.

When thinking about building styles like this, using them actually seems a bit similar to building standardization in the wider animal world. Most animals use fixed methods and sometimes even standardized materials to construct their building, simply because reinventing the wheel all the time can be risky. Moreover, trying to reinvent the wheel can be costly, because large and energy guzzling 'inventor brains' are required. In contrast, when non-human animals build with fixed methods and materials, such behavior is generally hard-wired and does not require large brains (Hansell 2007: ch. 3). Likewise, in the human world not sticking to established building styles may require expensive expert architects, whereas sticking to culturally hard-wired styles can be a bit cheaper because it requires less innovation and, therefore, fewer innovative specialists.

When it comes to the relation between architects and building styles, it may be interesting to note that overall, the influence of the main architect of the imperial city of which Tiananmen was a part seems to have been rather limited when compared to the importance attributed to building styles and traditions. This situation becomes particularly intriguing when contrasted to the situation on the other side of the Eurasian continent. In Europe, building styles were important too, but they seem to have been much more volatile than the Chinese traditions were. Unlike Chinese traditions, European styles could change drastically within hundred years or so. Famous examples of such transitions include the change from fairly modest Romanesque to extravagant

Gothic and from extravagant Gothic to classical Renaissance styles (Kostof 1995: chs 14 and 17). In China, architectural styles were much more stable. I do not mean to imply that these styles did not change, but changes, like roof lines that obtained slightly different curvatures, were smaller and appeared more gradually (Boyd 1962: ch. 2). The role of architects in China is probably closely linked to this. Architects in China, including Cai Xin and Nguyen An, the people who were responsible for the construction of the imperial city complex, were more or less government officials, intellectuals responsible for the design and planning of large complexes (Zhu 2004: ch. 2; Mallas 2001: 42; Mote and Twitchett 1998: 240; and Boyd 1962: ch. 2). Such people usually did not design individual buildings. That task was left to master craftsmen. While designing individual buildings, such master craftsmen based themselves on manuals like the previously mentioned Yingzao Fashi, which did not only include a long list of all kinds of building practices, but also prescribed in detail which sets of practices should be used in which specific situations. For instance, it contained rules about the exact dimensions different types of buildings, like palaces, mansions and pavilion halls, should have and which structural details should be applied to which building types (Guo 1998: 8). Master craftsmen, therefore, had little room to experiment with all kinds of new ideas. Consequently, buildings did not change that much over the centuries, and the image of architects as innovative artists did not emerge in China like it did in the West.

There may be several reasons why the values attached to architects and building styles differed in the East and West. To me and many other scholars it seems that during much of Chinese history, people have put greater emphasis on groups and less emphasis on individuals than people, for instance, in Europe did (Nisbett 2003). This greater emphasis on groups has been linked to the types of agriculture that dominated Chinese societies, leading people to be more dependent on the group they lived in than people elsewhere were (McNeill J. and McNeill W. 2003: 32–33). A greater emphasis on groups can, perhaps, also be linked to the geography of China. When you look at China on a map, you can see that the country is bordered by the highest mountains on Earth to its west, by the largest ocean on the planet to its east, by an immense steppe where only nomads could survive to its north, and inhospitable mountainous jungle to its south. Therefore, influences coming from the outside have been fairly limited, at least when compared to the effects ideas from other regions had on the development of, for example, Europe. This may have made it easier to keep Chinese culture unified and Chinese society stable after the formation of the first Chi-

nese empires. Both a greater emphasis on groups, on a unified culture and on the stability of social structures that prevailed during much of the Chinese history may have influenced the development of Chinese architecture, as the need to distinguish oneself from predecessors or competitors was not that great. In fact, distinguishing oneself from the rest of a group or society could easily backfire, because it could negatively influence group dynamics and threaten social stability. This may be one of the reasons why the Chinese, including the emperors who ordered the construction of Tiananmen, may have preferred sticking to traditional styles. For European rulers, on the other hand, distinguishing themselves from their predecessors and competitors with the aid of building often was worthwhile, and one of the main reasons why the French kings became the patrons of early Gothic builders like Abbot Suger and Italian merchants and bankers became the patrons of early Renaissance architects like Filippo Brunelleschi (Kostof 1995: 329 and 403).

A difference in emphasis on individual architects and buildings styles may have put European and Chinese architectural history each onto their own unique paths. The starting points of these paths may not have been too dissimilar. It is remarkable how much many ancient Greek or Roman dwellings resemble traditional Chinese houses. All of these houses generally consisted of a series of one or two-storied compartments or halls, organized around one or a few courtyards and closed off from the outside world by a wall. The way the roofs were supported and the decorations differed in the east and west, but apart from that, ancient housing traditions in Europe and China were quite alike (Kostof 1995: 141, 197–201 and 232; Boyd 1962: chs 2 and 4). It seems that from these starting points, the Western architecture went on to develop lots of different types of buildings and corresponding building styles, introducing new ideas and changing styles with every alteration in social structure. In China, on the other hand, people preferred to refine existing styles instead. As a result, many traditional Chinese buildings, including temples and palaces, still look a bit like the traditional courtyard house.

Tiananmen fits into this tradition: it is part of a wall surrounding a gigantic imperial courtyard complex that housed smaller courtyard complexes like the Forbidden City and gardens, altars, palaces, offices and royal workshops and warehouses (Zhu 2004: ch. 2). Of course, the scale of the complex, the use of materials and the richness of decorations are not comparable to those of ordinary houses, but the spatial organization of the imperial city, the nature of its halls and the applied building techniques most definitely are. Furthermore, the gatehouse itself is quite similar to the halls that are also present in traditional courtyard houses. Like almost all other halls in China it consists of a wooden post

and beam structure that supports a curved roof and envelops one single space.

It is tempting to expand this argument much further by analyzing how more detailed characteristics of Tiananmen do or do not fit into this story. Yet for the purpose of this article, the short description given above must suffice. For the purpose of this article it has been more important to demonstrate how the reasons why people built Tiananmen the way they did can be linked to broader trends, like the emergence of architects and architectural styles, the varied and flexible building strategies developed by humans, the development of building strategies by life in general and the fundamental forces and processes that shaped these strategies.

Reflection

Now that we have completed a journey that covered 13.8 billion years of history, it may be a good time to reflect briefly on it.

Trying to see 'a world in a grain of sand', or in this case in Tiananmen, definitely changed my appreciation for it, and triggered my curiosity. It led to all kinds of questions people who usually study subjects like the gate have not asked before. For example, architects or architectural historians generally do not wonder about the delicate balance between gravity and electromagnetism that enables us to build. They also do not ask themselves why some animals, including humans, build whereas other animals do not. And few of them think about why architects or architectural styles exist in the first place. Trying to see a world in a building also led to some Big History questions big historians have not asked before. For instance, the question how energy considerations involved in early tool use and building may have helped shape human evolution and human history has not been examined yet. This Little Big History made it easy to discover such questions. It can therefore serve as an example of how Little Big Histories can be used as fruitful research tools, perhaps in the way Albert Einstein had in mind when he wrote: 'To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science' (Einstein and Infeld 1938: 92).

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5
Chinese Traditions and Big History

Sun Yue

Abstract

The article first points out that Big History, according to the Chinese historians' perception, fails to unite natural and human history. In short, it contextualizes without necessarily connecting. It then discusses this failure in light of the traditional Chinese concept and practices of 'unity of Heaven and humanity', which manifests itself in the historiography of Sima Qian and in such technological feats as the Dujiangyan Irrigation System, as well as in scholarly ambitions as exemplified by Zhang Zai of the Song Dynasty. Finally, the paper elaborates on another Chinese traditional notion of diversity and harmony, which, hopefully, can contribute to further development of Big History, especially in China.

Keywords: *Big History, China, unity of Heaven and humanity, diversity, harmony.*

At the Seoul Asian Association of World Historians (AAWH) Congress, April 26–29, 2012, I talked about the reasons why Big History has been, sadly enough, neglected in China so far. For one thing, David Christian's now classic *Maps of Time*, despite being translated into Chinese and published as early as 2007, has not generated much attention. Today, instead of repeating the sad story of looking backwards, I will look forward and anticipate the future of Big History by reflecting on the Tao or the Way of Big History in China.

But anyway, a recap of my major points for why Big History has been neglected seems in order, because these are closely connected with what I am going to talk about in the present paper. First, conceptually, the Chinese concern for unity of natural and human histories is a task which Big History, as practiced in the West, has so far failed to fulfill. Second, in institutional terms, there is a separation of scientific and sociocultural histories in Chinese universities and research institutions. Thirdly, at present in China, pragmatic rather than cosmic concerns grow faster, like the one of sustaining its high economic growth. And fourthly, one can speak about the lack of attention on the side of the Chinese historians to the few Big History books published so far.

I know that many Big Historians, including David Christian, are indignant about the first point, namely, why the Chinese scholars regard

Big History as failing to live up to its promise of uniting natural and human histories, the 'fact' positively confirmed by no less a world history figure than William McNeill! (Christian 2011: xv) Therefore, I will focus on this point in my contribution. In a certain sense, I argue that before human beings are energized and obliged to fly to another planet to colonize and to settle on, they have a lesson to learn, a lesson which is, perhaps, also of value even if they do succeed in colonizing another planet in the cosmos.[1] And that is the lesson of the Chinese 'unity of Heaven and humanity', something that is often regarded as the very core and kernel of the Chinese civilization. I will substantiate this by an example of how the Chinese deal with human-nature relationship and another example of what Chinese scholars aspire for in their scholarly undertaking. Finally, I will try to elaborate a little bit on the Chinese ideal of harmony in diversity, which may also be of service to Big History on its way to winning the heart and soul of the world's peoples, especially the Chinese.

Why Big History does not Unite Natural and Human Histories

First, why do the Chinese think that Big History has failed to unite natural and human history? And as you will see, I will not go into details, but only categorically outline the argument structure.

Big History contextualizes but does not necessarily connect. Big History puts all humanity, nay, all living beings, within a larger cosmic context, for sure. But in what ways are human and natural histories united?

Big History, to be sure, does put forward a number of key concepts or central threads in an effort to connect, but these concepts are neither fully elaborated nor effectively employed in its narrative. For example, David Christian, in his *Maps of Time*, does point to 'collective learning' as an 'emergent' property of *Homo sapiens*, but obviously leaves it as such, probably as an indication of possible directions for further research. The same is true of Fred Spier's 'Goldilocks conditions' and Eric Chaisson's 'density of energy flow'. In other words, these, especially the latter two, sound rather more 'scientific' than 'humane'.

If human history is reduced to spasms of 'energy flow', in an obvious attempt to debunk the various kinds of human superiority or centrist rhetoric, it naturally leads to accounts where humanity is seriously

[1] David Christian and others have argued convincingly that '[n]o complex species is likely to survive intact for more than a few million years'… and we humans 'would be well-advised to hop a spaceship to another solar system' in due time. See http://www.ibhanet.org/.

marginalized, as a pitiably negligible creature in a larger cosmic framework.[2] These may turn out to be superficial Chinese 'impressions', but they are not at all pleasing to the Chinese, who always insist on putting humanity first, or at least on a par with the Grand Design of nature.

We can argue that Big History arises in reaction to World History not living up to its name, rampant postmodernist nihilistic tendencies, and cycles of prevalent crises confronted by humanity as a whole. But even so, more thought need to be given to defining human nature and to coordinating collective human behavior so as to combat these unwholesome tendencies and crises in order to realize a more harmonious and sustainable existence.

The Chinese 'Unity of Heaven and Humanity' and Its Implications for Big History

This failure on the part of Big History is most obvious if we put it under the spotlight of the Chinese concept and practice of 'unity of Heaven and Humanity' (Zhao 2002: 5–17; Wu 2000: 3–7; Ho 1991: 139–146). In fact, most recently, three leading Confucian thinkers – Qian Mu of Taiwan, Feng Youlan of Mainland China, and Tang Junyi of Hong Kong – independently made conclusions that the most significant contribution that the Confucian tradition, in fact, Chinese culture in general, can make to the global community, is the idea of the 'unity of Heaven and Humanity' (Tu 2001: 243–264).

Now, what is the 'unity of Heaven and Humanity'? (Chan 2011: 64–77; Chan 2012: 106–120; Cheng 1984: 95–98)

Sima Qian and His Successors

To understand this concept, let us first turn to the first historian in China, Sima Qian (145–90 BCE). In his now much publicized, *Letter to Jen An* (Sima Qian 1965: 95–102; 1993: 236; Ban Gu 2005: 2068–2069; Chang 1981: 157; Wang 1999: 293) Sima Qian clearly stated his purpose of writing history:

> To inquire into the relationship between Heaven and humanity, to comprehend the vicissitudes of past and present, and to form a single narrative of it all.

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[2] *Editors' note*: We have referred the author to several works in Big History, including some major ones, that do not reduce Big History or humankind in such a way, since they classify human society as one of the most complex things in the Universe, rather than being the product of 'a pitiably negligible creature'. We ultimately leave the author's assertions to the judgement of the reader.

Now, intuitively, the critical issue is our understanding of 'Heaven'. What does 'Heaven' mean? According to one interpretation, the 'heaven' here is Nature, and Sima Qian was doing nothing short of uniting natural and human histories to construct his own version of 'Big History'. Moreover, Sima Qian was ready to justify the relationship between Heaven and humanity, to forge a coherent story of the past and present, and to shape out his own narrative from prevailing narratives (Huang 1997: 72–75).

Of course, besides denoting Nature, 'heaven' can mean a host of other things, like 'God', the 'Mandate of Heaven', 'morals', 'strength', and 'strategy' – and can refer to aspects of each of these things all at the same time, sometimes tinkering with political justification (Wang 2008a: 64–66; 2008b: 80–85). And, as you can see, even the talk of the 'Mandate of Heaven' entails a 'correlative' or 'coordinative' relationship between humanity and Heaven. The British scientist Joseph Needham calls this kind of 'correlative thinking' or 'coordinative thinking' the very heart of traditional Chinese cosmology (Henderson 1984: xiv–xv; Needham 1956: 280–281; Tang 1988: 321–322). Or in his own words:

> In coordinative thinking, conceptions are not subsumed under one another, but placed side by side in a pattern, and things influence one another not by acts of mechanical causation, but by a kind of 'inductance'… The symbolic correlations or correspondences all formed part of one colossal pattern (Needham 1956).

This 'colossal pattern' is made most explicit by the sixth century BCE Daoist philosopher Laozi in his *Daodejing* (Sima Qian 2006: 388; Lai 2006: 7; Henderson 1984: 35).

> The ways of men are conditioned by those of earth. The ways of earth, by those of heaven. The ways of heaven by those of Tao, and the ways of Tao by the Self-so [*ziran*] (Lao Tzu 1998: 53).

Yet, what is our concern here is rather the message and the philosophy underlying it, rather than the exact meaning of those ancient sages. The Chinese philosophy is said to have started, among other things, with the *Book of Changes* (henceforth *BC*), the ancient Chinese book of prognostication which is often revered as the first of all Confucian classics. Now *BC* considers a change as the only permanent thing about our world, and that 'a change communicates with the Dao of nature and the Dao of man'; further explications accredit *BC* as encompassing the 'Dao of Heaven', the 'Dao of earth', and the 'Dao of man', the first finds its manifestation in *yin* and *yang*, the second – as 'hardness' and 'softness', and the third – in 'benevolence' and 'righteousness'. What is more im-

portant, the basic principles of the three are united, commonly determined by forces of *qian* (strength) and *kun* (yielding) (Tang 2008: 484–491; Mou 2009: 63–64).

Of course, one may easily discredit all this as a superstitious talk of years gone by, with no room for it whatsoever in our modern temple of 'sciences'. But do not be so sure. The dualistic pattern of contemporary science itself may be problematic, while the talk of the 'unity of Heaven and humanity' involves a totally different mode of thinking, the one that incorporates the whole humanity, the earth, and Heaven in a grand integrative scheme of Oneness. In other words, the Chinese answer to this problem of humanity and nature is that nature and humanity mutually shape and condition each other through numerous rituals, consciously instituted or unconsciously there, so as to maintain a harmonious sustainability.[3]

So, the Heaven-human relationship continues to call for justification even nowadays, not necessarily in either the Chinese Tao or in the Western Logos, but possibly in other transcending alternatives. A more reasonable attitude is, perhaps, to give the past and the 'other' its own due, since – following the science writer Robert Matthews – the past may really be our future, as the past observations may turn out to be more accurate than we assume (Matthews 1998: 6–9).

More than two thousand years ago, the philosopher Yang Xiong of the Western Han (53 BCE – 18 CE) said: 'Only he who knows heaven, earth and man can be called a scholar' (Ye *et al*. 1999: 18; Yang Xiong 2002: 121). This sets a high demand on scholars, yet it is exactly this outlook towards which generations of the Chinese scholars have been aspiring – to be fully conscious of one's place in nature and society, as well as of the interconnectedness that this consciousness provides, to live out the meaning of one's existence in a network of duties and responsibilities, and to crave for a permanent harmony among the three.

One can guess that despite the vicissitudes of history and especially the turmoil of the modern times, this tradition of 'uniting Heaven and humanity' has never been lost to the Chinese, if not among historians, though latent. In recent years, it resurfaces again among Chinese non-historians. In terms of constructing China's 'Big History', a most notable

[3] These rituals demand more detailed discussions than allowed by a limited scope of the paper, for example, music and rituals representing the harmony and orderliness of Heaven and Earth (Wu 2000: 5–6). With science or logic alone and without these rituals, a harmonious sustainability can never be realized on earth, as Francis Bacon laments in the first of his Essays, 'Of Truth': 'Certainly, it is heaven upon earth, to have a man's mind move in charity, rest in providence, and turn upon the poles of truth' (quoted in Fernández-Armesto 1997: 203).

non-historian is the environmental scientist and professor Ye Wenhu of Beijing University and others who work with him. Ye unites, or at least, tries to unite natural and human histories as the two main threads of his 'Big History', and by doing so, has been able to delineate a miniature world history of barely four pages! (Ye and Mao 1999: 1–6; Ye and Song 2002: 1–4; Wang and Ye 2005: 10–13; Ye 2010: 106–109)

The Example of Dujiangyan Irrigation System (DIS)

To bolster this notion of 'unity of Heaven and humanity', let us take a look at the Dujiangyan Irrigation System.

This ancient irrigation system, located in present-day Sichuan province of China, was built over two thousand years ago between 256–206 BC by Li Bing, the governor of the Shu Shire under the Qin State, in perfect keeping with the principle of promoting harmony between mankind and nature. This is not the place for technical details and the ancient Chinese wisdom of ecology (Li and Xu 2006: 291–298; Cao *et al.* 2010: 3–13; Tu 2001: 243–264; Fang 2003: 207–217; Sima Qian 1959: 1407); what is relevant to us is that the irrigation system was designed and constructed in conformity with the terrain and topography of the river and the Chengdu plain and thus, it successfully simultaneously solved the problem of silt sedimentation, flood control, and water distribution, so that more than two thousand years later, with its basic structure intact, it still plays a crucial role in flood control, irrigation and water supply for the Chengdu plain in Sichuan province. Thus, it is regarded as 'a model of harmonious coexistence between mankind and nature', and was duly recognized by UNESCO as the World Cultural Heritage site in 2000. And amazingly, after intensive and careful researches since the 1970s, it was found that the design and construction of this ancient irrigation system correspond fully to concepts of modern hydraulic sciences. So, despite the inability of the ancient Chinese architects to travel through time to meet with our modern scientists, a due reverence for Heaven does connect great minds.

Aspirations of Zhang Zai, the Song Dynasty Chinese Scholar

Let us consider another example of the scholarly ambitions of the Chinese Confucians. Zhang Zai or Chang Tsai (1020–1077) was a Neo-Confucian philosopher of the Northern Song dynasty. In a certain sense, Zhang Zai lived a paradigmatic Confucian scholar's life, so when he died he had almost nothing to bequeath this world except a few memo-

rable lines showcasing the aspirations of his scholarly undertaking. According to Zhang, Confucian sages are capable of 'establishing the mind of Heaven and Earth, determining the destiny of human lives, restoring discontinued traditions of learning from the past, and commencing a period of supreme peace for one's descendants' (Tang 1988: 322; T'ang 1991: 55–57; Liu 2007: 69–73, 129).

If this is a little bit vague, we can move on to enjoy his highly esteemed 'Western Inscription' (Lin 2009: 58; Zhang 1997: 2–3; Chan 1963: 497–498) which begins with '[p]eople are my compatriots; things, my fellow beings' and ends with '[l]iving is following my nature; death, my tranquility' (Tang 1988: 321–322). Thus, when alive, one should fulfill the responsibility of realizing the ideal of 'great harmony', and thus one can enjoy serenity without feeling shame or regret till the end of one's life. One can argue that this notion of the 'unity of Heaven and humanity' probably plays the role of a religion for the well-cultivated Chinese, if not the Chinese in general: it puts them in the domain of eternity; it defines clear duties and obligations for them in life; and it brings them solace and tranquility in death.

The Chinese Notion of Harmony in Diversity

And finally, let us elaborate on the Chinese notion of harmony in diversity. In the West, especially in academic debates, people would say 'we agree to disagree', and to be sure, we also disagree to agree. That is why in my most recent essay I cautioned that 'Big History should not proceed in such a way that other historians take Big History to be nothing, whereas Big Historians take history to be nothing else' (Sun 2013). But still that may sound more like a political expediency. If we go deeper, we may find in it the Chinese philosophical position which is more ontological and basic. The expression goes as *heshi shengwu, tong ze buji*, or in English, 'Harmony generates and sameness stifles vitality' or in another interpretation, 'Harmony fosters diversity, homogeneity undermines sustainability'.

There is a story about the emergence of this concept, as recorded in *Guo Yu*, China's earliest history book of the Spring and Autumn Period by historian Zuo Qiuming (*ca*. 502 – *ca*. 422) of the State of Lu. It says:

> Duke Huan of Zheng asks: 'Will the Zhou Dynasty fall?' Shi Bo or Count Shi replies: 'This is for sure… Since King You of Zhou has abandoned the upright and virtuous and takes a fancy for those mean and treacherous. He rejects those who disagree with him and accept only those sharing the same opinion as his. Now harmony

> fosters diversity, homogeneity undermines sustainability. This means that the coming together of different things creates harmony, which in turn nourishes thing; and if you add up things of the same nature, they will sustain for a while and then perish' (Guoyu 1978: 515–516; Zhang 1996: 43).

I hope this lesson is also of service to Big History, for it certainly wants to sustain in the harmony of diversity.

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6
The Universal Breakthroughs of Big History: Developing a Unified Theory

Ken Gilbert

Abstract

The currently unfolding panoramic view of the eons, which the modern scientific and historical disciplines present, reveals an outstanding series of critical and transformative universal breakthroughs running throughout the history of the cosmos, life, and man. This paper begins to explore and develop an orderly framework for Big History based on this remarkable overall pattern of similarly sudden and rapid outbursts of expansive creative power marking the entire course of evolutionary manifestation. On this basis I consider and propose: (1) 'A Great Story of Origins' with sixteen 'Origin Events', each of which in turn dramatically establishes and defines a new 'Regime' and subsequent 'Evolutionary Era' with emergent qualities; (2) a reconsideration of current issues at the cutting edge of evolutionary theory including 'punctuated equilibrium'; (3) a recognition of the essential 'twofold' or 'biphasic' nature of developmental change in time; (4) an expansion of evolutionary thought in the context of Big History; and (5) approaches towards developing a Unified Theory.

Keywords: *thresholds, punctuated equilibrium.*

I. Introduction: Origin Events

The Big Bang theory of the origin of the universe, along with its profound implications, has been resonating in human awareness for only a relatively short time. It is certainly a striking and uniquely impressive discovery. However, if in addition to that one event we were to examine the currently unfolding Big Picture – namely the scientific and historical story of the cosmos, life, and man – the original Big Bang can be recognized also as the first phenomenal episode in a sequence of similarly outstanding outbursts of expansive creative power marking the entire course of universal evolution. In a sense, there has not been just one Big Bang, but one Big Bang after another! The unfolding panoramic view reveals a marvelous series of comparably critical and transformative breakthroughs running all the way from the Big Bang to the present. Indeed, we may very well be living in such a momentous time.

I will refer here to these awesome universal breakthroughs, during which entire new stages of irreversible evolutionary developments emerge, as the 'Origin Events' (including the eight 'thresholds of in-

creasing complexity' along with several others). This designation highlights what I find most significant about them: first, how they present us with a powerful Modern Origin Story about the emergence of the elements and qualities that make us what we are; and second, they reveal a pattern of evolution that unfolds largely as an eventful process, not just a slow, step-by-step, gradual and continuous one as we are more accustomed to thinking. These qualities are intrinsic to what the historical evidence in its entirety seems to be telling us, and ought to be primary factors in proposing a unifying story and general theory for the discipline of Big History.

This paper begins to explore and develop an orderly framework for the emerging discipline of Big History based on this essential 'Key Concept' that a fundamental and overall historical change on a grand scale takes place through Origin Events. Such an episodic pattern has often been noted in relation to each of the three Realms of Big History individually (Cosmos, Life, and Humanity), but never before have they been synthesized into a unified whole.

David Christian (2011a: 24) has posed the question, 'Are we on the verge of a grand unification of historical sciences?' including a Grand Unified Story (GUS) and Grand Unified Theory (GUT). A wide range of source material from diverse specialized disciplines must go into the making of any Big History theory. However, by treating history as a science of origins, a growing synergy and integration can begin to come forth directly from the historical knowledge itself through a process of pattern recognition along with inductive generalization. Initial considerations are introduced regarding how our Key Concept provides the basis for a coordinated approach that can:

- integrate the Realms of Big History;
- facilitate the Periodization of Big History;
- expand the newly emerging global creation story of Big History into 'A Great Story of Origins';
- provide elements to consider towards developing a Grand Evolutionary Synthesis and Unified Theory of Big History.

II. The Axial Period and Cultural History

The possibility of envisioning an intelligible structure of world history as a whole, first occurred to me years ago through a discovery inspired by my favorite professor, Huston Smith, upon being introduced to Karl Jaspers' intriguing concept of 'the Axial Period' (Jaspers 1953: 1–21). The remarkable mid-first millennium BC stands out on the timeline of history with the sudden, simultaneous, widespread, and independent appearance of prominent Culture Heroes and memorably innovative

figures across the Old World including: 1) the Buddha along with the many 'heterodox sects' and beginning of the classical schools of philosophy in India; 2) Confucius and the 'Hundred Schools of Thought' in China; 3) the major Old Testament Prophets along with the Exile and Restoration, and the 'new covenant' in Israel; plus 4) the Presocratics, Socrates and Plato, and the Golden Age in Athens.

The Axial Period was a time of widespread crisis and breakdown, but also a breakthrough because within a century or two, there is the beginning of a monumental shift in the orientation of human cognition from the previous mythopoeic type of thought and experience to a more abstract form of conceptual thought based on logic and reason (Frankfort *et al.* 1977). More recently, Robert Bellah and Hans Joas (2012) have edited an innovative volume of studies, particularly significant for Big History, looking further at the Axial Age in the broader setting of human cognitive and socio-cultural evolution. Some consideration is likewise given here to characterize the 'profound common element', which Jaspers indicated was the essential thing shared by all the movements of the time, as a new self-reflective way of thought and 'theoretic culture' that is more investigative and analytic than the previous more narrative-oriented 'mythic culture'. We are so used to taking our particular way of thinking and operating for granted that it is difficult to imagine how this cognitive orientation, along with its new form of collective learning, came into existence at a certain time in history, and that it did so, in its first appearance, dramatically and universally.

How deep, dramatic and sudden was the axial shift presumably from one cognitive and socio-cultural stage to another? We know this remarkable period well in the West particularly because of the birth of the classical forms of culture and society in Greece. Athens was in a distinctively pivotal position where the former world was culminating while the new one came into being (Finley 1966: 80–108). John Herington, professor of classics at Yale, is one of the many who has marveled at the 'great transition' which took place, describing how archaic society and the universal mythic vision and language, upon which it was based, were beginning to be radically transformed. He notes how a new type of civilization was emerging and the ancient ways were disintegrating under the impact, 'It is hard to measure the world-historical significance of that collapse. Geological analogies might be found in those natural catastrophes that seem to occur so many million years, obliterating entire life systems' (Herington 1986: 15).

In Israel, the exceptional circumstances of the breakthrough involved the destruction of the Temple followed by the Exile and Restoration. The great biblical scholar, Gerhard von Rad emphasized how important it is to realize 'there is this break which goes so deep that the

new state beyond it cannot be understood as the continuation of what went before' (von Rad 1965: 115, 271). He adds, 'we have still to consider the "revolutionary significance of the amazing new factor" the Axial prophets introduced, the prophecy of a "new covenant" no longer communal in emphasis but written in the "heart"' (Hebrew for mind and will) of the individual.

Likewise, in China (Creel 1960: 120–141, 169–170) and India (Thapar 1975: 119–132), with the spread of urbanization having set the stage for greater social mobility, the time was ripe for a new spirit of freedom and empirical inquiry to arise and a leap forward was made, setting the tone for millennia to come. Both Confucius and Buddha ('be ye lamps unto yourselves'), parallel to the other central figures of the time, taught the importance of thinking and arriving at the truth for oneself. In India 'this led to a new perspective on the significance of the individual' where 'Buddhism in particular, turned the earlier perspective inside out, and, and the focus shifted to the individual rather than the social group to which he belonged' (*Ibid.*: 125–126). In China also, 'a kind of critical, reflective questioning… a new vision', along with the Confucian teachings that made ethical learning available to all men, 'established a range of thought that was to shape all future developments' (Schwartz 1975: 3, 63, 68).

In summary, within the time frame of only a century or two, seeds were planted from the Orient to the Mediterranean, for the increasingly widespread and revolutionary transformation from the archaic, primarily oral and poetic, communal and mythopoeic civilizations to a new world of collective learning based on literacy and the written word (Thapar 1975: 130), education for all, an ethic of individual conscience, personal rights and responsibilities, democratic and egalitarian ideals, rational justice, the development of philosophy, systemization of mathematics, the growth of scientific thought, empirical methodology, and the principles of the world religions. Whatever we prefer to call it, the new type of collective learning emerging in the Axial Period came to inspire, characterize and pervade the cultural, social, artistic, political and technological developments throughout the centuries to come in all these regions.

The mid-first millennium conjunction has been marveled at by generations of historians as a unique phenomenon and a mystery for good reason. In the broader context of Big History, however, it may be seen as not such a singular occurrence after all. Mircea Eliade, the great historian of religion, spent much of his career brilliantly elucidating how people all over the world have memorialized in myth and ritual a series of 'Great Times' or 'Times of Origin' during which 'the central axis for all future orientation' comes into existence all at once (Eliade 1959: 21).

It occurred to me that this might also be the appropriate context for appreciating the outstanding significance of the Axial Period.

As I began to investigate Jasper's concept in more depth along with this larger perspective in mind, I saw that it could perhaps provide a 'Master Key' for the recognition of a universal structure to world history. Considering the nature and meaning of the mysterious mid-first millennium event, we may not be looking at a unique or anomalous occurrence at all, but a typical one. This transitional configuration might in actuality be just the most recent episode in a sequence of comparably dramatic turning points which characterize the entire course of cultural history, and ultimately as we are also beginning to see, Big History.

The key is to recognize and begin to appreciate how, as Giorgio de Santillana, MIT's eminent history of science professor, emphasized, 'Mistaking cultural history for a process of gradual evolution, we have deprived ourselves of every reasonable insight into the nature of culture… no one is willing to imagine that civilization appeared in a thunderclap' (de Santillana 1969: 68–71).

As we survey on the large scale, humanity's historical advance and the evolution of collective learning, it seems that fundamental change is an exception rather than a rule. The outstanding and universal innovations do appear as thunderclaps. There are immense intervening eras when there is little essential change: most societies during these times remain tradition-bound as similar cultural forms and experiences develop accordingly, based on a preceding original breakthrough.

For example, in both the Agricultural Revolution and the Urban Revolution we witness a sudden appearance in several locales of new worldviews and cultural orders, which thereafter spread and become the traditional ways of life for peoples throughout the world. The rapid transition during a few critical centuries to highly complex 'civilizations' has been observed but never explained by several scholars of ancient history. This has been noted by many including William McNeill (1963: 36–41) on Sumerian civilization, and Henri Frankfort (1956: 50–51) on the evidence from Egypt.

In the Narmer Palette and Memphite Theology, we find the archetype of Egyptian kingship and its method of artistic representation set once and for all. Within only a few centuries the conventions are fixed, and last for millennia; that is, until the mid-first millennium BC when as Jaspers (1953: 6) points out, 'the thousands of years old ancient civilizations are everywhere brought to an end by the Axial Period'.

III. Punctuated Equilibrium and the Paleontological Record

A similar pattern of change has become increasingly evident in the realm of geological and natural history as well. Paleontologists and bi-

ologists are increasingly recognizing that the evolutionary process of life on Earth can best be described at various levels, not only as one of gradual and steady change, but in terms of sudden, rapid and dramatic points of transition or 'punctuated equilibria' (Gould and Eldredge 1977: 115–151). Stephen Jay Gould (1978), in his article entitled 'Evolution: Explosion Not Ascent', explains this changing conception regarding the process of change in nature:

> In short, stasis and sudden replacement mark the history of most species… the history of life… is not as many people assume, a tale of slow progress, leading to greater complexity of forms and greater diversity of kinds and numbers. It is, in important respects, a series of plateaus punctuated by rare and seminal events that shift systems from one level to another.

This pattern has long been evident to paleontologists. It was stasis in the geological strata, interspersed by the abrupt appearance of radically different layers of fossil species that made biostratigraphy work so well in the first place. It is important to underline that stasis during the relatively long stretches in which it occurs, does not necessarily mean no change at all, but that during these times it does not 'accumulate'. 'Instead, over time, the species wobbles about its phenotypic mean' (Sterelny 2007: 96). In other words, adaptations occur resulting in some minor variations but the basic phenotype remains. For example, proponents of punctuated equilibrium have pointed out how Cambrian species, while demonstrating variational changes, tend to maintain their basic forms through extended stretches of time. In addition, for Big History purposes, noteworthy stasis and punctuation occur at higher levels of taxa than speciation: the major phyla have remained basically stable for the entire Phanerozoic span of geological history since their rapid emergence together in the Cambrian explosion (Valentine 1995: 190–194).

There were basically two main components to Gould and Eldredge's original punctuated equilibria article: simply to highlight the long-standing paleontological evidence that life's history is better described by a picture of stasis interrupted occasionally by episodic events than by the notion of phyletic gradualism, and to offer species selection as a theoretical explanation for that pattern especially as it could apply to macroevolution. In fact, their focus on the overall pattern had been preceded in certain aspects by the Russian paleontologists (Ruzhentsev 1964; Ovcharenko 1969), and their proposed mechanism of speciation theory by their colleagues Ernst Mayr (allopatric speciation) and Steven Stanley.

Ongoing analyses of the data since then have generally confirmed the reality of the pattern, at least for paleontologists (Prothero 2007: 81). In conjunction, the relatively new and growing field of paleobiology has been inspired to explore the wide range of potential insights paleontology can provide towards further developments in evolutionary theory (Sepkoski and Ruse 2009). However clear the evidence may be for the punctuational pattern of the fossil record, the concept of stasis in particular has been a lightning rod for ongoing disagreement and debate even among some paleobiologists, let alone in the larger community of evolutionary biology.

Much of the issue here centers on whether macroevolution can be understood as 'just microevolution scaled up'. There is disagreement even about whether there is any need for expanding evolutionary theory based on the much greater amount of macroevolutionary evidence available today. For example, just regarding the possible role of group selection in evolution at all among prominent evolutionary biologists, David Sloan Wilson and Edward O. Wilson are its advocates, while Jerry Coyne and Richard Dawkins downplay it, still favoring the more traditional view of phyletic gradualism based on organismic gene-level selection. It is in this context that Australian philosopher of science, Kim Sterelny concludes his analysis of the differing views of Gould and Richard Dawkins: 'Dawkins is right about evolution on local scales, but maybe Gould is right about the relationship of events on a local scale, and those on the vast scale of paleontological time' (Sterelny 2007: 178). We will return later in this paper to this important and often charged issue.

There are various approaches now being taken towards understanding and explaining macroevolution in evolutionary biology. Some do take into account the fossil record, often proposing some form of species selection where ecological conditions are radically altered and phenotypic change is accelerated. However, there is not wide agreement on whether this is a sufficient alternative. Donald Prothero (2007: 81), a specialist in mammalian paleontology, is one of those who maintains that the punctuational pattern, and especially the prevalence of stasis in the fossil record, still presents a significant challenge: 'there is not yet any good mechanism in neo-Darwinian theory for it, suggesting we still have a lot to learn about evolution and speciation'.

IV. A Great Story of Origins

One of the great achievements of the scientific quest for knowledge is showing us that the universe we live in is quintessentially a story. The cosmos itself, beginning with the Big Bang, has now come to be seen, not as an inert or static backdrop for the planet, but an ever-

changing manifestation in which everything is essentially historical and developmental. Time and space, matter and energy, atoms and elements, stars and galaxies, the earth and the diversity of life, our bodies and civilizations, cultures and traditions, ways of thought, the qualities we possess, everything we see and are made of has had a marked and identifiable origin during some salient time of crisis and creative explosiveness.

That is why I believe research and current theories in both the sciences and humanities should begin to consider and investigate the perspective that evolution at all levels of manifestation, as I have emphasized, is not just a process of gradual and continuous development. From the larger universal perspective, it appears to be more like an impressive series of marked 'Threshold moments' or great 'Origin Events', punctuating much longer Eras of gradual elaboration and extension of what the punctuations produced. These outstanding paradigmatic and formative periods beginning with the Big Bang and leading up to the present time, provide the story with its major episodes, and ultimately I would suggest illuminate it with meaning and significance. A Modern Origin Story, featuring the universal breakthroughs of Big History, tells us we are part of a world that is, in some profound sense, still in process of becoming.

Thus, the universal breakthroughs provide not only the structure that brings the story together, but also mark the identity and duration of its major chapters as well. Each of the Origin Events in turn can be seen as a turning point that simultaneously concludes a previous 'Evolutionary Era' while rapidly establishing and defining a subsequent one characterized by the extension, with developmental variation, of its newly emergent 'Regime' as a principal order of being or way of life on a large scale. I will delineate sixteen Origin Events along with the characteristic Regimes and ensuing Eras they introduce. They are divided into three main 'Worlds' of manifestation (Matter, Life, and Mind) that I find to be a suitable and descriptive classification, corresponding with the three Realms of Big History and their consecutive phases of evolution (physical, biological, and cultural).

I am building here on the Big History term 'regime', introduced by Fred Spier (1996: 14). In this context the term does not refer only to a system's outer form or structure, but also to the 'core of the process' (Adams 1966: 1–2), the very essence of what originates in the universal breakthroughs, and then proceeds to manifest on a large scale throughout the following Era. They are each, in the famous words of Vergil, *novus ordo seclorum*, a 'new order of the ages', bringing a novel formative principle or quality into the universe at every movement of advance along the way of the general evolution.

First, in the Realm of Cosmic Evolution we can see marked steps in the increasingly complex organizations of Matter like atoms, galaxies, and higher elements. These are the Regimes at that level. In the Realm of Earth and Life's evolution we also see increasing degrees of complexity in the organic forms and nervous systems arising with each breakthrough, but in the organisms involved at each stage, there are also signs of awakening types of sensitivity and more coherent interactions with their developing ecosystems (eukaryotes; complex multicellular animals having primitive nervous systems, eyes, notochords, and hard parts; reptiles; mammals).

When we enter into the Realm of Human History and the evolution of Mind, where the parameters are not yet as apparent, there are at first some notable anatomical differences, but these are clearly not the essence of the story. The challenge then is to begin to identify the chief features of certain paradigmatic socio-cultural orders, powerful systems of collective learning characterizing distinct Eras, which in this case clearly also involves a particular status of cognition, self-awareness and identity out of which the human experience and overall development unfolds. Colin Renfrew's excellent survey of prehistory (Renfrew 2008) brings together several new approaches that can be useful here, including his 'material engagement theory' and the rise of 'cognitive archaeology'.

Fortunately, with increases in our knowledge of history and prehistory, we are now in the position to perceive, as David Christian (2011a: 23) has said, 'patterns of change so large that they appear to be emergent properties of human history as a whole', so there is a prospect for generalization on a grand scale. Renfrew acknowledges the large-scale patterns initiated by the Neolithic and Urban Revolutions that were originally brought to our attention by V. Gordon Childe. The revolutionary shift in human existence which came with the appearance of agriculture is already a familiar one in Big History, but I believe the breakthrough to the complexity of city-states and the emergence of 'civilizations' should be also considered as an Origin Event. Robert Adams (1966: 1–2) stresses both the comprehensive nature of this change and its relative rapidity in Mesopotamia and pre-Hispanic Mexico, aptly demonstrating how in significant ways they are 'variants of a single processual pattern' that is 'clearly one of these great transformations which have punctuated the human career only rarely, at long intervals'.

I offer an outline of these sixteen proposed Origin Events here for purposes of further consideration and discussion. In my view they share a number of peculiar qualities or features serving to identify and explain the reasons for why they in particular, and not others, have been chosen for inclusion. Due to space limitations, I will just mention several

of those features to reflect on for now: outstanding, emergent, universal and transformative, sudden (punctuated), and constitutive. In the future, there may also be more events to add as our knowledge of the past increases. This whole topic remains a matter of interpretation that calls for ongoing research, further analysis, deliberation, and prospective revision.

First of all, these events stand out because they are the major historical milestones pre-eminent to and arising out of the subject matter of the many contributing disciplines to Big History. David Christian has noted the beautiful association of the eight Thresholds with a particular discipline, and I am suggesting expanding that a little further.

Secondly, the Origin Events are 'emergent' in the sense that at each stage of the evolution they give rise to a particular quality or principle that is not specifiable or predictable in terms of what came before them. In other words, as Theodosius Dobzhansky put it, they 'surpass the ordinary, accustomed, previously utilized well-trodden possibilities of a system' (quoted in Stebbins 1982: 162). They are certainly prepared for in some necessary way by what came before, but then the breakthrough occurs and a newly emergent quality enters which 'creates the impression of something utterly new appearing almost out of nowhere in the universe' (Christian 2011b).

Thirdly, they are 'universal' and 'transformative' in the largest sense: they change the course of evolution as a whole. These are distinctively discontinuous before-and-after 'Threshold Moments', not explainable as just a continuation or culmination of what preceded them because their newly emergent principle produces an epochal shift in the overall direction of evolutionary change. After a new Regime emerges during each Origin Event, often synchronistically in several places at once, it steadily spreads and develops for an extended Era of time into an entirely new stage of manifestation.

Fourth, with regard to the question of punctuation, it is important to note that degrees of suddenness are evaluated relative to the vastly different time scales in each Realm. Whereas, a century or two may qualify an event for punctuational status in the context of thousands of year long cycles of human cultural evolution, a process of a few or several million years may qualify on the geologic scale for life's evolution where the longer Eras last tens or hundreds of millions of years, let alone of course even much longer on the immense and mind boggling astronomical scales of cosmic evolution.

Fifth, and ultimately, they have been 'constitutive' of our world and our being in a most essential way. Professor Eric Weil (1975: 23) in his article 'What Is a Breakthrough in History?' summed it up well, 'We are what we have become owing to certain events… precisely the break-

throughs, the Axial times, the bifurcations that mark the road that looking backward, we see as meaningful'. In witnessing the eventful emergence of these particular Regimes and their ensuing transformations, which have ultimately combined to make us what we are today, we have a unique perspective unprecedented in the history of humanity. The Modern Origin Story is a global one, and these are our roots on a grand scale.

'A Great Story of Origins'

> In that deep force, the last fact behind which analysis cannot go, all things find their common origin.
>
> *Ralph Waldo Emerson*

A. Evolution of Matter

1) The Big Bang

Space and Time

Matter and Energy

Radiation Era

2) Recombination Epoch

Atoms – Hydrogen and Helium

Matter Era

Decoupling and Transparency – Release of Cosmic Microwave Background Radiation

3) Galaxy Formation

Sudden emergence of Galaxies and Stars

'The universe transformed itself from gas clouds to billions of galaxies all in what amounts to a cosmological instant' (Swimme 2000).

4) Supernova Explosions

Heavier Elements of the Periodic Table

5) Origin of Our Solar System

Earth, Sun and Planets

The stable Solar System was likely born in a dramatic and eventful climax of long-standing planetesimal accretion when the Sun finally ignited, releasing a stream of outgoing matter and energy which suddenly blew the remaining debris and gas from the system.

B. Evolution of Life

6) Origin of Life

Simple Life

7) Oxygen Crisis and Opportunity

Eukaryotes (Complex Cells)

8) The Cambrian Explosion

'Biology's Big Bang'

Complex Multicellular Organisms

Origin of Nearly All the Major Animal Phyla
Organized and Selective Sensitivity
Paleozoic Era

Douglas Erwin and James Valentine (2013: 5, 226), in their new book on the subject, date this event precisely to 'a geologically brief interval between about 530 to 520 Ma'. Many other Cambrian experts, including MIT geochronologist Samuel Bowring and others (Bowring *et al.* 1993: 1293–1298), have also been focusing on this particular window, or an even narrower one of five-six million years when most of the higher morphological novelty appeared, and defining the explosion as such. Robert Carroll (2000: 27–32) noted that, 'The extreme speed of anatomical change and adaptive radiation during this brief time period requires explanations that go beyond those proposed for the evolution of species within the modern biota'. The Chengjiang site in China, with fossils ten million years older than the Burgess Shale, strongly supports this view. Previous interpretations calling the Cambrian a 'slow fuse' instead (Prothero 2007: 161–171), and redefining it as a series of stages continuous with the Ediacaran, I find to be less refined and possibly outdated.

9) Permian Mass Extinction
'The Great Dying'
'Age of Reptiles'
Symbiotic Biosphere (on Land and Sea)
Ecological Sensitivity (Co-adaptation)
Mesozoic Era
10) Cretaceous Mass Extinction
Extinction of Dinosaurs
Golden Age of Mammals
Varieties of Sensitivity
Cenozoic Era

C. Evolution of the Mind
11) Pleistocene Glaciation
Emergence of genus Homo
Origin of the Human Brain
12) Paleolithic Transition
'The Mind's Big Bang'
Emergence of Modern Man (Cro-Magnon)
13) Neolithic Revolution
Origin of Agriculture and Domestication
Settled Societies based on the Mythico-Ritual Fertility Culture
14) Urban Revolution
Transition from Prehistory to History

Origin of 'Civilization'

City-States and Territorial States based on the Classic Mythico-Ritual Culture of Sacral Kingship.

15) The Axial Period

Emergence of a new type of cognition and collective learning

'Theoretic Culture' (Bellah 2012: 3).

The Axial Regime emerged rather suddenly during the sixth-fifth centuries BC with the synchronistic but independent appearance of the central figures and events in each region. This marked the breakthrough to a more critical, analytic, and self-reflective thought and culture at a time when the thousands of years old ancient civilizations were breaking down, previous communal and ritualistic traditions had lost their spark and were being questioned, and societal orders were in flux (Weil 1975: 21–36).

T. W. Rhys Davids (1903), one of the great scholars of early Buddhism, reflects on how, 'In each of these countries similar causes, the same laws regulating the evolution of ideas, had taken just about the same number of centuries to evolve, out of similar conditions, a similar result. Is there a more stupendous marvel in the whole history of mankind? Does any more suggestive problem await the solution of the historian of human thought?'

While an economic historian would likely add the Industrial Revolution next, I interpret it not as an Origin Event in itself but rather, like the American Revolution and other movements around the same time, as chiefly a prominent extension and culmination of certain principles of thought and activity originated in the Axial Period. These two revolutions shared a common purpose: promoting individual freedom. The United States was founded on the ideal of a government 'of the people, by the people, and for the people', and the industrial developments of the time stand out especially because for the first time in history, the living standards and opportunities available for the masses of common people experienced steady growth. It was not until the outbreak of World War I in 1914 that we enter the crises of the Modern Age and are at the threshold of the next Origin Event.

16) The Twentieth Century

An extraordinary time of culminating developments, tremendous change, crisis, opportunity, and emergent possibilities.

Holistic Thinking

Global Identity

Human Unity.

V. Evolutionary Theory in Big History

1. Evolution as History

In a century and a half after the concept of evolution arose to prominence, it has been a keynote of human thought and become increasingly a central theme for many modern disciplines. One of the leading figures in the establishment of the 'Modern Synthesis', Theodosius Dobzhansky (1973), published an essay entitled 'Nothing in Biology Makes Sense Except in the Light of Evolution'. With the scope of the concept of evolution expanding since to include cosmic and cultural history as well, the same observation is appropriate to Big History now.

The principles of evolution would seem to be a *sine qua non* to any grand unifying theory. However, what are those principles? There is no real issue as to whether evolution as 'developmental change in time' has occurred, but questions regarding the tempo, mode, source, and meaning of the evolutionary process have continued to swirl since its inception, and still do today. In this section and the next, I will offer some suggestions regarding tempo and mode which I find worthwhile from the scientific angle of establishing as accurately as possible what has happened in the past, along with briefly considering some of the alternative interpretations and perspectives arising recently with regard to cause and explanation, the how and the why.

One might think that since evolution is essentially about what has occurred in history, that traditionally the knowledge we have about the past would have been the foundation stone for constructing any theory regarding the historical development of life. Remarkably, however, this has not been the case. The insightful Berkeley historian and social scientist of the early twentieth century, Frederick J. Teggart (1977: 141), emphasized that, 'no study of "how things work" to produce something new in the course of time can dispense with historical inquiry and historical evidence'. He goes on to explain how, 'viewed in this light, the difficulties and contentions which have occupied so prominent a place in biological literature since 1859 follow inevitably from Darwin's initial acceptance of the idea of "progressive change", and his adaptation of Lyell's "uniformitarianism", with its negation of historical evidence and its emphasis on "continuity" and "present process"'.

As we have pointed out, this discussion is still with us – at least for paleontologists and a growing number of evolutionary biologists – and I maintain rightly so. Just last year the Smithsonian paleobiologist, Douglas Erwin (2011), likewise pointed out how 'the Modern Synthesis is a curiously ahistorical view of a historical discipline'. From a larger perspective, the growth of biodiversity is not only a question of alterations in species, but also the origin and relatively rapid spread of higher

taxa during periods when circumstances and ecological relationships are radically changing and we witness the rise and fall of entire ecosystems. In such a case, and thus without the uniformitarian assumption, the present is not always the key to the past. Erwin (1999: 626), who specializes in the Cambrian, emphasizes how, whatever caused, such a macroevolutionary event was active in biological systems back then in a certain way different from today. These higher order changes are not continuously happening all the time and gradually accumulating: they are special events that occur once-and-for-all, relatively rapidly under certain unique circumstances only at a particular time in history, and thus, in retrospect remain outstanding on a vaster scale of universal significance.

The modern synthesis has long advocated that macroevolution takes place like microevolution only faster, as the result of natural selection operating upon small-scale genetic mutations or variations of organisms within populations. Nevertheless, this consensus is no longer so solid, notes Erwin (2007): 'In the past few years every element of this paradigm has been attacked'. What developmental biologist Scott Gilbert once referred to as 'an underground current in evolutionary theory' has been rising ever since the famous macroevolution conference in 1980 at the Field Museum of Natural History in Chicago. In addition to numerous paleontologists and paleobiologists like Erwin (2000: 78–84), many evolutionary biologists and geneticists have also begun to confront the same issue of how to explain large-scale macroevolutionary change from their special vantage points, now that the adequacy of incremental changes at the genetic level ('survival of the fittest') in explaining large-scale morphological innovation (actually 'arrival of the fittest') is being widely questioned (Gilbert, Opitz, and Raff 1996; Müller and Newman 2003).

Such prospects for new approaches to evolutionary theory have been part of the discussion ever since the concept of 'punctuated equilibria' arose in an effort to bring evolutionary theory more in alignment with the patterns of geological and biological history that are evident in the fossil record. Punctuated equilibrium theory questioned the sufficiency of phyletic gradualism as a mechanism to account for the punctuations, but its alternative solution of allopatric speciation or species selection in various forms, rather than the more traditional gene-centered or organismic selection, has also been found wanting for significant reasons.

One of these reasons has to do with a central paradox of life's history related to how and when the 'diversity' of various distinct species in a group appear in the evolution, in contrast to the emergence of 'disparity' in the different body plans or higher taxa (Gould 1989: 49). Based

on neo-Darwinian theory, whether evolution occurred via the conventional phyletic gradualism, or a revised version of species selection accelerated by the radical alteration of ecological niches, one would expect to see species diversity appearing beforehand so that small-scale variations could little by little accumulate through natural selection to produce the increasingly complex forms that ultimately led to taxonomic disparity. The evidence of life's history in the fossil record, however, reveals an opposite evolutionary pattern. The disparities of each of the higher taxa emerge before the multiple diversities of the lower taxa, as Erwin, Valentine and Sepkoski (1987: 1183) explain, 'This is not to say that each higher taxon originated before species (each phylum, class, or order contained at least one species, genus, family, *etc.* upon appearance), but the higher taxa do not seem to have diverged through an accumulation of lower taxa'.

For example, this remarkable pattern in the Cambrian has proven to be quite pronounced with evidence now from not only the Burgess Shale, but also the more recent dramatic finds at Chengjiang in southern China. These fossil records demonstrate the clear absence of any accumulated multitude of diverse species upon which either neo-Darwinian mechanisms or species selection could have acted to generate this striking and relatively sudden first appearance of the higher taxonomic categories, already distinct enough to be definitively classified. As a result, Valentine and Erwin (1987: 96–97) have concluded that 'neither of the contending theories of evolutionary change at the species level, phyletic gradualism or punctuated equilibrium, seem applicable to (explaining) the origin of new body plans' and that a new theory is needed to account for the 'evolution of novelty'.

Another issue in extrapolating microevolution to macroevolution has arisen with regard to genetics. Prof. Eric Davidson of Cal Tech is a pioneering leader in the field of developmental biology and embryology as they relate to evolution. He has been investigating interactions between developmental gene regulatory networks (dGRNs) and the evolutionary emergence of new body plans, receiving the 2011 International Prize for Biology in recognition of this work. What he has discovered is that these dGRNs, which control the development of an organism, are so intricately complex that mutational alterations significant enough to produce morphological changes on the macroevolutionary level – as distinct from the microevolutionary level variations of 'enzymes or flower colors' – are not survivable, thus leaving natural selection with nothing to continuously act upon. Davidson (2006: 195) explains how, 'contrary to classical evolution theory, the processes that drive the small changes

observed as species diverge cannot be taken as models for the evolution of the body plans of animals'.

A paradigm shift may or may not be underway yet within evolutionary biology, but it is in the air with a variety of issues. There have been growing calls for open-endedness in evolutionary theory and new approaches to how evolution operates from several angles but a consensus is yet to emerge (Erwin 2007). In this regard, sixteen evolutionary biologists met in 2008 for a conference in Altenburg, Austria to discuss some of the possibilities for an extended evolutionary synthesis including: evolutionary developmental biology, epigenetic inheritance, niche construction, symbiosis, systems biology, plus evolution of the brain and cognition among others (Pigliucci and Müller 2010).

Biologist and genomics specialist, Eugene Koonin (2007: 21), a Senior Investigator at the National Center for Biotechnology Information, has summed up the present 'postgenomic era' in evolutionary thought – in which 'all major tenets of the modern synthesis have been, if not outright overturned, replaced by a new and incomparably more complex vision of the key aspects of evolution' – as a 'pluralism of processes and patterns… that defies any straightforward generalization' (Koonin 2009: 473–475). The alternative he offers, 'the Biological Big Bang model for the major transitions in evolution' (*Idem* 2007: 21), is remarkably similar to the punctuated equilibrium pattern highlighted here. It is a biphasic model of evolution in which novel forms rapidly emerge at higher levels of complexity in the first phase, and then the process slows down in the second phase where multiple variations on the new forms develop more gradually.

I find this to be quite a valuable formulation worth focusing on in the next section as it applies not only to the broadest patterns in the Evolution of Life, but also – as 'A Great Story of Origins' demonstrates – to Big History overall. In this context then, it becomes a distinctive contributor to a much larger and ongoing effort for considering the basic structure of Big History in general and how evolutionary changes take place throughout all of time.

2. The General Biphasic Process of Evolutionary Change

The nature of historical change in such a comprehensive evolutionary context appears to be a twofold process that occurs by way of what could be called two different types of time: 1) the rare and opportune in-between or before-and-after moments of crisis and opportunity, in which something of special quality happens; and 2) the longer stretches of chronological time, ordinary and steady with more of a quantitative nature. Ultimately, the two phases function as complementary facets of the universal process as it unfolds in time through Macroevolution and

Microevolution. In such a context, the old uniformitarian-catastrophist debate could turn out to be not necessarily a matter of either/or, but a both/and combination of the two.

In 1944, the great American paleontologist, George Gaylord Simpson (1944: 206), anticipated punctuated equilibrium, referring to the moments of macroevolutionary change as 'quantum evolution'. He considered this idea 'the most important outcome of (my) investigation, but also the most controversial and hypothetical'. Inductive reasoning, based on the overall view we now have, elicits the general nature of the concept. Outstanding, sudden and relatively brief but very special Origin Events or Threshold Moments, featuring the emergence of utterly new Regimes, initiate much longer 'Evolutionary Eras' of 'adaptive radiation' and developmental variation, with the more gradual elaboration, extension, diffusion and culmination of each of the new Regimes.

In this view, the relatively brief Origin Events are not created by their previous Eras, but rather they each in turn create their subsequent Era. These universally definitive moments do build upon and incorporate the developments that preceded them, but are discontinuous emergent events in their own right bringing unprecedented principles or qualities into the evolution. We will consider how these thresholds come about in the concluding section.

This principle characterization of evolution in general as a dual or biphasic process has previously appeared in the works of both Professor Teggart, and the prominent American anthropologist Marshall Sahlins. Teggart (1977: 148–149) had referred to the two complementary phases as (1) 'advancement', which occurs distinctly through events; and (2) 'fixity', featuring stability and continuity, predicting that with their recognition, 'the conceptual model for the study of change in time will be subjected to a radical alteration'.

Likewise, in the Introduction to their edited volume *Evolution and Culture*, Sahlins and Service (1988: 4–11) sought to embrace both biological and cultural evolution within one overall perspective by proposing just such a biphasic process, based on the work of their great predecessor, Edward Burnett Tylor. They consider the evolution of life and culture to be not just analogous but homologous in the sense that they both can be understood in terms of these same two aspects of the total evolutionary process: general progress and specific adaptation.

Sahlins (Sahlins and Service 1988: 12–44) continues to elaborate this theme in his chapter of the book, referring to the grand and universal macroevolutionary movement as 'General Evolution', in contrast to the adaptive phase of 'Specific Evolution'. The former features the emergence of higher forms of life and is also the means by which culture progresses 'stage by stage'. The more 'specific' microevolutionary de-

velopments occur in the latter adaptive, phylogenetic 'succession-of-forms' phase, applying also to variations in the 'evolution of culture along its many lines'.

In the view of Sahlins (*Ibid.*: 11, 39–40), quoting Julian Huxley before him, the 'much lauded modern synthetic theory' of biology, combining genetic principles with natural selection, is devoted primarily to the unraveling of not the overall progression of general evolution but specific evolution's 'mere frill of variety… a biological luxury without bearing upon the major and continuing trends of the evolutionary process'. Adding that although a prospective 'triumphant synthesis' which would unify the particular and general aspects of evolution did not exist in biology – and still does not as many other scientists have been saying – he did anticipate that 'a broadly similar course' towards such a synthesis, embracing anthropology as well, could eventually take place.

Now almost a century later, Gould (2002: 884–885, 951) affirms how this 'probable generality of punctuation and stasis as a powerful… style of change across all scales must lead us to reassess our previous convictions about "important" and "interesting" phenomena in evolutionary theory and the history of life'. He stresses how the basic problem of evolution itself now needs to be re-conceptualized, since the nature of evolutionary change revisited 'requires a different set of explanatory concepts and mechanisms – a different view of life, really'.

It is a boon for Big History to be in such a propitious position, due to its comprehensive subject and opportune timing, for contributing towards the development of a new and wider evolutionary synthesis, both by bringing together and integrating whatever developments may already be underway within particular disciplines, and by advancing its own theoretical prospects. I will conclude with some thoughts about what such an approach might look like.

VI. Towards a Unified Theory: Probing the Mystery of the Universal Breakthroughs

> Every advance in knowledge brings us face to face with the mystery of our own being.
>
> *Max Planck*

Evolution in the context of Big History, with its three Realms, is certainly about the changes of living forms through time, but it is also about the spectacular unfolding of the cosmos and the epic adventure of human history. The growth of the idea of evolution in our time involves nothing less than the emergence of a new worldview with unique possibilities and unknown dimensions that are still being explored and formulated. Big History gives us a renewed and larger perspective on

both what it is that we see changing throughout time, and the patterns and principles related to how the changes occur.

In this paper, we have been considering two distinctive perspectives for extending the scope and depth of a newly developing evolutionary worldview. Firstly, evolution in the past has generally been understood as a slow and gradual movement in a straight line with each successive state or condition directly related to and arising from, perhaps even logically or materially necessitated by, what came before it. However, as we have seen, there are many with good reason and standpoint who have been indicating that this interpretation does not fully fit the historical evidence for the cosmos, life, or humanity. Therefore, our whole view of evolution begins to change. Rather than minute and steady gradations developing gradually and continuously from one stage to the next, it is now being suggested that there are also relatively sudden and rapid outbursts, surprising and dramatic punctuations, marking the course of evolutionary transformation not just in the history of life but throughout Big History as a whole.

Secondly, especially when surveying the Big Picture including human history, we can begin to realize that it is not just the physical form, that is the world out there, that is evolving, but also the world inside us. It is about what it is like: to be a trilobite able to see for the first time and react to a world suddenly full of newly complex predators; to be a bat with sonar (Nagel 1974); to construct 'the world's first temple' at the 12,000 year old megalithic site of Gobekli Tepe in Turkey (Mann 2011); to recite the Enuma Elish at the Babylonian New Year's celebration; to reject mythological explanations of the world as a Presocratic philosopher in order to ask questions and reason about the essential unity of things; to behold the wondrous primordial spectacle of the original galaxies bursting forth in the Hubble Deep Field. As Klaus Schmidt, director of the German archaeological team excavating Gobekli Tepe reflects, 'Twenty years ago everyone believed civilization was driven by ecological forces. I think what we are learning is that civilization is a product of the human mind' (quoted in Mann 2011: 58).

It has become clear in our time, as advances toward an evolutionary worldview and a Big History perspective show, that in this world we are part of a universal process that is, and has always been, on the move. We are not static beings, but transitional ones; we are becoming. However used to this general idea of formal evolution we have become though, we are not so familiar with the perspective that the inner quality of being itself is something that has also been evolving, and still is. Such a frame of reference can be valuable in exploring alternative ex-

planations for how and why the punctuational breakthroughs of Big History's Grand Narrative occur as they do.

Combining these general indicators together and considering them along with the particular properties and insights we have seen arising out of the sciences and cultural history, I have found that our perspective on evolution can be extended and prospectively transformed. In addition, new light is shed on how to approach the question of cause, and whether this increasingly evident universal evolutionary process even has a cause we can theorize about and begin to comprehend.

All of the great origins and breakthroughs in the history of the cosmos, earth, life, and humanity evoke wonder, and to some degree, mystery. What force drives them, and what is their source and goal? If evolution at large shows a biphasic pattern of punctuated equilibrium, with awesome and unexpectedly new properties or qualities appearing at every critical step along the way, what is the explanation for this? I propose one answer lies in considering what strikes me to be the crux of the matter: the fundamental mystery of 'emergent novelty'.

The idea of 'emergence' was introduced around the time of Aristotle, and has since been discussed by various scientists and philosophers, but it has recently come to the fore and acquired a more solid and scientific footing in both 'complexity theory' (Bedau and Humphreys 2008) and in relation to evolution (Corning 2002; 2005). In Big History, Fred Spier (2011: 36–38) has drawn attention to how the 'Goldilocks Principle' characterizes the circumstances for the emergence of complexity. Morowitz (2004) presents emergence as a new more holistic way for science to view the world's evolutionary unfoldment that is complementary to reduction. I find, as Goldstein (1999: 58) notes, that although complexity theory adds much towards giving us a clearer picture of emergent phenomena in nature, it still functions as more of a descriptive term than an explanatory one. In this case, for now, the causation of the punctuated pattern of emergence in evolution, along with the source of such awesome novelty, remains a mystery.

To further address this question, and consider a possible explanation for the patterns we see unfolding, I would postulate the presence of what could be called an 'evolutionary force' in nature analogous to the force of gravity. We cannot see either of these forces directly, but we can perceive and experience the processes, patterns, and characteristics of their operation in the world. For evolution on a grand scale, the great scientific advances along with the extension of knowledge in all the disciplines have brought this possibility to the human mind. Such a force of evolution could be posited to have not only quantitative characteristics, but also evidently the capacity to kindle the development of the novel

qualities that emerge throughout history. Perhaps, the experience of awe and wonder that the great story of Big History evokes is indicative of this force in a similar way that heaviness is an experience of gravity.

The evolutionary manifestation of increasing levels of complexity, along with the emergent novelty of their Regimes and Eras, is what the Origin Events all have in common. In a unified theoretical synthesis applicable at all levels of Big History, the properties of outer form and inner force or quality of being function like the basic factors of matter and energy in physics which originally burst forth in the Big Bang. Eric Chaisson's explanation of rising complexity in 'cosmic evolution', utilizing the concept of increasing energy flows, is a case in point (Chaisson 2001). I am suggesting adding a qualitative aspect to the conception of energy in addition to the quantitative measurements of Chaisson's research. But whether using the term 'energy' or 'inherent force', shall we say that it is the material complexity which gives rise to the energy/force, or is it the energy/force that evolves the complexity in order to manifest in the universe?

In this sense, evolution is about not only the development of increasingly complex material forms, but also essentially the 'strong emergence' of already involved forces or energies of existence at each stage when the forms and conditions of the time have become ready and able to manifest them. I submit that this is – in addition to whatever the other physical mechanisms or explanations turn out to be – a considerable cause of the Origin Events, each appearing with their definitive Regimes intact. Taking an evolution of inherent forces or qualities of being into account contributes to a fuller elucidation of the punctuated pattern we see where these indelible universal breakthroughs burst forth so impressively in brilliant flower the way they do, and then are followed by a wide-ranging but relatively stable development of the various potentialities they contain throughout their microevolutionary Eras.

Such an extended view of the evolutionary process ultimately explains how the spectacular organizations of matter and energy in the cosmos, the existence of living organisms with their increasing sensitivities, plus the cognitive and collective learning capacities of humanity, in all their manifold expressions have emerged in the world; not after all as accidents or contingencies, nor necessarily as the result of some hypothesized intervention from without, but rather out of a deep force or essential energy contained within all along. Novel principles and capabilities can be seen to arise with each ascending level of complex order in the universe. A grand evolutionary synthesis for Big History, rather than remaining solely based in a reductionist approach to complexity, can embrace a more pluralistic and ultimately holistic outlook, a variety

of complementary perspectives, and the reality of multiple levels of causation.

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7
The Future of Global Civilization: Commentary of Big Historians

Ekaterina Sazhienko

Abstract

This article analyzes the views of big historians on the current state of civilization, its future, and possibilities of global regulation. The conclusions are based on the results of the content analysis of the original research papers published in two journals as well as of the interviews with 16 people involved in Big History. The findings indicate a certain variation with regard to the forecasts for the future.

Keywords: *intelligence as an evolutionary factor, forecasting, global crisis, regulation, global problems.*

The Current State of Civilization and the 'Singularity' Point

In the present paper we describe some possible scenarios of social development in the next decades and some possible mechanisms of global regulation that we have identified based on the opinions of 16 big historians received via interviews in the autumn of 2010. In addition, for our content analysis we have selected articles from the journals *Vek globalizatsii* (Age of Globalization) and the *Journal of Globalization Studies*. We have analyzed articles from issues of the journal *Vek globalizatsii* published from 2008 (the first issue) to issue 1(7), 2011 (see Appendix 2), and the *Journal of Globalization Studies* (volume 1, numbers 1 and 2, 2010) (see Appendix 1). Articles irrelevant to the objectives of the study were excluded from the analysis. Thus, we analyzed 63 articles in Russian from *Vek globalizatsii*, and 16 articles in English published in the *Journal of Globalization Studies*.

The tools for content analysis were tested in August-September of 2011. Based on those tests, the categories and units of analysis have been defined. We have analyzed 22 articles selected using a random number table. Modern society faces many challenges that threaten its development and human survival in general and that can reduce living standards, deepen political tension and environmental degradation, as well as increase the number of social conflicts. The content analysis indicates that sociocultural issues are more frequently discussed than any others.

In our opinion this proves that they are of utmost importance, especially the ones related to religious contradictions of the global civilization. The religious factor can cause serious problems, such as terrorism, wars, ethnic, and confessional conflicts. One can argue that we are dealing with a collision not just between two world religions, but between traditional Islam and Capitalism, between the Eastern and Western civilizations that are based on different values and life goals.

The articles under study pay little attention to environmental and socio-economic issues. Probably, the reason is that people have already gained positive experience in solving the problems associated with various restorative measures for environmental management and protection, as well as humanitarian relief to the poorest of the developing countries.

The units of analyses in the category of demography, especially those related to overpopulation, are less frequently used than all others. This may probably indicate that the problem of overpopulation is considered less urgent than it used to be. One can explain this by the fact that the population growth-rates have been decreasing, although the population decline is still too slow. Meanwhile, the migration increases, which probably leads to numerous ethnic conflicts and to the change of ethnic composition of Europe and North America. The words and phrases somehow associated with Huntington's 'clash of civilizations' (Huntington 1993) are more frequently used than the words and phrases from other categories of analysis (Table 1).

Table 1. A comparison of various aspects of life of modern civilization (the data of content analysis)

Categories	The number of units of analysis	The total number of usages	Median	Average
Environmental aspects	16	1,273	24.5	79.6
Demographic aspects	12	802	15.5	66.8
Sociocultural aspects	27	3,899	43.5	144.4
Socio-economic aspects	16	1,000	24	62.5

Notes: Averages were used because of the difference in the number of units of analysis. Median is the middle of the ordered series of numbers (the number

of uses of each word in this category). Arithmetic average is the ratio of the total number of uses to the number of units of analysis.

The word 'crisis' was used 736 times in the articles on economic, cultural, environmental, political, and social issues. Thus, one can suppose that many participants of our survey believe that modern society runs into systemic crisis. According to Akop Nazaretyan (2008), this crisis is more dangerous than the previous ones because of globalization processes, and it means that the next generation will probably decide the fate of the whole civilization. This hypothesis is supported by a series of mathematical calculations that are summarized below.

Professor Graeme Snooks has developed a theory, according to which the output of one phase (genetic or technological) becomes the input leading to the next phase. The result of these processes generates an accelerating rate of change (Snooks 1996). A few years later, Russian scientist Alexander Panov came to the same conclusion in independent studies based on different data. Panov finds that 'the duration of each subsequent stage in the evolution of planetary system is on average $a = 2.67 \pm 0.15$ times shorter than the previous one' (Panov 2005: 39). This is a simple logarithmic equation, and the rates of social and biological evolution tend to infinity at certain points. Nazaretyan (2008) calls this phenomenon the 'Snooks-Panov vertical'. Some scholars call the point at which the rate of evolutionary change tends to infinity 'the point of singularity' (Kurzweil 2005; Nazaretyan 2008). Nazaretyan (2008) considers this 'point of singularity' as a 'bifurcation point' of a system in general and of the social system in particular. In other words, according to Nazaretyan, in the middle of the twenty-first century the world will reach a bifurcation point. Of course, different ways of system development (future scenarios) are possible, for example, a destruction of global civilization, a stabilization of development, or a transition to a qualitatively different level of system complexity.

According to Panov, 'the development of crisis coincides with … the completion of the scale-invariant attractor of planetary evolution. Therefore, the approaching evolutionary crisis is, apparently, not a usual evolutionary crisis, of which there have been many; it is a crisis of the very evolution of intelligence on Earth, stretching back four billion years. One might say that this is … the crisis of crises' (Panov 2005: 44–45). Moreover, according to Panov, one cannot totally exclude that not only the civilization itself will change, but the human inherent mechanisms of evolution, the biosphere of Earth, and the Universe on the whole will also change. Snooks thinks that the vertical is 'a pattern of the past – which

cannot be extrapolated into the unknown without the very real risk of making erroneous and, hence, misleading predictions' (Snooks 2005: 51), but some non-trivial predictions of the future are still possible (though, of course, they may well be entirely wrong). In his concept the vertical will continue indefinitely, since the rate of the basic processes remains unchanged.

The Future of Civilization: The Interview Data[1]

Most of the interviewed big historians (14 out of 16) also assess the present state of civilization as a crisis or pre-crisis. The question to the respondents was: 'What are the possible consequences if the crisis is not resolved?' The answers can be divided into two main categories: 1) the extinction of *Homo sapiens* and possible mass extinction of most life forms, and 2) survival of some people. The respondents offered several possible outcomes in case the humanity fails to overcome the crisis: a) fragmentation of societies around individual capitalist leaders with the rest of the population living in extreme misery; b) war of all against all; and c) general deterioration of living conditions, destruction, pandemics, endless wars, scarcity of freshwater, forced migration of millions of people to more prosperous regions due to environmental pressures, and depletion or extinction of some natural resources. And there is another vision, which summarizes all of the above – a gradual return to earlier forms of social organization and social reproduction.

Big historians have provided some ideas how to overcome this potential crisis. Please, note that the ideas offered by some of those interviewed, by no means, are representative of the opinions of all the interviewees. Barry Rodrigue considers building a sustainable global community as crucial for the survival. David Christian sees education of people as citizens of the world, not of a certain state, as an important step for humanity's survival. He confirms that this may contribute to the formation of a broader worldview which can help find a way to avoid competition between states as well as to concern not about any particular country, but about the whole planet. Jonathan Markley considers scientific and technological progress to be the crucial point. Robert King suggests a restructuring of social organization towards more egalitarian forms of property, in other words, it is necessary to create a class of united producers who are

[1] *The list of informants:* Robert Drury King, Esther Quaedackers, David Christian, Craig Benjamin, Dan Stasko, Kathryn Begg (undergraduate student), Alexander Panov, Frederick Paxton, Jonathan Bruce Markley, Barry Rodrigue, James Tierney (undergraduate student), Eric Joseph Chaisson, Tom Gehrels, Akop Nazaretyan, Andrey Korotayev, and Richard Blundell.

free to manage their own work and who plan to achieve common goals necessary and useful for society. Alexander Panov considers the transition from an extensive to intensive development as an important pathway toward stability. He also suggests some indirect measures of state regulation: the use of taxation and subsidies to encourage corporations and consumers, reducing global social differentiation through developing the poor countries by substantial financial, technical and intellectual support, and, finally more vigorous SETI programs. Akop Nazaretyan predicts the diminution of religious and ideological outlooks that inspire groups to look at others as enemies and considers this to be an important step.

Some respondents think that it is necessary to reduce the rate of consumption, to create products and services that are less harmful to the environment, and to slow the population growth. Thus, in the opinion of our interviewees, we need some changes in people's outlook and also in economic and political systems to solve global social problems. Suggestions are offered to solve these problems (if the name of a Big History expert is not indicated, it means that several of them offer this suggestion):

1. To create a system of taxation that will encourage the respect for the environment (Craig Benjamin).

2. To reform political systems in the developing world in order to establish forms related to liberal democracies that can contribute to solving demographic problems (Alexander Panov).

3. To reorient governments from competition (in which the increasing consumption of energy and natural resources serves the criterion of 'growth') to progress of human creativity and intelligence (David Christian).

4. International organizations and developed countries should support the poor countries both in terms of finance and technology. (These measures imply that we should contribute to the technological development of these countries, because it can be the key factor for their successful development and thus, it will safeguard our own development in the future).

5. To reform the system of education and training, this can contribute to the formation of a global outlook and better critical thinking. Such reform may be based on the working out the global educational standards.

The scholars, whom we interviewed, expressed their opinions on the future social development. Some of them think that a new technological revolution is coming that will change the whole world (Jonathan

Markley). Many talk about changes in the sphere of economic relations and forms of production (Robert King, Dan Stasko, and Barry Rodrigue). Some argue that there may be changes in the political structure of the state (Eric Chaisson, Andrey Korotayev). This can be some new laws and regulations that will restrict freedoms, or, conversely, increase the democratization of political systems. Finally, some suggest that demographic problems should be solved (Craig Benjamin, Andrey Korotayev).

Thus, the experts suggest two ways of overcoming the crisis: 1) a restriction of production and consumption that can lead to stabilization of development, and 2) a breakthrough in technologies that should become more environmentally friendly and efficient. Of course, one may also imagine various combinations of both (Andrey Korotayev).

Basing on the content analysis and the interviewees' opinions, we have selected some of the most important actions that can help overcome the crisis in social development. These ideas are preliminary, and they should not be regarded as a fully-fledged manifesto:

1. Creation of uniform educational standards for the sake of the formation of critical thinking and global outlook, which eventually can help solve environmental and sociocultural problems. Big History might serve the basis for such educational standards.

2. Technological assistance to the poor countries.

3. The most important management actions can hardly be realized by the middle of this century. The creation of a single coordination center, which is not a political institute, can help realize these actions. It could be an international organization capable to work out some recommendations for national governments.

Our content analysis has shown that current social and economic problems are also urgent ones, particularly those associated with inequality between different countries in terms of unequal access to technologies. The interviewees advocate the acceleration of financial and technological support to poor countries. Maybe, we should not just 'drop boxes' with humanitarian assistance, but create modern research centers and establish high-tech manufacturing instead of multinational corporations' subsidiaries to those countries, because it may create the basis for independent socioeconomic development.

The Possibility of Global Regulation: Intelligence as a Cosmological Factor

According to some of our informants, the opportunities engendered by the impact of intelligence are not limited by social systems, and it seems

that the role of consciousness as an evolutionary factor is increasing. One of the megatrends of evolution is the growth of complexity. Eric Chaisson's model of free energy rate density is a quantitative criterion stating that the more complexly organized a system is, the higher is the ratio of energy per unit time to its own mass (Chaisson 2001). Under that logic, the brain is the most complex entity that has been created by biological evolution without technological interference, because of the number of connections between neurons, and all further development and growth of complexity is associated with the creation of the anthroposphere (a peculiar realm of the Earth's spheres, which is created and changed by humans).

At the beginning of the last century, Russian cosmists Nikolay Fyodorov and Konstantin Tsiolkovsky wrote about the possibility of the transformation of consciousness into the factor of cosmic evolution. According to Fyodorov, chaos dominates in the Universe, and it can be overcome by bringing people together to cope with global challenges. In other words, overcoming of chaos involves scientific management of nature and space exploration (Fyodorov 1982[1903]). Tsiolkovsky (2001[1903]) introduced the idea of human settlement of outer space and developed the first spacecraft project.

Chaisson claims that humanity that has become a powerful evolutionary factor on the planet is on the verge of becoming a significant factor in the evolution of the Universe in general. Thus, he concludes that 'we have an obligation, a moral responsibility to survive, especially if we are alone in the Universe' (Chaisson 2005: 101).

Nazaretyan comes to a similar conclusion, arguing that 'for the creative mind, there are no absolute limits for the mass and energy process control and the potential prospect of its development is associated with an expanding influence on cosmic evolution'. He also argues that physical laws cannot constrain the engineering creativity (Nazaretyan 2009: 12). Less optimistically, Fred Spier thinks that 'if biological evolution continues in the same direction in which it took place over the past billions of years, our species can disappear very soon ... if we as a species can survive longer, it is only thanks to our extremely developed intelligence' (Spier 2010: 93). According to him, the ability of human mind to influence rising complexity is limited by the extent of the Earth and near-Earth space, because interplanetary travels require prohibitive expenses. Flights to other planetary systems are impossible, because they would take centuries, and traveling faster than the speed of light contradicts the common-known laws of physics (*Ibid.*: 93).

The opinions of the interviewees can be classified in four general forecast scenarios. According to the first one, there will be a complete change of civilization (a transition to a new stage of evolution, some changes in the political world system and so on). The second scenario presupposes the beginning of a descending stage of evolution (the general deterioration of living conditions, the fragmentation of society). The third scenario predicts the probable extinction of humans and of most life forms. And there is a fourth scenario advocated by Andrey Korotayev according to which, the World System is now escaping the blow-up regime in which it has been developing over the recent centuries, and this makes it probable that by the mid-twenty-second century, the World System complexity will more or less stabilize at a certain level at least for a few centuries. This scenario implies that it is not in the future that we will witness a complete change of civilization, but it is already happening (*e.g.,* Korotayev 2010). Note that all the positive scenarios imply the necessity to regulate global processes.

The attempts to regulate global processes are unprecedented; until the twentieth century nobody had ever tried them. And at the present stage of social evolution, there exist supranational structures that can serve the basis for global governance. But they have a long way to go.

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II. BIG HISTORY'S PHASES, REGULARITIES, AND DIMENSIONS

8
The Star-Galaxy Era of Big History in the Light of Universal Evolutionary Principles

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Abstract

Big History provides a unique opportunity to consider the development of the Universe as a single process. Within Big History studies one can distinguish some common evolutionary laws and principles. However, it is very important to recognize that there are many more such integrating principles, laws, mechanisms and patterns of evolution at all its levels than it is usually supposed. In the meantime, we can find the common traits in development, functioning, and interaction of apparently rather different processes and phenomena of Big History. Of special importance is the point that many principles, patterns, regularities, and rules of evolution, which we tend to find relevant only for the biological and social levels of evolution, may be also applied to the cosmic phase of evolution. The present article attempts (within such a framework for the first time in the Big History framework) at combining Big History potential with the potential of Evolutionary Studies. It does not only analyze the history of the Cosmos. It studies similarities between evolutionary laws, principles, and mechanisms at various levels and phases of Big History. Such an approach opens up some new perspectives for our understanding of evolution and Big History, their driving forces, vectors, and trends; it creates a consolidated field for interdisciplinary research.

Keywords: *Star-Galaxy Era, cosmic phase of Big History, laws of evolution, universal evolutionary principles, Universe, preadaptations, Evolutionary Studies, evolutionary selection, additive and substitutive models of evolution, large-scale structures of Universe, gas-dust clouds, non-uniformity concentration of matter, circulation of matter in the Universe, dark and light matter.*

Introduction

Big History provides unique opportunities to consider the development of the Universe as a single process, to detect vectors of changes of certain important characteristics of the Universe (such as complexity and

energy) at various phases of this development. However, one should note that the Big History studies tend to pay little attention to such an important aspect as the unity of principles, laws, and mechanisms of evolution at all its levels.[1] I believe that combining the Big History potential with evolutionary approaches can open wider horizons in this respect (see Grinin *et al.* 2011). Indeed, common traits in development, functioning, and interaction can be found in apparently quite different processes and phenomena of Big History. In this respect the universality of evolution is expressed in those real similarities that are detected in many manifestations at all its levels.

This article is an attempt to combine Big History potential with the potential of Evolutionary Studies in order to achieve the following goals: 1) to apply the historical narrative principle to the description of the star-galaxy era of the cosmic phase of Big History; 2) to analyze both the cosmic history and similarities and differences between evolutionary laws, principles, and mechanisms at various levels and phases of Big History. As far as I know, nobody has approached this task in systemic way yet. It appears especially important to demonstrate that many evolutionary principles, patterns, regularities, and rules, which we tend to find relevant only for higher levels and main lines of evolution, can be also applied to cosmic evolution. Moreover, almost everything that we know about evolution may be detected in the cosmic history, whereas many of the evolutionary characteristics are already manifested here in a rather

[1] Of course, some authors analyze important general evolutionary mechanisms and patterns, which can be seen at all phases of Big History (see, *e.g.*, David Christian's 'Swimming Upstream' and the conclusion of David Baker's 'Shoulders of Giants' in this volume). One can also mention Fred Spier (2010) and David Baker's '10^{500}. The Darwinian Algorithm and a Possible Candidate for a "Unifying Theme" of Big History' (2013). However, we should state our position on Baker's general idea in that interesting paper. While also dealing with universal evolutionary principles like ours, Baker innovates by starting his article with analyzing the selection of universes within which there could appear some physical laws and parameters allowing the universes to evolve. Baker explores the selection mechanism among an enormous number (potentially 10^{500}– a fabulous number even for modern cosmology) of universes in the 'multiverse'. We suppose that his algorithm with respect to the selection of universes could hardly be called properly Darwinian. He rather speaks about the evolutionary selection in general – that is not the selection of the fittest, but rather the selection of those capable to evolve – which is much wider than the Darwinian selection. The idea that such selection is not Darwinian is confirmed if one employs Christian's (this volume) and Smolin's (2008: 34, which Christian refers to) definitions of the Universal Darwinian mechanism. Such mechanism should obviously include a mechanism of reproduction. It is clear that there is not any mechanism of reproduction in the case of isolated universes. However, for a theory of the presence of Darwinian reproduction in the evolution of multiple universes see Smolin's earlier book *The Life of the Cosmos* (1997).

clear and salient way. One should also bear in mind that the origin of galaxies, stars, and other 'celestial objects' is the lengthiest evolutionary process among all evolutionary processes in the Universe. Such an approach opens new perspectives for our understanding of evolution and Big History, of their driving forces, vectors, and trends, creating a consolidated field for the multidisciplinary research.

Our world is immensely diverse and unlimited in its manifestations. However, fundamentally it is a single world – that is why it is so important to study those fundamentals.

I. THE FORMATION OF THE LARGE-SCALE STRUCTURE OF THE UNIVERSE

Preconditions. After the Big Bang, our Universe 'lived' for quite a long period of time without any stars, galaxies, clusters, and superclusters of galaxies (Khvan 2008: 302). The formation of modern structure of the Universe lasted for billions of years. However, the first stars and galaxies turn out to have emerged not later than 200–400 million years after the Big Bang. And what was the matter from which they had emerged?

Approximately 270,000 years after the Big Bang, a large phase transition occurred resulting in the emergence of matter in the form of atoms of hydrogen and helium. Later, they started to consolidate in new structures (see below). The main mass of this matter concentrated in gas-dust clouds that could have tremendous sizes (dozens parsecs, or even more).[2] For the first time we observe Nature in the role of a constructor. Before that, it had formed just the basic elements. Now one could observe the emergence of enormous structures from tiny particles and 'specks of dust'. After that one could observe this constantly: *large-scale structures are composed of myriads of minute particles and grains*.

The formation of clouds (and later stars and galaxies) meant a concentration of matter on enormous scale, which could have been caused only by gravity. However, this only force is insufficient for structuring, because in 'an absolutely homogenous universe the emergence of large-scale structures (galaxies and their clusters) is impossible' (Dolgov *et al.* 1998: 12–13). Thus, certain seed grains are necessary – this is comparable with formation of rain drops that emerge around particles of dust or soot; or with formation of a pearl around grit. *Small fluctuations are often needed for the powerful forces to start working.* Actually, minor fluctuations (minute deviations from homogeneity) occurred in the Universe early on. Then the larger fluctuations happened. They could act as seed grains for the formation of galaxies and the matter concentrated around them

[2] 1 parsec ≈ 31 trillion km.

on a much larger scale until the quantity started to transform into a new quality. This is a perfect example of the point that *the non-uniformity (in particular with respect to the distribution of matter, energy, etc.) is a universal characteristic*. Any major evolutionary shift in biological and social systems is preceded by the concentration of certain forms, resources and conditions in certain niches and places. Thus, in the major system the common processes may proceed in their usual way, whereas in the concentration zone some peculiar processes start (this is what takes place in star formation zones).

Dark and light matter. Nowadays it is generally accepted that dark matter plays an important role in the formation of the first galaxies, as it appeared capable of consolidating into clusters much earlier than the light (baryon) matter. The latter could not contract until the end of the hydrogen recombination (atom formation) due to radiation (270,000 years after the Big Bang). Only when hydrogen nuclei and electrons were able to merge and form atoms, whereas photons separated from the matter and flew away, the pressure of the radiation dramatically dropped. As a result, the light matter would fall in potential holes prepared for it by the dark matter. Though the dark matter was initially more capable to structuring than the light matter, the progress toward structuring turned out to be very short and leading to almost a dead-lock.[3] Meanwhile, the evolutionary potential of the light matter was based on the 'achievements of the dark matter'. Such a model of development is rather typical for evolution. For example, long before the transition to agriculture some gatherers of cereal plants invented many things (sickles, granaries, and grinding stones) that later turned to be rather useful for agriculturalists, whereas specialized hunter-gatherers turned out to be an evolutionary dead end.

The epoch of formation of the large-scale structure of the Universe. First galaxies and stars. There are rather diverse opinions on timing, process characteristics and sequence of formation of stars, galaxies, galaxy clusters and superclusters. There is a hypothesis that galaxy protoclusters were first to originate. However, a more commonly held hypothesis suggests that protogalaxies (in the form of giant condensed gas clouds) were the first to emerge within the structure of the Universe, and later they became the birthplace for separate stars and other structural elements (see, *e.g.*, Gorbunov and Rubakov 2011).

[3] However, as with any evolutionary dead end, this does not mean an absolute stagnation. At present, in galaxy halos the dark matter is structured in certain smaller structures (see, *e.g.*, Diemand *et al.* 2008).

However, in recent years new evidence has come to hand to support the idea that those were the stars that appeared first. This discovery somehow modified the previous theories. At present, it is widely accepted that the stars were first to emerge, but those were the giant stars, much more massive than most of the later-formed ones (May *et al.* 2008). Because of the absence of carbon, oxygen and other elements that absorb the energy from condensing clouds, the process proceeded more slowly in that epoch; thus, only giant clouds could condense producing massive stars hundreds times larger than the Sun (*Ibid.*). Such giant stars lived only a few million years (the larger is star, the shorter is its life). In addition, the first stars contained a small amount of heavy elements. Thus, more than one generation of stars could change, until the quantity of heavy elements gradually increased. The emergence of 'heavy elements' from the 'dead star stellar remnants' resembles the formation of fertile soil from the remnants of dead plants. The circulation of matter in the Universe is always observed everywhere and at all levels.

In recent years we have witnessed the discovery of a few galaxies that are claimed to be the oldest in the Universe. Meanwhile, the dates of formation of the first galaxies are shifted closer and closer to the Big Bang. The emergence of the first galaxies is dated to less than 400 million years after the Big Bang; and there are even claims that some more ancient galaxies have been discovered. They are claimed to have emerged only 200 million years after the Big Bang (see European Commission 2011). The evidence on the first stars refers to *c.* 150–200 million years after the Big Bang – hence, stars and galaxies appear to have emerged almost simultaneously.

II. THE ERA OF THE STAR-GALAXY STRUCTURE OF THE UNIVERSE

The whole history of the star-galaxy phase of cosmic evolution is basically the history of formation of various structures of different size, as well as their merging into larger structures (but it is a history of their disintegration as well).

1. The structure of the Universe

1.1. Some principles describing the basic structure of the Universe may be applied to different levels of evolution (below we will consider just two of them).

1) *The combination of antagonistic qualities.* For example, in the structure of the Universe one can find the combination of uniformity and non-uniformity. The uniformity is already manifested at the

inflation phase, when the Universe started inflating evenly in all dimensions. The uniformity has preserved till present, but only at the largest scale (of an order of magnitude of 100 megaparsecs[3]). For reference, the size of the largest galaxy clusters (such as our Local Group with the center in the Virgo constellation) is 40 megaparsecs at most (Gorbunov and Rubakov 2011). The non-uniformity of the Universe is manifested at scales smaller than 100 megaparsecs; and the smaller is the scale, the more salient is the unevenness. The combination of antagonistic qualities is a phenomenon that is rather characteristic for many other evolutionary levels.

2) *Density and sparsity can be traced everywhere,* starting from the atomic structure, where the mass is concentrated in a tiny nucleus, while most of the atom is an empty space. There is a huge non-uniformity between the scale of the Universe and the space that the main mass of the light matter occupies within it. It is concentrated, first of all, in stars which actually occupy only a 10^{-25} part of the total volume of the Universe (not taking into account the galaxy nuclei [Pavlov 2011: 43]). Not only the hard matter is distributed very unevenly throughout the Universe; the same is true of the gas. Much of this gas is concentrated in giant molecular clouds which are of many thousands of solar masses (Lipunov 2008: 37). The principles of uneven distribution of the matter mass at different evolutionary levels are rather similar. For example, at present the main mass of the Earth's population is concentrated in a rather small territory in comparison with the total territory where life on the Earth is possible.

1.2. The structure of the contemporary Universe

The main structural elements of the Universe are galaxies, their clusters, and superclusters. All the structural elements are rather stable in terms of gravitation, though they can split, merge, and collide. Galaxies are integral structural entities with a rather complex structure which includes, in addition to regions and arms, a nucleus (core), semi-periphery (so called 'disc'), and periphery (so called 'halo') (Baade 2002: 255). The halo consists of both single stars and various stellar clusters. The halo's radius (a few hundred thousand light years) is much larger than the radius of the galaxy's disc.[4]

[4] There might be an invisible halo consisting of dark matter behind the visible halo. It may be found in many (if not all) galaxies, whereby the diameter of the dark halo might exceed the diameter of the visible halo by an order of magnitude (see Ryabov *et al.* 2008: 1131).

According to Hubble, the galaxies are classified into spiral, elliptical, and irregular with various subtypes (*Ibid*.: 18–32); yet, by now one more galaxy type has been identified – the lenticular galaxies.

A galaxy contains around 100 to 200 billion stars. There are small (dwarf) galaxies with a few million stars, there are also giant galaxies consisting of up to a trillion stars. Our galaxy with its mass of about 10^{11} solar masses is one of the largest ones. It contains 200–300 or even more billions of stars. However, the mass of our neighbor – the Great Andromeda Nebula – is about three times larger.

Stars are distributed rather unevenly throughout galaxies, stars are parts of various groups and clusters; some of them consist of just a few stars, but some clusters can contain a few million stars. For example, within our Galaxy more than 1,500 star clusters have been identified (Surdin 2001). There are many globular clusters – spherical clusters tightly bound by gravity and consisting of hundreds of thousands, as a rule, rather old stars.

Galaxies are complex and (to a considerable extent) self-regulating systems, within which some stars disintegrate, whereas new stars form from cosmic gas and dust. The circulation (which results in processes of renovation of matter and its mixing) takes place at all levels of the Universe – both spatially and at different levels of evolutional complexity.

An average galaxy cluster consists of 500–1000 galaxies. Galaxy clusters have a rather regular structure which is likely to include a massive nucleus in the center. Galaxy superclusters are entities consisting of 2–20 galaxy clusters and galaxy groups as well as of isolated galaxies. In general, there are known more than 20 superclusters, including our Local Group.

1.3. Generations of galaxies and stars

There are rather diverse opinions on the number of generations throughout the evolution of the Universe. In addition, there is no consensus on which galaxies should be regarded as old, and which galaxies should be considered young. The point is that within a single galaxy one can find stars and their aggregates that considerably differ in their type, age, and other parameters. For example, the age of our Milky Way galaxy is more than 12 billion years, but that is the age of just its halo while many stars in its branches are only two–five billion years or less. Yet, it appears possible to single out a few widely accepted basic ideas.

1) In the evolution of the Universe, there have been three (or at least two) generations of galaxies and stars. In general, old galaxies are smaller and dimmer. Their stars contain dozens of times smaller quantities of heavy elements than the Sun. The astronomers can hardly observe any star formation processes within such galaxies. There is also a hypothesis

that more dark mass is concentrated in old galaxies in comparison with younger ones. The same way, older and younger stars differ from each other in their size, luminosity, and chemical composition.

2) It is difficult to speak about a clear periodization of generations of galaxies, because of the ongoing process of formation of galaxies and stars. Galaxies need to constantly renew their composition in order to retain their identity. As Joseph Shklovsky maintains, in this respect galaxies are very similar to primary forests with its mix of tree ages (whereas the age of trees is much less than the age of the forest itself [Shklovsky 1984: 45]). The motility and variability of the celestial landscape resembles very much the motility of geological landscapes.

3) The formation of galaxies can proceed in different ways, for example, through the absorption of smaller galaxies by the larger ones. Another way is merging. Galaxies of younger generations can sometimes form through the accretion of a few small, weak and compact galaxies into a single galaxy. In this case they became 'building blocks' for galaxies. Finally, it may happen that two large galaxies collide. Such a collision may take billions of years and be accompanied with active star formation and emergence of very large and bright stars. Finally, galaxies may diverge again, but in this case they turn out to be very different from what they used to be before the collision, whereas one more galaxy may emerge out of the matter estranged from the both galaxies (see May *et al.* 2008: 142).

There are numerous analogies to those models of galaxy formation in biological, geological, and, especially, social evolution. As stars and galaxies are composed of more or less homogenous matter (that can be divided or united rather easily), they somehow paradoxically resemble societies that consist of people who can be included into other societies through integration or capture. On the other hand, captures are also attested among social animals (*e.g.*, among ants see Genet 2007).

4) Galaxies are collections of different types of stars. However, there are certain peculiarities as regards the position of old and young stars within galaxies. Thus, within our galaxy the younger stars (such as the Sun which is a few billion years old) are generally larger, hotter and brighter. They are located toward the disc plane, and, especially, within the galaxy arms; whereas in the galaxy periphery (in its halo) one would find older stars more than 12 billion years old (which suggests the overall age of our galaxy). Yet, older and younger stars may be also located rather close to each other. Thus, one may find many old stars near the galaxy center (bulge), but there are also young stars that emerged from the matter produced by the disintegration of older stars. The highest

stellar density is found in the galaxy center where it reaches a few stars per cubic parsec.

On the one hand, the preservation of generations of stars and galaxies demonstrates an additive character of the evolution of abiotic systems, whereas we can see elements of substitutive model of evolution at biological phase and its full system at social phase of Big History. However, the capture of stars and galaxies with their subsequent integration and prolonged processes of collision of galaxies demonstrates that in abiotic natural systems one may still find some other models of evolution – connected with 'wars' and 'submission of outsiders'.

The type of development through the emergence of different generations of individuals and species (preserving certain generic features, on the one hand, and accumulating important changes in their structure and characteristics, on the other) is rather widespread at all phases and levels of universal evolution. Within any biological class or order (*e.g.*, perissodactyls) we can see how important characteristics vary and gradually change from one species to another, whereas due to those characteristics some species press out others and occupy better niches (see, *e.g.*, Grinin, Markov, and Korotayev 2008). Various types of states and civilizations also rather vividly illustrate the progress: for example, more organized and developed states emerge through the absorption of the achievements of less developed generations of states, which one can illustrate using examples from the history of Ancient Rome, Byzantium, some Medieval European states and so on. The coexistence of different generations sometimes leads to the situation when younger and more advanced entities either transform the older ones or form a symbiosis with them (though in some places one may find 'restrictions' for older types and generations).

1.4. Change of the chemical composition of the Universe

Hydrogen has always been the most abundant element in the Universe chemical composition; yet, its share constantly decreased. This occurred (and occurs) because hydrogen is the main fuel for the nuclear fusion reactions that support life and luminosity of stars. Increasing temperatures inside the core of some stars were needed for the formation of new elements that were absent in the era of recombination. However, all of the fusion reactions that occur to produce elements larger than iron no longer release energy. Reactions of another type are needed for the formation of elements heavier than iron – those reactions consume more energy than release. That is why there are such relatively small amounts of heavy elements in the Universe. Yet, such peculiar reactions do take place – for example, in neutron stars and during explosions of supernovas. When supernovae explode, heavy elements are expelled through

the Universe with stellar winds and through the fall of the dispersed matter on the surface of cosmic bodies (so-called accretion). As stars turn to be the main centers of the synthesis of chemical elements, the distribution of heavy elements in the Universe is very inhomogeneous.

The emergence of heavy elements and their concentration in certain bodies and compositions are extremely important processes, which lead to an enormous increase in the number of matter combinations, and consequently have an evolutionary potential; in particular, they lead to the start of the full-scale chemical, biochemical, and biological processes. In certain respects, such a slow and uneven accumulation of new structural elements (heavy elements) resembles the process of an accumulation of valuable mutations in biological evolution, or the accumulation of valuable innovations in social evolution (all of them bring the expansion of the evolutionary potential and increase the rates of evolutionary changes).

2. The Evolution of Galaxies and Stars

2.1. Processes of the formation of galaxies and stars

Until quite recently, the processes of star formation were entirely concealed from an external observer; however, at present due to the technological progress one can observe some aspects of those processes in many parts of our galaxy. Those observations confirm the theory of stellar formation from cold clusters that are heated by gravitation and pressure.

Briefly, this process may be described as follows. Within giant hydrogen and helium clouds, some heterogeneities emerge, which launch (under certain conditions) the gravitation processes that start to collect that mass into spherical forms. Sometimes a direct formation of a giant mass of gas clouds takes place, from which a galaxy or a star cluster later emerges. In this case the cloud fragmentation may occur and thus, more and more gas-cloud spheres (there could be hundreds of millions, or even hundreds of billions of them) emerge, which can gradually transform into protostars. This process continues up to the point when the gas density becomes so high that each new fragment already has a mass of a star (Surkova 2005: 49). Then the gravity starts impeding further fragmentation. This process is denoted as 'cascade fragmentation'. It is remarkable that it resembles certain processes in social evolution – for example, the fragmentation of large early states into separate parts that decentralize up to the point when further division becomes unreasonable (*e.g.*, in certain periods there were dozens and hundreds of independent states in the territories of Germany or France).

As enormous gas/dust clouds appear unstable, they disintegrate into large bundles, so the formation of stars proceeds in groups. This phenome-

non is of interest not only with respect to stellar evolution. The group formation is rather typical for evolution in general (in this way populations and sometimes new species emerge; chiefdoms, city-states, and sometimes political parties emerge in groups, and so on).

The further process of the star formation is connected with the point that the initial compression heated the gas to a rather high temperature that, on the one hand, prevents the further compression of the gas, and, on the other hand, eventually contributes to the onset of the nuclear fusion reaction (Hawking 2001: 63–64).

2.2. Diversity of stars and galaxies

Diversity is an absolutely required condition of evolutionary development. And this condition is fully realized within cosmic evolution. As has been mentioned above, galaxies differ in their types, age, size, and structure. In particular, a galactic structure is to a large degree determined by the initial conditions of its formation (*e.g.*, by the character of rotation of the original gas clump from which a galaxy is formed). Stars differ in mass, temperature, chemical composition, luminosity, age, and other characteristics. Those differences may vary greatly. For example, with respect to masses, stars range in mass from about 0.1 to 100 or more solar masses. It is rather natural that the number of smaller entities is orders of magnitude larger;[5] actually, the same phenomenon may be observed, for example, in Zoology or Political Geography where the number of small animals or countries is much larger than that of large ones.

2.3. The life-cycle of a star: Stages of stellar birth, aging, and death

Protostars. As mentioned above, stars emerge through the condensation and compression of gas clouds under the influence of gravitational forces. This is a protostar phase. In comparison with the subsequent life of a star, the period of its slow contraction seems rather short; however, actually this is not a quick process as it continues sometimes up to 50 million years (Surkova 2005: 50). During this period of time, there is a tremendous rise in the temperature at the core of the protostar, the temperature may grow up to 8–10 million Kelvin, and, as a result, thermonuclear reactions become possible. The protostar becomes a young star. However, an external observer will only be able to see it in a few hundred thousand (or even a few million) years when the cocoon of gas and dust surrounding the protostar dissipates.

[5] Thus, for every ten million red dwarfs we find only 1,000 giants and one supergiant (Surkova 2005: 26).

Actually, we deal with a sort of miracle – a giant shining incandescent body, which is capable of living for billions of years, emerges from an absolutely amorphous, lacking any structure, opaque, and cold mass of gas mist. In other words, we deal here with a vivid example of self-organization that takes place under the influence of gravitation and thermodynamic laws. In particular, an intensive contraction leads to heating, which increases the internal pressure, which, eventually, stops the compression process.

One may also note that the emergence of stars and galaxies must have a certain trigger that creates turbulence and heterogeneity. Those triggers and catalyzers are the inherent components of evolutionary mechanisms that may be found in many processes: in chemical and geological processes, within biological evolution with respect to fast formation of species, or within social evolution with respect to state formation (see Grinin 2011 for more details). The supernova shock wave, the collision of a molecular cloud with spiral arms of a galaxy and other events can become such a trigger of the star formation (Surkova 2005: 50).

Another (the longest) macrophase is the main sequence star. During this phase of the stellar lifetime, nuclear-fusion reactions that burn hydrogen to helium in the core, keep the star shining. That is why the duration of the main sequence phase depends mainly on the stellar mass. The more massive is the star, the shorter its lifespan on the main sequence (as with a larger mass the 'fuel combustion' processes run more intensively). A star preserves its size and form due to the mutual struggle of two forces: the gravity that tries to compress the star and the gas pressure produced as a result of nuclear reactions and powerful heating. There is a dynamic equilibrium between temperature and gas pressure. With growing temperature, the gas expands and works against the gravitation forces, which results in cooling of the star; this way the thermal balance is kept. In the lifetime of stars and galaxies, as well as at all other levels of evolution, we find numerous cases and different forms of the interaction between two opposite processes which make it possible for 'individuals' to live. The processes of assimilation and dissimilation support vital activities within biological organisms; the processes of animal reproduction and their extermination by predators support the population balance; interaction between processes of production and consumption is the basis of the reproduction of social systems, and so on.

Red giants. The new phase of stellar evolution is connected with the exhaustion of hydrogen supplies. The gas pressure (that maintained the star balance when necessary fuel was available) decreases and the stellar core compresses. This leads to a new increase in temperature. A star

starts to burn heavier elements and thus, the stellar composition significantly changes. Simultaneously with the compression of the core, the star's outer layers expand. In general, the star inflates and expands a few hundred times, and it transforms into a red giant. This phase lasts for about one tenth of the 'active lifetime' of a star, when the processes of nuclear fusion go on in its depths.

Star death: three cases. The next phase is the transformation of a red giant or supergiant. Actually, the new form depends on stellar mass and a number of other characteristics such as the stellar rotation and velocity, the degree of its magnetization, and so on. The following three outcomes are considered most typical. They depend on stellar mass (but the limit value estimates vary significantly, and so below I will mention the main alternative values after the slash).[6] Stars with the masses smaller than 1.2–1.4/3 solar masses transform from red giants into the so-called 'white dwarfs', when the star sheds its outer envelope to form a planetary nebula with an extremely contracted core (down to the size of the Earth). The further compression does not occur because of the so-called degenerate electron gas pressure that does not depend on temperature. As a result, the white dwarf is rather stable. However, due to the lack of hydrogen and helium, thermonuclear fusions can no longer proceed within such a star. A white dwarf is very hot when it is formed; yet, afterwards the star cools and transforms into a 'black dwarf', that is, it becomes a cold dead cosmic body.

For stars with an initial mass of more than 1.2–1.4/3, but less than 2.4–3/7–10 solar masses, their slow and gradual aging results in an 'infarct', that is a collapse. After the depletion of hydrogen and the decrease of the internal gas pressure (that used to balance the gravity), under the influence of gravity the core gets extremely compressed (by dozens thousand times – up to the radius of ten kilometers) just in less than a second. Almost simultaneously the external layers of the star are blown away with a huge speed as a result of shock wave. This supernova shines brighter than millions of ordinary stars, but for a very short period of time. This explosion expels the stellar material into interstellar medium and thus, there occurs the formation of considerable quantities of heavy (heavier than iron) elements that afterwards concentrate in various celestial bodies. The remaining core contracts to become a neutron star. In its size, such a star is 5 billion times smaller than the Sun,

[6] According to one of classifications (that might be more correct than the one reproduced below), it appears possible to subdivide all the stars just in two classes: a) massive stars (with a mass exceeding *c.* 10 solar masses), producing neutron stars and black holes, and b) non-massive ones producing white dwarfs (Lipunov 2008: 99).

but it is hundreds of thousands of times brighter because the temperature on its surface is 1000–1500 times higher than on the Sun (Lipunov 2008: 133).

If stellar mass exceeds the limit of 3/7–10 solar masses, after hydrogen is burnt out it will start collapsing and explode (though sometimes it may collapse without an explosion), but the force of compression will be unlimited, as the gravity becomes enormous because of the huge mass and absence of internal forces that can prevent the collapse. The action of the gravitational force which is balanced by nothing leads to the situation when the stellar diameter becomes infinitesimally small. According to theoretical calculations, the star is transformed into a black hole whose gravity fields are strong for light to escape.

III. UNIVERSAL EVOLUTIONARY PRINCIPLES IN THE STAR-GALAXY ERA

1. Life, Death, and Catastrophes in the Evolutionary Aspect

The lifetime of stars in terms of maintaining and breaking the dynamic equilibrium

First of all, there is a thermal equilibrium, when the rate of energy produced in the core (through thermonuclear fusions) balances the loss of energy through the emission of radiation into space. This equilibrium is broken when hydrogen fuel is gone. The reserves are apparently compensated when a star starts using another type of energy. This may occur through the contraction of the star which begins fusing helium into carbon, thus producing many times more energy for every atom; afterwards heavier elements may be used as fuel, and each heavier element will produce more and more energy per atom. Meanwhile, the core of the star begins to increase in temperature. There is equilibrium in terms of pressure of different forces and preservation of a certain form and size of the star. Within the main sequence phase, the balance is maintained as the gravity pulls all the stellar matter inward, toward the core, while gas pressure pushes heat and light away from the center. This pressure exists until the reserves of nuclear fuel are exhausted (Efremov 2003: 97). With respect to red giants one may speak about equilibrium of another kind in two dimensions. In the core the temperature grows due to contraction and thermonuclear reactions of higher levels (described above) start; as a result of those reactions the temperature may grow up to 100 million Kelvin. That is why a stronger gravity is balanced by a stronger (due to temperature) gas pressure. In the meantime, within the shell the equilibrium is achieved through the multifold expansion of the outer layers.

In neutron stars and white dwarfs, the subsequent phases of the stellar lifetime, there is their peculiar equilibrium.

The problem of the individual's death. Death as an opportunity for life to go on. Stellar life and death can hardly leave anybody indifferent. Actually, within the Big History framework, this is the first time when we come across the problem of a life cycle of individual objects in such an explicitly expressed form. On the one hand, the star's fate, lifespan, and type of death depend on initial parameters, as if they were 'genetically programmed' (and, hence, they may be forecasted); on the other hand, they may be altered by some contingencies. Thus, the star's fate is not 'fatal', indeed. Binary star systems increase highly the variability of the individual star fates; as Lipunov (2008: 252) puts it, we deal here with a kind of 'quadratic evolution'. What is more, it is actually possible to speak about differences in the 'individual' stellar behavior or 'within a group', because the interaction of two, three, and more stars may lead to very significant differences and unusual results that cannot emerge within the development trajectory of individual stars. In fact, similar patterns are observed at other levels of evolution, when behavior of pairs or groups of individuals produces outcomes radically different from the ones observed with respect to the behavior of an individual not interacting with others.

Finally, the meaning of individual's death for evolution may be different. Up to a certain degree one may observe a direct correlation between the 'strength' of death, the power of the stellar explosion, and the formation of conditions for a new evolutionary search. Stellar explosions affect the dynamics of their environment; consequently, they may help create unusual conditions that contribute to the emergence of certain developmental deviations. Within tens of thousands years the zone of explosion expands to a vast area of interstellar medium (covering the distances of dozens of parsecs); in this area one can see the formation of new physical conditions (in particular, temperature, density of cosmic rays and magnetic fields strength). Such a disturbance enriches the respective zone with cosmic rays and brings changes to chemical composition (Shklovsky 1984: 209). The explosions also contribute to star formation. Thus, a star does not die in vain. One can draw here an interesting analogy with extinctions in biological evolution which contribute to new directions of speciation. The stellar destruction can be also compared with the disintegration of large empires with all the subsequent repercussions. The disintegration of a large empire leads to a cascade of new states forming both in the place of the empire and even beyond its

borders. Historical detonation contributes to politogenesis the same way as the cosmic detonation contributes to star formation.

Synthesis of gradualism and catastrophism. With respect to cosmic evolution one may observe a combination of two principles that provoke endless discussions in geology and biology. The subject of those discussions is what principle prevails in evolution. Are we dealing mostly with slow gradual changes, eventually leading to major changes (gradualism)? Or, does the development mostly proceed through sharp revolutionary breakthroughs which in biology are often connected with catastrophes? Within star-galaxy evolution the combination of both principles is more than just evident. Here, as at no other evolutionary level, both modes of evolution are organically combined in individual fates of the stars. The main sequence phase of stellar evolution (when the fusing of hydrogen occurs) demonstrates the gradual character and the importance of slow and prolonged processes. However, catastrophes of various scales can take place within the lifetime of any star. For some stars, such radical changes may manifest in major – but still local – changes (such as shedding the outer layers), whereas for other stars these might be tremendous catastrophes when stars die, figuratively speaking, 'brightly' and 'heroically', illuminating the Universe, leaving a billion-year-long footprint of light. The latter, that is the extraordinary phenomena and events, both among the stars and among humans are less numerous than the former, that is the common ones.

2. Some Evolutionary Ideas in Connection with the Star-Galaxy Phase of Evolution of the Universe

In the evolutionary process of formation of stars, galaxies, nebulae, and cosmic clouds one can distinguish a number of important evolutionary principles and laws that are not evident. Their detection is important for understanding the unity of principles of development of the Universe. Those principles and observations are grouped below into several blocks.

2.1. Evolution proceeds with constant creation and destruction of objects

Nature, when creating, destroying, and renewing various objects, 'tests' many versions, some of which turn out to be more effective and have more chances to succeed in terms of evolution. For such a situation of selection within constant destruction and creation process, it appears possible to apply a rather appropriate notion of creative destruction introduced by Josef Schumpeter (1994).

- **'Evolution is stronger than individual objects'.** Cosmic processes are accompanied by constant emergence, development, change, and

death of various objects (stars, galaxies, and so on). Thus, here one can point as relevant the principle that was expressed by Pierre Teilhard de Chardin (1987) with respect to life in the following way: 'life is stronger than organisms', that is, life goes on exactly because organisms are mortal. The same is relevant to stellar evolution. We may say here that the cosmos is stronger than stars and galaxies; and in general, evolution is stronger than individual objects.

• **Rotation and keeping balance** take place due to constant destruction (or transition to new phases in the lifecycle) of some objects and the emergence of others. This keeps balance and creates conditions for development, because development is a result of change of generations and species.

• **In every end there is a beginning. Star-evolutionary 'relay race'.** The material of dead objects becomes building blocks for the formation of new objects. This represents the circulation of matter and energy in nature; on the other hand, this represents a sort of 'relay race'.[7] The latter allows using the results of long-lasting processes (in particular, the accumulation of heavy elements).[8] Thus, we deal here with the above mentioned 'creative destruction' – the creation of new objects due to the destruction of the old ones, which ensures continuity and provides new forms with space for advancement (*e.g.*, the change of generations of biological organisms always results in certain transformations). The change of rulers may not necessarily lead to radical social changes; however, each new ruler is somehow different from his predecessor, as a result the accumulation of historical experience occurs.

• **New generations of organisms and taxa are a mode of qualitative development.** One may also detect generations of taxa, which already have significant evolutionary and systemic differences. Thus, generations of stars differ in terms of their size, chemical composition, and other characteristics. Only through the change of several generations of objects this class of objects acquires some features that, nevertheless, are considered to be typical for the whole class of objects.

2.2. Individuality as a way to increase evolutionary diversity

• **Individual fates within evolution.** It appears possible to maintain that with the formation of stars one observes the emergence of individ-

[7] For more details on the 'rule of evolutionary relay race' see Grinin, Markov, and Korotayev 2008.

[8] For example, the Solar System emerged from the remnants of a supernova explosion. It is believed that due to this fact there are so many heavy and super-heavy elements on the Earth and other planets.

ual objects in nature, 'individuals' that, on the one hand, are rather similar, but have rather different individual fates much depending on circumstances of their birth and various contingencies. For example, stars with small masses (in which nuclear fusion occurs at a slow rate) can use all of their fuel (*i.e.*, remain in the main sequence) for many billions of years. On the other hand, blue giants (in which the rate of fuel consumption is rapid and which lose most part of their mass due to their instability) burn out hundreds of times faster.

The stars can end their lives in a rather different way. Some of them, having lost one or a few outer layers, would cool, slowly transforming into cold bodies; some others may contract a few dozen times, or may end their lives with huge explosions blowing their matter into open space. Finally, a star may become a black hole that does not allow any matter to come out of its immensely compressed depths.

• **Ontogenesis and phylogenesis.** The evolution proceeds at various levels: through the development of its certain branch, a certain class, species and so on (and sometimes even at the level of an individual organism). In addition, applying biological terminology, at every level of evolution we find a combination of processes of *ontogenesis* and *phylogenesis*. Of course, within star-galaxy evolution the phylogenesis is represented much weaker than in the evolution of life. Nevertheless, it still appears possible to speak about the history of transformation of certain types of galaxies and stars, and, hence, up to a certain extent the cosmic phylogenesis does occur (see as above with respect to change of a few generations of stars and galaxies that differ from each other as regards their size, structure, and composition).

• **Required and excessive variation as conditions of a search for new evolutionary trajectories.** Within the processes described above one can observe the formation of the taxonomic diversity of space objects; we may even speak about occupying the evolutionary 'niches'. There emerge different types of stars and galaxies (see above). Such diversity is extremely important. Only the achievement of a necessary level of taxonomic and other diversity allows a search for ways to new evolutionary levels. This is sometimes denoted as the rule of necessary and excessive diversity (see Grinin, Markov, and Korotayev 2008: 68–72; for more details see also Panov 2008).

• **Norm, averages, and deviation from a norm.** Only when we find a sufficient diversity, it appears possible to speak about norm, average level, exceptions, and outliers. Scientists have long known that the breakthroughs to new forms usually happen at the periphery, and in those systems that diverge from the previous mainstream.

• **Continuity,** which actually means the emergence of a continuum of forms, sizes, life spans, and lifecycles, is rather characteristic for space objects. Thus, the stars can be presented as a continuum from heavier to lighter ones (whereas the latter become hardly distinguishable from planets). The types of planetary systems uniformly cover a wide range of parameters. There is also a sequence of phases in the transformation of cosmic clouds into stars: condensation of clouds – formation of protostars – formation of young stars, and up to the death of stars. The continuum of forms and sizes of objects may be observed at geological, biological, and social phases of the evolution.

2.3. Object, environment, competition, development systems, and self preservation

• **The relations between structure and environment.** Multilevel systems (galaxy – galaxy cluster – galaxy supercluster) act as systems of a higher order for stars, and, simultaneously, they create an environment that produces an enormous influence on those stars. A star directly interacts with its immediate environment (*e.g.*, with neighboring stars because of the strong gravity which affects the movement of both stars), whereas with the distant environment the interaction proceeds at higher levels. Within star-galaxy evolution the role of environment is generally less important than at other evolutionary levels, because single stars are separated by great distances and that is why collide rather infrequently. On the other hand, one should not underestimate the role of the environment. For example, the role of the immediate environment is very important in systems of double, triple, or multiple stars. For a small galaxy the influence of neighboring larger galaxy may turn out to be fatal, if it leads to its absorption. *External factors* play the major role in *changes* (*e.g.*, a large cosmic body can pass by a giant molecular clouds, there can occur a star explosion, and so on) and may trigger the process of formation of stars and galaxies (by launching the gas contraction process). Collisions of cosmic bodies may create new cosmic bodies – for example, there is a hypothesis that the Moon emerged as a result of the collision of some large objects with the Earth.

With the development of a certain form of evolution, its own laws and environment gain a growing influence on the development of its objects and subjects. For example, both abiotic nature and the biotic environment influence biological organisms. However, within a complex ecological environment, it is the intraspecies and interspecies competition that may have larger influence than any other natural factors, whereas within a complex social environment it is just the social surrounding that affects individuals and social systems more than the nat-

ural forces do. Thus, with the formation of star-galaxy structure of the Universe there emerged macro-objects which start to interact with environments which are larger by many orders of magnitude.

• **The urge toward self-preservation and origins of the struggle for resources.** Stars, galaxies, and planets (as well as other cosmic bodies) have their definite, quite structured, and preserved form. The 'struggle' for the preservation of those forms, the capacity to live and shine, the use of different layers to minimize energy losses lead to a slow but evident evolutionary development. This way the atomic composition of the Universe changes, whereas the diversity of variations of the existence of matter increases. On the one hand, the emergence of structures that strive for their preservation creates a wide range of interaction between the system and its environment; on the other hand, this creates a basis for the 'evolutionary search' and evolutionary advancement. This evolutionary paradox – *the struggle for the self-preservation is the most important source for development* – can be observed here in its full-fledged form. However, star-galaxy evolution demonstrates the emergence of this driving force which will become very important in biological evolution; and it appears to be the most important driving force in social evolution. This is the struggle for resources that among stars and galaxies may proceed in the form of weakening of another object or its destruction (*e.g.*, through a direct transfer of energy and matter from one body to another), in the form of 'incorporation', 'capturing', that is 'annexation' of stars and star clusters by larger groups. We have already mentioned above galactic coalescences. Thus, some astronomers maintain that throughout a few billions of years our galaxy has 'conquered, robbed, and submitted' hundreds of small galaxies, as there are some evident 'immigrants' within our galaxy, including the second brightest star in the northern sky, Arcturus (Gibson and Ibata 2007: 30). It is widely accepted that emergence and expansion of a black hole may lead to the 'eating' of the matter of the nearby stars and galaxies. However, the 'eating capacity' of the black holes is greatly exaggerated in popular literature. In systems of double stars or in star-planet systems one may also observe such a form of interaction as the exchange of energy and resources.

2.4. Multilinearity

Multilinearity is one of the most important characteristics of evolution. Unfortunately, it does not get sufficient attention, and there is a tendency to reduce evolution to a single line – the one that has produced the highest complexity level, which is often interpreted as the main line of evolu-

tion. *However, at every stage of evolutionary development one can find an interaction of a few lines that can have rather different futures*. In other words, in addition to the main evolutionary line one can always identify a number of lateral ones. Firstly, they contribute to the increasing diversity; secondly, they allow expanding the range of search opportunities to move to new levels of development; thirdly, the lateral lines may partly enter the main evolutionary stream, enriching it. We quite often deal with two or more coexisting and comparable lines of development whose convergence may lead to a quantitative breakthrough and synergetic effect. Various lines of development may transform into each other. Elsewhere we have written a lot on the issue of social evolution in this context (see, *e.g.*, Grinin and Korotayev 2009; Grinin and Korotayev 2011; Bondarenko, Grinin, and Korotayev 2011; Grinin 2011).

• **Classical forms and their analogues.** The main and lateral lines of evolution may be considered in two dimensions: 1) horizontal (as regards complexity and functions), 2) vertical (concerning the version that would be realized later at higher evolutionary phases). It appears also possible to speak about classical versions and their analogues. Thus, various forms of aggregation and specialization of unicellulars can be regarded as analogues of multicellulars (see Eskov 2006), whereas various complex stateless polities can be regarded as state analogues (see Grinin and Korotayev 2006; Grinin and Korotayev 2009; Grinin 2011 for more detail). Classical forms and their analogues can transform into each other; however, these are just the analogues that tend to transform into classical forms, rather than the other way round (the latter may be regarded as a forced adaptation to sharply changing conditions, and sometimes even as a direct degeneration).

• **Stars and molecular clouds: two parallel forms of existence of cosmic matter.** In this respect we may consider stars and galaxies as the main line of evolution and the giant clouds as its lateral lines; the former may be denoted as 'classical forms', and the latter may be designated as 'analogues'. On the one hand, those forms actually transform into each other. Galaxies and stars emerge from giant molecular clouds, whereas stars through explosions and shedding their envelopes may transform into gas-dust cloud. On the other hand, giant molecular clouds are able to concentrate; the energy exchange occurs within them, and thus, in terms of gravity and structural complexity they are quite comparable to stars and galaxies. They generally have a rather complex 'Russian nesting doll' structure, whereby smaller and denser condensations are placed within larger and sparser ones (see Surkova 2005: 48). The Russian-doll structure is also typical for higher levels of evolution. Thus, smaller groups of social and gregarious animals constitute larger groups

and tend to reproduce their structure. The same refers to social evolution, in particular to the non-centralized entities: for example, the tribal formations, whose constituent parts (lineages, clans, and sub-tribes) often reproduce the structure (and structural principles) of the tribe. That is why tribes can easily split and merge when necessary. The same is true of herds of gregarious animals.

Conclusion: The Formation of Various Evolutionary Lines at the Microworld Level

Astrophysical and astrochemical evolution. Almost from the very beginning of the development of the Universe (when the temperature reached thousands of Kelvin) chemical evolution emerges as accompanying physical and astrophysical evolution. Of course, chemical evolution also occurs within stars with the emergence of heavier elements. However, that was rather the formation of the basis for chemical evolution, because chemical processes involve the reactions which lead to the emergence of new substances. Such processes proceed, first of all, within gas-dust clouds where molecules emerge. Hydrogen molecules are absolutely prevalent quantitatively; however, molecules of water and some other substances also emerged. Chemical evolution goes on also on planets (where it combines with geological, or rather planetary evolution) as well as on small celestial bodies (asteroids and meteorites).

In contrast with biological and social forms which from their very start displayed substantially higher levels of organization of the matter, the chemical form (that emerged a rather short time after the physical form) did not represent a higher form of evolution for a rather long period of time. That is not to say that chemical evolution is not important in the framework of general stellar and galactic evolution; however, before the emergence of the Earth-like planet, the physical and chemical forms of organization of matter should be regarded as equally important; note also that they constantly transform into each other. The development of astrochemical evolution is not limited by the formation of simple nonorganic molecules. The processes of formation of molecules proceed further towards the formation of organic substances. More than hundred types of organic molecules have been detected in space (see Surdin 2001; Surdin and Lamzin 1992; Shklovsky 1984). Naturally, this facilitated the emergence of life in a rather significant way.

The Formation of 'Preadaptations' as Points of Future Evolutionary Growth. Within the star-galaxy era the chemical form of development may be regarded as a 'preadaptation' for new levels of evolution. Let us note that in biology the term 'preadaptation' denotes those adaptations that may turn out to be useful in a different environment and to give sig-

nificant advantages to those species that have them[9] – and generally – to give an impulse to the formation of new taxa. Within the Big History framework, the principle of 'preadaptation' means that at the level where a preadaptation emerges, it generally plays insignificant role; however, at a new evolutionary level such 'innovations' generally give evolutionary impulses.[10] Respectively, chemical compounds (as is common for preadaptations) do not mean much for cosmic evolution, they were rather 'in reserve' to reveal all their significance at the level of planetary evolution.

I would like to finish this article with a note on one more peculiarity of preadaptations. Appropriate conditions are necessary for their formation. Within biological evolution, the preadaptations often emerge in peculiar environments. Thus, it is supposed that the transformation of fins of the fleshy-finned fish (from which Amphibia descended) into primitive legs occurred within the environment of shallow waters that often dried out. In a similar way, within star-galaxy evolution the emergence of complex chemical compounds can take place only within certain structures of cosmic clouds that made their existence possible as they protected the molecules from cosmic radiation.

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[9] This omnivorous ability of hominids allowed their transition to hunting at a very early phase of the anthropogenesis.

[10] On preadaptations in megaevolution see also Grinin, Korotayev, and Markov 2011: 159–160.

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9
Mathematical Modeling of Biological and Social Phases of Big History

Andrey V. Korotayev and Alexander V. Markov

Abstract

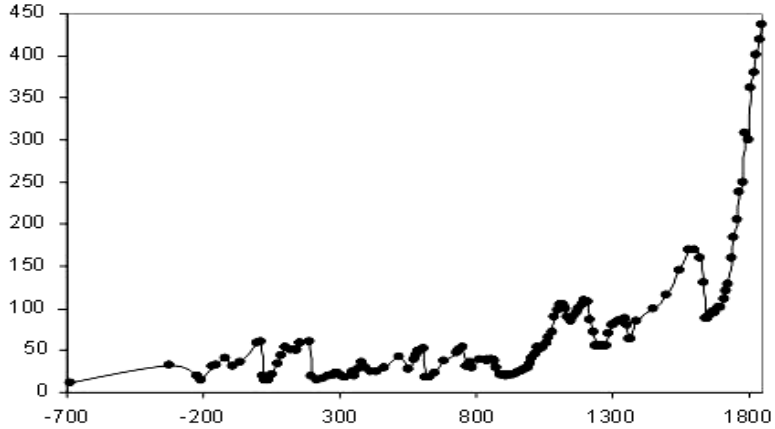
The present article demonstrates that changes in biodiversity through the Phanerozoic correlate with a hyperbolic model (widely used in demography and macrosociology) much more strongly than with exponential and logistic models (traditionally used in population biology and extensively applied to fossil biodiversity as well). The latter models imply that changes in diversity are guided by a first-order positive feedback (more ancestors – more descendants) and/or a negative feedback arising from resource limitation. The hyperbolic model implies a second-order positive feedback. The authors demonstrate that the hyperbolic pattern of the world population growth arises from a second-order positive feedback between the population size and the rate of technological growth (this can also be identified with the collective learning mechanism). The feedback between the diversity and community structure complexity can also contribute to the hyperbolic character of biodiversity. This suggests that some mechanisms vaguely resembling the collective learning might have operated throughout the biological phase of Big History. Our findings suggest that we can trace rather similar macropatterns within both the biological and social phases of Big History which one can describe in a rather accurate way with very simple mathematical models.

Keywords: *biological phase of Big History, social phase of Big History, mathematical modeling, collective learning, positive feedback, biodiversity, demography, sociology, paleontology, geology, hyperbolic growth.*

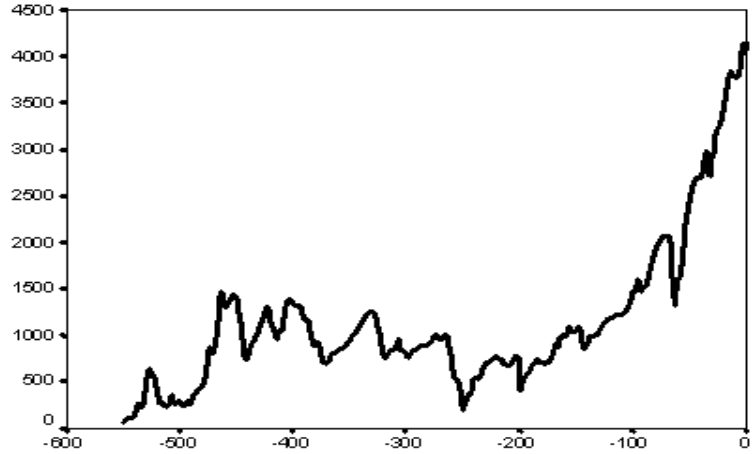
In 2005, in the town of Dubna, near Moscow, at what seems to have been the first ever international conference devoted specifically to Big History studies, the two authors of the present article – sociologist/anthropologist Andrey Korotayev and biologist/paleontologist Alexander Markov – one after another demonstrated two diagrams.[1] One of those diagrams illustrated the dynamics of the population of China between 700 BCE and 1851 CE, the other illustrated the dynamics

[1] We would like to emphasize that we saw each other at that session for the first time, so we had no chance to arrange in advance the demonstration of those two diagrams.

of marine Phanerozoic biodiversity during the last 542 million years (see Fig. 1):



a



b

Fig. 1. Similarity of the dynamics of Phanerozoic marine biodiversity and long-term population dynamics of China: **a** – Population dynamics of China (million people, 700 BCE – 1851 CE), based on estimates in Korotayev, Malkov, and Khaltourina (2006b: 47–88); **b** – Global change in marine biodiversity (number of genera, *N*) through the Phanerozoic based on empirical data surveyed in Markov and Korotayev (2007a)

Nevertheless, one can hardly ignore the striking similarity between two diagrams depicting the development of rather different systems (human population, on the one hand, and biota, on the other) at different time scales (hundreds of years, on the one hand, and millions of years, on the other) studied by different sciences (Historical Demography, on the one hand, and Paleontology, on the other) using different sources (demographic estimates, on the one hand, and paleontological chronicles, on the other hand). What are the causes of this similarity in the development dynamics of rather different systems?

* * *

In 1960, von Foerster, Mora, and Amiot published a striking discovery in the journal *Science*. They showed that between 1 and 1958 CE the world's population (N) dynamics can be described in an extremely accurate way with an astonishingly simple equation:[2]

$$N_t = \frac{C}{t_0 - t}, \tag{1}$$

where N_t is the world population at time t, and C and t_0 are constants, with t_0 corresponding to an absolute limit ('singularity' point) at which N would become infinite.

Of course, von Foerster and his colleagues did not imply that one day the world population would actually become infinite. The real implication was that prior to 1960 the world population growth for many centuries had followed a pattern which was about to come to an end and to transform into a radically different pattern. Note that this prediction started to come true only a few years after the 'Doomsday' paper had been published, because *after the early 1970s the World System growth in general (and world population growth in particular) began to diverge more and more from the blow-up regime, and now it is not hyperbolic any more with its pattern being closer to a logistic one* (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2006a, where we present a compact mathematical model that describes both the hyperbolic development of the World System in the period prior to the early 1970s, and its withdrawal from the blow-up regime in the subsequent period; see also Korotayev 2009).

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[2] To be exact, the equation proposed by von Foerster and his colleagues looked as follows: $N_t = \frac{C}{(t_0 - t)^{0.99}}$. However, as von Hoerner (1975) and Kapitza (1999) showed, it can be simplified as $N_t = \frac{C}{t_0 - t}$.

Parameter t_0 was estimated by von Foerster and his colleagues as 2026.87, which corresponded to November 13, 2006; this allowed them to give their article an attractive and remarkable title – 'Doomsday: Friday, 13 November, A.D. 2026'.

The overall correlation between the curve generated by the von Foerster equation and the most detailed series of empirical estimates looks as follows (see Fig. 2).

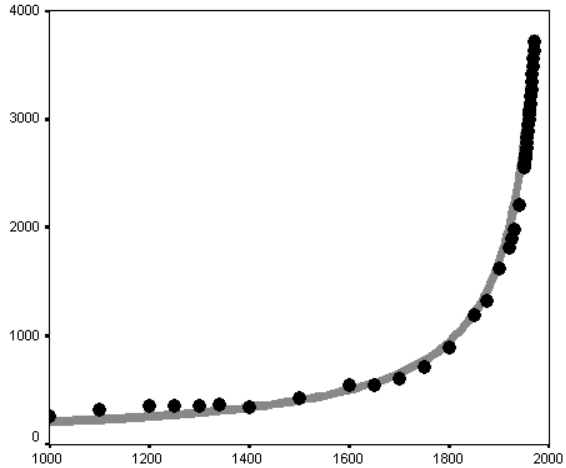

Fig. 2. Correlation between empirical estimates of world population (in millions, AD 1000–1970) and the curve generated by the von Foerster equation

Note: black markers correspond to empirical estimates of the world population by McEvedy and Jones (1978) for the interval between 1000 and 1950 and the U.S. Bureau of the Census (2014) for 1950–1970. The grey curve has been generated by the von Foerster equation (1).

The formal characteristics are as follows: $R = 0.998$; $R^2 = 0.996$; $p = 9.4 \times \times 10^{-17} \approx 1 \times 10^{-16}$. For readers unfamiliar with mathematical statistics we can explain that R^2 can be regarded as a measure of the fit between the dynamics generated by a mathematical model and the empirically observed situation, and can be interpreted as the proportion of the variation accounted for by the respective equation. Note that 0.996 also can be expressed as 99.6 per cent.[3] Thus, the von Foerster equation

[3] The second characteristic (p, standing for 'probability') is a measure of the correlation's statistical significance. A bit counter-intuitively, the lower the value of p, the higher the statistical significance of the respective correlation. This is because p indicates the probability that the observed correlation could be accounted solely by chance. Thus, $p = 0.99$

accounts for an astonishing 99.6 per cent of all the macrovariation in the world population, from 1000 CE through 1970, as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2014).[4]

Note also that the empirical estimates of world population align in an extremely accurate way along the hyperbolic curve, which convincingly justifies the designation of the pre-1970s world population growth pattern as 'hyperbolic'.

To start with, the von Foerster equation $N_t = \frac{C}{t_0 - t}$ is just a solution of the following differential equation (see, *e.g.*, Korotayev, Malkov, Khaltourina 2006a: 119–20):

$$\frac{dN}{dt} = \frac{N^2}{C}. \tag{2}$$

This equation can be also written as:

$$\frac{dN}{dt} = aN^2, \tag{3}$$

where $a = \frac{1}{C}$.

What is the meaning of this mathematical expression, $\frac{dN}{dt} = aN^2$? In our case, *dN/dt* denotes an absolute population growth rate at a certain moment of time. Thus, this equation shows that at any moment of time an absolute population growth rate should be proportional to the square of population at this moment.

Note that this significantly demystifies the problem of the world population hyperbolic growth. Now to explain this hyperbolic growth, we should just explain why for many millennia the absolute rate

indicates an extremely low statistical significance, as it means that there are 99 chances out of 100 that the observed correlation is the result of a coincidence, and, thus, we can be quite confident that there is no systematic relationship (at least, of the kind that we study) between the two respective variables. On the other hand, $p = 1 \times 10^{-16}$ indicates an extremely high statistical significance for the correlation, as it means that there is only one chance out of 10000000000000000 that the observed correlation is the result of pure coincidence (in fact, a correlation is usually considered as statistically significant with $p < 0.05$).

[4] In fact, with slightly different parameters (C = 164890.45; t_0 = 2014) the fit (R^2) between the dynamics generated by the von Foerster equation and the macrovariation of world population for CE 1000–1970 as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2014) reaches 0.9992 (99.92 per cent), whereas for 500 BCE – 1970 CE this fit increases to 0.9993 (99.93 per cent) (with the following parameters: C = 171042.78; t_0 = 2016).

of world population growth tended to be proportional to the square of population.

The main mathematical models of the hyperbolic pattern of the world's population growth (Taagapera 1976, 1979; Kremer 1993; Cohen 1995; Podlazov 2004; Tsirel 2004; Korotayev 2005, 2007, 2008, 2009, 2012; Korotayev, Malkov, and Khaltourina 2006a: 21–36; Khaltourina, Malkov, and Korotayev 2006; Golosovsky 2010; Korotayev and Malkov 2012) are based on the following two assumptions:

1) 'the Malthusian (1978 [1798]) assumption that population is limited by the available technology, so that the growth rate of population is proportional to the growth rate of technology' (Kremer 1993: 681–682).[5] This statement seems rather convincing. Indeed, throughout most of human history the world population was limited by the technologically determined ceiling of land carrying capacity. For example, with foraging subsistence technologies the Earth could hardly support more than 8 million people, because the amount of naturally available useful biomass on the planet is limited, and the world population could overgrow this limit only when people started to apply various means to artificially increase the amount of available biomass, that is with a transition from foraging to food production. However, the extensive agriculture can only support a limited number of people, and world population further growth became possible only with the intensification of agriculture and other technological improvements (see, *e.g.*, Turchin 2003; Korotayev, Malkov, and Khaltourina 2006a, 2006b; Korotayev and Khaltourina 2006).

However, it is well known that the technological level is not a constant, but a variable (see, *e.g.*, Grinin 2007a, 2007b, 2012). And in order to describe its dynamics the second basic assumption is employed:

2) 'High population spurs technological change because it increases the number of potential inventors…[6] In a larger population there will be proportionally more people lucky or smart enough to come up with new ideas' (Kremer 1993: 685), thus, 'the growth rate of technology is proportional to total population'.[7] In fact, here Kremer uses the main

[5] In addition to this, the absolute growth rate is proportional to the population number – with a given relative growth rate a larger population will increase more in absolute numbers than a smaller one.

[6] 'This implication flows naturally from the non-rivalry of technology… The cost of inventing a new technology is independent of the number of people who use it. Thus, holding constant the share of resources devoted to research, an increase in population leads to an increase in the probability of technological change' (Kremer 1993: 681); note that in the framework proposed by David Christian (2005) this corresponds precisely to the pattern of *collective learning*.

[7] Note that 'the growth rate of technology' means here the relative growth rate (*i.e.* the level to which technology will grow in a given unit of time in proportion to the level observed at

assumption of the Endogenous Technological Growth theory (Kuznets 1960; Grossman and Helpman 1991; Aghion and Howitt 1998; Simon 1977, 2000; Komlos and Nefedov 2002; Jones 1995, 2005, *etc.*). To our knowledge, this supposition was first put forward by Simon Kuznets (1960), so we will denote a corresponding type of dynamics as 'Kuznetsian', while the systems in which the 'Kuznetsian' population-technological dynamics combines with the 'Malthusian' demographic one will be denoted as 'Malthusian-Kuznetsian'. In general, we find this assumption rather plausible – in fact, it is quite probable that, ceteris paribus, within a given period of time, a billion people will make approximately a thousand times more inventions than a million people.

This assumption was expressed by Kremer mathematically in the following way:

$$\frac{dT}{dt} = kNT \quad . \tag{4}$$

Actually, this equation just says that the absolute technological growth rate at a given moment of time (dT/dt) is proportional to the technological level (T) observed at this moment (the wider is the technological base, the more inventions could be made on its basis), and, on the other hand, it is proportional to the population (N) (the larger the population, the larger the number of potential inventors).[8]

The resultant models provide a rather convincing explanation of *why* throughout most of human history the world population followed the hyperbolic pattern with an absolute population growth rate tending to be proportional to N^2. For example, why would the growth of population from, say, 10 million to 100 million, result in the hundredfold growth of dN/dt? The above mentioned models explain this rather convincingly. The point is that the growth of world population from ten to a hundred million implies that human subsistence technologies also grew approximately ten times (given that it will prove, after all, to be able to support a ten times larger population). On the other hand, the tenfold population growth also implies a tenfold growth of the number of potential inventors, and, consequently, a tenfold increase in a relative technological growth rate. Hence, the absolute technological growth rate would grow 10 × 10 = 100 times (as Equation 4 shows that an order of magnitude larger number of people with an order of magnitude broader technological basis would likely make two orders of magnitude more inven-

the beginning of this period).

[8] Kremer did not test this hypothesis empirically in a direct way. Note, however, that our own empirical test of this hypothesis has supported it (see Korotayev, Malkov, Khaltourina 2006b: 141–146).

tions). And as throughout the Malthusian epoch the world population (N) tended to the technologically determined carrying capacity ceiling of the Earth, we have good reason to expect that dN/dt will also grow just about 100 times.

In fact, one can demonstrate (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2006a, 2006b; Korotayev and Khaltourina 2006) that the hyperbolic pattern of the world's population growth can be explained by the nonlinear second order positive feedback mechanism that was shown long ago to generate just the hyperbolic growth, known also as the 'blow-up regime'(see, *e.g.*, Kurdyumov 1999). In our case this nonlinear second order positive feedback looks as follows: more people – more potential inventors – a faster technological growth – a faster growth of the Earth's carrying capacity – a faster population growth – with more people you also have more potential inventors – hence, faster technological growth, and so on (see Fig. 3).

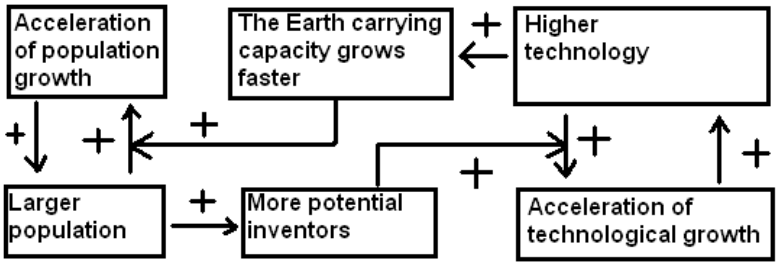

Fig. 3. Cognitive scheme of the nonlinear second order positive feedback between technological development and demographic growth

Note that the relationship between technological development and demographic growth cannot be analyzed through any simple cause-and-effect model, as we observe a true dynamic relationship between these two processes – each of them is both the cause and the effect of the other.

Note also that *the process discussed above should be identified with the process of collective learning* (on the notion of 'collective learning' see first of all Christian 2005: 146–148; see also David Christian's and David Baker's contributions to the present volume). Respectively, the mathematical models of the World System development discussed in this article can be interpreted as mathematical models of the influence of collective learning on the global social evolution. Thus, a rather peculiar hyperbolic shape of the acceleration of the global development observed prior to the early 1970s may be regarded just as a product of the global collective learning. Elsewhere we have also shown (Korotayev, Malkov, and

Khaltourina 2006a: 34–66) that for the period prior to the 1970s the World System economic and demographic macrodynamics driven by the above mentioned positive feedback loops can be described mathematically in a rather accurate way with the following extremely simple mathematical model:

$$\frac{dN}{dt} = aSN, \tag{5}$$

$$\frac{dS}{dt} = bNS, \tag{6}$$

while the world GDP (G) can be calculated using the following equation:

$$G = mN + SN, \tag{7}$$

where G is the world GDP, N is population, and S is the produced surplus per capita, over the subsistence amount (m) that is minimally necessary to reproduce the population with a zero growth rate in a Malthusian system (thus, $S = g - m$, where g denotes per capita GDP); a and b are parameters.

Note that the mathematical analysis of the basic model (not presented here) suggests that up to the 1970s the amount of S (per capita surplus produced at the given level of World System development) should be proportional, in the long run, to the World System's population: $S = kN$. Our statistical analysis of the available empirical data has confirmed this theoretical proportionality (Korotayev, Malkov, and Khaltourina 2006a: 49–50). Thus, in the right-hand side of equation (6) S can be replaced with kN, and as a result we arrive at the following equation:

$$\frac{dN}{dt} = kaN^2 . \tag{3}$$

As we remember, the solution of this type of differential equations is

$$N_t = \frac{C}{(t_0 - t)}, \tag{1}$$

and this produces simply a hyperbolic curve.

As, according to our model, S can be approximated as kN, its long-term dynamics can be approximated with the following equation:

$$S = \frac{kC}{t_0 - t} .$$

Thus, the long-term dynamics of the most dynamic component of the world GDP, SN, 'the world surplus product', can be approximated as follows:

$$SN = \frac{kC^2}{(t_0 - t)^2}. \quad (8)$$

Of course, this suggests that the long-term world GDP dynamics up to the early 1970s must be approximated better by a quadratic hyperbola than by a simple one; and, as we could see below (see Fig. 4), this approximation works very effectively indeed:

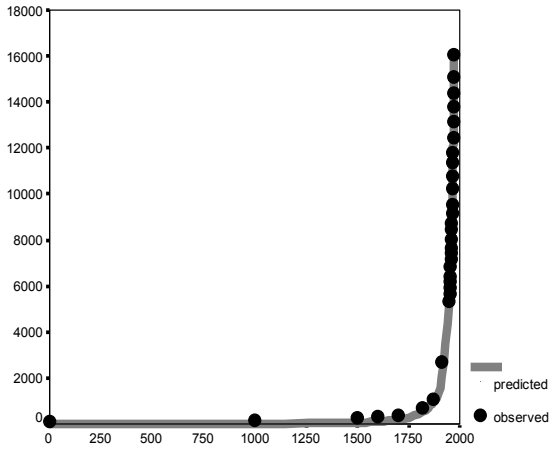

Fig. 4. World GDP Dynamics, 1–1973 CE (in billions of 1990 international dollars, PPP): the fit between predictions of a quadratic-hyperbolic model and the observed data

Note: $R = .9993$, $R^2 = .9986$, $p << .0001$. The black markers correspond to Maddison's (2001) estimates (Maddison's estimates of the world per capita GDP for 1000 CE has been corrected on the basis of [Meliantsev 2004]). The grey solid line has been generated by the following equation:

$$G = \frac{17749573.1}{(2006 - t)^2}.$$

Thus, up to the 1970s the hyperbolic growth of the world population was accompanied by the quadratic-hyperbolic growth of the world GDP, just as our model suggests. Note that the hyperbolic growth of the world population and the quadratic-hyperbolic growth of the world GDP are tightly interconnected processes, actually two sides of the same coin, two dimensions of one process propelled by the nonlinear second

order positive feedback loops between the technological development and demographic growth (see Fig. 5).

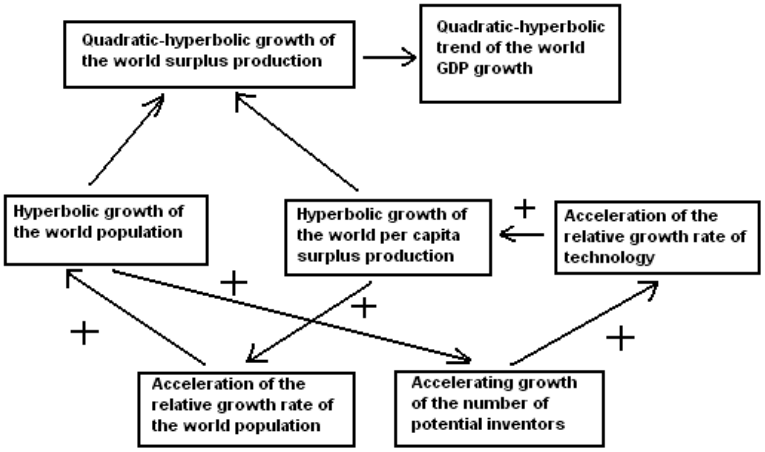

Fig. 5. Cognitive Scheme of the Generation of Quadratic-Hyperbolic Trend of the World Economic Growth by the Nonlinear Second Order Positive Feedback between Technological Development and Demographic Growth

We have also demonstrated (Korotayev, Malkov, and Khaltourina 2006a: 67–80) that the dynamics of the World System population's literacy (l) is rather accurately described by the following differential equation:

$$\frac{dl}{dt} = aSl\ (1-l), \tag{9}$$

where l is the proportion of the population that is literate, S is per capita surplus, and a is a constant. In fact, this is a version of the autocatalytic model. It has the following sense: the increasing literacy is proportional to the fraction of the population that is literate, l (potential teachers), to the fraction of the population that is illiterate, $(1 - l)$ (potential pupils), and to the amount of per capita surplus S, since it can be used to support educational programs (in addition to this, S reflects the technological level T that implies, among other things, the level of development of educational technologies). Note that, from a mathematical point of view, Equation 9 can be regarded logistic where saturation is reached at literacy level $l = 1$, and S is responsible for the speed with which this level is approached.

It is important to emphasize that with low values of l (which correspond to most part of human history except for the recent decades), the increasing rate of the world literacy generated by this model (against the background of hyperbolic growth of S) can be approximated rather accurately as hyperbolic (see Fig. 6).

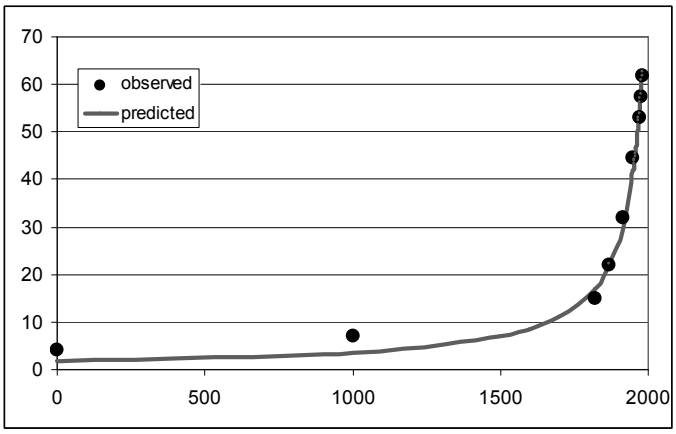

Fig. 6. World Literacy Dynamics, 1 – 1980 CE (%%): the fit between predictions of the hyperbolic model and the observed data

Note: R = 0.997, R^2 = 0.994, p << 0.0001. Black dots correspond to UNESCO/World Bank (2014) estimates for the period after 1970, and to Meliantsev's (2004) estimates for the earlier period. The grey solid line has been generated by the following equation:

$$l_t = \frac{3769.264}{(2040 - t)^2}.$$

The best-fit values of parameters C (3769.264) and t_0 (2040) have been calculated with the least squares method.

The overall number of literate people is proportional both to the literacy level and to the overall population. As both of these variables experienced a hyperbolic growth until the 1960s/1970s, one has sufficient grounds to expect that until recently the overall number of literate people in the world (L)[9] grew not just hyperbolically, but rather in a quadratic-hyperbolic way (as the world GDP did). Our empirical test has confirmed this – the quadratic-hyperbolic model describes the growth of

[9] Since literacy appeared, almost all of the Earth's literate population has lived within the World System; hence, the literate population of the Earth and the literate population of the World System have been almost perfectly synonymous.

the literate population of the planet with an extremely good fit indeed (see Fig. 7).

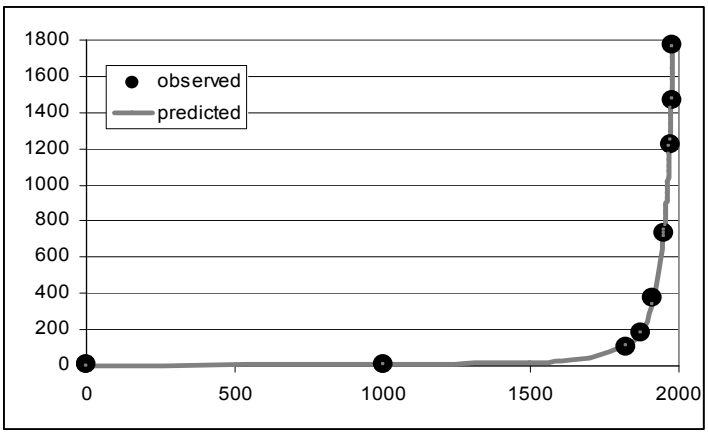

Fig. 7. World Literate Population Dynamics, 1–1980 CE (*L*, millions): the fit between predictions of the quadratic-hyperbolic model and the observed data

Note: $R = 0.9997$, $R^2 = 0.9994$, $p << 0.0001$. The black dots correspond to UNESCO/World Bank (2014) estimates for the period since 1970, and to Meliantsev's (2004) estimates for the earlier period; we have also taken into account the changes of age structure on the basis of UN Population Division (2014) data. The grey solid line has been generated by the following equation:

$$L_t = \frac{4958551}{(2033 - t)^2}.$$

The best-fit values of parameters *C* (4958551) and t_0 (2033) have been calculated with the least squares method.

Similar processes are observed with respect to world urbanization, whose macro dynamics appears to be described by the differential equation:

$$\frac{du}{dt} = bSu\ (u_{\lim} - u)\ ,$$

where u is the proportion of the population that is urban, S is per capita surplus produced with the given level of the World System's technological development, b is a constant, and $u_{\lim}$ is the maximum possible proportion of the urban population. Note that this model implies that during the blow-up regime of the 'Malthusian-Kuznetsian' era, the hyperbolic growth of world urbanization must have been accompanied by a quadratic-hyperbolic growth of the urban population of the world, which is supported by our empirical tests (see Figs 8–9).

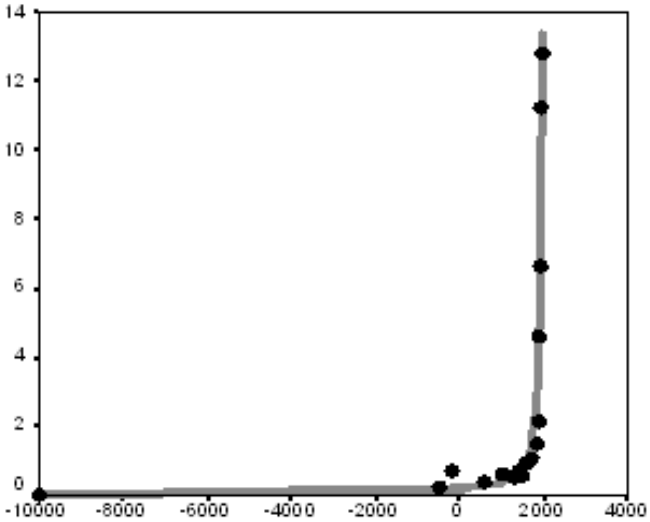

Fig. 8. World Megaurbanization Dynamics (% of the world population living in cities with > 250 thousand inhabitants), 10000 BCE – 1960 CE: the fit between predictions of the hyperbolic model and empirical estimates

Note: R = 0.987, R^2 = 0.974, p << 0.0001. The black dots correspond to Chandler's (1987) estimates, UN Population Division (2014), Modelski (2003), and Gruebler (2006). The grey solid line has been generated by the following equation:

$$u_t = \frac{403.012}{(1990 - t)}.$$

The best-fit values of parameters C (403.012) and t_0 (1990) have been calculated with the least squares method. For comparison, the best fit (R^2) obtained here for the exponential model is 0.492.

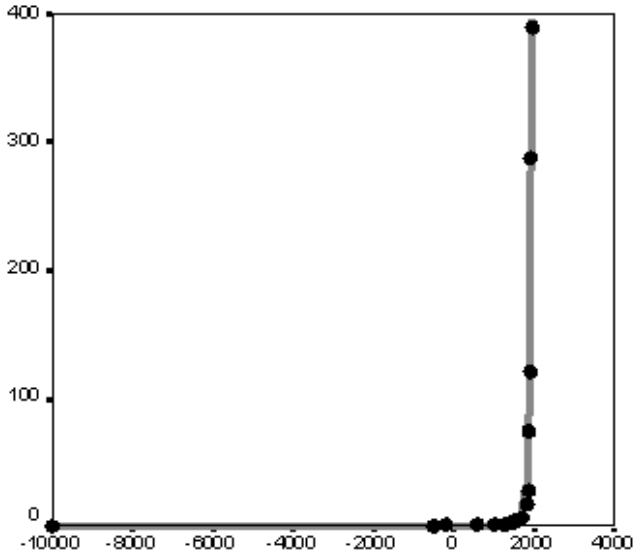

Fig. 9. Dynamics of World Urban Population Living in Cities with more than 250,000 Inhabitants (mlns), 10000 BCE – 1960 CE: the fit between predictions of the quadratic-hyperbolic model and the observed data

Note: R = 0.998, R^2 = 0.996, p << 0.0001. The black markers correspond to estimates of Chandler (1987) and UN Population Division (2014). The grey solid line has been generated by the following equation:

$$U_t = \frac{912057.9}{(2008 - t)^2}.$$

The best-fit values of parameters C (912057.9) and t_0 (2008) have been calculated with the least squares method. For comparison, the best fit (R^2) obtained here for the exponential model is 0.637.

Within this context it is hardly surprising that the general macro dynamics of the size of the largest settlement within the World System is also quadratic-hyperbolic (see Fig. 10).

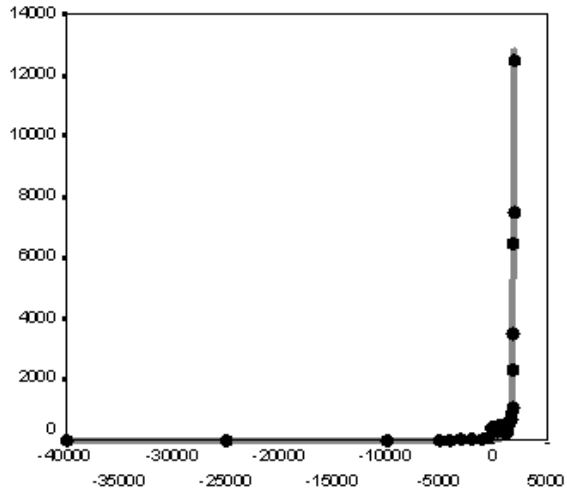

Fig. 10. Dynamics of Size of the Largest Settlement of the World (thousands of inhabitants), 10000 BCE – 1950 CE: the fit between predictions of the quadratic-hyperbolic model and the observed data

Note: R = 0.992, R^2 = 0.984, p << 0.0001. The black markers correspond to estimates of Modelski (2003) and Chandler (1987). The grey solid line has been generated by the following equation:

$$U_{\max t} = \frac{104020618.573}{(2040 - t)^2}.$$

The best-fit values of parameters C (104020618.5) and t_0 (2040) have been calculated with the least squares method. For comparison, the best fit (R^2) obtained here for the exponential model is 0.747.

As has been demonstrated by cross-cultural anthropologists (see, *e.g.*, Naroll and Divale 1976; Levinson and Malone 1980: 34), for pre-agrarian, agrarian, and early industrial cultures the size of the largest settlement is a rather effective indicator of the general sociocultural complexity of a social system. This, of course, suggests that in the 'Malthusian-Kuznetsian' era the World System's general sociocultural complexity also increased, in a generally quadratic-hyperbolic way.

As we have noted in the beginning, the dynamics of marine biodiversity is strikingly similar to the population dynamics in China, the country with the best-known demographic history.

The similarity probably stems from the fact that both curves are produced by the interference of the same three components (general

hyperbolic trend, as well as cyclical and stochastic dynamics). In fact, there is a lot of evidence that some aspects of biodiversity dynamics are stochastic (Raup *et al.* 1973; Sepkoski 1994; Markov 2001a; Markov 2001b; Cornette and Lieberman 2004), while others are periodic (Raup and Sepkoski 1984; Rohde and Müller 2005). On cyclical and stochastic components of the long-term population dynamics of China (as well as other complex agrarian societies) see, e.g., Korotayev and Khaltourina 2006; Korotayev, Malkov, and Khaltourina 2006*b*; Chu and Lee 1994; Nefedov 2004; Turchin 2003, 2005*a,* 2005*b*; Turchin and Korotayev 2006; Turchin and Nefedov 2009; Usher 1989; Komlos and Nefedov 2002; Grinin, Korotayev and Malkov 2008; Grinin *et al.* 2009; Grinin 2007c; Korotayev 2006; Korotayev, Khaltourina, and Bozhevolnov 2010; Korotayev *et al.* 2010; van Kessel-Hagesteijn 2009; Abel 1980; Braudel 1973; Goldstone 1991; Grinin, Korotayev 2012 *etc.*).

In fact, similarly to what we have observed with respect to the world population dynamics, even before the start of its intensive modernization, the population dynamics of China was characterized by a pronounced hyperbolic trend – as we can see below (see Figs 11 and 12), the hyperbolic model describes traditional Chinese population dynamics *much* more accurately than either linear or exponential models do:

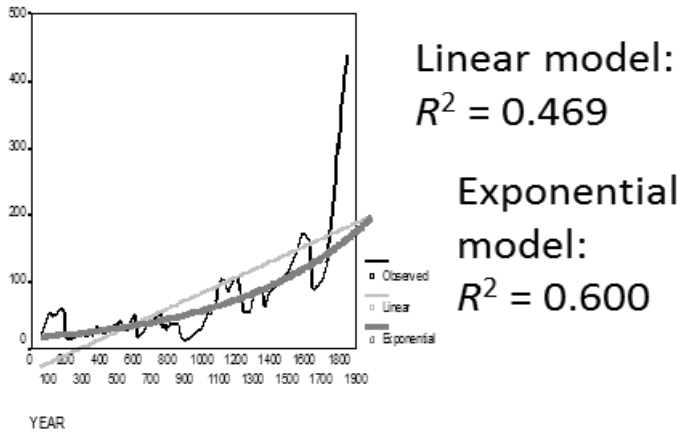

Fig. 11. Population Dynamics of China (million people), 57–1851 CE: fit with linear and exponential models

Note: based on calculations in Korotayev, Malkov, and Khaltourina 2006b: 47–88.

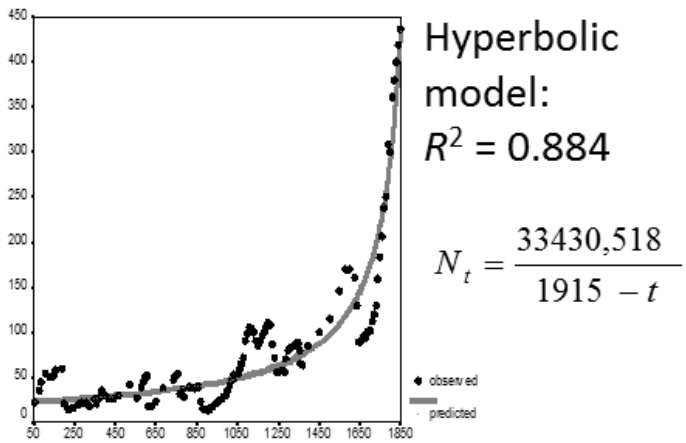

Fig. 12. Population Dynamics of China (million people), 57–1851 CE: fit with a hyperbolic model

The hyperbolic model turns out to describe mathematically the population dynamics of China in an especially accurate way with respect to the modern period (see Fig. 13).

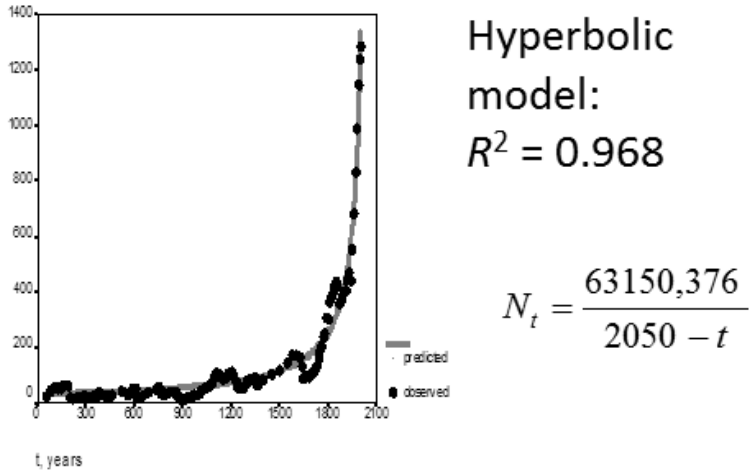

Fig. 13. Population Dynamics of China (million people), 57–2003 CE: fit with a hyperbolic model

Note: based on calculations in Korotayev, Malkov, and Khaltourina 2006b: 47–88.

In a rather similar way the hyperbolic model turns out to describe the marine biodiversity (measured by number of genera) through the Phanerozoic much more accurately than the exponential one (see Fig. 14):

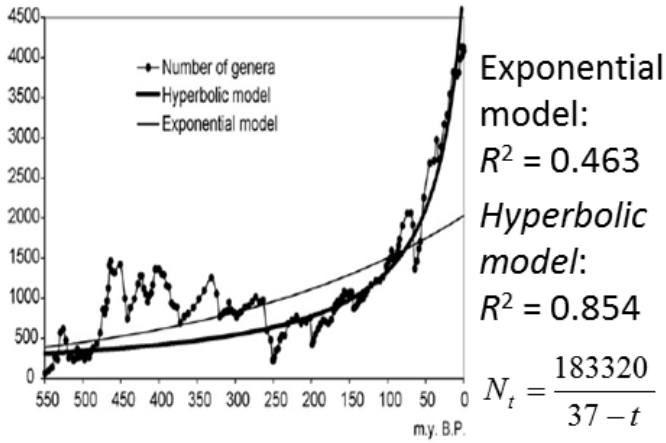

Fig. 14. Global Change in *Marine* Biodiversity (Number of *Genera*, N) through Phanerozoic

Note: based on empirical data surveyed in Markov and Korotayev (2007).

When measured in terms of species number the fit between the empirically observed marine biodiversity dynamics and the hyperbolic model becomes even better (see Fig. 15):

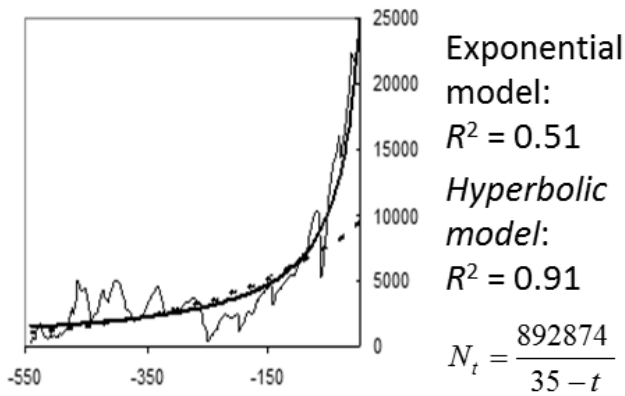

Fig. 15. Global Change in *Marine* Biodiversity (Number of *Species*, N) through Phanerozoic

Note: based on empirical data surveyed in Markov and Korotayev 2007b.

The hyperbolic model describes the continental biodiversity in an especially accurate way (see Fig. 16).

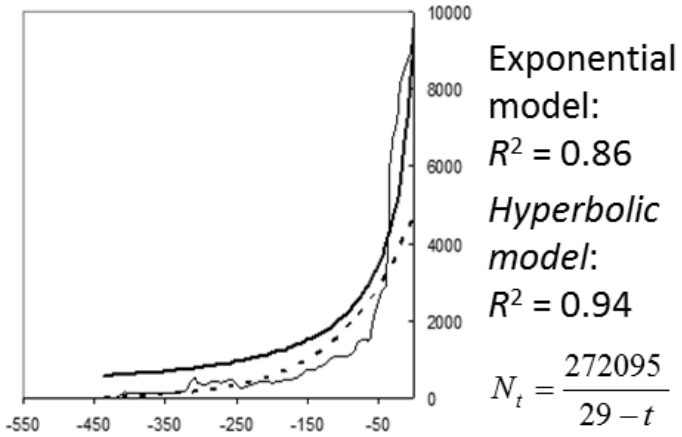

Fig. 16. Global Change in *Continental* Biodiversity (Number of *Genera*, N) through Phanerozoic

Note: based on empirical data surveyed in Markov and Korotayev 2007b.

However, the highest fit between the hyperbolic model and the empirical data is observed when the hyperbolic model is used to describe the dynamics of total (marine and continental) global biodiversity (see Fig. 17).

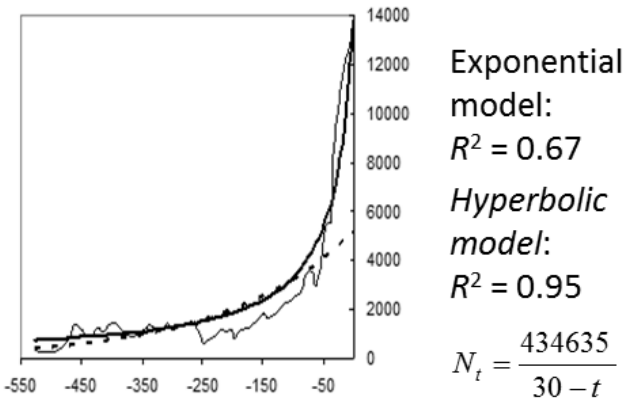

Fig. 17. Global Change in *Total* (Marine + Continental) Biodiversity (Number of Genera, N) through Phanerozoic

Note: based on empirical data surveyed in Markov and Korotayev 2007b.

As we see, the hyperbolic dynamics is most prominent when both marine and continental biotas are considered together. This fact can be interpreted as a proof of the integrated nature of the biosphere.

But why throughout the Phanerozoic did the global biodiversity tend to follow the hyperbolic trend (similarly to what we observed within social World System in general and China in particular)?

As we have noted above, in macrosociological models, the hyperbolic pattern of the world population growth arises from a non-linear second-order positive feedback (more or less identical with the mechanism of collective learning) between the demographic growth and technological development (more people – more potential inventors – faster technological growth – the carrying capacity of the Earth grows faster – faster population growth – more people – more potential inventors, and so on).

Based on the analogy with macrosociological models and diverse paleontological data, we suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by a non-linear second-order positive feedback[10] between the diversity growth and community structure complexity (more genera – higher alpha diversity – the communities become more stable and 'buffered'– average life span of genera grows; extinction rate decreases – faster diversity growth – more genera – higher alpha diversity, and so on).

The growth of genus richness through the Phanerozoic was mainly due to the increase of average longevity of genera and gradual accumulation of long-lived (stable) genera in the biota. This pattern reveals itself in the decrease of extinction rate. Interestingly, in both biota and humanity, growth was facilitated by the decrease in mortality rather than by the increase in birth rate. The longevity of newly arising genera was growing in a stepwise manner. The most short-lived genera appeared during the Cambrian; more long-lived genera appeared in Ordovician to Permian; the next two stages correspond to the Mesozoic and Cenozoic (Markov 2001a, 2002).We suggest that diversity growth can facilitate the increase in genus longevity via the progressive stepwise changes in the structure of communities.

Most authors agree that there were three major biotic changes that resulted in fundamental reorganization of community structure during the Phanerozoic: Ordovician radiation, end-Permian extinction, and end-Cretaceous extinction (Bambach 1977; Sepkoski *et al.* 1981; Sepkoski 1988, 1992; Markov 2001a; Bambach *et al.* 2002). Generally, after each

[10] One wonders if it cannot be regarded as a (rather imperfect) analogue of the collective learning mechanism that plays such an important role within the social macroevolution.

major crisis the communities became more complex, diverse and stable. The stepwise increase of alpha diversity (average number of species or genera in a community) through the Phanerozoic was demonstrated by Bambach (1977) and Sepkoski (1988). Although Powell and Kowalewski (2002) argued that the observed increase in alpha diversity might be an artifact caused by several specific biases that influenced the taxonomic richness of different parts of the fossil record, there is evidence that these biases largely compensated each other, so that the observed increase in alpha diversity was probably underestimated rather than overestimated (Bush and Bambach 2004).

Another important symptom of progressive development of communities is the increase in evenness of distribution of species (or genus) abundances. In the primitive, pioneer or suppressed communities, this distribution is strongly uneven (community is overwhelmingly dominated by a few very abundant species). In more advanced, climax or flourishing communities, this distribution is more even (Magurran 1988). The former type of community is generally more vulnerable. Evenness of distribution of species richness in communities increased substantially during the Phanerozoic (Powell and Kowalewski 2002; Bush and Bambach 2004). Most probably there was also an increase in habitat utilization, total biomass and rate of trophic flow in biota through the Phanerozoic (Powell and Kowalewski 2002).

The more complex the community, the more stable it is due to the development of effective interspecies interactions and homeostatic mechanisms based on the negative feedback principle. In a complex community, when the abundance of a species decreases, many factors arise that facilitate its recovery (*e.g.*, there will be more food and fewer predators). Even if a species becomes extinct, its vacant niche may 'recruit' another species, most probably a related one that may acquire morphological similarity with its predecessor and thus, the taxonomists will assign it to the same genus. So a complex community can facilitate the stability (and longevity) of its components, such as niches, taxa and morphotypes. This effect reveals itself in the phenomenon of 'coordinated stasis': the fossil record shows many examples of persistence of particular communities for many million years while the rates of extinction and taxonomic turnover are minimized (Brett *et al.* 1996, 2007).

Selective extinction leads to accumulation of 'extinction-tolerant' taxa in the biota (Sepkoski 1991b). Although there is evidence that mass extinctions can be non-selective in some aspects (Jablonski 2005), they are obviously highly selective with respect to the ability of taxa to endure unpredictable environmental changes. This can be seen, for in-

stance, from the selectivity of the end-Cretaceous mass extinction with respect to the time of the first occurrence of genera. In younger cohorts the extinction level was higher compared to the older cohorts (see Markov and Korotayev 2007a: Fig. 2). The same pattern can be observed during the periods of 'background' extinction as well (Markov 2000). This means that genera differ in their ability to survive the extinction events, and that in the course of time the extinction-tolerant genera accumulate in each cohort. Thus, taxa generally become more stable and long-lived in the course of evolution, apart from the effects of communities. The communities composed of more stable taxa would be, in turn, more stable themselves, thus creating a positive feedback.

The stepwise change of dominant taxa plays a major role in biotic evolution. This pattern is maintained not only by the selectivity of extinction (discussed above), but also by the selectivity of the recovery after crises (Bambach *et al.* 2002). The taxonomic structure of the Phanerozoic biota was changing in a stepwise way, as demonstrated by the concept of three sequential 'evolutionary faunas' (Sepkoski 1992). There were also stepwise changes in the proportion of major groups of animals with different ecological and physiological parameters. There was a stepwise growth in proportion of motile genera compared to non-motile; 'physiologically buffered' genera compared to 'unbuffered', and predators compared to prey (Bambach *et al.* 2002). All these trends should have facilitated the stability of communities (*e.g.*, diversification of predators implies that they become more specialized; a specialized predator regulates its prey's abundance more effectively than a non-specialized predator).

There is also another possible mechanism of the second-order positive feedback between the diversity and its growth rate. Recent research has demonstrated a shift in typical relative-abundance distributions in paleocommunities after the Paleozoic (Wagner *et al.* 2006). One possible interpretation of this shift is that the community structure and the interactions between species in the communities became more complex. In the post-Paleozoic communities, new species probably increase ecological space more efficiently, either by facilitating opportunities for additional species or by niche construction (Wagner *et al.* 2006; Solé *et al.* 2002; Laland *et al.* 1999). This possibility makes the mechanisms underlying the hyperbolic growth of biodiversity and human population even more similar, because the total ecological space of the biota is analogous to the 'carrying capacity of the Earth' in demography. As far as new species can increase ecological space and facilitate opportunities for additional species entering the community, they are analogous to the 'in-

ventors' of the demographic models whose inventions increase the carrying capacity of the Earth.

Exponential and logistic models of biodiversity imply several possible ways in which the rates of origination and extinction may change through time (Sepkoski 1991a). For instance, exponential growth can be derived from constant per-taxon extinction and origination rates the latter being higher than the former. However, actual paleontological data suggest that origination and extinction rates did not follow any distinct trend through the Phanerozoic, and their changes over time look very much like chaotic fluctuations (Cornette and Lieberman 2004). Therefore, it is more difficult to find a simple mathematical approximation for origination and extinction rates than for the total diversity. In fact, the only critical requirement of the exponential model is that the difference between the origination and extinction through time should be proportional to the current diversity level:

$$(N_o - N_e)/\Delta t \approx kN, \tag{11}$$

where N_o and N_e are the numbers of genera with, respectively, first and last occurrences within the time interval Δt, and N is mean diversity level in the interval. The same is true for the hyperbolic model. It does not predict the exact way in which origination and extinction should change, but it does predict that their difference should be roughly proportional to the square of the current diversity level:

$$(N_o - N_e)/\Delta t \approx kN^2. \tag{12}$$

In demographic models discussed above, the hyperbolic growth of the world population was not decomposed into separate trends of birth and death rates. The main driving force of this growth is presumably the increase of the Earth's carrying capacity and the way this capacity is realized – either by decreasing death rate, or by increasing birth rate, or both – depends upon many factors and may vary from time to time.

The same is probably true for biodiversity. The overall shape of the diversity curve depends mostly on the differences in the mean rates of diversity growth in the Paleozoic (low), Mesozoic (moderate), and Cenozoic (high). The Mesozoic increase was mainly due to lower extinction rate (compared to the Paleozoic), while the Cenozoic increase was largely due to higher origination rate (compared to the Mesozoic) (see Markov and Korotayev 2007a: 316, Figs 3a, 3b). This probably means that the acceleration of diversity growth during the last two eras was driven by different mechanisms of positive feedback between diversity and its growth rate. Generally, the increment rate ($(N_o - N_e)/\Delta t$) was changing in a more regular way than the origination rate $N_o/\Delta t$ and extinction rate $N_e/\Delta t$. The large-scale changes in the increment rate cor-

relate better with N^2 than with N (*Ibid.*: figs 3c and 3d), thus supporting the hyperbolic rather than the exponential model.

Conclusion

In macrosociological models the hyperbolic pattern of the world population growth arises from a non-linear second-order positive feedback between the demographic growth and technological development (more people – more potential inventors – faster technological growth – the carrying capacity of the Earth grows faster – faster population growth – more people – more potential inventors, and so on, which is more or less identical with the working of the collective learning mechanism). Based on the analogy with macrosociological models and diverse paleontological data, we suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by a non-linear second-order positive feedback between the diversity growth and community structure complexity (which suggests the presence within the biosphere of a certain analogue of the collective learning mechanism). The feedback can work via two parallel mechanisms: 1) decreasing extinction rate (more taxa – higher is the alpha diversity, or mean number of taxa in a community – communities become more complex and stable – extinction rate decreases – more taxa, and so on), and 2) increasing origination rate (new taxa facilitate niche construction; newly formed niches can be occupied by the next 'generation' of taxa). The latter makes the mechanisms underlying the hyperbolic growth of biodiversity and human population even more similar, because the total ecospace of the biota is analogous to the 'carrying capacity of the Earth' in demography. As far as new species can increase ecospace and facilitate opportunities for additional species entering the community, they are analogous to the 'inventors' in the demographic models whose inventions increase the carrying capacity of the Earth. The hyperbolic growth of the Phanerozoic biodiversity suggests that 'cooperative' interactions between taxa can play an important role in evolution, along with generally accepted competitive interactions. Due to this 'cooperation' (~ 'collective learning'?), the evolution of biodiversity acquires some features of a self-accelerating process. The same naturally refers to cooperation/collective learning as regards the global social evolution. The discussed above suggests that we can trace rather similar macropatterns within both the biological and social phases of Big History that produce rather similar curves in diagrams and that can be described in rather accurate way with rather simple mathematical models.

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10
The Dynamics of Evolution: What Complexity Theory Suggests for Big History's Approach to Biological and Cultural Evolution

Ken Baskin

Abstract

The twentieth century science, from physics to neurobiology, redefined our understanding of the world, overturning the linear worldview of Newtonian physics for a more dynamic image. Especially as illuminated by complexity theory, this worldview suggests a conception of evolution in which phenomena adapt to each other, at many scales, embedded in a continually expanding universe of interconnected agents. Given this conception, human culture has evolved to adapt to changing conditions which, thus far, have generated a social world whose complexity has increased to serve a larger, more technologically advanced, more highly interconnected population. To demonstrate this conception of evolution, one can examine the Axial Age and Modernity as cultural 'phase transitions,' periods of experimentation punctuating periods of relative stable social structures. Such an examination offers an insight into the potential for Big History to contribute to solutions of the many challenges that call for innovative adaptations across our world.

Keywords: *relational evolution, world story, Axial Age, Modernity.*

Big History often focuses on the increasing complexity in the cosmos, life on Earth, and human culture that evolution has produced. David Christian discusses 'the endless waltz of chaos and complexity' (2004: 511), and Fred Spier, 'the rise and demise of complexity at all scales' (2011: 21). Yet, with the possible exception of Eric Chaisson (2001), writers in our discipline have not examined the dynamics by which complexity increases. In this essay, I want to reframe this discussion, drawing on the principles of complexity theory, because, while Big History treats complexity as a *measure* of diversity and interaction, complexity theory treats it as a *dynamic* to be examined (Bondarenko 2007). My purpose is to explore how an understanding of this dynamic – and the conception of evolution it suggests – can become an intellectual tool for our discipline.

My argument is that evolution is a much 'thicker' process than traditional theory suggests. Such a conception of evolution can enable students of Big History to reconsider any number of issues and develop a deeper understanding of the dynamics of both biological and cultural evolution. To explore this argument, I want to touch on four major issues:

- two key principles of complexity theory;
- the conception of 'relational' evolution suggested therein;
- the resulting theory of historical evolution;
- an examination of the Axial Age and Modernity in terms of this theory, as periods of punctuation, and why this perspective can be so valuable.

In an essay of this length, I can only begin this exploration. In addition, I have little choice but to oversimplify a number of issues that deserve deeper consideration. So I want to ask the readers' indulgence for this obvious limitation. With that caveat, I turn to the dynamics explored in complexity theory.

Complexity Theory Dynamics

Complexity theory emerged in the late 1970s, as researchers in fields, ranging from fluid dynamics to economics, armed with desktop computers, modelled their subjects on non-linear mathematics and began finding striking similarities across disciplines and scales (for a full discussion see Pagels 1988). Those similarities suggested a meta-discipline, complexity theory, which, for me, is best understood as the study of 'the patterns that emerge as complex, multi-scaled phenomena evolve' (Baskin 2013: 4). I prefer the word 'phenomenon', to the more generally used 'system', to describe the networks complexity theory studies, because, where the concept of systems suggests mechanical stability, that of phenomena (see Barad 2007) indicates more dynamic structures.

Two principles of complexity theory are critical to my argument – the structure of matter as nested networks and 'attractors'. First, physical reality is composed of networks of agents embedded in networks at many scales, from atoms networked in molecules to organs networked in living bodies, and solar systems in galaxies. As a result, understanding the behaviour of an ant colony as phenomenon requires *at least* knowledge of the behaviour of the ants that are its micro-scale agents, the colony itself, and its macro-scale environment.

The second critical principle is the attractor, which represents the dynamic balance between the behaviour of the agents and the constraints of the environment. The term attractor comes from non-linear mathematics, describing the pattern in phase space into which the solutions to equa-

tions are drawn. Lorenz's 'Butterfly Attractor' is among the best known. In complexity theory, more generally, an attractor describes the pattern of behaviour, of all possible behaviours, that characterizes any phenomenon under specific conditions (Cohen and Stewart 1994: 204–207). Over time, a phenomenon's attractor will draw it to behave something like this figure, which I first scribbled as a 'back-of-the-cocktail-napkin' doodle when I was wrestling with complexity theory's basic principles.

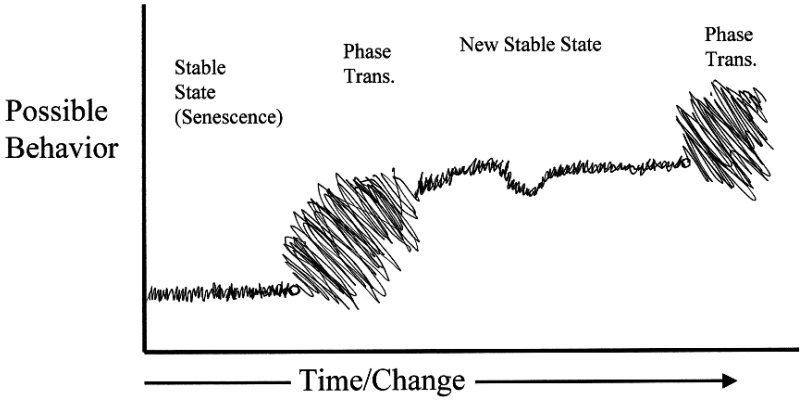

Fig. 1. Life Cycle of an Attractor

Put a chunk of ice in a pot on the stove and turn up the heat. It will remain solid until it approaches its melting point, then enter a turbulent phase transition, and transform into liquid. It will remain liquid until it approaches its boiling point, become turbulent again, and transform into gas. Phenomena, then, oscillate between turbulent phase transitions, in which their agents seek the behaviours that enable them to survive current conditions, and the stable states in which those behaviours form their characteristic attractors.

To my surprise, I soon realized that much human behaviour conforms to this pattern. Human psychological development, the economy's boom/bust cycle, and the rise and fall of human empires (Baskin 2008, 2009) – all conform to this pattern. It also reflects other thinker's analyses, from Foucault's evolution of Western *episteme* (1994) to Arrighi's cycles of Western Capitalism (1994). At some point, I realized that this pattern also reflects the still-controversial theory of punctuated equilibrium (Gould 2002), and that I had probably been strongly affected by the discussions of it I had read.

The Life Cycle of an Attractor is meant to be what Bruno Latour (2005) calls a 'panorama' – overly neat and coherent, an approximation

of the networks it maps, not a mathematical or even literal representation. The panoramic map is not the territory, merely a guide for the explorer. Nonetheless, the behaviour of many evolving phenomena conforms to this figure, suggesting a model of evolution.

Evolution like Molasses

We live today in an environment in which a new worldview is emerging (see Laughlin 2005; Boje and Baskin 2010; Smolin 2013), and our understanding of evolution is changing to meet this new worldview. The traditional conception of evolution, the 'neo-Darwinian' 'modern synthesis' 'asserts that this history of life at all levels – including and even beyond the level of speciation and species extinction events, embracing all macroevolutionary phenomena – is fully accounted for by the processes that operate within populations and species' (Hoffman 1989: 39). Like the Newtonian worldview in which it developed, neo-Darwinian evolution is linear, focusing on cause-and-effect changes in distinct entities, a 'straight line of continuous transformation of one species into the next' (Tattersall and Schwartz 2001: 33). Richard Dawkins' theory of the 'selfish gene', which reduces organisms to vehicles for their genes, is an excellent example of this approach (Dawkins 1976).

Mainstream cultural evolution articulates a similar conception of 'evolutionism'. As Robert Carneiro (2003) notes, evolutionism has gone in and out of favour with anthropologists since Herbert Spencer began discussing the idea in the 1850s. Much of the disagreement about such cultural evolution centred on the Newtonian sense of determinism often associated with its 'stages' and 'directionality'. Carneiro insists that this Newtonian reading misinterprets such thinkers as Leslie White and Gordon Childe. With his more dynamic reading of evolutionism, for example, Carneiro explains that, while cultural evolution has a direction, increasing social complexity – that is, movement toward more hierarchical socio-political levels – 'a process can have a direction without having a goal' (*Ibid.:* 163). He goes on to define cultural evolution as 'a series of adaptive readjustments, each adding to the structural complexity of the society and often initiating a series of other internal changes that further contribute to its evolution' (*Ibid.:* 199). Nonetheless, Carneiro does not develop a fully dynamic interpretation of cultural evolution.

With this traditional view of evolution, researchers made great strides during the twentieth century. However, a more dynamic and non-linear worldview is emerging today, and the conception of evolution itself is evolving. The point I want to make is not to criticize theorists such as Dawkins or Carneiro; the traditional understanding of evo-

lution reflects the worldview in which it developed. As a new worldview emerges, so does a different understanding of evolution. I shall follow Lee Smolin (2013: xvi) in calling it 'relational' – that is, phenomena are best described in the context of the networks of which they are part. Many of my ideas are certainly not original. I draw on or independently developed ideas, to name only a few, that include the 'punctuated equilibrium' of Niles Eldredge and Stephen Jay Gould (2002), Stuart Kauffman's 'adjacent possible' (2000: 150), Henri Claessen's Complex Interaction Model, which incorporates many of the dynamics of my model (Claessen 2000); and Mark Taylor's image of living things as both 'genuinely creative' individuals and the 'product of the matrix of relationships in which they exist' (Taylor 2007: 335). By organizing such ideas with a complexity-oriented discourse I am trying to move toward a fuller and a more coherent theory.

Consider the image most often used to express the traditional conception of evolution – the 'Tree of Life' (*e.g.*, Pyne and Pyne 2012: 269), a static, two-dimensional image, beginning in its roots as the most primitive form of life and growing to its apogee in Man. With dynamic evolution, a more appropriate image might be molasses moving downhill, a colloid of many particles, affecting each other, and being affected by both the hill and the weather. Relational evolution moves, then, at multiple scales, along the balance between the demands of external conditions and the conditions of a set of phenomena's internal networks. Over time (see Fig. 1), the still-weakly-connected agents of an incipient phenomenon in a phase transition – whether the living things in an ecosystem after an extinction event or the people in a social network after a collapse – search for behaviours that enable them to survive and thrive in current conditions. When those agents find successful behaviours, they begin to practice them and continue as long as the behaviours produce success.

Over time, they build relationships by practicing these behaviours, and the longer they succeed, the deeper the relationships become and the more the welfare of the agents comes to depend on those relationships. It is this dependence on specific behaviours and relationships that gives any attractor its power to constrain its agents' responses. Agents in the phenomenon continue to adapt to external change, until, at some point, those agents have become too wedded to their behaviours to adapt. At this point, the phenomenon enters 'senescence', a concept Stan Salthe (1993) developed to describe the evolution of ecosystems, and the agents subsume environmental change to their characteristic patterns. Finally, the external change becomes so great that agents can no longer

survive; so the attractor collapses. At that point, agents, often connected in less extensive networks, must either dissipate so that the phenomenon no longer exists as a functioning network or re-enter the phase transition so that it can develop another attractor. Clearly, other processes – ageing or the tendency to form self-reinforcing cycles – are also at work, often interacting with evolution. A fuller consideration would touch on them more.

Today, societies across the world seem in senescence. One sees evidence in the gridlock in American government or the corruption in Russia and China, in the economic crisis in the European Union or the chaos of the 'Arab Spring'. Overwhelmed by decades of rapid change, those in power depend so deeply on the old attractors that support their wealth, power and sense of self, that they cannot make the fundamental changes today's conditions demand.

Because phenomena evolve at many scales simultaneously, the agents that make up any network continually undergo what Francois Jullien (2011) describes as 'silent transformations'. The process of ageing goes on every moment of every day throughout our bodies, even though most people rarely note it. In this way, Jullien notes, we are not so much getting older as the ageing world is taking us with it. Most of these transformations are habitual, often programmed; others are essentially experiments by which agents strive to respond to changes in their environments, Kauffman's exploration in the adjacent possible (Kauffman 2000). In this way, a myriad of micro-scale changes among agents, often barely noticeable, are tested within the phenomenon, and those that survive become available for further development. Such micro-scale changes are only partially expressed in stable states; however, during a more chaotic phase transition the agents are freed to explore the full potential that these changes have inherent within them. In biological evolutionary theory, these tendencies are described as 'developmental canalization' and 'developmental plasticity', respectively (Hoffman 1989); similarly, Elman Service (1988) described this dynamic as the 'Law of Evolutionary Potential'. One advantage of a complexity-oriented conception of evolution is that it explains this dynamic in both organic and cultural evolution at a more detailed level.

In genetic theory, mutations build up in organisms when ecosystems are stable, and remain latent or not fully expressed until the more chaotic phase transitions, when organisms explore survival strategies (Cohen and Stewart 1994). Mammals first appeared about 210 million years ago; they remained 'mainly small, nocturnal, tree-dwelling creatures' (Leakey and Lewin 1995: 66), surviving in ecological niches in

which they could avoid dinosaur predators. They would then accumulate the mutations that would enable those that survived to dominate all the world's ecosystems, until the extinction event that removed the dinosaurs 65 million years ago. It was only in the ensuing ten-million-year phase transition that mammals could explore the full potential of their 140 million years of silent transformational mutations, in the wide-open ecosystems they now inhabited. Once again, I have oversimplified; any dynamic as complex as the emergence of mammal dominance deserves much fuller examination than is possible here.

In cultural evolution, innovations, such as writing, also develop through millions of silent transformations. Written notation appeared in a variety of times and places, as knots, notches, or pictographs, as an aide to memory (Fischer 2001). With growing populations, agricultural surpluses, and increased trade, such marks became invaluable for keeping records. Full writing systems appear to have emerged as a part of the process of state-formation, in order to manage increasingly great resource bases, in the late fourth century BCE in, first, Sumer, and, then, Egypt (Nissen 1988). Throughout the pre-axial period, however, the resulting literacy would remain what Assmann (2012) calls 'sectorial' – that is, used in the accounting, religious, and government sectors in which it emerged. Used more and more widely in such cultures, it was still constrained in a stable state where culture was predominantly communicated and managed orally. With the phase transitional Axial Age, people in such cultures as Greece, India, and China, freed of the constraints of their stable state, would experiment with writing and develop its most powerful potentialities. Literacy would become 'cultural', penetrating 'into the central core of culture' (Assmann 2012: 383), enabling the personal reflection that reading drove or the 'religions of the book', for instance (Ong 1982).

What makes relational evolution different from the neo-Darwinian approach is not the facts of evolution; many neo-Darwinians will agree with most of what I have thus far written here (*e.g.*, Hoffman 1989). The difference is in the basic discourse, some would call it a paradigm that makes these agreed-upon facts significant. The discourse in traditional evolution focuses attention on the development of individual changes, the most extreme example being Dawkins' selfish genes (1976). A relational approach, on the other hand, focuses on both individual developments and the context of wide, deeply interconnected networks of evolving phenomena, perhaps even of the universe itself. Evolution therefore suggests the thickness of molasses. It occurs on many scales – biological evolution on the molecular, cellular, organic, species and eco-

system, geologic and climatic scales, and cultural evolution on the individual, family, social organizational, cultural, ideological, technological and economic scales. The interaction of all such changes creates evolutionary patterns. In addition, the evolution of the inanimate Universe, life on Earth, and human culture all affect each other. The first major shift in human social evolution occurred after a development in inanimate evolution, the end of the Ice Age, which made more complex social structures necessary. Similarly, events in the evolution of life, the domestication of grains and animals, for example, have contributed to human social evolution. Thus, interactions between events in the three forms of evolution further thicken the process.

This relational discourse suggests ways to re-examine a variety of issues in biological and culture evolution. For example, is evolution gradual, as neo-Darwinians believe, or subject to punctuated equilibrium (*e.g.*, Hoffman 1989)? So intense was the disagreement that, in *The Blind Watchmaker* (Dawkins 1986), Dawkins entitles a chapter 'Puncturing punctuationism'. Yet, a relational approach largely resolves the disagreement. On the micro-level, agential evolution, in genes or individual people, is gradual; however, when the stable state of the macro-level goes into phase transition, the environment, whether ecosystem or culture, punctuates its equilibrium, driving radical adaptive changes for survival purposes at the micro- and meso-levels. Both processes are essential to evolution; to focus on only one is to misrepresent the full complexity of the facts. Similarly, the suggestion that biological and cultural evolution are different because the biological is mostly 'Darwinian' and the cultural, mostly 'Lamarkian' (*e.g.*, Grinin *et al.* 2011) shifts with relational evolution. The difference here is in the carriers of 'genotypic' information. In biological phenomena that carrier is DNA, embedded in the body; in cultural phenomena it is a variety of stories, narratives, and meta-narratives people in any culture tell each other (*e.g.*, Lyotard 1984). Take into account these differences in how information is carried, and the mechanism of both types of evolution seem remarkably similar.

Toward a Dynamic Theory of Human Social Evolution

From this relational point of view, a panorama of human history over the last 50,000 years might look something like this (first presented in Baskin and Bondarenko 2011).

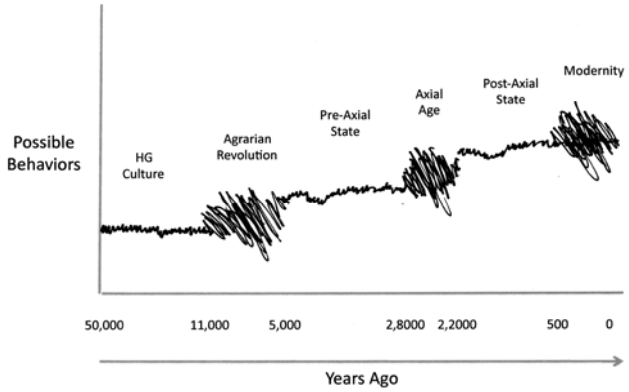

Fig. 2. Human history as 'punctuated equilibria'

History is too messy and abundant, and, what we know with certainty, too limited, to assume that events should conform to our abstractions; so I left this figure imprecise. For example, the movement indicated in the figure is overly linear. For the most part, cultural stable states do not simply end and phase transitions begin; rather, societies often move back and forth between the two. Still, the basic pattern seems valid as a Latourian panorama, rather than attempt to articulate the truth.

This conception of cultural evolution has a significant explanatory power. For instance, the period from c. 3000 BCE to 1500 CE is often defined as the 'tribute' (Tainter 1988; Amin 2009) 'stage' of society. Yet, the social institutions in Greece, India and China, before and after the Axial Age, are clearly distinct – mythic religion *vs.* religions of the book, for example, or government by royal lineage *vs.* bureaucracy (*e.g.,* Lewis 1990). The evolutionary model I am developing explains those differences as two cultural stable states that represent adaptations to different levels of complexity. This understanding was recently validated by its similarity to the more mathematically rigorous work of Korotayev and Grinin (2012: 34), in modeling the growth of urban populations.

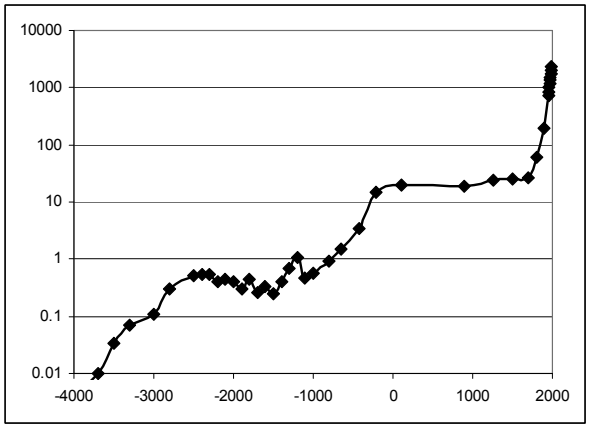

Fig. 3. Dynamics of World Urban Population

Note: In millions, for cities of more than 10,000, 4000 BCE–1990 CE, logarithmic scale.

Here we see that urban population remains essentially flat in pre-axial and post-axial stable states, while it increases exponentially in the Axial Age and Modernity. According to Korotayev and Grinin, such rapid population growth results largely from an acceleration in technological innovation. Viewed in terms of relational evolution, this acceleration of innovation reflects the phase transition and the enhanced ability to experiment with and to socially integrate the wide range of social mutations – manifested, for example, in the feedback loops of increased collective learning – that had already developed, as well as new innovations.

In the rest of this essay, I shall explore whether, as a relational theory of evolution suggests, the Axial Age and Modernity share similar dynamics. Space limitations make it impossible to explore key issues such as capitalism, imperialism, or developments outside Eurasia in any detail. If this theory does seem accurate, however, it should offer fascinating insights into such topics at another time.

At the heart of events in both cultural phase transitions is the transformation in the cultural 'phenotype', the institutional structures that enable continuing survival, which requires a new cultural 'genotype', the equivalent of organic DNA. Bondarenko and I call that cultural genotype a 'world story'. Such culture-defining sets of stories must answer a series of questions about survival including:

- How did we human beings get here?
- What is our purpose?
- Who are 'we' as a group, and how should we behave toward each other and our world?
- How should we manage the communities in which we live?
- Why, in a world full of fear and pain, should we not kill ourselves?

In this way, the world story of hunter-gatherers had to explain the 'profane', day-to-day issues of survival, from how to hunt and gather, house and clothe themselves to social relationships in groups that rarely exceeded 30 members; yet, it also had to explain the sense that 'sacred' forces 'incomprehensible, intractable but eminently efficacious' (Caillois 2001: 22), were continually moving things – from climate shifts to the animals they hunted and the flora they gathered. Such world stories are not merely 'religious' (see Nongbri 2013); they articulate a discourse that integrates spiritual concerns with social, economic and political questions, encoding any society's cultural attractor. Moreover, as Taylor (2007) notes of his expanded concept of religion, world stories function both to create the ground for social structure and to destabilize it, especially during times of cultural phase transition.

The world stories of the predominant pre-axial states (*c.* 3000 BCE – *c.* 800 BCE) focused on maintaining order amid the forces of chaos that threatened large societies dependent on agricultural surplus. In Sumeria, Egypt, and China, for example, controlling the sacred forces threatening large-scale agriculture, from drought and flood to the devastation of war, was central. In all of them, the king was conduit to the divine, whether as god himself or, more often, master of order-creating ritual. In Egypt, for example, the pharaoh had to practice the rituals that ensured *Ma'at*, both the triumph of order over chaos and justice for society at large (Assmann 2008, 2011). The resulting societies were institutionally integrated, so that worship, politics, and economics – as in the use of temples for grain collection and distribution (*e.g.*, the story of Joseph administering the seven years of plenty and seven of famine, Genesis, 41) – function as parts of an order as integral and natural as the order and chaos they balance. This style of world story successfully governed these societies until *c.* 1000 BCE, when the combination of increased trade and wealth, a wider use of writing, and rapid improvements in warfare, especially the iron metallurgy that made weapons cheaper and more plentiful (McNeill 1982), as well as a doubling of world population between 3000 and 1000 BCE (Livi-Bacci 1992), demanded a new way of living in the world.

The Axial Age

Pre-axial social structure began to break down in the Mediterranean world *c.* 1200 BCE, when the 'Sea People' (*e.g.*, Sandars 1987) destroyed both Hittite and Mycenaean cultures and drained the power of Egypt during the twelfth century BCE. In China, the Zhou Dynasty began losing control of its territories by the middle of the tenth century BCE, eventually disintegrating into 170 competing kingdoms (Fairbank and Goldman 2006). Karl Jaspers (1953: 1) named the resulting transition the Axial Age (800–200 BCE), the 'axis in world history ... which has given birth' to everything that followed. The school that follows his lead (*e.g.*, early Bellah 1976; Eisenstadt 1982; Armstrong 2006) explains the similar experiences in these states largely in terms of a spiritual transformation that, for them, happened unpredictably in unconnected cultures. Relational evolution, on the other hand, suggests that this period represents, as Assmann (2008, 2012) points out, cultural breakdowns followed by breakthroughs that drove total social transformations in societies that were experiencing the same sort of increase in complexity.

To adapt to it, people in these societies needed to recreate their institutions, from the pre-axial order that emphasized loyalty to one's lineage to a more formal connection and sense of obligation. In describing China's axial experience, Mark Lewis (1990: 246) notes that, just as warfare was transformed from a means of defending honor among aristocrats to the tightly organized extension of armies of hundreds of thousands directed by the will of a single man, the commander, 'all of society was re-imagined in terms of the hierarchical ties of superior and subordinate'. In Greece, this movement toward order and control appeared in the phalanx and later the troops of Philip of Macedon, as well as the bureaucratic empires that emerged from Alexander's conquests.

To transform their institutions in this way, they would first have to re-interpret their world by evolving new world stories. As Assmann (2011) notes of the Israelite experience, the new world stories evolved through roughly three phases. In each, people, freed of their older world-story attractors, behaved according to their evolving stories, experienced the results, and then changed the stories in response. Assmann identifies the phases of axial world story as 'foundational texts', 'religious texts', and 'commentary'. Rather than his 'religious texts' (for a discussion of some problems with this term, see Nongbri 2013), I shall use the term 'tragic/new world story texts', to include Timothy Reiss' understanding of tragedy. For him, the tragic reflects a 'sense of injustice' and 'the inevitable gap between the human known and knowable and all that escapes discourse', 'appearing at certain moments of seem-

ingly abrupt epistemic change ... making a new class of discourse possible' (Reiss 1980: 20, 2). Tragedy recognizes the terror that people experience as their old order no longer works.

For the sake of brevity, I shall focus on the axial experiences in Greece and China (for a treatment of the process in Israel, see Assmann 2011; for the Indian experience, several essays in Eisenstadt 1986).

Each culture's foundational texts articulate group identity as 'remembered past', mixing myth and history (Assmann 2011: 59), translating pre-axial mythos into a world where the cultural attractors have collapsed. The fear of chaos dominates all of them. In Greece that fear appears in the poetry of Hesiod and the epics of Homer, articulated in divine figures who eat their children and precipitate a decade-long war over a beauty contest. Faced with this chaotic and capricious world, Homer shows the aristocracies of the Greek states as fractious brothers, coming together to protect each other's honor, going to war over Helen and defeating the eastern enemy, Troy. The Greek *poleis* enacted this story when they cooperated to defeat the Persians in 490 and 480 BCE. Having achieved this success in enacting their foundational texts, these city-states acted like brothers again, fighting among themselves over political and economic control in alliances led by Athens and Sparta. The devastation of the Peloponnesian Wars would drive Greece's Golden Age of tragic/new world story texts.

In China, the foundational texts are also about taming chaos, although the High God of the Shang Dynasty (*Di*) had been translated into the concept of Heaven (Schwartz 1985). Order was Heaven's gift so that the key issue would be why people introduce disorder by deviating from it. The actors in China's axial foundational texts are not divinities, but early 'sages', such as Yu, who invented irrigation and water control after the Great Flood of the Yellow River, or the kings Yao and Shu, who exemplified an ordered practice of public rule (*Ibid.*; Lewis 1990). The ideal inherent in this foundational myth was of order through strong kingship in an extremely hierarchical, united China. Partly as a result, the central theme of China's Axial Age was the movement from fragmentation to unity, from chaos to order. In this way, in the Spring and Autumn period (771–476 BCE) early Axial Age China witnessed a constant state of war – one account lists 540 interstate wars and more than 130 civil wars in one 295 year period (Lewis 1990: 36) – intensifying the fear of chaos that had existed previously. By the end of the Spring-and-Autumn period, warfare had reduced the number of competing states from 170 to seven. It would also stimulate the tragic/religious texts that appeared in late axial China.

In the axial societies, the terror provoked by these wars would combine with the increased integration of writing beyond the scribes and formal keepers of social order to encourage a level of reflection previously unknown (see Assmann 2012). Literacy facilitated the rise of individualism, as reading, an individual activity, begins to replace communal storytelling, and it became possible for people to become more reflective with a text in front of them (Ong 1982). The tragic / new world story texts in these societies would be one result of this increased reflection.

In Greece, those texts appeared first in the tragedies of Aeschylus, Sophocles, and Euripides, which span the fifth century BCE, from the beginning of the Persian Wars in 499 BCE to the end of the Peloponnesian Wars in 404 BCE. The tragedies demonstrated how even good people become caught up in chaotic forces, no matter how hard they resist. These texts demonstrate Reiss' (1980: 21) 'moment of rupture', as people recognize that the old ways do not work, and that the order provided by reason can be disrupted by dark sacred forces.

The new world story to explain this chaos and terror emerges in Greece from its tradition of philosophy, with all the experimental variety one would expect in a period of phase transition: the Pythagoreans (fifth and sixth centuries BCE) insisted on the ultimate reality of numbers; Heraclitus (fl. 550) saw reality as a constant change; and the atomists, such as Democritus (fl. 410), viewed reality 'as a lifeless piece of machinery' (Lindberg 2007: 29–30). All this intellectual searching culminated in the philosophy of Plato (427–328 BCE) and Aristotle's practical application (384–322 BCE).

Having lived through the devastation of the Peloponnesian Wars, Plato knew first hand that human-induced chaos had to be controlled. To do so, his philosophy emphasizes rationality, insisting that the world was created by a rational spirit, the Demiurge (see *Timaeus*), based on the abstract Forms of things, their true reality. Chaos crept into the world, not because of the Forms, but the material with which the Demiurge worked (*e.g.*, Bellah 2011). Because, as the Parable of the Cave (*Republic*) indicates, most citizens never understand the reality of Forms, they are governed by emotions and appetites, and government must prevent those emotions and appetites overwhelming citizens' reason. To make such government work, Plato replaced the heroic leaders of Homer with his *theoros*, the philosopher who 'loves the spectacle of truth' (Nightingale 2004: 98). The *theoros* would allow most citizens to have their 'unfalsifiable' mythic beliefs (*mythos*), but they themselves would live by the rational, 'falsifiable' *logos*. Plato recognized that such a rationally governed life was only for a very few. For the rest, he sug-

gested that the gods, goddesses, and narratives of the old world story would be sufficient.

Aristotle, born after this devastation, 'was able calmly to look around the new world that Plato had opened up and explore its many possibilities, without rancor' (Bellah 2011: 395–396). Plato's Demiurge would become Aristotle's 'Unmoved Mover', a divinity of pure thought, beyond our world of matter, and the cosmos it created contained both the chaotic, ever changing world below the Moon and the unchanging Heavens (Freely 2012: 28), rotating in perfect circles. Humans created chaos only because they would not allow the pure intellect of the divine to guide them. To avoid chaos, the *polis* must train citizens in using their reason. Aristotle's many other studies continued to apply his own rational principle to one field of study after another, answering the questions behind any world story. His *Ethics*, for example, explored how the individual could achieve *eudaimonia* to live the life of *theoria*. In these and other explorations, Aristotle would 'sketch out most of the fields of inquiry that would preoccupy later thinkers' (Bellah 2011: 395).

The Chinese experience with tragic/new world story texts manifested itself as the philosophical flowering of the 'hundred schools', which arose in the century leading to the Warring States period (403–221 BCE). These schools reflected the wide variety of thought responding to the violence of the Spring-and-Autumn period, as articulated by the *shih*, the growing class of often-wandering scholars dispossessed from their noble lineages (Schwartz 1985). All of them were trying to understand the same tragic dilemma: If order was the gift of Heaven, why was chaos so widespread? Why had men lost 'the Way of Heaven'? Three of these schools would define the positions that would be negotiated into China's post-axial world story. For the Confucians, the issue was social: the Zhou had already achieved a 'universal, all-embracing, ethicopolitical order' (*Ibid.:* 65). Only by re-establishing that order could social order be recaptured. To do so, Confucius (551–479 BCE) and his followers focused on living life according to the ritual formulas for one's position and on education as a means for both individuals and society at large to understand the 'Way' of humans in society. For the Daoists, the issue was more personal: the overly civilized order of the Confucians had made it impossible for people to behave naturally, in consonance with the Way and the Heaven-given laws of change (Graham 1989). Only by the individual learning the Way and acting according to it could order be returned. Finally, the Legalists believed that the problem was the passionate, unruly nature of human beings and that order required clear, harshly enforced laws so that people knew exactly what behavior

would be expected and what would happen if they did not conform (Feng 1976). Throughout the Warring States period, the intensity of warfare increased, as armies reached several hundred thousand men (Lewis 1990). By 300 BCE, even Mencius (*c.* 372–289 BCE), the strongest Chinese believer in human goodness, recognized that the only way to social order was unity (Schwartz 1985). With a complex cosmology already in place (*Ibid.*: 350–382), these three perspectives would become more and more closely intertwined throughout China's commentary period.

Assmann (2011: 269) describes the period of commentary as 'an indispensable accompaniment to the cultural transformation ... keeping those texts alive by bridging the ever widening gap between them and the changing reality of life'. In this way, as Alexander spread Hellenism, Rome rose in the West, and the Qin united China at the end of the Axial Age, as population and wealth increased, and technology accelerated, new ways of governing and behaving in increasingly complex societies could be articulated and enacted.

In Greece, this commentary would play itself out in philosophy and science, continuing its evolution through the Hellenistic period and later. The rationalist commentary that began with Plato and Aristotle continued through the work of thinkers such as the Cynics and Neo-Platonists in the Hellenistic period, early scientific thinkers such as Ptolemy and, later, the Fathers of the Church, such as Augustine and Origen (*e.g.*, Gillespie 2008). Significantly, their central assumptions were set in place by Plato and Aristotle, including the analysis of the world as distinct 'things', the concept of a soul separate from the body, the idea of an Unmoved Mover, and the emphasis on moral distinctions. All these assumptions would be integrated into the world stories of the Roman Empire and, later, that of Western culture.

The Chinese commentary period seems to have been underway in the fourth century BCE. Throughout it, the Chinese thinkers of all schools would borrow from each other to develop the most effective philosophies for aiding kings in the seven states in their efforts to unite the country. The Legalist Han Fei (d. 233 BCE), for example, briefly the chief minister for the King of Qin as he was uniting China, borrowed from Daoist *Laotzi*'s ideas about the Way and *wu-wei*, probably best translated as effortless action (Slingerland 2003), to provide a metaphysical basis for his emphasis on punishment (Graham 1989). In spite of a reaction against the extreme Legalistic policies of the First Emperor, so that it lost its position as a school of philosophy, the concepts of Legalism remained key assumptions for the Chinese government. Neo-Confucianism, with its emphasis on right behavior and education, in-

corporating elements of both Daoism and Legalism, would become the state philosophy (Fairbank and Goldman 2006).

Modernity as Another Axial Phase Transition

The terms in which Modernity is often described – Latour's (1993: 10) 'new regime, an acceleration, a rupture, a revolution in time', for example, or Samir Amin's (2009: 13) 'claim that human beings, individually and collectively, can and must make their own history' – could also characterize the Axial Age. As a result, it makes sense to examine Modernity (*c.* 1500 CE to the present) as a phase transition in human history with remarkably similar dynamics.

As with the Axial Age, the ability of an older world story to govern an increasingly complex society was breaking down. For more than a millennium, the bureaucratic empires of Byzantium, the Islamic world, and China had justified themselves with world stories in which religions of the book were integrated with the efforts of the secular kings and bureaucracies that enabled them to govern vast territories. So successful were the post-axial empires that the conquests of the Yuan Dynasty, led by descendents of Genghis Khan, united Eurasia as a world economic system in the thirteenth century (Abu-Lughod 1989). Then, in 1453, the Ottomans took Constantinople, threatening to overwhelm Christian Europe.

Yet, within 200 years, these empires were losing the ability to respond to the social complexity that they had enabled. With a world population that would exceed one-half billion before the end of the sixteenth century (Livi-Bacci 1992: 31), the first system of worldwide trade by the end of the thirteenth century (Abu-Lughod 1989), and acceleration in the rate of technological innovation in Islam and China (*e.g.*, Lindberg 2007; Temple 2007), their old world stories began to falter. As Jack Goldstone (1991) notes, the inability of government to adapt to the needs of growing populations as economic activity evolved caused the mid-seventeenth century revolts in England, China and the Ottoman Empire. The Ottomans and Chinese fell back into the older behaviors that would enervate them when faced with Western imperialism. The English, in the midst of their phase transition, moved forward.

In addition, the European politics was fragmented, as in early axial China and Greece, with Italian city-states, German principalities, and emerging national states in Spain, Portugal, France and England (*e.g.*, Bondarenko and Korotayev 2011). In fact, writers such as Eric Jones (2003) claim that Europe's political fragmentation in 1500 CE was key to its subsequent rise. Moreover, as the axial transformations were partly driven by innovative applications of writing and iron metallurgy, early

modern Europeans took printing (Eisenstein 2005) and the commercially efficacious machine, both invented in China, 'to a high pitch' (Jones 2003: 58), that, together, made a higher level of complexity possible, and with it the ability to respond to a more complex environment.

Since the fall of Rome, Western Europe had experienced a chaos of diverse influences – from the rationality of ancient Greece, through the memory of the Roman Empire, and monotheism, through Christianity, to the Germanic, Viking and Islamic invasions. By the end of the twelfth century, the foundational text of the modern period began to emerge, initially in the stories of the Quest for the Holy Grail (Spengler 1932), combining the restless spirit of multiple invasions with the Christian, theocentric tradition of worship and belief, especially as articulated in the Apocalyptic millennialism of that period (*e.g.*, Noble 1999; Gillespie 2008). As suggested below, these stories would not express their full power until some time around 1500, when the breakthrough of the modern phase transition followed the breakdown of the medieval period.

Even as the grail quest literature was championing the authority of a social order joining the Catholic Church and the feudal economic/political class, events continued to provoke chaos. The loss of Jerusalem in 1187, followed by the failure of the Third Crusade (1189–1192) to retake it, undermined the legitimacy of the Papacy's claim to represent God on Earth. After the Mongol creation of a world economic system in the thirteenth century, increasing trade and wealth would build the fortunes that would finance the Renaissance, but also encourage the corruption in the Church, especially the Papal indulgences, which allowed the rich to 'buy' salvation, outraging Martin Luther. Finally, the Black Death (1348–1350) and the Hundred Years War between England and France (1327–1453) would devastate the population of Europe (Gillespie 2008). The medieval world story would then break down and the modern phase transition would begin.

This phase transition would consist of a series of social explorations of Kauffman's adjacent possible, each of which led to a social consensus, the enactment of that consensus, a series of (mostly unexpected) results, and new explorations. Perhaps the most striking, this evolving modern world story repeatedly destabilized the institutions and belief systems created when it was enacted.

At the beginning of the sixteenth century, both the Renaissance and Reformation looked to different paths for governing an increasingly complex society. The printing press introduced by Gutenberg *c.* 1450 (see Eisenstein 2005) changed the nature of communication, making increasing amounts of knowledge available to the Renaissance and personal

reading of the Bible to the Reformation, generating a significant acceleration of the collective learning so central to cultural evolution (Christian 2004); the machine, employed in everything from the printing press to the newly improved firearms, intensified politics, warfare and commerce. Building on these innovations, the Renaissance strove to improve human life by employing the increasing store of knowledge; the Reformation used the availability of Bibles in the vernacular to challenge the often-abused spiritual monopoly of the Catholic Church (Gillespie 2008). For Martin Luther, the End of Time was near. As a result, for many in the Reformation, there was no need for the attempts at education and reform championed by Renaissance spokesmen such as Erasmus. The Reformation won out, plunging Europe into 150 years of devastating religious wars, as the Spring-and-Autumn wars had devastated China.

Even before these wars culminated in the Thirty Years' War (1618–1648) and the English Civil War (1642–1651), the tragic/new world story texts would begin appearing in Shakespeare's major political tragedies, *Hamlet*, *King Lear,* and *Macbeth*, in the first few years of the seventeenth century. There, he demonstrates the inadequacy of the medieval model of monarchy, with its dependence on family lineages and the relationship between the king and his knights. As with the Greek tragedians' criticism of Homeric ideals, Shakespeare points us to Reiss' (1980) moment of rupture when a new way of governing a more complex world must emerge. By the end of the religious wars, the new world story was also emerging.

That story had roots in a growing tradition of scientific rationalism. Francis Bacon (1561–1626), for example, called for an experimental science whose priest-like devotees would 'discover the hidden powers by which nature moves in order to gain mastery over it' (Gillespie 2008: 39). In addition, Kepler, Copernicus and Galileo conceived of 'the machine of the universe ... similar to a clock', to use Kepler's words (quoted in Dolnick 2011: 182), and written in the language of mathematics. The explorations of this mechanistic worldview turned on the issue of how best to apply scientific realism to govern a world weary of war's chaos.

For René Descartes (1596–1650), science was the rational search for the Truth that would 'discover the ground for a radical transformation of European society' (Gillespie 2008: 177). Such a science of *certainty* was possible for two reasons. First, the human being alone was a thinking being with the godlike ability to remake the world. Second, science can be true because mathematics, as the language of the universe, is true, and, Descartes believed, God is not a deceiver. A different version of this rational world story came from Thomas Hobbes (1588–1679), for whom science was not so much the search for the truth, but for knowl-

edge of how things worked. Because God was omnipotent – and thus capable of deceiving human beings – science must study the dynamics by which God willed motion to occur. Human beings can never know the truth of these dynamics, only that an explanation works, enabling them to manipulate a segment of the world (*Ibid.*).

Descartes' version, with its emphasis on the ability of science to achieve certainty, would become the central statement of the modern era's world story for the next 300 years. Its emphasis on mathematics, in particular, allowed those enacting the story to dismiss the messiness of life, especially after the century and a half of religious wars, as deviation. Only mathematics, the language in which God revealed His Book of Nature, was real. Such a science would fulfill the growing belief in progress, 'leading toward ever greater perfection of human nature' (Nisbet 1970: 5). The story would be enacted and further articulated in Robert Boyle's experiments in physics, William Harvey's description of the circulation of blood, Isaac Newton's mechanical physics and calculus. In many ways, Descartes and Newton were Modernity's Plato and Aristotle, the two thinkers who finally crystallized the theory and practice of their world story.

Meanwhile, Europe's grail quest knights were exploring the world – first the Spanish and Portuguese, then the Dutch, English and French – trying to do God's work of bringing salvation to the heathens and, incidentally, profits back home. They looted the gold and silver of the Americas, buying themselves ever more tightly into the world economic system and whetting their taste for the fine products of the East (Frank 1998).

The commentary on the new world story would emerge over the next 250 years, exploring how best to apply it. Among the key issues were the transformation of worship and belief from a shared part of the common world story to a private matter (Nongbri 2013) and the intensified application of Modernity's great social experiments – nationalism, the nation state and capitalism – throughout the Enlightenment. Among the mutations of the world story that would contribute to this process are:

- Baruch Spinoza's (1632–1677) 'obscene', 'profane', and 'blasphemous' (Nadler 2011: 2–3) interpretation of the Bible, his identification of God with Nature, and his insistence that democracy and freedom of expression would enhance the power and stability of the state;
- John Locke's (1632–1704) social contract with which people form government to protect their interests (Pagden 2013), key for the democratic nation-state; and

- Adam Smith's (1723–1790) 'invisible hand', which created a quasi-religious free-market philosophy to replace Christianity's omnipotent God (Israel 2011).

Throughout this period, people would enact this evolving world story, introducing social mutations ranging from a host of scientific discoveries and technologies to more effective industrial organizations, better weapons to more efficient military structures, as well as the imperialistic successes they enabled. As long as society seemed to exhibit the Enlightenment ideal of progress, the rationality so critical to its worldview seemed to promise the perfection of man envisioned by Descartes (*Ibid.*). However, when French finances began to fail and the monarchy could no longer meet its responsibilities to the people (Goldstone 1991), a wave of destabilization, articulated by *philosophers*, such as Diderot and D'Alembert, in France, and Priestly in England, began to create a 'widespread consciousness in influential circles of the need to abolish privilege and rank' (Israel 2011: 229), as well as a conservative reaction. When the French monarchy failed, however, the result was not government by the ideals of Enlightenment rationality, but a devastating destabilization in an explosion of full-flowered nationalism and revenge, leading to two decades of war, evoking the same emotions religion had during the religious wars.

After Napoleon was finally exiled in 1815, Europe continued following its ideal of progress, with further commentary on the world story and enactment of it. The Industrial Revolution and its critics, from Charles Dickens' novels to Karl Marx's economics, drove the evolution of the new world story into new areas of the adjacent possible. And Bacon's 'priests' of science would continue to destabilize the world story as they enacted it. The geological theories of Charles Lyell and evolutionary theory of Charles Darwin set the stage for driving God out of the modern world story, exciting the same reaction as Spinoza had. More and more, the modern world story was appearing increasingly unstable.

Then, in the twentieth century, it began to collapse. First, scientists, practicing the Newtonian methodology they had learned, discovered that their worldview was, if not wrong, then, at least, askew. Albert Einstein's theories of relativity showed the dead matter of Newtonian physics to be structures of transformed energy. Then quantum mechanics demonstrated that Newtonian distinct 'things' were intimately interconnected, and its determinism open to chance and contingency (Smolin 2013). Second, after three generations of peace in Europe, at a point where Enlightenment progress appeared to be pointing toward human perfection, two world wars erupted, with levels of devastation proving

that rationality could not be the cornerstone of human nature Descartes and those who followed him had believed (*e.g.*, Berman 1992).

In addition, since World War II, the modern confidence in the value of education, free trade, and human equality has destabilized the political order by which Western Europe had dominated the world for more than two centuries. As people in formerly 'backward' nations have taken advantage of scientific education, they have entered into full partnership in a world economy where China is likely to become the leading power. As the Internet has accelerated the process of global interconnection, the nations of the world are becoming increasingly interdependent in trade, financial dealings, and resource allocation, as well as their attempts to control the dangers posed by terrorism, environmental contamination and global warming (Sachs 2008). Here one of the most powerful experiments of the modern world story, national culture, has become one of the chief obstacles to solving all these problems (*e.g.*, Smith 1995). Because different national cultures, based on their unique histories, include different ways of thinking about the world, it has become increasingly common for people from those cultures to experience the world very differently (*e.g.*, Nisbett 2003). For example, Western and Chinese business people have different understandings of the concept of Law (Baskin 2009), leading to significant mutual antagonism over issues of intellectual property.

In order for our societies to adapt to all these changes, still another world story is emerging. Nobel Laureate in Physics Robert Laughlin (2005) calls its worldview 'emergent', David Boje and I (Boje and Baskin 2010) 'post-Newtonian', Smolin (2013) 'relational'. In this paper, I have used Smolin's relational, a term used similarly in Taylor (2007), because it implies that the 'things' we experience as distinct behave *both* as agents *and* as members of networks interconnected to other agents, in the moment and historically. Such a worldview, I believe, stands at the heart of Big History, and has also been incorporated in other social sciences – Latour's (2005) sociology of actor networks, for example, or the philosophy of Karen Barad (2007) as well as much of Michel Foucault's (1994) 'anthropology'. It is, after all, the relational interconnection of agents, often on many scales, in both space and time, that makes a relational conception of evolution so thick.

Conclusion

Despite the unavoidable oversimplification, I hope that I have demonstrated that the basic dynamics of the Axial Age and Modernity seem similar, from the social breakdown and political fragmentation through

the intense social, political and technological innovation, from the terror roused by periods of intense warfare through the evolution of new world stories. Clearly, the Axial Age and Modernity also have significant differences. The axial transformation occurred in four very different cultures, which remained only tenuously connected. On the other hand, the modern transformation began in one area and spread across a globe that became increasingly interconnected. Yet, both periods seem unmistakably to confront the need to adapt to a significantly higher level of social complexity.

I believe that further examination will show relational evolution can be valuable to the study of Big History. A relational perspective, after all, offers tools to explore how national cultures evolved as parts of their societies' world stories, under deep historical pressures. This analysis is essential because it is the world story that contains any culture's definition of identity – our group *vs.* the other. As Ed Hall (1976) points out, most people still believe that anyone who does not behave according to their own culture is a barbarian, uncouth at best and insane at worst. Yet, with all the problems the world faced that can only be solved by international cooperation, the human community needs to redefine this issue of identity. Such a redefinition has been part of past cultural phase transitions. During the Agrarian Revolution, group identity was expanded from membership in a small band to membership in a state. During the Axial Age, it was again from the state to the empire. Unfortunately, we humans seem to need to define the world as 'us' and 'other'. Yet, without an invasion from space, we have run out of others.

The alternative is, not to expand, but to thoroughly redefine what we mean by us and other. As Big History demonstrates, the human race comes from a single origin. The differences between us are a matter of adaptations to different circumstances, and the question becomes whether human beings can let go of the implication of enemy that has been built into the other. Can we see the other as someone like us, who merely found a different story? Without such a redefinition, it seems unlikely that people from different cultures can come together to discuss issues of mutual interest – from economic integration to nuclear proliferation and ecological degradation – without the distortions of cultural difference and enmity.

At first, this seems an impossible goal. When the United Nations cannot address the chaos in Syria, the European Union is increasingly troubled, and some of the most industrialized nations refuse to agree with treaties on global warming, the combination of power politics and cultural difference seems insuperable. Yet, who, living in a hunter-gatherer band 1,500 years ago could have imagined identifying as

a member of a city of 80,000, such as Ur in 2800 BCE (Modelski 2003: 28), or a nation of a billion, such as China and India today? We, human beings, are capable of learning to live and think very differently, especially when our survival depends upon it. For me, Big History has the potential to contribute to this effort of relearning what it means to be a human being in a fully globalized world, rather than one largely segregated by culture, as the world was even 500 years ago. And I invited the reader to consider the analysis in this essay, as sketchy and oversimplified as it is, as a set of tools in the further development of Big History.

Acknowledgement

This paper is largely the result of three years of writing and discussion with Dr. Dmitri Bondarenko. While his expertise in areas with which I was not familiar was invaluable, the give and take within our explorations and discussions is the one factor that most enabled me to make this argument.

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11
The Animals of the Spanish Empire: Humans and Other Animals in Big History*

Abel A. Alves

Abstract

Big History allows us to ask whether human behavior merely reflects patterns already exhibited in the natural world by other social animals. While animal behavior can be interpreted through a prism that stresses 'the struggle for existence', territories and ranks in social animals require cooperative behaviors, with the 'in-group' often reserving its most aggressive competitive behaviors for other species and rival groups of the same species. In human history territoriality, hierarchy and cooperation combine in the institutions of the empire. The Spanish Empire, therefore, can be used to test the hypothesis proposed by David Christian, and elaborated by Russell Genet, that we are 'the chimpanzees who would be ants'.

Keywords: *Big History, Spanish Empire, chimpanzees, cooperation, human ethology.*

Big History is not merely a cultural construction fabricated by some contemporary historians and scientists. There is a real empirical precedent for a Big Historical approach that reflects upon the human story in the context of natural history. Like other animals, we have evolved our own species-specific arrangement of Earth's DNA, but we still share with all other terrestrial life forms the same nucleobases that define life on this planet. Big History allows us to ask whether human behavior merely reflects patterns already set in the natural world and exhibited phenotypically by other social animals. By exploring our accounts of interaction with other animals, and comparing human efforts to subordinate them and our fellow human beings, broad evolutionary patterns that impinge upon our behavior come to be detected in other time periods and cultures. From the days of the Roman Empire, with its slaugh-

* This essay is based on my presentation at the International Big History Association Inaugural Conference (Grand Rapids, MI: August 4, 2012) and draws on material previously published in Alves 2011. An earlier form has appeared as 'The Spanish Empire: Adaptive Animals in the Natural World' (Alves 2012).

ter of people and nonhuman animals alike in the arena, to the British Empire's exploitation of its colonies, including the trophy-hunting of wildlife, historical documents portray human efforts at dominance over people and nature reduced to resources (Kalof 2007: 27–34; Ritvo 1987: 243–288). On occasion, the documents even demonstrate some ambivalence. Plutarch (AD 45–120) was concerned that the killing of animals for food has made it easier to murder our conspecifics in war and peace, and Alfred Russel Wallace (1823–1913) was critical of some British imperial practices and personally lamented his shooting an orangutan mother and leaving her infant an orphan whom he unsuccessfully attempted to raise (Plutarch 1958: 573; Wallace 2002: 136–138; Slotten 2004: 219–222). As noted by Elliott Sober and David Sloan Wilson in *Unto Others: The Evolution and Psychology of Unselfish Behavior*, we are a complex enough species that we do not exhibit uniform behaviors across human communities and even within communities, but that is true of other species as well (Sober and Wilson 1998: 228–229, 301). Chimpanzees, who last shared a common ancestor with us some six to seven million years ago, have been observed to kill each other in territorial and hierarchical disputes, while also sharing 'incidental, extra food' to bind their ranked communities. Primatologist Frans de Waal observed that the alpha males Yeroen and Luit in his Arnhem Zoo study were loser supporters in internal conflicts. Apes like Yeroen and Luit proved to be defenders and sustainers of the weak, while Goblin, 'a very tempestuous alpha male' at Jane Goodall's Gombe site in Tanzania, was overthrown in a particularly violent way that nearly claimed his life (de Waal 1998: 117–118, 145–146, 197–199; Goodall 1992: 139, 141). Our primate cultures display dominance and react against it at the same time, while individual societies caught in the web of time may exaggerate brutality or benevolence through custom and inculcation. Social animals balance the competitive with the cooperative in their efforts to survive. However, to demonstrate the existence of such a natural, cross-species template, Big History needs a collection of detailed case studies. Isolated anecdotal references to ancient Rome and the modern British Empire may be enough to develop a working hypothesis, but that hypothesis requires testing through the accumulation of data found through the examination of examples in some detail.

The case study with which I am most familiar is that of the early modern Spanish Empire. Those involved in the construction of that imperial project were animals like ants or chimpanzees, only differentiated from other animals in a capacity for more elaborate reflection on their

actions – reflection which sometimes led to the evolving critique of imperial abuse so central to the writings of the Dominican priest Bartolomé de las Casas (*c.* 1484–1566). Of las Casas, Rolena Adorno has written, 'His concerns evolved from his initial attempts in 1516 to protect the Indians while ensuring the economic prosperity of the crown, to his ultimate recommendation, made forty-eight years later, that Spain abandon altogether its rule of the Indies' (Adorno 2011: 28–29). He also changed his position on the enslavement of Africans, initially wishing to eliminate abusive tributary demands made of Amerindians in the Caribbean islands by importing African slaves, and then regretting that he had ever made such a suggestion when he finally recognized the horrible abuses that Africans faced as slaves on Spanish estates (Clayton 2011: 79–81, 137–138, 146). Today, the moral reflections of Bartolomé de las Casas survive as part of our collective memory found in written records, and, as noted by David Christian in *Maps of Time*, this capacity for collective learning through symbolic language and abstraction may be exactly that which has enhanced our species' ability to form the most elaborate and solid of communal bonds, generating our planetary dominance (Christian 2004: 146–148). Through fragile and complex social entities that balance competition and cooperation we have come to dominate and shape the biosphere, and that process clearly was accelerated by sixteenth-century Iberian expansion into the western hemisphere, with the Columbian Exchange in biota like wheat, maize, the smallpox virus, tobacco and horses, among other things (Crosby 1973: 52–58, 64–81, 170–171).

When alien conquerors from the Iberian Peninsula invaded the western hemisphere in 1492, they were accompanied by subjugated humans and animals. In the very act of using African slaves as tools of transformation, boundaries between humans and beasts of burden were invidiously blurred. Both the slave and the mule became 'objects' providing labor, but the sheer inappropriateness of reducing people in particular and sentient, conscious beings in general to the status of mere things was consistently contested by humans from Africa and animals from the eastern and western hemispheres. Slaves, cows and pigs all escaped at times, becoming *cimarrones*, 'wild' and 'renegade' in the eyes of the Spaniards (Real Academia Española 1963–1964, 1: 350). By escaping from Spanish '*império*' – defined as 'dominion', 'authority' and 'territory' in the Spanish Royal Academy's eighteenth-century *Diccionario de Autoridades*, originally published from 1726 to 1739 (Real Academia Española 1963–1964, 2: 224) – these *cimarrones* proved their agency. They

were fully animate beings and not insensible things. Empire, '*império*', is an embodied confusion of categories that would reduce independent beings to nothing more than means to an end, rather than appreciating their status as actors who choose, compromise and are compelled. Spaniards were guilty of this confusion in their imperialism, but like the Africans and Amerindians whom they tried to control, Spaniards were both highly adaptive human beings and creatures like the ants that herd aphids and 'milk' them for their honeydew (Wilson 2000: 356; Hölldobler and Wilson 1994: 147, 149).

The reduction of another animal to a mere resource is not only a human behavior after all, and honey ants of the genus *Myrmecocystus* will raid neighboring colonies of their conspecifics to bring back larvae, pupae and honeypot ants who store food to be used by their sisters. The conquered and captured, often called 'slaves' by entomologists, go about enhancing the resources of their new anthill, with larvae and pupae raised to be coworkers with their conquerors (Kronauer, Miller, and Hölldobler 2003). The quest for domination and control of resources in nature has a long evolutionary history, and among our chimpanzee cousins, as shown in the 2012 film *Chimpanzee*, fruit- and nut-bearing trees can be warred over by two different communities (Linfield, Fothergill, and Hahn 2012). Chimpanzees will kill each other over the questions of territory and resources, with the first detailed study of a chimpanzee war being that between the Kasakela and Kahama communities of Tanzania in the 1970s (Goodall 1986: 503–514). By the end of 1977, Kasakela had completely eliminated its rival, even as the Roman republic razed Carthage to the ground in 146 BCE. With their woolbearing sheep, human slaves and imperial wars, the Spaniards replicated behavioral patterns already found in the rest of the natural world, but acts of violent domination do not themselves dominate nature. Cooperation between ascribed estates, mutual aid within hierarchy, helped to maintain the Spanish imperial project, even as the anthill and the beehive survive as cooperative superorganisms (Sober and Wilson 1998: 96–98, 147–149).

Bert Hölldobler and Edward O. Wilson define 'superorganism' as:

> A society, such as a eusocial insect colony, that possesses features of organization analogous to the physiological properties of single organisms. The eusocial colony, for example, is divided into reproductive castes (analogous to gonads) and worker castes (analogous to somatic tissue); its members may, for example, ex-

> change nutrients and pheromones by trophallaxis and grooming (analogous to the circulatory system) (Hölldobler and Wilson 2009: 513).

As suggested by David Christian and elaborated by Russell Genet, we well may be 'the chimpanzees who would be ants' (Christian 2004: 250–252; Genet 2007: 51–53, 86, 93), but this already was recognized by early modern Europeans who referred to their hierarchical and cooperative societies as social organisms: 'the body politic' (Sober and Wilson 1998: 132–133; Alves 1989). They were aware of their place in nature, with the influential Jesuit professor Francisco Suárez (1548–1617) arguing that '… "humanity" is really a certain sensitive nature and has in this fact some agreement and similarity with the nature of "horse" and of "lion", taken in the abstract; for all are the integral principle of "being sentient"…' According to Suárez, there is 'a certain analogy of proportionality' whereby 'animal' can be applied equivocally to humans and horses in that both integrate sentience and sensitivity into their very natures. They are alike in genus, though essentially different in species. As with Aristotle, humanity is 'rational animality', and Spanish political thinkers like the diplomat Diego de Saavedra Fajardo (1584–1648) readily drew on his culture's perceptions of the behavior of everything from lions to bees in the advice he offered princes (Suarez 1964: 117, 101; Aristotle 1992: 60; Berns 1976; Saavedra Fajardo 1947: 113–114, 171–173).

In the Iberian Peninsula itself, Spaniards were shaped by their economic domination of nonhuman animals like sheep, goats and cows – and by the ranked human society that cooperatively maintained the Spanish economy. To Miguel Caja de Leruela (also Caxa de Leruela), a seventeenth-century official of Castile's sheepherding guild, the Mesta, a Spain without livestock would be an impoverished land since nonhuman animals plowed the fields and provided their hides and fleece for clothing. Spain without herds would be a place where rural children would be abandoned by poor parents because they were no longer needed to tend livestock (Caja de Leruela 1975: 17–25, 177–178). Paternalistically demonstrating concern, Caja de Leruela worried about the poor who owned a few animals being denied pasturage because of the enclosure of grazing lands by wealthier individuals (*Ibid.*: 88–90; Vassberg 1984: 172). Likewise, he argued against the killing of valuable oxen and cows before their time. He recommended that Spain adopt prohibitions on slaughtering fertile cows and oxen still capable of pulling plows and carts, saying that some ten years of life seemed reason-

able for these animals (Caja de Leruela 1975: 109; Vassberg 1984: 160, 162). Before being punished for damaging crops, livestock were also to be judged, with substantial evidence necessary to convict any culprit (Caja de Leruela 1975: 130–131). Harmony in Caja de Leruela's Spain required a certain level of unequal reciprocity between human elites and the humans and other animals who labored for them. This was reflected in actual eighteenth-century Mesta laws that protected sheepherding dogs from abuse and provided payment to human employees of the Mesta according to rank. Thus, fines as onerous as five sheep or more could be exacted from anyone who injured one of the Mesta's sheepdogs, and each Mesta shepherd received two pounds of bread a day and another two pounds for his dog, with assistant shepherds in the eighteenth century earning anywhere from 6 to 18 ducats a year and the *rabadán*, or shepherd in command of subordinate herders, dogs and a *rebaño* of 1,000 to 1,500 sheep receiving 20 ducats a year in addition to the food allotment, which also included oil and tallow for all the shepherds (Klein 1920: 25; Phillips and Phillips 1997: 103–105).

From the level of the peasant village with its communal pasture lands, or *dehesas*, to that of the aristocratically dominated Mesta, with its individual flocks numbering in the thousands, Spaniards associated with livestock. But not all shepherds throughout the empire were valued equally. According to a 1748 report by the scholarly naval officers Jorge Juan (1713–1773) and Antonio de Ulloa (1716–1795), a flock of 500 sheep in Andalusia was tended by one shepherd and an assistant. The shepherd earned 24 pesos a year, and his helper 16 pesos. Bread, oil, vinegar, salt, donkeys and food for sheepdogs were also provided, with an overseer hired to supervise three flocks. For the care of 800 to 1,000 sheep, an eighteenth-century Amerindian shepherd in Peru earned 18 pesos annually. The document also says that goods were costlier in Peru than Spain, and that no food or paid assistant were provided to the Amerindian shepherd, with 8 of the 18 pesos going to annual tributary payments (Juan and Ulloa 1826: 273–275; 1978: 132–134). Indigenous American shepherds prejudicially were ascribed less remuneration than European shepherds for comparable amounts of labor. Veritable castes existed in the Spanish imperial superorganism, with different individuals and subgroups playing out their particular roles toward common societal goals, just as they do among the ants.

However, even as Andean shepherds adapted their methods of tending alpacas and vicuñas to sheep, Amerindians in general were able to express dominion over nonhuman animals, thereby finding a trun-

cated *império* in relation to nature. As early as the late sixteenth century, in Crown-commissioned reports known as *relaciones*, officials in the viceroyalty of New Spain noted the presence of American turkeys and Castilian chickens in Amerindian communities (Paso y Troncoso 1905, vol. 4: 20, 67, 103, 107, 112–113, 147, 180, 210, 241, 246; Paso y Troncoso 1905, vol. 5: 3, 109, 167; Paso y Troncoso 1905, vol. 6: 4, 18, 23, 25, 30, 33, 37, 92, 98, 104, 112, 121, 126, 130, 136, 143, 148, 151, 249, 280, 301, 307, 320; Gibson 1964: 344). In the sixteenth-century viceroyalty of Peru, *relaciones* reported both Castilian sheep and llamas and alpacas identified as 'native sheep' or '*ovejasde la tierra* (Jiménez de la Espada 1965a: 206; 1965b: 189, 213). Cows and pigs were also to be found in both viceroyalties (Paso y Troncoso 1905, vol. 4: 56, 75, 79, 84, 103, 113, 147, 210; Jiménez de la Espada 1965b: 170, 189, 213). Amerindians obviously dominated and used domesticated animals, from native turkeys and camelids to the new arrivals from Spain. And just as the fictional Quixotic squire Sancho Panza was capable of both using his donkey and embracing him as his friend and companion (Cervantes 1949: 858; 1998: 787), historical Amerindians demonstrated care and concern, as well as *império* vis-à-vis nature's sentient beings.

Andeans kept dogs. While noting that Quito was a place where good meat could be found, the young Spanish explorer, intellectual and naval officer Antonio de Ulloa also noticed that the Amerindians of eighteenth-century Quito demonstrated great affection for their dogs, who reciprocated by offering intense loyalty and protection against Spaniards and *mestizos* who might threaten their masters. Ulloa made an interesting observation that Spaniards and *mestizos*, in turn, taught their dogs to guard against *indios*, whom they feared (Ulloa 1990, vol. 1: 369, 511–512). In a backhanded way, he recognized the educative capacity of dogs, even while he also made note of human xenophobia at work. In fact, he took some time to reflect on the ways in which humans associated with other animals in Quito, and he wrote that Amerindian women so loved the chickens they raised that they did not eat them and only sold them with great sorrow and regret if they were in dire need (Ulloa 1990, vol. 1: 512). A city whose population grew through migration in the sixteenth century, Quito was a locus for the accumulation of diverse Amerindian traditions, and while evidence points to the Eurasian chicken's becoming a substitute for culturally preferred guinea pig meat among Quechua speakers, there are also sources that tell us of Amerindians who kept chickens as pets and suppliers of ornamental feathers (Powers 1995: 7–8, 13–43; Morales 1995: 13, 62; Seligmann 1987: 143; Nor-

denskiöld 1922: 9–12). Like other humans, Amerindians both used and loved nonhuman animals in a hierarchy of beings that jointly recognized human dominance and mutualistic symbiotic relationships with other animate, sentient beings in nature. As 'chimpanzees who would be ants', our species reflects on its interactions with other animals in ways that the ant who herds aphids probably cannot. However, primatologists like Frans de Waal do make note of how apes can empathize with the needs of other species. When a starling hit the glass of her enclosure and was stunned, the bonobo Kuni went out of her way to help the bird to fly again, while, in a 1996 video shown around the world and still easily available on YouTube today, the Brookfield Zoo gorilla Binti Jua, carefully took a boy who had fallen into her enclosure to the access point where humans could enter her cage, guarding the boy from harm until she could hand him over (de Waal 2005: 2–3; NBC Chicago 1996). Like our ape cousins, and to the benefit of our societies, we are capable of intra- and interspecies care and concern, but that is certainly not the entire story where our complex 'anthills' are concerned.

Indeed, a conflicted relationship with nonhuman animals, and with other humans, characterized the Spanish Empire, as it characterizes us today. The Africans forcibly brought from their homeland across the Atlantic were tallied according to their ability to work. On slave ships, a *pieza de India* measured the labor done by a young, healthy male adult. Children, women and the old were horrifically counted up as fractions of one *pieza* (Curtin 1969: 22). Literally a 'piece' or material article, the '*pieza*' also referred to game animals and, on occasion, Amerindian captives (Weber 2005: 235). In turn, when either a slave or a nonhuman animal like a cow or pig escaped Spanish subjugation, they were called '*cimarrón*', wild and renegade (Real Academia Española 1963–1964, vol. 1: 350; Jiménez de la Espada 1965b: 296). Likewise, the Spaniards were concerned about the '*casta*', or lineage, of both livestock and humans. Prejudicial concerns about racial mixtures arose along these lines, even as breeders of merino sheep judged the wool of newly born lambs to determine whether they were to be culled or not (Phillips and Phillips 1997: 116). The sad truth is that Spaniards, in ascribing value to sentient beings, leveled the difference between humans and other animals in ways we, appropriately, are not comfortable with today. Africans could be *cimarrones* like livestock, and children of mixed ethnicity might be judged by their lineage or *casta*. However, it is interesting to note that *casta* was also used to discuss the noble lineage of knights (Real Academia Española 1963–1964, vol. 1: 219–220). Many Spaniards

admitted their animality, but they usually insisted on a superior, more rational grade of being for those Spaniards, especially males, in positions of authority. Spanish dominion, *império*, involved its verbal dominance displays and outright brutal acts, even as dominance is put on display by other highly ranked individuals in the animal kingdom. However, just as an alpha male chimpanzee will alternatively food-share with an appropriately subordinate ape and pummel a rival, the Spanish *império* balanced compassion with competition in its pursuit of power. Different individuals play their roles, even as different roles exist among the eusocial insects.

The testimony taken at the 1660 process of beatification for Martín de Porres (1579–1639; canonized 1962) is consistent in identifying him as a man who tended to the sick and hungry regardless of rank, race or species. Multiple witnesses said he cared for Blacks, Spaniards and Amerindians, and that animals came to him to be cured 'as though they had reason' (*Proceso de beatificación* 1960: 100, 105, 125–129, 139, 194–195, 201, 206, 228, 245, 249, 252, 275, 291–293, 310–311, 318). The witnesses also said that he disciplined his body in the approved manner of the day, sleeping without a real bed, refusing to eat meat, and whipping himself (*Proceso de beatificación* 1960: 98, 136, 193, 299).

To some Fray Martín's actions and his very being might have been transgressive, but to those around him, who later testified on his behalf at his 1660 beatification process, he was admired and saintly because of his behavior, with his humility always being raised in this context. According to one witness, he focused on his own *casta* status – his own biracial and boundary-challenging status as a '*mulato*' – while praying and whipping himself, referring to himself as a *mulato* dog – '*un perromulato*' (*Proceso de beatificación* 1960: 193).[1] Whether the '*perromulato*' incident occurred or not, de Porres' charitable acts, testified to by many witnesses, illustrate a man who shared food, medicine and love regardless of how the prejudicial in his society judged the so-called purity of one's blood, or *limpieza de sangre*.

[1] During Martín de Porres' own lifetime, the *castas* – racial lineages and mixtures that derived from Amerindians, Africans and Europeans – came to be an increasingly significant challenge to a Spanish American empire that initially saw itself as divided into a *república de los indios* and a *república de los españoles* (Elliott 2006: 170–171; Earle 2012: 179–186). The *Diccionario de autoridades* explicitly says that early modern Spaniards derogatorily compared the generation of '*mulato*' to the generation of a *mulo* or mule (Real Academia Española 1963–1964, vol. 2: 628).

Indeed, by being a food-sharer and healer, Martín de Porres helped to illustrate and maintain one of the Spanish Empire's justifications for its very existence: that it provided aid and comfort to those in need, and that though there were ranks, there was sharing according to rank, with charity trying to minimize suffering (Alves 1989; 1996: 148–149, 157). In the Dominican priest Bernardo de Medina's seventeenth-century biography of Martín de Porres, the Dominicans' slaves at the hacienda of Limatambo are included among those he cured, and it can be argued that de Porres thereby protected his order's economic interests while also performing a charitable act (Medina 1964: 88). A sort of reciprocal sharing among the ranks was maintained, with fundamental physical needs taken into account. Likewise, in sixteenth-century New Spain, while Amerindian production of wheat was tithed, the production of maize was not, and the old Mexican staple was consistently sold at lower prices than wheat, both establishing wheat as an elite Spanish grain and providing Amerindians with their culturally preferred grain at a charitably lower cost (Alves 1996: 154; Gibson 1964: 322–323). The Spanish imperial vision of a well-functioning body politic called for charitable donations of food to be dispensed from hospitals, and even Cortés, the conqueror of New Spain, provided a legacy for the hospital he founded, the Hospital de la Limpia y Pura Concepción de Nuestra Señora y Jesús Nazareno, in his last will and testament (Paso y Troncoso 1905, vol. 3: 23; Muriel 1956–1960, vol. 1: 40–43; Alves 1996: 183–211). In the Christian context, charity could become a display of power and worth, and by living Christian humility and service, Martín de Porres enhanced his own status, gaining respect and the liberty for an occasional criticism of what he perceived as heartless domination. Medina wrote that de Porres rebuked the Dominican in charge of his convent's food for having his smelly, old kitchen dog killed after years of loyal service. Challenging the man's lack of charity toward his loyal dog, Fray Martín still addressed him respectfully as '*padre*'. After a night in San Martín's cell, the dog was restored to life and cured of his ill health and odor according to Medina. His new protector, Martín de Porres, then told the dog to avoid his ungrateful former master's pantry, which the dog did for the rest of his life (Medina 1964: 106–107). Far from being San Martín's only companion, this resurrected animal joined the future saint's multi-racial and multi-species community. When a dog and cat gave birth in a cellar of the convent, de Porres began to feed them, telling them, 'Eat and remain calm and don't fight'. And so… they appeared to be of one species in their conformity' (*Proceso de beatificación* 1960: 158; Medina 1964: 98).

This scene of a dog and cat eating together (and they would eventually be joined by a mouse as well) meant much to Spaniards as a metaphor of harmonious interaction regardless of race or rank (Cussen 1996: 141, 150–151, 172, 246; García-Rivera 1995: 4–5). However, it also presented a quiet challenge to the hierarchical boundaries between species.

San Martín's example resonated with his fellow Dominicans, who bore laudatory witness on his behalf after his death. Today's ethology presents cases of other-oriented behavior in our close relative the chimpanzee, including the adoption of the orphan Oscar by the alpha male Freddy in the movie *Chimpanzee* and the aunt-like care given a succession of infants by the infertile dominant female Gigi at Goodall's Gombe site (Linfield, Fothergill, and Hahn 2012; Boesch *et al.* 2010; Goodall 1990: 154–160; Warneken *et al.* 2007). Even primates less closely related to us, capuchin monkeys, have demonstrated a conception of justice and reciprocity in experiments. If one capuchin is generous with a piece of cucumber, Frans de Waal has found that a second capuchin is more likely to share a piece of apple (de Waal 2005: 205). In his book entitled *Good Natured*, de Waal reminds us that social animals do cooperate as well as compete, and nature is not only 'red in tooth and claw' (de Waal 1996: 148). David Sloan Wilson and Edward O. Wilson argue that, from bacteria to humans, group selection can operate in such a way that an individual in a given community will sacrifice individual genetic fitness so that the community competes more successfully with other groups of conspecifics (Wilson D. and Wilson E. 2008; Wilson 2002: 9–25, 35–37, 138–140). Soldiers on the battlefield do sacrifice themselves for their fellows, and nuns fail to have children while often educating and tending to the offspring of others. Already in the early seventeenth century, Martín de Porres was demonstrating to his world a pattern of behavior that might earn respect without focusing on the aggressive pursuit of power. He also demonstrated that community might be built thereby, and that his community could include other animals as well as humans of different ranks. He was not able to discuss this or demonstrate this using the evidence of evolutionary biology, where species are far from hermetically sealed, but he lived in a world that had its own ways of discussing these principles. A number of the Dominicans around him would have been well aware of Biblical passages envisioning perfect peace through the wolf's dwelling with the lamb (*Isaiah* 11: 6) and calls for communal harmony through all humans playing their roles to the common good in the mystical body of Christ (1 *Corinthians* 12) and feeding and clothing the least of Christ's brethren (*Matthew* 25: 35–40). Ag-

gression and violence, dominance and brutality, were really not the only things imperial Spaniards embraced.

Social animals cannot live by dominance alone. The Spanish Empire was more than the sum total of its most brutal displays. It sometimes was the peaceful interaction of people, and other animals too – a play with acts full of communication, community and compassion, as well as atrocity and violence. It is time for us to recognize, as Miguel de Cervantes already did, that in the midst of their virtual reality Don Quixote and Sancho Panza always, 'returned to their beasts and the life of beasts that they led' ('*Volvieron a susbestias, y a serbestias*…' Cervantes 1949: 703; 1998: 639). The pursuit of *império* is testimony enough of the basic animality we share across the centuries, but so too is the compassion of San Martín de Porres. In *Mothers and Others*, Sarah Blaffer Hrdy presents a strong case for the elaborate, complicated and convoluted achievements of human cultures being rooted in our ability to read each other's needs, and that this is developed through human (and, perhaps, hominin) levels of allo-parenting not as pronounced in the other extant hominids: orangutans, bonobos, chimpanzees, and gorillas. According to her, at some point (*i.e.*, perhaps starting with *Homo ergaster*, or early *Homo erectus*, some 1.8 million years ago), hominin infants were selected to read the intentions of multiple caregivers, including grandmothers, siblings, fathers and the completely unrelated. In the much studied foraging cultures of the twentieth century, this led to a nexus of cooperative behaviors that restrained extreme hierarchical construction and competition (Hrdy 2009: 4–5, 17, 76–78, 133–134, 179–180, 273–275, 278–286; Wood 2005: 23, 84–87). While variations obviously exist, our human cultural superorganisms are more complex elaborations on a natural hominid propensity for cooperation and group selection which struggles with our more competitive tendencies. We may not communicate chemically like ants, but communicate we do, constructing a highly adaptive collective consciousness of sorts (Christian 2004: 146–148; Hölldobler and Wilson 2009: 178–183; Grassie 2010: 89–90). Equality before the law, democratic institutions, universal human rights, the United Nations and the question of animal rights have become some of our twenty-first-century efforts at combating the competitive lust to dominate each other and what we term natural resources. Our twenty-first-century challenge is whether we will learn to emphasize our cooperative and self-effacing behaviors, or whether we only will use our cooperative capacity to form armies and compete violently over ever dwindling 'resources' in a natural world reduced to objects to be used

and used up. By reviewing historical case studies like the Spanish Empire in all its complexity, Big History accumulates data on both variations and flexible templates appearing in animal life and human history. Can group selection embrace Gaia and her multiplicity of ecosystems and life-forms, or will it continue to be community- and species-specific? Can reflection and learning in our highly adaptive species trump the competitive tendencies found in warring chimpanzees and anthills? Without being overly reductionist, it must be asked whether the twenty-first century will belong to San Martín de Porres or Caesar.

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12
Big History, Collective Learning and the Silk Roads*

Craig G. Benjamin

Abstract

The Silk Roads are the quintessential example of the interconnectedness of civilizations during the Era of Agrarian Civilizations, and the exchanges that occurred along them resulted in the most significant collective learning so far experienced by the human species. The primary function of the Silk Roads was to facilitate trade, but the intellectual, social, and artistic exchanges that resulted had an even greater impact on collective learning. The Silk Roads also illustrate another key theme in Big History – evolving complexity at all scales. Just as the early universe was simple until contingent circumstances made it possible for more complex entities to appear, and that the relatively simple single-cell organisms of early life on the planet were able to evolve into an extraordinary, complex biodiversity, so human communities and the connections between them followed similar trajectories. The comingling of so many goods, ideas, and diseases around a geographical hub located deep in central Eurasia was the catalyst for an extraordinary increase in the complexity of human relationships and collective learning, a complexity that helped drive our species inexorably along a path towards the modern revolution.

Keywords: *Silk Roads, Collective Learning, Agrarian Civilizations, Afro-Eurasia, trade.*

Introduction

During the Era of Agrarian Civilizations (*c.* 3000 BCE – 1750 CE) human communities did not exist in isolation. As confederations of pastoralists, states and large-scale agrarian civilizations expanded and stretched their boundaries, they joined together to form larger systems. Sometimes they joined up simply because their borders met and merged, but more often they joined in a looser sense as people from one region traded with, or traveled to, or borrowed ideas from, or fought with people from other regions within and beyond agrarian civilization. Because of this regular commingling the very idea of distinct agrarian civi-

* Some of the material presented at the first IBHA Conference in this paper was later incorporated into *Big History. Between Nothing and Everything*, by David Christian, Cynthia Stokes Brown and Craig Benjamin.

lizations with rigid borders is misleading. Borders that we identify on maps are, for the most part, modern inventions. The borders of agrarian civilizations were more often vague regions within which the control of rulers fluctuated or was contested by the claims of neighbors or local rulers.

Despite the complexity and fluidity of these processes, the slow linking up of different agrarian civilizations was immensely important because it facilitated a dramatic expansion in the size and diversity of collective learning, which can be described as the human capacity to share ideas so efficiently that they accumulate in the collective human memory from generation to generation. From the very beginning of human history the exchange of information and ideas between diverse peoples and cultures has been a prime mover in promoting change through this process of collective learning. As the smaller exchanges of the Early Agrarian Era began to expand, the enhanced collective learning that followed led to more and more significant changes in the material, artistic, social, and spiritual domains of human history. Eventually within the Afro-Eurasian world zone in particular, every human community was connected together within a vibrant web. This was true within each of the individual world zones, although not between them. Significant linkages developed during the era in the Americas, Australasia, and the Pacific, but the four zones were so isolated from each other that human populations in each remained utterly ignorant of events in the others.

The most influential of the intensified Afro-Eurasian exchange networks emerged around a trading hub located deep in Central Asia, along the Silk Roads. The trans-civilizational contacts that occurred through this exchange resulted in the most significant collective learning so far experienced by the human species. The first important period of the Silk Roads was between roughly 50 BCE and 250 CE, when material and intellectual exchange took place between the Chinese, Indian, Kushan, Iranian, steppe-nomadic and Mediterranean worlds. The demise of the Western Roman, Parthian, Kushan and Han Chinese empires resulted in several centuries of less regular contact, but the second 'Silk Roads Era' subsequently operated for several centuries between *c.* 600 and 1000 CE, connecting China, India, Southeast Asia, the Dar al-Islam, and the Byzantines into another vast web based on overland and maritime trade. The primary function of the Silk Roads during both periods was to facilitate trade. Not only material goods were carried along the Silk Roads, however, but intellectual, social, and artistic ideas as well, which together had an even greater impact on collective learning (Christian *et al.* 2013: 174–175).

An early example of intellectual exchange, which took place before the Silk Roads had started to operate with real intensity, was the spread of Greek and Hellenistic culture from the Eastern Mediterranean to Central Asia and India. This happened because Greek merchants and colonists followed in the footsteps of Alexander and spread Greek language, art, religion, philosophy, and law throughout much of the region. Perhaps, the most important spiritual consequence of material exchange was the spread of religions across Afro-Eurasia, particularly Mahayana Buddhism, which moved from India through Central Asia to China and East Asia. An example of cultural exchange that led to enhanced collective learning was the spread of artistic ideas and techniques, particularly the diffusion eastwards of syncretistic sculptural styles that developed in the second century CE in the workshops of Gandhara (in Pakistan) and Mathura (in India), where the first ever representation of the Buddha was conceived (*Ibid.*: 176).

The major biological consequence of Silk Roads trade was the spread of diseases and plague. Not only did the passing of disease bacteria along the Silk Roads by traders play a significant role in the depopulation and subsequent decline of both the Han and Roman Empires, but the exposure of millions of humans to these pathogens meant that antibodies spread extensively throughout the Afro-Eurasian world zone, and important immunities were built up within populations. These immunities proved of great significance in the pre-modern age, when Muslim, Chinese, and particularly European traders and explorers carried Afro-Eurasian diseases to the other world zones, with disastrous consequences for native populations (McNeil 1998). These four brief examples all support the claim that the Silk Roads profoundly affected the subsequent shape and direction of all human history.

Commercial and cultural exchange on this scale became possible only after the small river valley states of the early era had been consolidated into substantial agrarian civilizations, a process that was largely the result of warfare. Continuing expansion by the major civilizations meant that, by the first Silk Roads Era, just four imperial dynasties – those of the Roman, Parthian, Kushan, and Han Empires – controlled much of the Eurasian landmass, from the Pacific to the Atlantic. The consolidation of these states established order and stability over a vast and previously fragmented geopolitical environment. Extensive internal road networks were constructed, great advances were made in metallurgy and transport technology, agricultural production was intensified, and coinage appeared for the first time. By the middle of the last century BCE, conditions in Afro-Eurasia were ripe for levels of material and cultural exchange – and collective learning – hitherto unknown (Benjamin 2009: 30–32).

Also critical in facilitating these exchanges were the pastoral nomads, who formed communities that live primarily from the exploitation of domestic animals such as cattle, sheep, camels, or horses. The exact chronology of the origins and spread of pastoralism remains obscure, but certainly by the middle to late fourth millennium BCE the appearance of burial mounds across the steppes of Inner Asia indicates that some communities that were dependent upon herds or flocks of domestic animals had become semi-nomadic. There were varying degrees of nomadism, ranging from groups that had no permanent settlements at all to communities like the Andronovo that were largely sedentary and lived in permanent settlements. The highly mobile, militarized pastoralism of Inner Asia, associated with the riding of horses by the Saka/Scythians and other groups, probably did not emerge until early in the first millennium BCE (Christian *et al*. 2013: 177–178).

In Afro-Eurasia, by the time the first cities and states appeared, the technologies of the secondary products revolution had generated more productive ways of exploiting livestock, some of them so productive that they allowed entire communities to depend almost exclusively on their herds of animals (Sherratt 1981: 261–305). The more they did this, however, the more nomadic they had to be, so that they could graze their animals over large areas. The result was that there developed, over several millennia, entire lifeways based mainly on pastoralism, capable of exploiting the arid lands that ran in a long horizontal belt from northwest Africa through Southwest Asia and Central Asia to Mongolia.

By the middle of the first millennium BCE, a number of large pastoral nomadic communities had emerged with the military skills and technologies, and the endurance and mobility, to dominate their sedentary agrarian neighbors. Some of them, including the Saka, Xiongnu, Yuezhi, and Wusun, established powerful state-like confederations that formed in the steppe lands between the agrarian civilizations. These confederations demonstrated the ability of pastoral nomads to prosper in the harsh interior of Afro-Eurasia. Once such communities emerged, they facilitated the linking up of all the different lifeways and communities. Prior to the success of pastoralists in these more marginal zones, agrarian civilizations were considerably more isolated from each other. Ultimately it was the role of pastoralists as facilitators and protectors of trade and exchange that allowed the Silk Roads and other networks to flourish (Christian *et al.* 2013: 177–178).

First Silk Roads Era (*c.* 50 BCE – *c.* 250 CE)

With these preconditions in place, it was the decision by the Han Chinese to begin to interact with their western neighbors and engage in long-distance commerce that turned small-scale regional trading activ-

ity into a great trans-Afro-Eurasian commercial network. The Han became involved in the late-second century BCE after Emperor Wudi dispatched envoy Zhang Qian on a diplomatic and exploratory mission into Central Asia. When Zhang Qian returned after an epic journey of twelve years, he convinced the emperor that friendly relations could be established with many of the states of the 'Western Regions' because they were 'hungry for Han goods' (Benjamin 2007b: 3–30). Those that were not eager to trade could be subdued by force and compelled to join the Han trade and tributary network. Within a decade the Han had established a tributary relationship with dozens of city-states of Central Asia, and mercantile traffic began to flow out of China along the ancient migration routes into Central Asia. Half a century after the Han began to engage with their western neighbors, Augustus came to power in Rome following a century of civil war. This restored peace and stability to much of Western Afro-Eurasia, leading to a sharp increase in the demand for luxury goods in Rome, particularly for spices and exotic textiles like silk (Benjamin 2009: 30–32).

The major Chinese export commodity in demand in Rome was silk, an elegant, translucent, sensual material that soon came to be regarded as the last word in fashion by wealthy patrician women. The Chinese, realizing the commercial value of their monopoly on silk, carefully guarded the secret of silk production, and border guards in Dunhuang searched merchants to make sure they were not carrying any actual silk worms out of the country. The Han iron was prized in Rome for its exceptional hardness. Fine spices were imported into the Roman Empire from Arabia and India, notably nutmeg, cloves, cardamom, and pepper, prized as condiments, but also as aphrodisiacs, anesthetics, and perfumes. Trade with China and Central Asia for such high-value goods cost the Romans a fortune. In 65 CE, Roman Senator Pliny the Elder wrote that trade with Asia was draining the treasury of some 100 million sestercii every year (*Ibid.*: 30–32). Even though Pliny's figure is undoubtedly exaggerated, it provides evidence of the incredible scale of Silk Roads commercial exchanges. In return for their high value-exports, the Chinese imported a range of agricultural products (including grapes), Roman glassware, art objects from India and Egypt, and horses from the steppes.

The major Silk Roads land routes stretched from the Han capital, Chang'an, deep into Central Asia by way of the Gansu Corridor and Tarim Basin. The animal that made Silk Roads trade possible in the eastern and central regions of Afro-Eurasia was the Bactrian camel. Native to the steppes of Central Asia, the two-humped Bactrian camel is a supreme example of superb evolutionary adaptation. To survive the

harsh winters, the camel grows a long, shaggy coat, which it sheds extremely rapidly as the season warms up. The two humps on its back are composed of sustaining fat and its long eyelashes and sealable nostrils help to keep out dust in the frequent sandstorms. The two broad toes on each of its feet have undivided soles and are able to spread widely as an adaptation to walking on sand. The bulk of overland Silk Roads trade was literally carried on the backs of these extraordinary animals (Christian *et al.* 2013: 178).

In western Eurasia, the major land route departed from the great trading cities of Roman Syria, crossed the Euphrates and Tigris Rivers, then climbed across the Iranian Plateau toward Afghanistan (then known as Bactria). Significant information on the geography of the western part of the Silk Roads has come to us from a document produced early in the first century CE – *Parthian Stations* – written by a Parthian Greek merchant Isodorus of Charax (Benjamin 2009: 30–32). Around the time *Parthian Stations* was being composed, the amount of trans-Afro-Eurasian trade taking place by sea was also increasing, particularly between Roman Egypt and the coast of India. The survival of the first century CE seaman's handbook, the *Periplus of the Erythrian Sea*, has provided historians with a detailed account of maritime commerce at that time (*Ibid.*: 30–32). The *Periplus* demonstrates that sailors had discovered the secrets of the monsoon 'trade' winds. The winds blow reliably from the southwest in summer, allowing heavily laden trade ships to sail across the Indian Ocean from the coast of Africa to India. In winter the winds reverse, and the same ships carrying new cargo would make the return journey to the Red Sea. Whether by land or by sea, however, no traders we are aware of ever made their way along the entire length of the Silk Roads during the first era of its operation. Instead, merchants from the major eastern and western civilizations took their goods so far, then passed them on to a series of middlemen, including traders who were operating deep within the Kushan Empire.

At the heart of the Silk Roads network, straddling and influencing both the land and maritime routes, was the Kushan Empire (*c.* 45–225 CE), one of the most important yet least known agrarian civilizations in world history (Benjamin 1998, 2009). By maintaining relatively cordial relations with Romans, Parthians, Chinese, Indians, and the steppe nomads, the Kushans were able to play a crucial role in facilitating the extraordinary levels of cross-cultural exchange that characterize this first Silk Roads Era. The Kushan monarchs were not only effective political and military rulers; they also demonstrated a remarkable appreciation of art and were patrons of innovative sculpture workshops within their empire. The output from these workshops reflects the sort of synthesis

typical of the intensity of collective learning during the Era of Agrarian Civilizations.

The sculpture produced in the workshops of Gandhara and Mathura during the first two centuries of the Common Era was created by the combined talents of Central Asian, Indian, and probably Hellenistic Greek artists who placed themselves at the service of a resurgent Buddhist spirituality and created a whole new set of images for worship. Until this moment the Buddha had never been depicted in human form, but had instead been represented by symbols including an umbrella or footprints in the sand. The first ever representation of the Buddha, which appeared in Gandhara (in modern-day Pakistan), was influenced by depictions of Greco-Roman deities. This physical representation then spread along the Silk Roads, penetrating south to Sri Lanka and east to China, Japan, Korea, and Southeast Asia (Benjamin 1998, 2009).

An equally striking example of this cross-fertilization of ideas and traditions is the spread of Buddhist ideology along the great trade routes. Buddhism first emerged in northern India in the sixth century BCE. Eight hundred years later, according to ancient Chinese Buddhist documents, the Kushan king, Kanishka the Great (*c.* 129–152 CE?) convened an important meeting in Kashmir at which the decision was taken to rewrite the Buddhist scriptures in a more popular and accessible language. This helped facilitate the emergence and spread of Mahayana (or Great Vehicle) Buddhism, partly because the scriptures were now written in a language the common people could understand, and not one that could be read only by religious elites (Benjamin 2013).

The well-traveled trade routes from India through the Kushan realm and into China facilitated the spread of Buddhist ideas which, because they offered the hope of salvation to all regardless of caste or status, was already popular with India's merchants and businessmen. The Chinese merchants active in the silk trade became attracted to the faith, too, and returned home to spread the Buddhist message. Chinese edicts of 65–70 CE specifically mention the spread of Buddhism and opposition to it from imperial scholars devoted to Confucianism. By 166 CE, the Han emperor himself was sacrificing to the Buddha, and the Sutra on the 'Perfection of the Gnosis' was translated into Chinese by 179 CE. By the late fourth century, during a period of disunity in China, much of the population of northern China had adopted Buddhism, and by the sixth century much of southern China as well. The religion also later found ready acceptance in Korea, Japan, Tibet, Mongolia, and Southeast Asia (Benjamin 1998, 2009).

The Silk Roads also facilitated the spread of Christianity, Manichaeism and, later, Islam. Christian missionaries made good use of the superb Roman road and sea transportation networks. The Christian missionary, Paul of Tarsus, may have traveled as many as 8,000 miles along the roads and sea-lanes of the eastern Roman Empire preaching to small Christian communities. Christianity eventually spread further to the east along the Silk Roads, through Mesopotamia and Iran, into India, and eventually into China. One branch of Christianity, Nestorianism, became particularly strong throughout the central and eastern Silk Roads. The Central Asian religion of Manichaeism also benefitted from the silk routes after it emerged in Mesopotamia in the third century CE. Its founder, Mani (216–272 CE) was a fervent missionary who traveled extensively throughout the region and also dispatched disciples. Like Buddhism, Manichaeism was particularly attractive to merchants, and eventually most of the major Silk Roads trading cities contained Manichaean communities (Christian *et al.* 2013: 180).

During the third century of the Common Era, the Silk Roads fell gradually into decline as both China and the Roman Empire withdrew from the trans-Afro-Eurasian web. Ironically, Silk Roads trade itself was at least partly responsible for this disengagement, because it contributed to the spread of disastrous epidemic diseases. Smallpox, measles, and bubonic plagues devastated the populations at either end of the routes, where people had less resistance. Population estimates from the ancient world are always difficult, but the population of the Roman Empire may have fallen from 60 million to 45 million between the mid-first and mid-second centuries CE. As smallpox devastated the Mediterranean world late in the second century, populations declined again, to perhaps 40 million by 400 CE. In China, populations fell from perhaps 60 million in 200 CE to 45 million by 600 CE (Bentley and Zeigler 2010: 282).

These huge demographic losses, which happened at the same time as the decline of previously stable agrarian civilizations (the Han Dynasty disintegrated in 220 CE, the Kushan and Parthian Empires collapsed under pressure from Sasanian invaders a decade or so later, and the Roman Empire experienced a series of crises throughout the first half of the third century) meant that, for the next several centuries, the prevailing political situation in many parts of Afro-Eurasia was not conducive to large-scale commercial exchange. However, with the creation of the Dar al-Islam in the eighth and ninth centuries CE, and the establishment of the Tang Dynasty in China at the same time, significant Silk Roads exchanges along both land and maritime routes revived.

Second Silk Roads Era *c.* 600 – *c.* 1000 CE

Both the Tang Dynasty (618–907 CE) and its successor, the Song Dynasty (960–1279 CE), presided over a vibrant market economy in China, in which agricultural and manufacturing specialization, population growth, urbanization, and infrastructure development led to high levels of internal and external trade. New financial instruments (including printed paper money) were devised to facilitate large-scale mercantile activity. At the same time, Arab merchants, benefiting from the stable and prosperous Abbasid administration in Baghdad, began to engage with Chinese merchants in lucrative commercial enterprises. Large numbers of Muslim merchants actually moved to China where they joined communities of Byzantine, Indian, and Southeast Asian migrants in the great Chinese trading cities. As maritime trade gradually eclipsed overland trade in volume, merchants and sailors from all over Afro-Eurasia flocked to the great southern port cities of Guangzhou and Quanzhou (Christian *et al.* 2013: 180–181).

The recent discovery of a sunken ninth-century CE Arab ship – the so-called Belitung Wreck—in the waters of Indonesia has provided historians with tangible evidence of both the intensely commercial nature of Chinese-Muslim trade and the significance of maritime routes in facilitating it (Worrall 2003: 112ff.). The dhow was filled with tens of thousands of carefully packaged Tang ceramic plates and bowls, along with many gold and silver objects. The Tang bowls were functional and intended for the ninth-century equivalent of a 'mass market'. Their almost factory-like manufacture demonstrates the existence of a well-organized commercial infrastructure. The bowls required the use of cobalt for blue coloring, which was imported by the Chinese manufacturers in significant quantities from Iran. The firing date of the bowls was carefully noted in the ship's manifest. The cargo also included large quantities of standardized inkpots, spice jars, and jugs, clearly export goods manufactured for specific markets. Decorative patterns painted or glazed on the various items – including Buddhist, Iranian, and Islamic motifs – show the specific market the goods were intended for. China and the Dar al-Islam were clearly engaged in intense commercial exchanges during this second Silk Roads Era, and Arab mariners undertaking lengthy seagoing voyages were maintaining this vibrant trans-Afro-Eurasian web late in the first millennium of the Common Era.

As with the first Silk Roads Era, although the material exchanges were important and impressive, the cultural exchanges seem in retrospect of even greater significance. As noted above, long before the Tang came to power, many foreign religions had made their way into East Asia. With the advent of Islam in the seventh century and the estab-

lishment of substantial Muslim merchant communities in the centuries that followed, mosques also began to appear in many Chinese cities. Yet of all the foreign beliefs that were accepted in China, only Buddhism made substantial inroads against Confucianism. Between 600–1000 CE, thousands of Buddhist stupas and temples were constructed in China. With its promise of salvation, Buddhism seriously challenged Daoism and Confucianism for the hearts and minds of many Chinese, and in the end the syncretic faith of Chan Buddhism (Zen Buddhism in Japan) emerged as a popular compromise (Christian *et al.* 2013: 181).

Conclusion

The Silk Roads, both the land and maritime variants, are the quintessential example of the interconnectedness of civilizations during the Era of Agrarian Civilizations. Along these difficult routes through some of the harshest geography on earth traveled merchants and adventurers, diplomats and missionaries, each carrying their commodities and ideas enormous distances across the Afro-Eurasian world zone. Each category of exchange was important, but perhaps the most significant consequence was the spread of religion, particularly Buddhism, which became one of the key ideological and spiritual beliefs of South and East Asia during the Era. To this day Buddhism remains one of the great cultural bonds shared by millions of Asian people, one of the many legacies that the modern world owes to the Silk Roads. As a result of this interaction, despite the diversity of participants, the history of Afro-Eurasia has preserved a certain underlying unity, expressed in common technologies, artistic styles, cultures and religions, even disease and immunity patterns, a unity that was to have profound implications for subsequent world history.

Silk Roads exchanges play an even more significant role in the big history narrative. The physical contexts that made the Silk Roads possible were the product of billions of years of geological change and biological evolution. Geography made it possible for the first agrarian civilizations of western Eurasia and northeastern Africa to form cultural and commercial connections, but geography also prevented Chinese civilization from joining these developing networks in any substantive way. Only with the biological evolution and then human domestication of the silk worm and the Bactrian camel did the Chinese have an export commodity valuable enough, and a transport mechanism hardy enough, to justify and facilitate the expensive and complex expeditions necessary to allow the Chinese merchants to join the pre-existing Afro-Eurasian exchange network. This joining together of previously separated human communities led to a steep increase in levels of collective learning and complexity that had regional and global ramifications.

The development of the Silk Roads is also an example of another key theme in Big History – evolving complexity at all scales. In the same way that the early universe was simple until contingent circumstances made it possible for more complex entities to appear, and that the relatively simple single-cell organisms of early life on the planet were able to evolve into an extraordinary, complex biodiversity, so human communities and the connections between them followed similar trajectories. The commingling of so many goods, ideas, and diseases around a geographical hub located deep in central Eurasia was the catalyst for an extraordinary increase in the complexity of human relationships and collective learning, a complexity that drove our species inexorably along a path towards the modern revolution.

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13
Retrofitting the Future

Barry Rodrigue

Abstract

This paper considers the subspecialty of adaptive technology. It looks at technology development in the light of our rapidly changing world and in the context of Big History. The author makes a case for past technologies serving as models from which new technologies may be developed. In this way, he sees a collective knowledge of the past, as well as considerations of the present and future, conferring survival benefits on civilization. In this way, Big History holds great pragmatic promise for humanity.

Keywords: *adaptive technology, Big History, traditional ecological knowledge (TEK), future studies, indigenous heritage.*

Big History is involved in a great project of expanding the view of humanity's place in the universe. Its studies are leading to new connections between previously separated entities, from cities and minerals to shipping lanes and thermoclines. But as scientists and scholars develop new insights of cosmic history, they should also think back to their ancestors – to our forefathers and foremothers who took their living from the land, sea, rivers and hillsides of the ancient world. They should also think about today's indigenous peoples who are custodians of a middle tradition between the old and the new ways. Such reflection on the past should not be a focus of just antiquarian interest but it should also reflect a present-day concern for sustainable adaptation to life on our rapidly changing planet.

Classically minded scholars tend to designate the small agrarian cities of 5000 years ago as the 'start of civilization' but, in fact, the individual components that collectively constitute 'civilization' existed long before Mesopotamia became its so-called cradle. The first understandings of the universe began with our Paleolithic ancestors, not with Neolithic rulers and priests. These understandings developed in continual and collective processes, beginning with the evolution of our genus more than two million years ago.

This is borne out with the discovery that many of the traditional hallmarks used to identify 'civilization' began before the adoption of agriculture. Take, for example, permanent residency in single locations and the development of ceramics. Hunters and gatherers lived in permanent

communities in places like Palestine and Japan over 10,000 years ago, while pottery has been pushed back 20,000 years with its recent discovery in southern China (Wu *et al.* 2012). Indeed, it was hunters and gatherers who developed strategies that led to the development of agriculture. While hardly news to most scholars, it is a fact that needs to be better articulated with a public that tends to focus on technological and social aspects of Neolithic society.

The hunting and gathering peoples of the world knew their landscapes and waterscapes better than the farmers who had to micromanage their crops on small plots of lands. Agriculture might have allowed the division of labor so that a few specialists could spend their time studying the stars, but, in the older tradition, a majority of hunters and gatherers acquired such knowledge of nature. This, indeed, is a point made by social scholar James Tierney: 'The tendency is to lump all our ancient ancestors into the category of hunter-gather. This implies to the lay person, as well as many scholars, that these were small bands forever on the move, with little or no behaviors that we might describe as "advanced culture"' (Tierney 2011: 290).

Examples

On low alpine peaks along the coast of Maine are small cuts in the granite ledges. These elongated holes were quarries dug a hundred years ago to extract mica. Maine was one of the world's large mica producers back then. Mica is an igneous form of silicon whose name can be translated from Latin as 'a glittering crumb'. Indeed, as you walk up the tote roads on these hills, the earth glitters with fragments that fell off horse-drawn carts a century ago. Mica is inert, flexible, lightweight, non-conducting, and opaque. In earlier days, it was used as windows in boilers (isinglass), in lanterns to shield lampshade fabric from a wick's flame, as well as insulation for electrical plugs and toasters. Today, mica is used in atomic force microscopy, which produces high resolution, three-dimensional imaging.

This is an example of how older uses of technology can be migrated into more modern uses. There is nothing unusual about this process. People have adapted older technologies into newer ones for millennia – this paradigm of transferrable technology is a backbone of material sciences. Pigments that our ancestors developed for use on the walls of caves, like Lascaux and Duogate and Blombos, have been developed for use on the walls of the international space station and are even enroute to Mars (NASA 2012).

My professional training lies in the disciplines of geography and archeology. The research that I entered focuses on the movement of hu-

mans into the northern Appalachian Highlands – the frontier region between Canada and the United States. While this research has been about past events, I soon discovered a specialty of adaptive technology that can be called 'futures archeology'. This specialty became apparent one day in 1994, when I discovered the remains of a half-dozen deserted farms, which lay on a hillside, in the woods, many kilometers from any presently existing habitation.[1]

After a long day of work, when I got back to my tent that night, I discovered that I had neglected to measure the downhill dimensions of a causeway. So I got up at 05:00 the next morning. It was raining. I had breakfast – as the rain got worse. I crossed the river, parked my car at the end of a dirt road, and began hiking through the forest. The rain came down even harder. However, it turned out that this torrential downpour was a very fortunate experience, since I got to see the causeway in action.

A causeway is a stone bridge that allows humans and livestock to cross over a stream but allows water to pass beneath it in such a way to minimize erosion. In this case, the causeway worked brilliantly, 150 years after its construction and abandonment.[2] The water pooled upstream and drained through the stonework, leaving the stone crossing dry and the streambed intact.

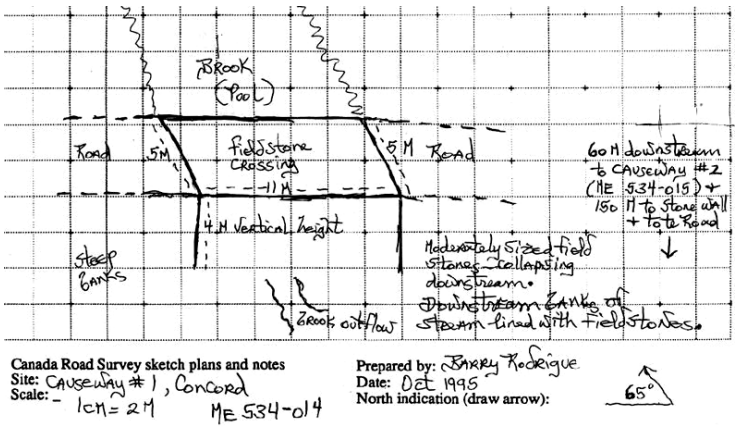

Fig. 1. Causeway plan. Barry Rodrigue, Causeway No.1, Concord, Maine, ME 534–014, for the Maine Historic Preservation Commission, Augusta, Maine (USA)

[1] Barry Rodrigue, Maine Historic Preservation Commission, ME 534-016.
[2] Barry Rodrigue, Maine Historic Preservation Commission, ME 534-014.

I took the measurements that I needed and hiked back out of the forest. Back at my field camp, I mentioned the experience to the owner of a hunting lodge. She said this design would solve one of their problems, as their stone causeways washed out every year. This began my thinking about old methods being used to solve modern problems. Conversations with archeologists and other professionals revealed similar examples of adaptive technology.

However, simple adoption of old techniques can be problematic. One infamous example is that of the sailing vessel, *John F. Leavitt*. In the wake of the oil crisis of 1973–1974, people began to search for alternatives to petroleum power. A well-designed adaptation of a traditional coastal schooner was developed in Waldoboro, Maine (USA) – it was 30-meters long and had two masts rigged with fore and aft sails. In the winter of 1979, it set sail down the eastern seaboard of the United States with a cargo of lumber, bound for Haiti. However, it foundered in moderate seas off Long Island, New York. After much study of the incident, the problem was identified as the crew not having sufficient knowledge of commercial deep-water sailing, which had been lost in the century since the era of 'wind, water and wood' (Koltz 1980: 40–42).[3] In other words, knowledge needs to go with technology.

Bridges to the Present

The examples of this more complete development of technology and its use abound. Two examples may be seen in Alaska. Archeologists, biologists and indigenous peoples in Southeast Alaska have begun collaborating to deal with declines in the region's basic fisheries economy. Traditional halibut hooks fashioned by the indigenous Tlingit were designed in such a way so as to avoid capture of immature fish and large breeding females, while their intertidal salmon weirs allowed for capture of fish only at certain times of an ebb tide. This was a technology-based method of conservation (Ratner and Holen 2007: 45–46, 48). Likewise, architectural studies of earth-fast, traditional housing among the indigenous peoples of Alaska led to construction of new housing forms in Anuktuvuk Pass, a Nunamiut Eskimo community in the Brooks Mountain Range in the Alaskan arctic. By merging traditional design and with high-tech design, the result was a cut in the cost of house construction and a reduction in the annual heating fuel use by a factor of ten. This kind of merger of traditional and modern skills is referred to as 'traditional ecological knowledge' or TEK (Ratner and Holen 2007: 45–46, 48).

Russian anthropologist Anatoly Alekseyevich Shtyrbul, who teaches in Western Siberia, at the Omsk State Pedagogical University, has

[3] I would like to thank Nathan Lipfert of the Maine Maritime Museum for his background information of this incident and others.

carried this view further by stating that the so-called 'primitive' traditional societies possess many of the skills that we will need to adapt to the future.[4] Shtyrbul is echoed by American archeologist, Stephen Scharoun, who specializes in eighteenth- and nineteenth-century farm technology and systems of farm management. His career was not chosen because of an atavistic appreciation for the past. His view is that with the decline of cheap fossil fuel, we should know such techniques, so that we can adapt them to soon-to-be changing forms of food production.

This is by no means a unique view, as many journals, societies, books, individuals and organizations advocate it. In the United States, *Foxfire* magazine was begun in 1966, the *Whole Earth Catalog* in 1968, and the *Small Farmer's Journal* in 1976. These are the kinds of technological compilation begun by encyclopediasts in fifteenth-century China and eighteenth-century France. The designer, Victor Papanek, devoted his life to such applied uses, as in his 1971 book, *Design for the Real World*.

Since the 1980s, agricultural scientist Anil Gupta of the Indian Institute of Management in Ahmedabad has researched grassroots innovation by common people throughout South Asia.[5] Alexander Petroff has successfully established a self-sustaining program of agricultural recolonization based on oxen power in eastern Congo, an area lacking petroleum access. Petroff envisions his organization, Working Villages International, to be applicable to other regions of the world.[6]

But what is new about these efforts is that the present and future circumstances of life on Earth have so dramatically changed, and that a new, degraded world is in sight – one with little cheap energy, one that is polluted, overpopulated, and trying to adapt to collapsing infrastructures. Such adaptations as articulated by Shtyrbul and others are perhaps more important than ever. So, what does this kind of adaptive technology mean for Big History?

Big History and Adaptive Technology

In a way, adaptive technology could be seen as an extension of *Little Big Histories*, where a complete historical profile is given on a subject. In this respect, Esther Quaedackers has analyzed Tiananmen Square as an expression of building styles, making connections between human and other animals' construction techniques, while Craig Benjamin has ana-

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[4] This discourse was part of Shtyrbul's presentation at the Fifth International Conference on Hierarchy and Power in the History of Civilizations (Shtyrbul 2009).

[5] Gupta's organization, the Honey Bee Network (http://www.sristi.org/hbnew/), promotes grassroots innovation.

[6] See the website for Working Villages International at http://workingvillages.org/.

lyzed the deep history of Jericho as the world's oldest and continually inhabited city (Quaedackers 2011; Benjamin 2011).

However, adaptive technology moves the concept of *Little Big Histories* a few steps further into the realm of filtering them for pragmatic lessons, for application to life. It thus could become prescriptive as well as descriptive. We, Big Historians, have done well in describing the past and beginning the assemblage of deep historical contexts. I propose that a next step might be more in the direction of applications.

In his study of the Little Big History of Jericho, Craig Benjamin has outlined the factors that gave Jericho such an advantage, such as reliable fresh water source, protected valley, closeness to a major trading route, fertile soil, *etc.* If we were to convert such a predictive model to a prescriptive model, it might point us in directions to plan our lives for more stable and equitable existence – for example, on site locations for cities like Camargue, France (below sea level) or San Francisco, USA (on an earthquake fault).

Our indigenous societies are repositories of knowledge and ways of learning that the modern world will increasingly come to need as our access to cheap fuel dwindles and the damage from industrial waste increases. This is not to advocate for the celebration of primitiveness or ethnic identity, but an acknowledgement that we need to establish a 'world heritage commons' where the best ideas, both technology and process, are assembled and adapted.[7]

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14
Galactic-Scale Macro-engineering: Looking for Signs of Other Intelligent Species, as an Exercise in Hope for Our Own

Joseph Voros

Abstract

If we consider Big History as simply 'our' example of the process of cosmic evolution playing out, then we can seek to broaden our view of our possible fate as a species by asking questions about what paths or trajectories other species' own versions of Big History might take or have taken. This paper explores the broad outlines of possible scenarios for the evolution of long-lived intelligent engineering species – scenarios which might have been part of another species' own Big History story, or which may yet lie ahead in our own distant future. A sufficiently long-lived engineering-oriented species may decide to undertake a program of macro-engineering projects that might eventually lead to a re-engineered galaxy so altered that its artificiality may be detectable from Earth. We consider activities that lead ultimately to a galactic structure consisting of a central inner core surrounded by a more distant ring of stars separated by a relatively sparser 'gap', where star systems and stellar materials may have been removed, 'lifted' or turned into Dyson Spheres. When looking to the sky, one finds that such galaxies do indeed exist – including the beautiful ringed galaxy known as 'Hoag's Object' (PGC 54559) in the constellation Serpens. This leads us to pose the question: Is Hoag's Object an example of galaxy-scale macro-engineering? And this suggests a program of possible observational activities and theoretical explorations, several of which are presented here, that could be carried out in order to begin to investigate this beguiling question.

Keywords: *galactic astrophysics, macro-engineering, search for extra-terrestrial intelligence (SETI), Threshold 9, thinking on cosmological time-scales.*

Introduction – Big History in Context

Big History is a powerful conceptual framework for making sense of the place of humankind in the Universe – a narrative leading from the Big Bang nearly 14 billion years ago to our present information-based technological civilization (*e.g.*, Brown 2008; Christian 2004, 2008; Spier 1996). It synthesizes many different knowledge domains and scholarly disciplines and, in the words of the International Big History Association (IBHA) 'seeks to understand the integrated history of the Cosmos,

Earth, Life, and Humanity, using the best available evidence and scholarly methods' (International Big History Association 2012).

Nonetheless, Big History is ultimately concerned with the history of just *one* planet – ours – among the trillion or so that are now thought to exist in the Milky Way Galaxy, not to mention the billions of trillions that can thereby be inferred to exist in the wider observable universe. Thus, it can be considered a single case in the even larger context of the unfolding of the broad scenario of Cosmic Evolution, as that scenario has played out on this particular planet (Chaisson 2001, 2007, 2008; Delsemme 1998; Jantsch 1980). It is easy to imagine other planets where life, and perhaps even intelligence, has arisen, as the Cosmic Evolutionary scenario has unfolded there, possibly giving rise to their own unique variant of Big History. A natural sub-set of the study of Cosmic Evolution is the discipline of Astrobiology (Chyba and Hand 2005; Mix *et al.* 2006), the study of life in the universe, which also includes its own associated sub-set of SETI, the search for extra-terrestrial intelligence (Ekers *et al.* 2002; Harrison 2009; Morrison, Billingham, and Wolfe 1979; Sagan and Shklovskii 1966; Shostak 1995; Tarter 2001). So, one can imagine an expanding set of nested fields of study, beginning with Big History (the history of our own small 'pale blue dot' [Sagan 1995]) enfolded by Astrobiology/SETI (the study of how life may arise in the universe and the search for intelligent forms of it) and encompassed by Cosmic Evolution (the study of how our universe as a whole has changed over the course of deep cosmic time). Whether there is a further enfoldment of our own universe within an even larger 'multiverse' of other universes is a fascinating open question currently receiving some attention among cosmologists.

Our focus here will be on using the step beyond Big History, specifically SETI as a framework for thinking about some of the broad contours that might characterize the unfolding future for intelligent technological civilizations, including possibly our own. Searching for signs of long-lived intelligent extra-terrestrial species, like those that will be sketched here, could provide a way for us to shift our collective thinking to become much more far-reaching and much longer-term – something that increasingly appears to be vitally necessary for the future of our civilization and planet. And if we can actually begin making this collective worldview change – albeit perhaps only minutely at first – then even this small shift of our current mindset could become a rational basis for some measure of hope in our ability to determine both wisely and well what the next stages will be in the long-term Big History view of the potential 'future histories' of our species.

Approaches to the Search for Extra-Terrestrial Intelligence

The modern search for extra-terrestrial intelligence has a history of just over half a century (Dick 2006). It has mainly involved searching for electromagnetic signals, usually at radio frequencies, although, more recently, it has also been undertaken in the optical spectrum (Shostak 2003). Just after the original proposal by Cocconi and Morrison (1959) to search for radio transmissions, Freeman Dyson (1960) suggested looking not for electromagnetic signals but instead for artificial signs of technology, an idea elaborated in further detail a few years later (Dyson 1966). Thus, some recent SETI researchers (Bradbury, Ćirković, and Dvorsky 2011; Ćirković 2006) consider there to be two main approaches to SETI: the '*orthodox*' approach, based on the detection of electromagnetic signals, whether they were deliberately signaled or are simply unintentional 'leakage' from the civilization; and the '*Dysonian*' approach, based on looking for signs of extra-terrestrial technology, without any presumption of deliberate signaling or attention-seeking at all.

The idea of searching for signs of extra-terrestrial technology or artefacts (*e.g.,* Freitas 1983) is an example of an approach that has more recently been called 'interstellar archaeology' (Carrigan 2010, 2012). Such a form of archaeology is hampered, of course, by the enormous distances to other stars, making the more usual pick-axe and soft-brush approach impractical (to say the least!), so any examples of technologies or artefacts we would be able to discover in this way would probably need to be executed on a stupendous scale. Some researchers have suggested, however, that we might possibly find artefacts in our own solar system (Kecskes 1998; Papagiannis 1983). Unfortunately such an enticing 'field trip' is currently beyond our technical ability, although there have been some ideas proposed for the exploration and use of near-Earth objects, including asteroids, in this next half-century (Huntress *et al.* 2006). Along similar lines, Davies and Wagner (2013) have recently suggested taking a closer look at the Moon for any possible traces of extra-terrestrial technology.

The emerging field of 'macro-engineering' is explicitly concerned with thinking about engineering on large scales, so it may be helpful as a framework for informing our thinking in the search for insights regarding examples of extra-terrestrial technology (Badescu, Cathcart, and Schuiling 2006; Cathcart, Badescu, and Friedlander 2012). Macro-engineering can be conceived of at a variety of scales, ranging from sub-regional to planetary, stellar, and galactic in scope (Badescu *et al.* 2006). In what follows below we consider the last of these – galaxy-scale macro-engineering – and how we might go about imagining what forms

such almost unimaginable feats of engineering might take, in order to think about how we might detect such artificial activities across intergalactic distances. But first let us examine more closely why this type of approach to SETI may be even more relevant today than it has conventionally been considered to be.

The Drake Equation

One of the pioneers of SETI, Frank Drake, developed an equation which has since become widely used as a conceptual framework for discussion and debate about the various terms which are included in it (Drake 1961). The Drake Equation can be written as:

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L,$$

where N is the number of currently-existing communicating technological civilizations in the Milky Way Galaxy; R_* is the average rate of formation of suitable stars per year in the Galaxy; f_p is the fraction of these stars which have planets; n_e is the average number of planets in each of these star systems with conditions favourable to life; f_l is the fraction of these planets which go on to actually develop life; f_i is the fraction of these inhabited planets which go on to develop intelligent life; f_c is the fraction of planets with intelligent life that develop technological civilizations which are capable of releasing signals into space; and L is the average communicative lifetime of such a civilization. There are several variants to this equation, and there have been many modifications made to it over the ensuing decades as well (Bracewell 1979; Ćirković 2004; Hetesi and Regály 2006; Maccone 2010; Walters, Hoover, and Kotra 1980).

With regard to the parameter L, initially this was often taken to mean the actual lifetime of the civilization. Some early estimates of this parameter tended to be rather gloomy, therefore, given our own case of the unwelcome possibility of hair-trigger nuclear annihilation under which humanity has lived since the mid-twentieth century CE. It was often thought, based on our own example, that many nascent technological civilizations might, therefore, destroy themselves not long after achieving the ability to send signals into space. More recently, as suggested by the above, the meaning of L has shifted subtly from the 'lifetime of the civilization' to the 'length of time such civilizations release detectable signals into space', a shift which changes the character of the term rather significantly. This newer meaning for L has again arisen through reasoning from our own example. The Earth's radio 'signature' has changed over the decades from very high-energy analogue broadcasts from ground-based transmitters aimed towards the horizon (where the suburbs and home viewers are) and which have thereby con-

tinued on further out into space, to very low-energy narrow digital beams from orbiting satellites that are targeted at particular regions of the Earth's surface, and therefore do not propagate to any great degree beyond the Earth. This shift from high-power analogue broadcasts to low-power digital 'narrowcasts' (so to speak) has meant that over time the Earth is becoming less and less visible due to 'leakage' from our own terrestrial use of radio waves (Drake 2010).

SETI commentators sometimes use the US TV show *I Love Lucy* as the archetypal example of the sort of broadcast material that is expanding outwards in a 'bubble' from the Earth at the speed of light as a 'cultural leakage' signal from our civilization. One might be moved to observe that, if *those* are the signals that form the basis of an assessment by extra-terrestrials as to whether there is intelligent life on Earth, then perhaps it is *no wonder* that extra-terrestrials have not sought to make contact! Whatever one's opinion about the value of the content it carries, however, over time this leaked electromagnetic energy will die down to a faint whisper, due to the changing pattern of electromagnetic radiation use on Earth. Eventually, once the initial several decades' worth of high-energy broadcasting has passed, the longer-term low-power digital signal emanating from Earth will likely become almost impossible to detect by chance above the normal background radio noise of space. Only some navigational beacons and radar are likely to remain detectable after this time.

This gradual disappearance over time of the Earth as a strong radio source has implications for the wider consideration of the value of *L* in the Drake Equation. It is possible to imagine that other civilizations might also make a similar transition, so that a civilization might indeed be very long-lived, even while having a value of *L* remaining relatively short (Drake 2010). This implies a need to re-think some of the conventional approaches to SETI, or at least some of the assumptions upon which orthodox SETI has been based for so long, if not to expand the thinking beyond conventionality altogether. Indeed, Frank Drake himself has commented that:

> Searching for extra-terrestrial signals is one of the most challenging tasks ever taken on by mankind. …We are challenged to use logic to predict what another civilization, probably much older and more advanced than us, might adopt as a technology we might detect. …To reach an answer, ***we have to become futurists****, reaching far beyond our usual comfortable world of telescope technology to arrive at possible scenarios for the distant future*. This becomes an exercise of intellect reaching far beyond the usual bounds of science theory (Foreword to Shostak 2009; emphases added).

Then, this is the challenge, as posed by one of the founding pioneers of SETI: to imagine how an advanced civilization might develop over the course of perhaps hundreds of thousands or even millions of years, and attempt to conceive of what sort of technology such a civilization might invent or use. We are challenged, in other words, to think on a truly 'cosmological' scale, thinking which will very likely need to include both temporal and spatial dimensions – vast distances and immense timeframes. In order to approach and meet this challenge, we will need some sort of organizing principle for doing so.

'Dysonian' Thinking

Fortunately, Dyson explicitly set out the three 'rules' for his 'game' of thinking about extra-terrestrial technology (Dyson 1966). With very little modification, it is possible to use them from the point of view of our current understanding of technology, and with a view to incorporating ideas coming from the above-mentioned field of macro-engineering. Dyson's three rules can be given as follows (*Ibid*.: 643–644):

1. Think of the biggest possible artificial activities, within limits set only by the laws of physics, and look for those;
2. All engineering projects are carried out with technology which the human species of the *current epoch* can understand; and
3. Ignore questions of economic cost;

and where, in Rule 2, the italicized term 'current epoch' replaces Dyson's original use of 'year 1965 AD'. The given modification allows the rule to be applied at any stage of human history, which will thereby yield different answers depending upon the state of our knowledge in any given epoch. In particular, Dyson stressed with respect to Rule 1 that he was not interested in what an 'average' technological civilization might look like, only in what the most conspicuous of perhaps one in a million might look like, as these would be the easiest to detect over great distances; hence the focus on the 'biggest possible artificial activities' (*Ibid*.: 643–644).

Dyson went on to outline how it would be possible to disassemble planets, build rigid structures in space, and also revisited some of the ideas in his earlier paper (1960) which suggested that attempts to harvest increasing amounts of stellar radiation from the civilization's home star would lead, in the asymptotic limit, to all visible radiation being intercepted by a vast 'swarm' or 'shell' of orbiting collectors completely enveloping the star. While no longer radiating in the visible spectrum, such an object would nonetheless remain visible in the infra-red, owing

to the black-body radiation law, whence Dyson's proposal in the initial paper's title to search for artificial sources of infra-red radiation. There have been several searches undertaken since the original proposal in 1960, although at the time of this writing none have been confirmed (see, *e.g.*, Bradbury 2001a; Tilgner and Heinrichsen 1998; Timofeev, Kardashev and Promyslov 2000). The idea of a 'Dyson shell', or 'Dyson sphere', was subsequently taken up and expanded upon by the astrophysicist Nikolai Kardashev (1964), who conceived of technological civilizations as being characterizable on a three-level scale with regard to their ability to use and control energy.

The Kardashev Scale

Kardashev's initial schema has frequently been revised and refined by many others in the five decades since it was first proposed. In brief, it is as follows (Sagan 1973: 233–234):

• **Type I: planetary.** A Type I civilization is the one which makes use of use all of the available energy of its planet, estimated to be on the order of 10^{16} watts (*i.e.* 10,000,000,000,000,000 W), or 10×10^{15} W = 10 PW (petawatts). This would include harnessing, for example, tidal, thermal, atmospheric, nuclear, fossil, internal geothermal and other planetary sources of energy.

• **Type II: stellar.** A Type II civilization is the one which harnesses all of the energy output of its star, something on the order of 10^{26} W = 100 × × 10^{24} W = 100 YW (yottawatts). This includes collecting all of the radiant energy of the star, and might perhaps even include harnessing the energy contained in its gravitational field.

• **Type III: galactic.** A Type III civilization is the one which has managed to harness the energy of an entire galaxy, something like 10^{36} W, although because galaxies vary considerably in size, this figure is somewhat variable. A civilization capable of using energy at this scale could probably make itself visible, if it chose to, throughout most of the observable universe.

The energy difference between adjacent types is ten orders of magnitude – a factor of 10 billion (*i.e.* 10^{10}). Astronomer Carl Sagan suggested that a decimal interpolation be introduced between the main levels, whereby each factor of 0.1 represents a ten-fold increase on the previous level (Sagan 1973: 234). Thus, a Type I.5 civilization uses ten times more energy than a Type I.4, which uses ten times more than a Type I.3 and so on. In this view, Earth is usually considered to be an approximately Type 0.7 civilization.

It is fairly simple to state the characterization of a civilization as 'using energy on a galactic scale', the definition of Type III, but it is not quite so simple to imagine what that situation might entail in terms of artificial structures we might be able to detect. Does it imply a vast system of beacons, each pulsing out transmissions in the tens of millions of yottawatts range, or would it be something more subtle, such as the ability to move whole star systems around at will, in order to reconfigure the wider structure of the galaxy? Is the energy usage expended in a single or small number of artefacts or activities, or is it spread out over innumerable activities whose aggregate total is of the order of magnitude considered galactic in scale?

In the Kardashev scheme, Dyson's idea of re-engineering a star or star system – now usually called 'astroengineering' – is considered to be an example of a Type II civilization. The nature and possible structure of Type III civilizations has received somewhat less attention, although there have been some researchers who have thought along these lines (Annis 1999; Bradbury *et al.* 2011; Carrigan 2012; Ćirković 2006). When this question has been considered in the literature at all – which does not appear to have been often – it has usually looked to expanding the scale of Type II civilizations into the galactic context. For example, Carrigan (2012) wrote of 'Fermi bubbles' or 'voids' as places where there is an apparent dearth of visible stars due to the existence of large numbers of Type II civilizations or Dyson Spheres. Such a void or bubble of reduced optical stellar density could, in principle, be detectable by our instruments, owing to the infra-red blackbody radiation signature it would still emit, combined with the unusual appearance that such a structure would produce. However, Carrigan also noted that detection of such voids in spiral galaxies is somewhat more difficult than in elliptical galaxies, owing to the presence of comparable voids that are naturally found in spiral galaxies. The few efforts made to date do not appear to have found definitive examples of galaxy-scale artificial activity (Annis 1999), but it would be very interesting to search the literature more exhaustively than has been possible for this paper.

What would a Type III Civilization Actually Look Like?

The ideas to be presented here arose in part from asking the question 'I wonder what a Type III civilization would actually look like?' as well as from some related exploratory investigations into the parameter space for possible scenarios of 'contact' – the usual shorthand term for the discovery of extra-terrestrial life, including intelligence. That paper is currently in preparation (where the technique is described in more

detail), but, in brief, the 'scenario space' of contact – that is, the range of possible scenarios under which contact might occur – is assumed to be characterized by several parameters, including (among others): the nature of the entity (biological, post-biological, hybrid); the complexity of the entity (simple, complex, intelligent); the form of 'signal' (electromagnetic, artefactual); the intentionality of the signal (deliberate, incidental); and the Kardashev type (0, I, II, III). One can see that the initial form of orthodox SETI (*i.e.*, deliberate or incidental leakage radio signals), later forms of orthodox SETI (*e.g.*, deliberate optical signals), and Dysonian SETI (incidental artefact-producing activities) are all accommodated in the parameters characterizing the form and intentionality of the 'signal'. The meaning of 'artefactual' is deliberately left somewhat open so as to encompass Dyson's own suggestion in his Rule 1 of looking for 'artificial activities', and is taken to mean any objects or artefacts produced by any such 'artificial activities'.

This parameterization can be expanded into a many-dimensional (one dimension for each parameter) combinatorial 'morphological space', following a technique devised by Fritz Zwicky in the early part of the last century, whereby every parameter value is systematically and exhaustively combined with every other parameter value for all parameters (Zwicky 1967, 1969). This results in a very large number of possible 'configurations', numerically equal to the product of the number of parameter values of all parameters. Zwicky used this technique to great effect in his scientific work (Zwicky 1947, 1948). Every distinct configuration of parameter values could, in principle, be examined for its characteristics, although in practice not all configurations necessarily appear as 'solutions' because some parameter value pairs may not be mutually 'consistent' and would thereby be excluded from the total 'solution space' (see Voros 2009 for a more detailed explanation of this method). By way of illustration, our own cultural leakage signals – for example, *I Love Lucy* – can be characterized by the following set of the above parameter values: biological, intelligent (or so *we* might think!), electromagnetic, incidental (*i.e.*, unintentional signalling), Type ~0. More colloquially, this might be rendered as incidental electromagnetic signals (*i.e.*, 'leakage') from an intelligent, biological, Type ~0 civilization.

For our purposes here, it suffices to say that by combining different classes of parameter value it is possible to systematically generate ideas for different potential scenarios for further consideration and investigation. One of these configuration classes (by which is meant that some parameters are left 'free' without being assigned a specific definite value so as to describe a range of related configurations) was as follows: intel-

ligent, artefactual, incidental, Type III, with the nature of the entity left open. This may be characterized more colloquially as a galaxy-scale artefact created by, or perhaps galaxy-scale artificial activities undertaken by, some form of intelligent entity going about its own business; in other words, galaxy-scale macro-engineering.

In what follows, I would like to consider two possibilities for how galactic-scale changes brought about by macro-engineering activities might manifest in terms of structures we might be able to detect over intergalactic distances. The timeframe for this scale of engineering is probably rather long, and might run to many tens of millions, or perhaps even hundreds of millions of years. Dick (2003) has called thinking on these immense timescales 'Stapledonian' and suggests that such a long-term thinking is a necessity when considering the question of intelligence in the universe. In the spirit of Dyson's rules, however, we are only concerned here with artefacts or artificial activities that we could actually detect over intergalactic distances and not with what might be considered an 'average' level of macro-engineering for a 'typical' engineering species. That is, we are concerned only with the biggest, most astonishingly vast engineering projects of which we can possibly conceive – so, we will be thinking along the lines of what Ćirković (2006) has characterized as 'macro-engineering in the galactic context'.

Multi-system Exponentiating Dysonian Astroengineering

Firstly, let us imagine a long-lived Dyson/Type II species branching out from its initial home system, which would likely have been somewhere in the Galactic Habitable Zone (GHZ) (see, *e.g.*, Prantzos 2008) where they most likely first arose as a biological species – although by this stage they may well have moved to a 'post-biological' form (Dick 2003, 2009). Over numerous iterations, new stellar systems are reached by a vanguard group sent from an existing 'Dyson-ified' system and subsequently engineered into new Type II systems, from which new groups are sent out, and so on. This is clearly a geometrically exponentiating process so that, over time, there will end up being a *very* large number of Type II/Dyson civilizations, spreading out in a roughly spherical bubble from the home system. This is similar to the scenario of Fermi voids or bubbles that Carrigan (2012) has imagined. However, we can push this idea a bit further by considering what an initially-spiral galaxy might look like some way further along the exponentiating process. Owing to slight differences in the orbital speed of star systems around the galactic centre due to differences in radial distance from the centre, this expanding bubble is not likely to remain completely spherical, and may end up getting

progressively 'smeared out' by differential rotation at the different radii (an admittedly fairly small effect). Over Stapledonian time-frames, however, comparable to several galactic rotations (say ~10^9 years), this process, which might otherwise have led to a (so to speak) Fermi 'arc' around the centre of the galaxy, could very likely end up filling out into a fully-blown 'gap' that completely separates the galactic core from the rest of the outer stellar disk, through the still-continuing process of diffusion from existing engineered systems into new un-engineered ones.

The radii of this 'gap' in the galactic disk would likely be determined, respectively, by the intensity of the radiative flux from the galactic core or bulge, for the inner, and by the availability of metal-rich stars which contain planetary and other materials suitable for disassembly and re-use for engineering purposes, for the outer. The resulting gap may end up encompassing much of what might have been considered the GHZ of the galaxy, at least to the outer radius in the galactic disk. It is also possible that the inner radius might extend even further inward towards the centre of the galaxy, if the species 'goes post-biological' and no longer has to worry about the effects of what would otherwise be lethal environmental conditions for a biological species. In this case, 'post-biological' is a general term which may be inferred to include machine-based intelligence, or an intelligence based on a technological/artefactual substrate. In SETI, this situation is sometimes referred to colloquially as the question of these intelligences either *having* machines or *being* machines, and the question itself is sometimes regarded as mere hair-splitting.

Galactic-Structural Macro-engineering and Stellar-System Removal

In the second possibility, we imagine a long-lived, most-likely a post-biological species inhabiting a spiral galaxy that either does away altogether with its earlier exponentiating Dysonian astroengineering program in favour of, or perhaps moves directly to, the even grander project of seeking to re-engineer the spiral-galactic structure as a whole. If this species transitions to a post-biological form while still planet-bound, or relatively early into a nascent exponentiating astroengineering phase, then this latter trajectory may perhaps be more probable.

Analogously with Dyson's original astroengineering proposal to harvest stellar energy, although on a much larger scale, this species decides that it wants to directly access and capture all of the luminous energetic flux emanating from the entire galactic core or bulge. Unfortunately, there is usually a considerable amount of intervening material in a typical spiral galaxy which occludes some of this radiant energy from regions further out in the galactic disk by the absorption of some wave-

lengths – this is why we ourselves do not see the centre of the Milky Way from Earth in visible light. A post-biological species would likely not have need of planets as habitat, and would most probably be able to exist in interstellar space, absorbing the radiant energy directly in a way analogous to our current solar panels, although undoubtedly much more efficiently. Such a species would not be constrained by biological timelines, and – if our own considerations about the implications of the Singularity on Earth are anything to go by (Eden *et al.* 2012; Kurzweil 2006; Smart 2003; Tucker 2006; Vinge 1993) – would effectively become immortal, subject only to accidental destruction, or a conscious decision to power-down.

An effectively-immortal species which wants to gain access to as much of the galactic centre's radiant energy as possible without it being degraded due to absorption and re-emission would likely consider clearing out the intervening material between itself and the galactic core/bulge. This would be macro-engineering on a truly galactic scale. One can imagine a number of possible scenarios for how this might proceed. The asymptotic end-state of these activities on Stapledonian timescales would likely be: a central core of stars, surrounded by a 'gap' in which there are relatively much fewer or perhaps even no stars or other natural material – and which contained uncounted octillions of post-biological entities orbiting the galactic core absorbing the unimpeded radiant flux as they go about their unfathomably post-biological business – with a ring of stars further out remaining from the initial structure of the spiral galaxy. The removal of intervening materials might include combinations of 'lifting' stars entirely for later re-use of their materials (Criswell 1985), or perhaps simply moving entire star systems further out into the stellar ring region, by means of some form of propulsion such as Shkadov thrusters or related 'stellar engines' (Badescu and Cathcart 2000, 2006a, 2006b). Or, it might perhaps be through a combination of lifting stars into Jovian planet – or brown dwarf-sized non-fusioning agglomerations for more convenient storage and then moving these with gravitationally-bound 'solar sails' utilizing the radiation pressure from the galactic centre. In this case, as well, one ends up with a core of stars surrounded by a quasi-toroidal region devoid of stars, ultimately out to a more distant ring of stars, whose inner radius is determined due to the radiant flux from the core being too weak for the post-biological species to utilize, whether directly or for propulsion. This argument is in direct contrast to the 'migration hypothesis' of Ćirković and Bradbury (2006) who have argued for a mass migration of

post-biological species to the *outer* regions of a galaxy, for computing-thermodynamic reasons.

Galactic Structure Arising from these Macro-engineering Projects

In both of these cases, the galaxy eventually ends up having a core + 'gap' + ring morphology, reminiscent of the planet Saturn, where the apparently empty 'gap' might merely be comparatively darker due to the presence of a vast number of Dyson spheres, or may actually have been emptied due to the original material having been cleared away – through star lifting, star system re-positioning or similar forms of removal – to make for more open 'living' space for the post-biological entities. We will consider further below some possible empirical observations that could be made of any such candidate galaxy. But for now, of course, the question arises: are there any examples of galaxies that have this morphology? And the answer is: yes, there are.

Hoag's Object – a Lovely Ringed Galaxy

The nature and structural characteristics of the beautiful ringed galaxy known as Hoag's Object, which has the formal designation PGC54559, have long been the subject of debate and speculation (Brosch 1987; Gribbin 1974; Lucas 2002). It was discovered by Arthur Hoag in 1950, who reported it in the scientific literature as a 'peculiar object' (Hoag 1950), hence its common name 'Hoag's Object'. It lies about 600 million light-years away in the constellation Serpens and is something like 100–120,000 light-years across, making it roughly comparable to or slightly bigger than the Milky Way (Brosch 1985; O'Connell, Scargle and Sargent 1974; Schweizer *et al.* 1987). Detailed analysis shows that the galactic plane is almost directly face-on to us, deviating from perfect alignment by only about 20 degrees or so (Schweizer *et al.* 1987). The interested reader can see a high-quality Hubble Space Telescope image of Hoag's Object at the Astronomy Picture of the Day web site for August 22, 2010 (Lucas and NASA Hubble Heritage Team 2010). There are several other such 'Hoag-type' galaxies known (O'Connell *et al.* 1974; Wakamatsu 1990), including the one that is, coincidentally, visible through the gap feature in Hoag's Object itself (Lucas and NASA Hubble Heritage Team 2010).

Hoag initially thought it might be a possible example of gravitational lensing, the ring being an optical effect caused by the bending of light from a more-distant galaxy by an intervening elliptical galaxy located by chance directly in line-of-sight between us and the more distant one. Later spectroscopic work showed this not to be the case (O'Connell *et al.* 1974), and as both the core and the ring appear to have

the same redshift, they are almost certainly co-located (Schweizer *et al.* 1987). A variety of other hypotheses have also been proposed for the origin of this lovely galaxy. They include: a 'bulls-eye' type collision between two passing galaxies – however there does not appear to be any sign of the putative 'bullet' galaxy in the vicinity (Schweizer *et al.* 1987); a dynamical instability in what was previously a barred-spiral galaxy, which case can be recovered from adjusting the parameters modelling the galactic dynamics in certain ways (Brosch 1985; Freeman., Howard, and Byrd 2010); an accretion event, wherein the object we see is a late stage in the coalescing process of two colliding galaxies merging into one system (Schweizer *et al.* 1987); and, more recently, that the structure we see can be modelled by a particular type of pressure wave in a self-gravitating gas (Pronko 2006). The last three of these appear to remain viable hypotheses.

However, given our use here of Dysonian thinking over Stapledonian timeframes, and the sometimes finely-tuned adjustments in the parameters that appear to be necessary to recover the structure of Hoag's Object via models of natural processes, what if we instead ask the question that is now almost begging to be asked: Is Hoag's Object actually an example of galaxy-scale macro-engineering? Or, put more simply:

Is Hoag's Object an Artefact?

Having asked this question, of course, the next step is to consider how we might go about answering it. This requires thinking about potential empirical observations that could be undertaken in order to look for 'signatures' that would indicate artificial activities rather than be explicable as due solely to natural processes.

There appear to be at least four empirical observations that could be made with respect to the question of the artificiality or otherwise of Hoag's Object. They range from rather less direct to considerably more direct, and are as follows:

1. *The distances from the centre of the galaxy of the major structural discontinuities* – the outer core/inner gap, and outer gap/inner ring radii – *with regard to what these distances might be expected to be from theoretical considerations arising from different scenarios leading to the core/gap/ring morphology.* If stars or stars systems *are* being moved outward by radiation pressure, for example, then there will be a certain radial distance at which the inward gravitational attraction, set by the core mass, and the outward radiation pressure, set by the core luminosity, are in balance. This would form the boundary of the core and gap. Similarly, the outer gap radius could also

be limited by the intensity of radiation pressure for moving material outwards. However, the outer radius of the gap might not be so strongly constrained if the stars are being moved using Shkadov thrusters. If the 'empty gap' appearance is caused by Dyson spheres rather than lack of material, there may perhaps be a different implied radius for the core/gap boundary. Comparisons of different theoretical values, obtained from imagining different scenarios, with the empirical values obtained from direct observation might reveal some interesting correspondences. This may well require more accurate observational data than currently appear to exist.

2. *The spectral profile of the 'gap'*. The difference between a 'gap' consisting of, say, almost empty space containing octillions of post-biological entities as compared to a volume of space filled with billions of Dyson Spheres should, in principle, be discernible, but in reality might be very difficult to determine conclusively. If there are Dyson spheres of the type considered by Dyson himself, these will emit blackbody radiation consistent with a temperature of ~300 K. However, if the engineering is very advanced – and we almost must assume it to be – then the efficiencies possible by use of a structure similar to, say, a 'Matrioshka Brain' (Bradbury 2001b) could produce waste heat with a blackbody radiation profile close to the temperature of the cosmic background radiation of space itself, ~3 K. Similar considerations for thermodynamic efficiency would probably also drive the construction of the substrate for the post-biological entities. This could make it very difficult to distinguish such structures from background empty space. In this instance, possible occlusion or diminution of radiation intensity from beyond the galaxy due to intervening absorptive material might be one way to probe the nature of the 'gap'.

3. *The metallicity profile and chemical composition of the ring*, with respect to anything 'unusual' compared to what is expected of the 'typical' composition of the interstellar medium (ISM) in a galaxy in which the normal processes of stellar evolution are occurring. A species that is converting gap-region star systems into Dyson spheres and not moving materials further outward would not therefore alter the composition of the ring region to any appreciable degree beyond what would be expected from the normal processes of enrichment over time of the ISM in a spiral galaxy. However, if the species *is* moving gap-region materials further outward, then this probably *would* alter the chemical composition and metallicity profile of the ring region and such an 'anomalous' composition might be detectable via spectroscopic observation. The ring structure in Hoag's Object also shows what Schweizer and co-workers (1987) characterized as an 'osculating braid', a smaller brighter ring within the main

ring, touching the inner and outer edges of the main ring at different places; it is clearly visible in the Hubble image mentioned above. The precise nature of this 'braid' is of some interest. It has the appearance of what are in other galaxies considered to be regions of relatively new star formation, although, if so, how so much star formation has managed to be so apparently spatially synchronized raises an intriguing speculation. Is the braid simply a pressure-shock effect caused by multiple and perhaps cascading supernovae events, or could it be due to the deliberate synchronized 'seeding' of new star systems? And to what end? It is possible to imagine that an effectively-immortal post-biological species which is already moving material into the outer ring region might decide as part of this project to undertake a further program of seeding the creation of new stars with the materials so displaced in order to create the potential for the emergence of new biological species. In other words, to perhaps 'cultivate' the sort of conditions conducive for the arising of new biological species (in a region of the galaxy for which they themselves have no direct use) perhaps for subsequent longitudinal observation and study. Or it might simply be to produce an aesthetic effect that changes relative position within the ring over very long timescales, possibly even as a signal to other galaxies. The prospect of effective immortality might require commensurately long-term projects to keep one occupied over the aeons.

4. *The existence of a time-keeping signal beacon* at or near the galactic core. If there are large-scale engineering activities going on which could be up to many tens of thousands of light-years apart and which may require some type of co-ordination, then it would be useful to have a time signal that would act as the standard clock by which these activities could be synchronized – a kind of Galactic Mean Time, as it were (Shostak 1999). A logical place for such a beacon would be at the galactic core, or perhaps immediately nearby, slightly above the plane of the galaxy, as the exact centre may not be feasible due to a black hole or other sources of possible interference with what would need to be a reliable signal. It is most unlikely that such a beacon would be broadcast isotropically – that would be a distinctly inefficient use of energy. An immortal species that is re-engineering a galaxy over Stapledonian timescales is quite likely to be somewhat careful in its use of energy, perhaps even frugal, as it would probably be thinking very much of the long term – and it would certainly have the luxury of time enough to use the most frugally efficient means possible. As such, the signal would most likely be directed mostly along the galactic plane (Shostak 2011: 363) to the regions where it would be needed. Given that Hoag's Object is almost directly face-on to us, this makes the detection of any potential beacon signal of this kind some-

what difficult, although one might hope for some re-emission scattering echoes being deflected in our direction. However, if there were other activities being undertaken further out in the galactic halo, the signal might then be broadcast somewhat more widely, so we might possibly get lucky. Needless to say, a very sensitive receiver would be required for carrying out such an observing program.

Concluding Remarks

This paper has been an attempt to apply 'Dysonian' thinking to the question of what galaxy-scale macro-engineering might look like when undertaken over 'Stapledonian' cosmological timeframes by intelligent species that are long-lived enough to do so, and which have very probably transitioned to an effectively-immortal 'post-biological' form (Bradbury *et al.* 2011; Ćirković 2006; Dick 2003).

By generalizing Dyson's original idea of an engineering species interested in harnessing ever more amounts of radiant energy from a single solar system to an entire galaxy, we arrived at the intriguing notion of a purposely re-engineered galaxy eventually having a core + 'gap' + ring morphology, somewhat reminiscent of the planet Saturn. When we look to the sky, we find that there are indeed several examples of such galaxies, the most well-known 'type specimen' of which is Hoag's Object, PGC54559. The unusual structure of this beautiful galaxy has long been remarked upon, and the attempt to resolve the question of its origin has seen a variety of hypotheses advanced based on the assumption of natural processes. Here a different question was posed concerning its origin – namely, whether it might actually be the result of artificial activities. Thus we asked: Is Hoag's Object an example of galaxy-scale macro-engineering? Several theoretical considerations were discussed and four specific empirical observations were suggested that could be carried out in order to begin to investigate this wonderfully beguiling research question.

Mounting a search for evidence of galaxy-scale macro-engineering, and the thinking required to seriously contemplate the possible forms such projects might take in order to be able to do so, could be one way to help us think much longer-term – something humankind would seem to be in desperate need of right now. If nothing else, simply entertaining the idea that someone somewhere in the Universe might have been able to successfully navigate the dangerous time Carl Sagan called 'technological adolescence' can give us some hope in our own ability to do the same at this critical point in the history of our species. Better yet, finding a definite example of such a success could be the very stimulus we need

that prompts us to begin to take our future seriously enough to guide it consciously, responsibly and foresightfully. A search for evidence of this kind would be relatively inexpensive to conduct. But it just might end up being an immeasurably valuable – perhaps even absolutely priceless – piece of information to possess. It could not hurt to have a careful look...

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III. TEACHING BIG HISTORY

15
Big History and Elementary Education

Michael Duffy and D'Neil Duffy

Abstract

Big History can be viewed as a comprehensive origin story of everything in the universe. It is perhaps the most important piece of scientific literacy that every well-educated person should know, at least in its general outlines. For this to happen, society cannot wait for the university level to begin teaching the story. Happily, there is already such a curriculum at the elementary grade level that has existed within the Montessori education community for most of the last century under the rubric of 'Cosmic Education'. Through a series of lessons that roughly track the thresholds of David Christian, Montessori elementary teachers provide their students with basic impressionistic concepts and a supply of materials for them to explore each chapter of the story.

Keywords: *Montessori, Cosmic Education, elementary education.*

The teaching of Big History should begin in elementary schools – and Montessori education provides a model for this to happen. The all-inclusive theory that science has developed, particularly over the past half century, attempts to explain everything from the Big Bang to modern human societies. By the time students finish their undergraduate degree, they should have a general knowledge of this theory to provide the context for any field of study they have chosen to pursue.

For this to happen, society cannot wait for the university level to begin teaching the story. The university structure is so geared toward specialization that this kind of general theory can easily be bypassed in favor of major-driven curriculum requirements that leave little time for such Renaissance outcomes. Hopefully, that is beginning to change. 'There is a growing sense, across many scholarly disciplines, that we need to move beyond the fragmented account of reality that has dominated scholarship (and served it well) for a century', notes David Christian, one of the founders of the Big History movement (Christian 2004: 3).

But even before the university level, some familiarity with the full scope of the story should be part of every high school curriculum. And,

even before that, it should be incorporated into the elementary and middle school curricula. Each level should build upon the previous one so that the story of the universe is visited in ascending cycles that lead students to an ever deeper appreciation of the full scope of the story.

Happily, there is already such a curriculum at the elementary level that has existed within the Montessori education community for most of the last century under the rubric of Cosmic Education. While elementary schools do not have to become Montessori schools to implement the major portions of this curriculum, much can be learned from the Montessori experience about how to translate the overall Big History message into terms that can be understood by children between the ages of 6 and 12. The pedagogy to deliver the content of Big History to younger students is a contribution that Montessori educators can make to the movement to make this all-inclusive story more familiar to all educated people.

Maria Montessori, the Italian physician who founded the Montessori method of education in the beginning of the 20th century, concluded from her work in the field of education that everything needs to be understood in the largest possible context.

> Let us give the child a vision of the whole universe… If the idea of the universe be presented to the child in the right way, it will do more for him than just arouse his interest, for it will create in him admiration and wonder… The knowledge he then acquires is then organized and systematic; his intelligence becomes whole and complete because of the vision of the whole that has been presented to him... No matter what we touch, an atom, or a cell, we cannot explain it without knowledge of the wide universe (Montessori 1973: 8–9).

As a result of this vision, so similar to the basic tenets of Big History, Montessori's pedagogy for the elementary aged child is based on putting everything in the context of the universe and gradually working inward toward the child and his immediate world. Every subject is studied as part of an integrated, step-by-step exploration of the unfolding of the universe, of the solar system, of our Earth, of life on this planet, and finally of the human race.

In *Children of the Universe* (Duffy M. and Duffy D. 2002), we depict this as a series of concentric circles representing the successive chapters of the story, with each chapter representing a story within the previous story and all of them contained within the story of the universe itself.

Thus, the story of the stars and the solar system (Chemistry and Physics) is part of the story of the universe (Astronomy and Cosmology), the story of the Earth (Geology and Geography) is part of the story

of the stars and solar system, the story of life (Biology) is part of the story of Earth, and the story of early humans (Archeology) and written history (History) is just part of the story of life on this planet.

Fig. 1

This is exactly parallel to the approach taken by Christian in his lecture course on Big History.

Big History surveys the past at all possible scales, from conventional history, to the much larger scales of biology and geology, to the universal scales of cosmology. It weaves a single story, stretching from the origins of the Universe to the present day and beyond, using accounts of the past developed within scholarly disciplines that usually are studied quite separately.

Human history is seen as part of the history of our Earth and biosphere, and the Earth's history, in turn, is seen as part of the history of the Universe. In this way, the different disciplines that make up this large story can be used to illuminate each other. The unified account of the past assembled in this way can help us understand our own place within the Universe (Christian 2006).

In his book, Christian explains that the creation stories involved in this approach to history 'offer answers to universal questions at many different scales, which is why they sometimes appear to have a nested structure similar to a Russian *matryoshka* doll – or to the Ptolemaic vision of the universe, with its many concentric shells' (Christian 2004: 6).

This is the vision embodied in the cover illustration of our book, *Children of the Universe*, following the original insight of Maria Montessori about the unified nature of the story of Cosmic Education. Christian's questions – 'Who am I? Where do I belong? What is the totality of which I am a part?' (Christian 2004: 1) – are very similar to the questions we express as the basic search of Cosmic Education – 'Who am I? Where do I come from? Why am I here?' (Duffy M. and Duffy D. 2002: 4–5)

Montessori and those who embraced her method developed an entire curriculum and collection of teaching materials to make the unified account of the past accessible to elementary-aged children. Spread throughout the curriculum are a series of timelines that highlight various chapters of the story, physical representations of each period that can be studied and manipulated by the students in many cases to construct their own versions of the timelines.

1. The Universe Story and the Story of the Stars

The story begins with the emergence of the universe itself in the Big Bang and the formation of the first stars and galaxies. The parts of the Montessori curriculum devoted to this chapter are the equivalent of the first three thresholds in Christian's course – Creation of the Universe, Creation of the Stars, and Creation of Chemical Elements in Dying Stars. The Montessori curriculum covers this for elementary-aged children in a simplified version with materials that help make the story accessible.

The elementary-level story told in the Montessori tradition is the youngest elementary child's introduction (in the equivalent of Grades 1–3) to the study of chemistry and physics. The story is followed by a collection of experiments (called 'Nature of the Elements') that the children can carry out on their own, with a series of trays containing the required materials and command cards to direct their work. For example, there is a tray with three glasses where students are directed to leave one with nothing in it but air, fill another with water, and a third with ice to demonstrate and experience the three states of matter. There are also simple experiments to distinguish the concepts of mixture, suspension and solution; saturation and super-saturation; and the effect of gravity on substances that have different densities (METTC 2013b: 80–83).

Some schools, seeking a more scientifically modern version of the story of the early universe for young children, use resources like Jennifer Morgan's *Born with a Bang* to tell this chapter. Her book, the first in a trilogy that tracks major elements in Montessori's Cosmic Education curriculum, is a beautifully illustrated and solidly scientific story about the early universe found in many Montessori classrooms (Morgan 2002). James Lu Dunbar's 'Universe Verse' comic book trilogy, starting with *Bang!* Is an-

other child-friendly resource that tells the comprehensive story of Big History – and Cosmic Education – in a form that is pedagogically accessible and engaging for elementary-aged students (Dunbar 2009).

At the upper elementary level (equivalent to Grades 4–6), some Montessori schools have developed a 'Timeline of the Early Universe' to explain how atomic matter came to be from the Big Bang through the successive Quark Era, Hadron Era, Lepton Era, and Radiation Era.[1] This is told in story form that first introduces the students to the main characters of the story – atoms, protons, neutrons, electrons, and quarks; then it traces the drama of the unfolding story as energy turns into particles of matter, quarks bind into protons and neutrons, protons and anti-protons nearly annihilate each other, electrons and anti-electrons go through a similar near annihilation, photons dominate for a time after these epic struggles, then the atoms we know emerge with electrons orbiting a nucleus of protons and neutrons.

Many other Montessori schools who have students at this level study the 'Life Cycle of the Stars', from small stars to medium to giant stars that end up as supernovae, so they can understand how stellar nucleosynthesis produces the elements of the periodic table above the early Big Bang elements of hydrogen and helium (using marbles and other models to illustrate nucleosynthesis). This is their introduction to 'Evolutionary Chemistry' – and the discovery for the students that we are all literally made of stardust (CMTE/NY 2012a: 9–12 Evolutionary Chemistry Resources).

This first chapter in the story – encompassing three of Christian's thresholds – is the least developed in the traditional Montessori curriculum, partly because much of the science behind it was not widely known by the time of Montessori's death and partly because it is more removed from the experience of children.

Montessori teachers could take advantage of resources developed by authors within the Big History community to flesh out their own understanding of the science behind the story, in this and the following chapters, particularly since the approach of those who teach Big History is rooted in telling a comprehensive story about the universe. Storytelling is the preferred technique for delivering information in a Montessori environment, and the accounts of those who teach Big History – science in the form of story – provide ready-made material for that approach for teachers whose preparation does not necessarily include a heavy background in science.

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[1] See Duffy 2011. Also *The Timeline of Light* which is an artistic depiction of part of the story of the Universe, created in scroll form by John Fowler.

2. The Story of the Solar System and Earth

The next chapter in the Montessori curriculum corresponds to the fourth threshold in Christian's course, Creation of Planets and Earth. For the lower elementary level (Grades 1–3), there is a series of manipulative-based lessons called 'Sun and Earth'. Young children are taught about night and day with the rotation of a globe around itself as it faces a light bulb, about the year by the revolution of the globe around the light, and the 'reason for the seasons' by the effect of the tilt of the Earth in relation to the sun as it makes its yearly dance (METTC 2013b: 103–128). In this series, the students learn about the equinoxes, the solstices, and the origin of the imaginary lines of the Equator, the Tropics of Cancer and Capricorn, and the Arctic and Antarctic Circles.

With a series of studies called 'Composition of the Earth', these younger students are taught about the formation of the early planet by the forces of gravity acting on particles left over from the Sun's formation following a supernova explosion of our Mother Star. They learn about the layers of the Earth – crust, mantle, and core – using clay models and other didactic tools. And they learn why the Earth is still alive with earthquakes and volcanoes (METTC 2013b: 129–148). Jennifer Morgan's *Born with a Bang* and *From Lava to Life* (Morgan 2002, 2003), while not specifically part of the official Montessori curriculum, flesh out these parts of the story beautifully and are widely used in Montessori classrooms.

The upper elementary grades, and even the lower elementary grades at times, expand on these subjects with studies called 'The Work of Air' and 'The Work of Water'. Both involve a series of lessons and activities on the part of the students with collections of materials to demonstrate major concepts about how the Earth is shaped and changed by air and water. The Work of Air begins with a number of simple experiments to explain the origin of the movement of air in our atmosphere and how wind patterns are formed (METTC 2013b: 149–153). The Work of Water consists in an examination of the impact of water on the planet as it creates rivers and causes erosion on its way to the sea in the water cycle (*Ibid*.: 172–190). Upper elementary students often expand on the lower elementary geography studies with a more advanced examination of tectonic plates, Pangaea to today's continents, formation of the Earth's major mountain ranges, the geology of rocks and minerals and similar studies.

As with the first chapter of the story, Montessori offers pedagogical tools to tell this part of the story to young children – and Montessori teachers can enhance their own scientific background by reading the works of Big History proponents.

3. The Story of Life

This chapter in the Montessori curriculum corresponds to the fifth threshold in Christian's course, the Creation of Life on Earth. As a physician before she became an educator, Montessori was particularly interested in Biology, and the traditional Montessori curriculum contains many lessons and materials to teach elementary children the story of the evolution of life on this planet.

The simplest of these for the emerging readers of first grade are a collection of classified cards called the 'External Parts of Animals'. They consist in a series of line drawings of a sample animal from each of the five familiar types of vertebrates, with each part highlighted in red. Each picture is accompanied by a label that names the part and a brief paragraph describing its function. There is a collection of these cards for the fish, the frog, the turtle, the bird, and the horse to introduce the very youngest of elementary children to the evolutionary order of familiar classes of vertebrates (METTC 2013a: 12–20). There is a similar series of cards to introduce children to the 'External Parts of Plants,' including seaweed, moss, fern, conifer, and flowering plant, again in evolutionary order (*Ibid*.: 21–27).

For the more advanced readers in the middle of lower elementary, there are the 'First Knowledge of Animals and Plants' cards, broadening the selection of plants and animals and introducing some of their primary characteristics with accompanying 'Who Am I?' cards that make a game out of guessing the right match from a carefully crafted description (children can check their work on their own with a control booklet once they have done their best to match the cards themselves) (METTC 2013a: 28–45). These young children are introduced to the rudiments of research with a series of 'Question and Answer' cards to apply to the First Knowledge cards – asking such questions as 'What does the animal eat?' with possible answers of 'plants', 'animals', or 'plants and animals' or 'Where does the animal live?' – water, land or air.

Another material, the 'Clock of Eons,' is in the form of a clock, with successive sections after the starting point of 12 o'clock indicating the passage of the Hadeon, Archean, Proterozoic, and Phanerozoic eons (METTC 2013c: 37–46). This traces the evolution of the Earth itself and introduces the children to a formal study of the evolution of life on this planet, a study that is continued with the 'Timeline of Life'. This timeline, generally introduced to third grade students, is a series of poster-sized panels that move them through the Paleozoic, Mesozoic and Cenozoic eras of the Phanerozoic Eon. These charts depict a representative sampling of animals and plants from the various eras and periods, and a mute chart with loose pieces allows the students to learn from hands-

on manipulation where each organism fits in the overall scheme of living creatures (METTC 2013c: 47–58).

Finally, the oldest children in lower elementary are introduced to 'First Classification' studies. This consists in a series of poster-sized charts to introduce them to the five-kingdom classification system and from which they can learn the principal characteristics of the different phyla, classes, and down to the level of orders for the most prevalent kinds of plants and animals. This at once reinforces the information from the Timeline of Life and gives characteristics that help explain the evolution and emergence of various groups of animals and plants without getting into a discussion of the mechanisms of evolution that would be beyond the developmental level of these young students (METTC 2013a: 62–85).

At the upper elementary level, the students begin (at the equivalent of 4th grade) with a study of the 'Vital Functions of Animals'. This consists in a series of materials to track the growing complexity of organisms in the animal kingdom along the evolutionary trajectory from single cell animals to mammals in relation to the functions of nutrition, respiration, circulation, support and movement, sensation, and reproduction (CMTE/NY 2012a: 7–21). This series of matching activities and accompanying descriptions provide a fairly dramatic lesson on the place of complexity in the forward movement of evolution as outlined by Christian in his course. It highlights the emergent characteristics at each higher level of complexity.

Students in the middle of upper elementary class do a more 'Advanced Classification' study, moving all the way down to the level of genus and species for some organisms and learning to distinguish for themselves the ways to separate one group of organisms from another with a nesting box system of materials. After doing this work with animals, many of the students are equipped to create their own classification nesting boxes for plants with a little guidance from their independent research (CMTE/NY 2012a: 62–71).

Finally, the oldest students at this level (equivalent to grade 6) study 'Human Biology,' surveying the anatomy and physiology of the systems of the human body dedicated to digestion, respiration, and circulation, the muscular-skeletal, immune and central and peripheral nervous system, and reproduction. Coming in the context of previous studies, this places the study of humans in the context of other developing life forms (*Ibid*.: 72–87).

Given the richness of this part of the Montessori curriculum, there are numerous pedagogical tools that are available to make the Big History chapter on the emergence of life and biological evolution comprehensible to younger students.

4. The Story of Humans

This chapter in the Montessori story of Cosmic Education contains the remaining three thresholds of Christian's Big History course, with special attention to the first of the three, Creation of our Species. Lower elementary students in Montessori classrooms are first introduced to a study of the way humans track time, using materials to learn about the clock and the calendar, about our BC/AD timeline, and about how to count centuries. (METTC 2013c: 13–27).

A fascinating lesson in the midst of this study is the one called the 'Long Black Line,' where the teacher unrolls a 30-meter length of black yarn while she tells a summary version of the story of the planet Earth and its life forms, alerting students to watch for the change in color to red signifying the arrival of humans on the planet – which finally reveals itself in the last centimeter of the roll (METTC 2013c: 30). Maria Montessori is said to have developed this lesson to put in perspective the boasts of the antiquity of their civilization by her student-teachers in India.

Yet another dramatically impressionistic lesson consists in stretching out the tiny strip of red (indicating the presence of humans) at the very end of the Timeline of Life into a long red strip of cloth indicating the full scope of human history. A human hand clutches a handaxe about halfway through to signify that we are toolmakers. Children are asked to look for a change in color once again to indicate another significant development. At the very end of the lengthy strip of red cloth is a thin gold strip indicating the relatively brief time since humans have used the tool of writing (CMTE/NY 2012b: 21–23).

Students are first exposed to what we traditionally call world history through a series of studies called 'Fundamental Human Needs'. This begins with the identification of elements that we tend to consider essential for human survival, such as food, shelter, clothing, defense, transportation, and more spiritual needs such as art and religion (METTC 2013c: 31–36). Students use picture and card materials placed on a timeline to do a 'vertical' study that traces particular needs back in time (the deeper we dig archeologically, the older artifacts we find); then they compile all the information from the same time period – or horizontal level of the dig – to do a profile of a particular culture. The main point of the whole study is that all groups of human beings, in every place and time, have the same fundamental needs and simply meet them in different ways because of the time and place they live – human unity in diversity, a major theme of Cosmic Education.

At the upper elementary level, beginning in the equivalent of 4th grade, students formally explore the 'Timeline of Humans', beginning with a cladagram-aided search for our closest living relatives and then our

closest fossil relatives. In the process, they learn that we are at once alike and different from other animals. Through a series of materials, students learn about Australopithecus, Homo habilis, Homo erectus, Homo sapiens neanderthalensis, and Homo sapiens sapiens, focusing on their growing similarity to us and the characteristics that distinguish them from each other. (CMTE/NY 2012b: 13–40) As they move into the study of the 'Timeline of Modern Humans', they learn about the impact of the transition from a hunter-gatherer, nomadic, tribal society to the agriculture-based beginnings of settled village life. This is when humans moved out of the Paleolithic into the Neolithic, or new stone age period (CMTE/NY 2012b: 54–75).

Next, students at this level study 'Ancient Civilizations' of every continent. These lessons focus more on the way each group of people met their fundamental needs and went about their daily living than on the rulers, monuments and events like wars that helped define each people (*Ibid.*: 76–89). This sometimes leads into studies of the Middle Ages and the Renaissance in Western culture.

Finally, they study their own nation within the context of the preceding chapters of the story. For those in the United States, for example, the study of US History is preceded by a lengthy preface on Early Americans from the time humans first settled the continent. The study of American History itself is in the context of all that has gone before, making it just an example of ways in which a particular group of people once met and continue to meet their fundamental human needs (CMTE/NY 2012b: 90–121). The same would be true for students anywhere in the world studying their own nation.

Some General Remarks

This survey of the Montessori curriculum contains many parts that are similar to what is taught in traditional schools (*e.g.*, Ancient Civilizations and U.S. History). However, there are other parts of the curriculum that are not usually taught to elementary-aged children (*e.g.*, The Life Cycle of the Stars and the Timeline of Early Humans). It is not unusual for Montessori elementary students to know as much about early humans, at least in broad outlines, as students in university level paleoanthropology courses. At a lecture of Donald Johanson at a local university in Georgia, Montessori elementary students interested in his account of the discovery of 'Lucy' were the only audience participants to raise their hands when Johanson asked if anyone knew the scientific classification of humans (and one 11-year-old Johanson called on recited the full classification flawlessly). Many of these non-traditional lessons for elementary children are needed to flesh out the comprehensive story of Big

History on its most basic level – and they are an integral part of Maria Montessori's concept of Cosmic Education. Even those parts of the curriculum that are similar to a traditional curriculum are taught in a different way:

• Lessons are given with materials, and students are expected to work independently with the materials to internalize the main ideas and to expand on them as their interest dictates. There are no textbooks or lengthy lectures in Montessori classrooms. Students are expected to be active explorers who discover information on their own once they have been introduced to an area of study.

• The Montessori curriculum moves from the big picture of the universe itself inward to the immediate surroundings of the child, rather than the traditional approach of beginning with the child and moving outward to family, classroom, neighborhood, city, country, and world. This means that everything is taught in a larger context for better understanding.

• The materials include a series of inter-connected timelines, starting with the Clock of Eons (the history of our planet), the Timeline of Life (the history of the evolution of life), the Timeline of Humans (the history of the emergence of humans), the Timeline of Modern Humans (the history of human development into the Neolithic period), and the Timeline of Civilizations (the recorded history of ancient people in every continent). Each timeline is an expansion of the final portion of the previous timeline. The pedagogical approach of using sequential, interconnected timelines could be put to good use at the middle or high school level as well to highlight the major events in the unfolding of Big History.

• There are large collections of 'classified card' materials, consisting of a picture, label, and definition, in the subjects of History, Biology, Geography and the Physical Sciences. These materials – in addition to being a tool for developing the reading skills of young students – offer a summary of the minimum amount of nomenclature and basic information students need to learn in each subject area, give students a means to learn independently of the teacher, and provide a stimulus to exploring a subject in further detail according to one's interest.

An elementary school does not have to become a Montessori school to teach elements of Big History. But the experience of Montessori schools with the Cosmic Education curriculum can provide any school with age-appropriate tools and strategies to teach the fundamentals of Big History and leave them better prepared for a deeper study at the high school and university levels.

Montessori teachers certainly have a lot to learn from the Big History movement, particularly in relation to the scientific discoveries of

the more than half century since Maria Montessori's death. Tools that could be particularly helpful are the Big History Project and Chronozoom; while developed with high school students in mind, they can be a rich resource for Montessori elementary teachers and their students. However, the Big History movement can also learn a lot from the more than century-old experience of Montessori pedagogy related to teaching elementary aged children the story of the universe and our place within it. Big History and Cosmic Education share the vision that we humans are truly 'Children of the Universe'.

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16
Big History and the Secondary Classroom: A Twenty-First Century Approach to Interdisciplinarity?

Tracy Sullivan

Abstract

Big History poses big questions addressing big issues like 'How did we get here? Where are we going?' and it encourages exploration of deep philosophical questions about the meaning of life and the nature of the cosmos. Answering these questions pushes teachers and students to move beyond the confines of traditional disciplinary boundaries to examine the interconnections between knowledge, ideas, and phenomena. Does this make Big History interdisciplinary? Does Big History move beyond the interconnection of disciplinary knowledge to transcend these boundaries? Harnessing the experiences of Australian secondary Big History teachers, this paper explores the practical nature and definition(s) of the twenty-first century curriculum, learners, and interdisciplinarity in the secondary context. Through the lens of a pedagogical vehicle to equip future generations with the skills they need to live responsibly and effectively in an interconnected global community.

Keywords: *interdisciplinarity, curriculum, pedagogy, secondary.*

> There are two ways to live your life. One is as though nothing is a miracle. The other is as though everything is a miracle.
>
> *Albert Einstein*

As both a high school teacher and a life-long learner, prior to engaging with Big History I did not much think about the Universe, my surroundings, or my place in them. I took my connection to our Universe for granted, as I am sure is the case for many people and students. As I learned more about Big History, I became increasingly aware of this vast expanse we inhabit, seeing wondrous things about me everywhere I looked. The mundane had become amazing and exciting. But beyond what I could see, at the level where I believe the transformative nature of Big History lives, was an approach to knowledge prioritising knowledge connection and exploration as an opportunity for learning and growth.

While Big History courses are growing in number at the tertiary level, the capacity of Big History to empower and engage secondary students is

great and much needed in a system traditionally dominated by disciplinary silos and a fragmented approach to knowledge dissemination.

This paper will explore the role of Big History as a model for interdisciplinary pedagogy at the secondary level, arguing for the powerful role of Big History as a vehicle for teaching students to make connections and understand the interconnected world in which they live. First, it identifies the characteristics that define twenty-first century learning at the secondary level. Second, it examines the 'spectrum' of disciplinarity identifying where current integration attempts in the Australian context fall along this 'spectrum' and identifying what makes Big History different. Third, it will take preliminary reflections from the Australian secondary students currently studying Big History. It may sound trite and definitely cliché to say children are the future, but this is ultimately true and we need to prioritise examination and experimentation with curriculum models and structures that will best equip them to face this future. Big History as a learning opportunity for secondary students most definitely needs to be a part of that conversation.

What do Twenty-First Century Learners and a Twenty-First Century Curriculum Look like?

What is this 'twenty-first century learner' and what do they need and want in a valuable educational experience? 'Twenty-first century learner' is one of those ubiquitous phrases thrown around to describe students sitting in classrooms around the world. They are students for whom we are working hard to provide empowering educational experiences. Anne Shaw (2009: 14) has identified the following framework, defining the key characteristics of these learners:

- they are pragmatic;
- they want to know how what they are learning relates to them and their lives;
- they want to know how will what they learn be of use to them as they navigate their practical day-to-day lives;
- the majority do not appreciate the process of learning for learning's sake;
- they are curious;
- they want to understand things and solve problems;
- they understand that knowledge is limitless and they want to know more, a critical characteristic of life-long learners;
- they are flexible, willing to follow their curiosity and be taken on a journey of discovery regardless of the 'rules' or perceived 'boundaries' of disciplinary knowledge, to make connections enacting their individuality and personal curiosities in the process;

- they are resourceful, understanding there is no one path to a destination, and keen to meet challenges, exploring options and possibilities as they are confronted.

From this arises the question of what characteristics a curriculum needs to embody to meet the needs of these learners and engage them in the learning process. Anne Shaw (2009: 13) has outlined six key characteristics of this type of curriculum (all of which are embedded in Big History through its themes and in its delivery). Primarily it is interdisciplinary (a more detailed discussion of interdisciplinarity will follow), providing enough flexibility for students to follow their curiosity and enact their resourcefulness. Big History aligns to these criteria via the posing of big picture questions requiring the connection of knowledge across disciplines as diverse as physics, chemistry, economics, archaeology, and anthropology. It is project-based, enacted as a pedagogical tool in Big History through the 'Little Big History' project. It is research driven, not only through student-based research as a vehicle for learning but at a curriculum assessment and measurement level. This is an area yet to be full developed in the field of Big History, but one with a huge growth potential as the popularity of Big History courses continues to expand at both the tertiary and secondary levels. It is community-connected: using the themes of increasing complexity and scale Big History helps students to see that community connection is enacted at the local, national, global, and universal levels. A twenty-first century curriculum requires students to engage multiple literacies, they need to be able to read across disciplinary-based literary conventions and make connections. An example in Big History would be reading across star charts, maps, the periodic table, narrative text, and film, to form hypotheses and answer large-scale questions. Finally, this curriculum embraces technology and multi-media as a tool for delivery and student engagement. The Big History Project course is a unique and valuable example of how this can be done effectively for the students' benefit.

Of the outlined six key characteristics of a twenty-first century curriculum it is no coincidence that interdisciplinarity is first and given a primary focus. Without a structure flexible enough to allow for students to read across disciplines and make connections, the requirements that follow cannot operate in a meaningful way. However, like the phrase 'twenty-first century learner' the word 'interdisciplinary' is often used without a clear understanding of what it actually means and how this looks in a curriculum model. This understanding is crucial if any model developed is to be effective.

What is 'Interdisciplinarity' and What does it Look like?

Terms related to the relationship between disciplines are commonly used in education circles, but what is less common is a clear definition

of what these terms mean: multi-disciplinary, interdisciplinary, trans-disciplinary *etc.* (Bahr, Bahr, and Keogh 2005: 3). Is this a question of semantics? Are these terms interchangeable? These terms definitely have their own unique meanings and to have a clear understanding of this is essential when undertaking curriculum development as a tool for enhancing student engagement and improving learning outcomes. Godinho and Shrimpton (2008: 3–12) have put forward the following basic definitions:

- Disciplinary silo: A branch of knowledge or teaching with a distinct set of rules or methods guiding its practise;
- Multi-disciplinarity: Examination of a problem or question through a specific discipline focus, with content from other disciplines added;
- Interdisciplinarity: Integration of knowledge to solve problems or answer questions that cannot be adequately addressed by one discipline alone;
- Transdisciplinarity: Transcending discipline boundaries, juxtaposing disciplinary perspectives, and interrelatedness of disciplines.

These categories may be interpreted as forming a hierarchy (Limerick and Thomas 1990: 3) of levels that one must successfully achieve before 'moving-up' to the next. I would rather view these categories as sitting along a spectrum allowing the flexibility for curriculum models to sit between categorisations (see Fig. 1). I would argue that historically 'traditional' curriculum models at a secondary level have been positioned strongly at the level of the disciplinary silo.

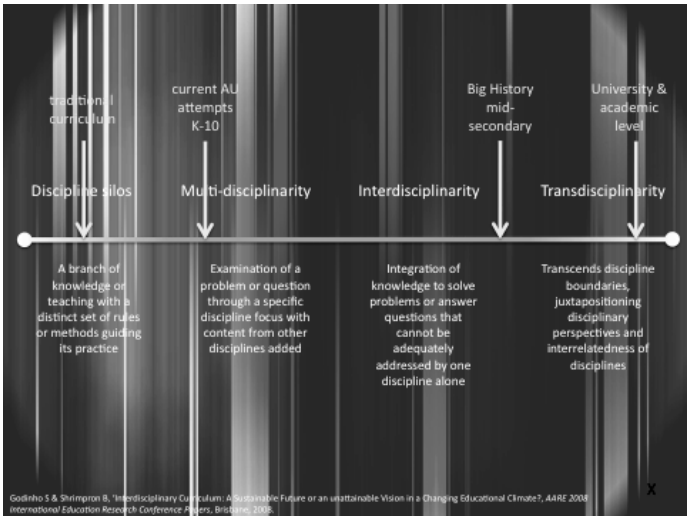

Fig. 1. Categories spectrum

In recent years in the Australian secondary educational landscape there have been large-scale attempts to embrace an interdisciplinary curriculum model, including developing:

- Key Learning Areas (Marsh and Harris 2005: 5): The grouping of disciplines is perceived to be complementary but the realities of school-based delivery are predominantly executed as discrete disciplines, for example Human Sciences and Environment (History, Geography, Commerce, and Legal Studies *etc.* [Board of Studies NSW 2008]); Technology at School (Computing, Industrial Arts, and Child Studies *etc.*); Studies of Sciences and the Environment (Collins 2009: 5) (an integration of History, Geography, and Social Studies *etc.*).
- Cross-Curriculum Priorities and General Capabilities: A key feature of the recent move to a nation-wide Australian Curriculum (Australian Curriculum and Reporting Authority 2011). Worthwhile and intended to be integrated into the delivery of all subjects. However, in light of time constraints and the reality of the day-to-day classroom environment may be viewed as having partially political underpinnings and essentially unrealistic considering prevailing resourcing and time issues.
- 'Interdisciplinary' electives: Offerings such as Environmental Studies, Humanities, and International Studies. These offerings stretch disciplinary boundaries to incorporate other content or sub-divide the broader discipline to incorporate knowledge from across these sub-divisions. These electives often do not necessarily use content and knowledge from other disciplines to answer broader big picture questions in a holistic way.
- Inquiry-based curriculum models (Board of Studies NSW 2003): In Australia, the examples of this type of framing include disciplinary-based questioning such as, in History: 'How did new ideas and technological innovations develop to contribute to the change during the period from 1750 to 1918?' or in Science investigate: 'How did the theory of plate tectonics develop, based on evidence of sea-floor spreading and occurrence of earthquakes and volcanic activity?' These are two very isolated content examples within much broader and complex curriculum documents, but it is the nature not the content of the questions that is the focus of this examination. This type of framing does go beyond detailing simple content lists of information that students must 'know', and it does require the integration of disciplinary skills to address the inquiry. However, they fall short of posing a broader problem (Williams 1996: 2) through which to direct the inquiry or investigation and pull together or integrate the varied disciplinary knowledge. There is no big picture question to umbrella the inquiries in a larger interdisciplinary context.

Thus, I would argue that in Australia the current attempts at producing large-scale interdisciplinary curriculum models move beyond the tra-

ditional disciplinary-silo bound structure to a more multidisciplinary approach, examining questions and problems from a key disciplinary focus by bringing in the content from other disciplines, but do not qualify as being interdisciplinary (see Fig. 1).

So what makes Big History different? I would argue that there are four key characteristics that define Big History as interdisciplinary: scope, balance, relevance, and interrelatedness. The fundamental questions posed by Big History, as a contemporary scientific origin story – where did we come from? How did we get here and where are we going – are broad enough in scope, so it is impossible to answer them using the content or conventions of a single discipline (Christian 2011: 1–4). They are also expansive enough to engage the pragmatism, flexibility, and curiosity of the twenty-first century student. The key themes and the narrative of increasing complexity and thresholds provide a balance whereby the framework is flexible enough for students to follow their curiosities but tight enough for them to enact their resourcefulness without becoming lost. This balance also gives voice to their pragmatism as they constantly face problems and inquiries perceived as relevant to their lives and the world around them not for the process of inquiry itself. The nature of the fundamental questions posed in Big History means that at every stage of the course students are continually being reminded of the relevance of what they are learning to their lives and the world they live in. Big History is not an offering that jumps from discipline to discipline for the sake of trying to make a connection. It demonstrates how within the scope of big picture questions, knowledge is intuitively interrelated and these connections appear naturally, not as a kind of forced symmetry. These factors move Big History along the disciplinary spectrum past being multidisciplinary to interdisciplinary, 'integrating knowledge to answer questions or solve problems that cannot be addressed by one discipline alone' (Godinho and Shrimpton 2008: 3–12) (see Fig. 1).

I would, however, argue that at a secondary level Big History does not present as trans-disciplinary. This is not because of the inherent structure or content of Big History but because of the learning and conceptual capabilities of secondary students, especially at a pre-senior secondary school level. In terms of a spiralled approach to developing understanding (Bruner 1967: 29) a student needs to be aware of disciplinary boundaries before they can transcend them, thus this is a pedagogically-based distinction. At tertiary level and beyond, the argument for Big History being defined as trans-disciplinary is valid and the one that, while not being in the context of this discussion, could be made (see Fig. 1).

The 'Big History Quilt': A Powerful Example of Interconnection

This is a photograph of the 'Big History quilt' (Fig. 2) and an excerpt from the accompanying blog (Fig. 3). It is appropriate and necessary to discuss student learning, approaches to curriculum frameworks, and pedagogies from theoretical and large-scale perspectives. However, the most meaningful enactment of all this discussion and decision-making plays out in the experience of an individual student. This is one such example.

Fig. 2. Big History quilt

Source: Diniyoyo 2012a.

Fig. 3. Big History Quilt blog

Source: Diniyoyo 2012b.

This woman, an avid quilt maker recovering from a stroke, listened to Professor David Christian's Teaching Company lectures (Christian 2008) while recuperating. She was inspired to create this quilt based on the eight thresholds of increasing complexity. Introducing her children to the field of Big History she enrolled them in the process of designing and creating this magnificent quilt. She also recruited them in creating a blog to accompany the quilt-making process cataloguing its creation and their journey of Big History discovery.

I would like to focus on the children's experience. Here is an example of the power of Big History as a framework to develop meaningful learning experiences for students, meeting their needs and the characteristics of a twenty-first century curriculum. Through this endeavour these children/students have engaged with the Big History narrative and themes to think critically about which images and patches are most appropriate to represent the eight thresholds of increasing complexity. They have developed an in-depth and meaningful understanding of the concept of increasing complexity including goldilocks conditions and emergent properties in the process of selection and creation of the patches. They have engaged in using multiple literacies, not only in creating and designing the quilt (calculating dimensions, sourcing information for varied texts and the quilting process itself), but have produced a narrative for a specific audience and purpose, harnessing digital technologies and multi-media in the form of a blog.

But at a completely different level, beyond the creation of the quilt itself, the connective power of Big History is demonstrated. A family in the United States created a quilt and blogged about it; based on a field of study pioneered by a British-Australian academic, located by an Australian teacher surfing the internet for presentation images, ultimately used as an example of implied Big History pedagogy presented to a group of Big History experts and enthusiasts from around the globe at a meeting in Grand Rapids Michigan. That level of interconnection in itself is quite remarkable not to mention the powerful back-story of the process of collective learning that over millennia has made these processes possible.

Australian Big History Student Preliminary Reflections

Throughout 2012, as part of the Big History Project pilot schools program, two Australian schools trialled a secondary course in Big History for Year 9 students. Below is a selection of quotes from a group of mixed-ability Big History students. Each demonstrates a different aspect of the power of Big History as an interdisciplinary and pedagogically

empowering tool for developing critical thinking in high school students.

> *I do enjoy Big History a lot. It lets me know what I am part of in the universe. But I feel there isn't enough* ***evidence*** *to be completely dependable. But I really love this course; it's amazing to learn about what's out there…* Katarina

By identifying that 'there is not enough evidence to be completely dependable' Katrina is actually making a judgement about the information that has been placed in front of her and has been empowered and given the flexibility to challenge the information presented.

> *I love Big History because it gives answers and asks great questions, for us to optimise with. It isn't like here's this, deal with it. It gives us a choice and* ***we can ask questions*** *for those choices…* Lachlan

Lachlan is demonstrating the power of Big History to empower him as having the ability and encouragement to ask questions rather than feeling his role is as a receptacle to store static information and content.

> *I love Big History as it teaches everything I want to know and tries to answer the questions I'm seeking. I find it so extremely interesting and it's the only subject I see a* ***purpose*** *in…*Dana

Dana is making a clear distinction between the enactments of Big History as interdisciplinary and combining her knowledge, in comparison to disciplinary-based subjects that do not necessarily speak to her pragmatism as a twenty-first century learner.

> *I enjoy Big History as it gives me a better understanding of the* ***world around us****…*Caitlin

> *Big History teaches and supports my view on history that not everyone understands. Every subject in Big History has interested me most of my life. Finally getting the answers to the questions I have kept bottled up makes me feel much better and confirms that* ***I am part of something much bigger****…*Kayla

Both Caitlin and Kayla are reflecting the sense of connection and belonging that comes with being able to place themselves in the bigger picture.

> *I enjoy Big History because it gives me a sense of understanding. It brings together different opinions; beliefs and values, which together help me, understand that things change. The main thing that I enjoy about Big History is that it changes as new evidence is discovered changing what we understand…* Elisha

However, this quote from Elisha really encapsulates the power of Big History in developing students understanding through developing a meaningful relationship to how knowledge is built and constructed.

This paper began with a well-known quotation from Albert Einstein 'There are two ways to live your life. One is as though nothing is a miracle. The other is as though everything is a miracle'. To truly appreciate the 'miracles' that surround us in everyday life we must first be able to see them, but how? Like all things we need to be taught. Throughout the inaugural International Big History Association conference the words 'awe' and 'wonder' emanated in some form or another from lecture halls, classrooms, and over lunch and dinner conversations for days. These are not words that are often associated with student experiences of traditional curriculum models. But they can be. I believe the power of Big History lays in its ability to transform the way we see the universe, our place in it and our connection to all that surrounds us. I also believe in the transformative (Pugh *et al*. 2009: 3) power of Big History for a generation of school students in offering a pedagogical tool to meet their needs as learners. To teach them to appreciate and understand the interconnection of knowledge and empower them to ask important questions that cannot be answered by looking to one discipline alone. To teaching them how to make connections across the boundaries of perceived discipline-based knowledge to find meaningful answers to questions relevant to their experience of the world around them. It is through providing opportunities for learning of this type and scale that we can teach students of all types and ages, including myself, to live and view life as if everything is a 'miracle'. That is a truly empowered learner.

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17
Constructing a Survey Big History Course

Cynthia Stokes Brown

Abstract

This article provides an overview of the decisions to be made in constructing a survey Big History course, whether done individually as a sole instructor or collaboratively with a group of interdisciplinary instructors. Topics covered include choosing a title, choosing a textbook, clarifying student learning outcomes, sequencing the topics, and choosing activities and assignments. The faculty's experience at Dominican University of California is used as an example of collaboration.

Keywords: *survey Big History course; collaboration.*

Those of us who founded the International Big History Association have a dream: that of transforming the content of education worldwide by engaging students in learning Big History. For students, this story provides a framework for all their studies, a transformative understanding of history, and a means for grasping the immense challenge of our time – how to achieve sustainability. For faculty, knowing this story unites all disciplines and enables knowledge and ideas to flow freely within universities.

For faculty to begin to teach Big History, they must eventually come to the concrete task of constructing a syllabus for such a course. In this paper I want to discuss how this might be done. First, I will describe the process from the point of view of a sole faculty member attempting to teach Big History, followed by how the process looks if it is done in collaboration with a group of faculties from several disciplines.

As a Sole Instructor

A single person within any department or discipline who wants to teach Big History must decide first whether to teach it with or without explicit permission from higher authorities. This involves whether to start a new course with a new title or to use an existing course and title. It also entails whether to construct the course in one or two semesters. If one has explicit permission from some department or interdisciplinary program, then one can use the title 'Introduction to Big History'. If one does not have explicit permission and is in the history department, an easy route is simply to use the title 'World History' and add the cosmos, solar system, and evolution of life while condensing human history. Those in

science departments often use some variation of 'Epic of Evolution' or 'Cosmic Evolution' for a title. Here are further examples of titles that have been used by Big History professors: 'Global Past, Global Present: From the Big Bang to Globalization', 'Big History from the Big Bang to the Blackberry', 'Zoom: A History of Everything', 'Introduction to World Civilizations', and 'Whole Earth History'.

A second step entails choosing a textbook or constructing a reader, if one chooses that route. Until the summer of 2013, choosing a textbook proved difficult; there was none formatted specifically as a college textbook. In August 2013, McGraw-Hill published the first one, written by David Christian, Craig Benjamin and myself, entitled *Big History: Between Nothing and Everything* (Christian *et al.* 2014). This book is laid out with an introduction and thirteen chapters to be covered in one semester or in two, if one wishes to expand each chapter by adding supplementary speakers and materials. Other likely books to use as texts or supplements are: Christian (2004, 2011), Brown (2007, 2013), Spier (2010), or Chaisson (2006).

The usual next step in developing a syllabus would be deciding what the objectives, or student learning outcomes (SLOs), should be. This crucial step is sometimes postponed to the end of syllabus design, but tackling it near the beginning gives clarity and saves revisions. The sequence of topics and assignments must flow from being clear about what students are expected to do in order to demonstrate their learning from the course.

Big History instructors commonly use SLOs such as these formulated by Kevin Fernlund at the University of Missouri, St. Louis (personal communication):

1. Comprehension of the major developments in the history of the universe, and how we think about and imagine the universe, from the Big Bang to the present. Assessment: quizzes and final exam.

2. An understanding of Big History themes addressed in the course through defining, explaining, and/or analyzing them. Assessment: field exercises, reader's responses, and two logically and coherently organized essays written in university-level Standard English and crafted through a process of drafting, revising, and editing.

3. The ability to locate and evaluate appropriate secondary sources, and extract and synthesize research; additionally, students must demonstrate appropriate summarizing, paraphrasing, and quoting in accordance with standard documentation styles, for example, *The Chicago Manual of Style* or Turabian Assessment: The documentation of the two papers.

After the SLO's have been clearly stated, the sequence of topics can be laid out over the calendar of one or two semesters. Here one has

many choices – to follow closely the textbook, to modify its pace somewhat to add one's own interests, or to devise one's own sequence of topics and assign the text as it fits the topics.

In a survey of 13.8 billion years, one major question is how much time to allocate to history before the appearance of humans and how much after. Scientists may teach the course with humans appearing rather briefly at the end, as befits the actual proportion of our time here. On the other hand, world historians who focus on human history may briefly add a few weeks of astronomy, chemistry, geology, and biology to the beginning of their world history course.

In the new textbook, we have chosen to emphasize human history, with a substantial portion on the cosmos, Earth, and life history. Our textbook uses the first three chapters to describe evolution up through the common ancestor of chimpanzees and humans. Chapter 4 covers the development of *Homo sapiens* and the Paleolithic era, followed by eight more chapters on human history and a final one on the future of humans, Earth and universe. In sum, three chapters out of twelve, or one-fourth of the total, are devoted to science, with three-fourths to human history (Christian *et al.* 2014).

At the same time, our textbook uses a device called 'thresholds' for organizing the vast scales of history. We see an overall pattern of increasing complexity so far, with new properties emerging at certain periods of time that we call 'thresholds'. We view the whole of history through eight main thresholds, namely: 1) the Big Bang; 2) birth of stars; 3) death of stars; 4) emergence of solar systems; 5) emergence of life; 6) emergence of modern humans; 7) emergence of agriculture; and 8) modern industrialization. These thresholds make sense of the story and give students and instructors a handle on which to grasp. Of the eight thresholds, only the last three pertain to human history. This helps students put human history into something closer to the proper perspective, even as our textbook devotes multiple chapters to describing human activities.

After sequencing the topics, the beginning Big History instructor may decide to invite guest lecturers in areas beyond his/her own reach. Even experienced instructors choose to do this if time and resources allow, for it enlivens the course and expands everyone's knowledge.

After sequencing topics, an instructor is also faced with decisions about what kind of assessment and assignments to make. These may include assigned readings, reader's responses, quizzes, mid-term and final exams, short and long papers, power point presentations, or other productions. For a final, written paper many Big History instructors have found effective an assignment called a 'Little Big History'.

This idea for this assignment originated with Esther Quaedackers in 2006–2007, as she was teaching Big History with Fred Spier at the Uni-

versity of Amsterdam. Spier came up with the name for it. In the assignment each student is asked to choose an everyday object that is special and meaningful to them and to trace its development back to the Big Bang (or from the Big Bang to the present). If using the textbook, *Big History: Between Nothing and Everything,* this would entail taking the chosen object through each of the eight thresholds.

Students have amazed their instructors with the range of objects they choose to write about. One high school student wrote an insightful paper about the Little Big History of Cheez-its. Students at Dominican publish their best papers in an on-line journal, 'Thresholds', which contains student essays on green tea, body art, cars, yoghurt, flip flops, iPhones, and South Korea. By offering students a choice of a topic specific and dear to them, instructors can help their students personalize and make concrete the otherwise enormous abstractions of Big History.

In designing any syllabus, one must make at least preliminary decisions about how to present the material. Will the instructor lecture with power point presentations most of the time? Will students be expected to read the text and discuss it in class? Will students present material? Lead discussions? Engage in other activities? These are the usual decisions; they vary depending on size of class, level of students, instructors' preferred modes, *etc*.

Before concluding a syllabus in Big History, one may want to consider how to deal with the conflict between religious faith and scientific information that will arise for a varying proportion of students. In many classes a wide range of student belief systems will exist, for example, in regard to the central idea of evolution, from little or no knowledge of it and little or no acceptance, on the one hand, to much familiarity and full acceptance on the other.

One can choose one of two strategies, or something in between. One can say that there is so much content to cover in class that students can discuss the religious and ethical issues outside of class and in other campus venues. Or one can allocate some, or much, time for class discussion of these issues and can find ways to engage students in leading these discussions.

However one allocates class time for these discussions, one can explain that students need to understand the Big History story as one possible origin story. It is the one that their culture is currently based on; it provides the framework for their university studies; and it provides the trans-disciplinary skills needed by employers – three good reasons for knowing it. This course is designed to help them know and understand the modern scientific origin story, but only they can decide whether they want to believe it. One can assure them that one is not attempting to change their religious beliefs, only to help them think about the big

questions in a more informed, nuanced way. They can reject the reality of evolution, or they can accept it and add religious beliefs to the story, as they wish. The scientific origin story will change as the quest for knowledge continues.

It may be appropriate to remind students that reflecting on the big questions of human existence is what a liberal education is about. Being exposed to new ideas that conflict with old ones is supposed to happen during the university years. These questions cannot be resolved during one or two courses; they provide a lifetime of reflection and participation in the on-going human conversation about what is real and what is really important. In a Big History class students can practice conversing with people with whom they disagree – a skill not easy to learn but a necessary one if a democratic society is to succeed.

As an Instructor Collaborating with Others

To describe how multiple instructors can collaborate in designing a Big History survey course, I must rely on my experience at Dominican University of California, since 2010 the first university in the world to require all its freshmen to take two semesters of Big History. Since Dominican has about 275 incoming students each fall and small classes of about 20 students, it needed to have 12–18 professors from multiple disciplines prepared to teach these courses.[1]

In a nutshell, this happened at Dominican when the faculty decided to revamp the two courses of its Freshman Year Experience. Leading faculty members were familiar, through the university's Catholic heritage, with the call of the Catholic priest and university professor, Thomas Berry, for the story of the universe as the proper foundation of the college curriculum (Berry 1999).

Led by Mojgan Behmand, an English professor, the faculty in January of 2010 voted to implement two semesters of Big History as the common intellectual experience for all freshmen. In order to begin these courses in the fall, the administration funded a summer institute of seven days, in which the faculty could prepare itself for the challenge of teaching such material (Behmand 2012–2013).

Even before the institute, leaders made two key decisions: first, the survey course would be one semester and in the second semester students would choose a discipline of interest to them to examine through the lens of Big History. This would provide a review of Big History tied more closely to students' own interests. Second, faculty would teach the first semester's survey course from a common syllabus that they would design collaboratively at the first summer institute and would revise annually at following institutes.

[1] See the Big History website at Dominican University of California. URL: http://www.dominican. edu/academics/bighistory.

Almost 30 people attended the first summer institute in 2010, including several librarians, one biologist and faculty from history, art history, English, religion and philosophy, women's and cultural studies. The major content of Big History was presented and discussed, along with a draft syllabus, which the participants re-worked until they could all agree to use it, with minor individual tweakings to reflect each instructor's interests and knowledge.

For the first year of instruction the Dominican faculty chose to use both Christian (2004) and Brown (2007), since neither seemed quite right – the former too advanced for many of their students and the latter too slight for a semester's work. By 2011, the faculty could use a Preliminary Edition of *Big History: Between Nothing and Everything* as a text more appropriate for its students and, as an added benefit, as a way to provide invaluable feedback to its authors for the final revisions of the first edition.

The Dominican faculty felt that it had to include some skill components, such as writing and library use, in the Big History survey course along with all the content. It revised and clarified the chosen SLO's at every summer institute; here is the 2012 version:

Students will:

1. Employ major Big History concepts and the eight Big History thresholds from the Big Bang to the present in developing a perspective that emphasizes a view of themselves as embedded in the fabric of an interconnected world. Assessment: Little Big History paper written in university-level Standard English and crafted through a process of drafting, revising, and editing.

2. Demonstrate an understanding of Big History themes addressed in the course through identifying, defining, explaining, and/or analyzing them. Assessment: a mid-term and a final exam.

3. Demonstrate the ability to locate and evaluate appropriate secondary sources, and extract and synthesize research; while summarizing, paraphrasing, and quoting in accordance to the MLA, APA, or CMS documentation styles. Assessment: two library exercises and Little Big History paper.

When laying out topics on the semester's calendar, the Dominican faculty decided to devote almost half the time to science topics – six of thirteen weeks. They condensed the time spent on covering the agrarian civilizations by sampling only some of them. The fourteenth week they devoted to review and the fifteenth to the future, a favorite part of the course for students.

At Dominican, instructors have found that many students need to engage in concrete activities in order to assimilate the abstract ideas. Since instructors have shared at summer institutes the activities they

have devised, the course now features several key common activities, such as mixing the ingredients of bread to illustrate the idea of emergent properties, circling around outside in a grassy area to re-enact the accretion of planets around the Sun, and examining plastic mini-skulls of hominines and *Homo sapiens*. Outside of class students enjoy a night of stargazing organized by the San Francisco Amateur Astronomers; this proves to be a significant experience for many who have little or no experience looking at stars.

Faculty collaboration continues to be at the heart of Dominican's program, both for learning the content of Big History and for sharing pedagogical ideas and activities. The fourth summer institute took place in June 2013; lunch meetings are held weekly in the fall semester and biweekly in the spring. A day's retreat usually occurs at each semester's end. The faculty has found this collaboration to be the most engaging and helpful professional experience of their careers.

Outcomes

What do we really hope our students will take away from their Big History courses? We put down as learning outcomes something along the traditional lines that we can document – that students will be able to pass exams on a body of knowledge and that they will exhibit writing and analytical skills in a research paper.

Yet based on our teaching experience we have come to expect much more than this. We expect that their Big History course will be a transformative experience for many students, meaning that they will come out of it perceiving their everyday world, both natural and cultural, in new ways and will be able to act in new ways. Long-term assessment studies to document this transformative experience are underway at Dominican and Macquarie, but the short-term surveys and anecdotal evidence for this are already overwhelming.

Students are not the only ones affected by Big History. Instructors find that its large-scale insights change the way they teach other courses. For example, when history professor Martin Anderson taught his course, '20th Century Global History', he de-emphasized the political history and emphasized the environmental history. Many instructors feel they could hardly have taught their Big History courses without the built-in collaboration, which has made these courses for many the most enjoyable teaching experience of their career.

Even the institution itself has not remained immune to the effects of Big History. The librarians have had to learn about a new category of books and visuals. Students have begun to ask new questions in their other classes. Advisors must explain what Big History is. The staff wants to understand Big History. Dominican's president views Big History as the intellectual frontier of the twenty-first century and uses it to

help define the institution's identity. At the very least, the idea that science and the humanities can be combined into one story has become familiar across the campus.

The dream of a worldwide revolution in educational content comes true one course at a time. Although universities are bound by traditions and firmly divided by divisions and disciplines, there are always individuals in any department who by nature think holistically across the whole range of human knowledge. These individuals are gradually becoming more able to introduce large-scale, interdisciplinary courses into the curriculum as challenges from the world outside of academia demand them. Big History is the ultimate interdisciplinary course – the core of a liberal arts education in one course, featuring humans as a unified group. What could be more appropriate for today's global world?

I must conclude by saying that both scientists and historians increasingly realize that humans have only a very short time – possibly five years – to reduce drastically the CO_2 we are pumping into the atmosphere and the pollutants we are discarding into the environment, or our civilization is toast. Only a Big History survey can help us and our young people understand how we got into this dilemma and can energize us all into action.

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18
Cosmology, Mythology, and the Timeline of Light

John Fowler

Abstract

This article summarizes the pedagogy and resultant insights of children formed when studying an original, integral, and stunningly artistic approach to cosmology, "The Timeline of Light". Through subsequent analysis, relationships gleaned by fifth and sixth grade students from the lessons are seen through Joseph Campbell's four functions of myth-the mystical, the cosmological, the sociological, and the pedagogical. These insights were formed by sixth grade learners over an eighteen year period at the Denison Montessori School in Denver, Colorado, a public magnet school program. Beginning with an explanation of those four functions, this paper moves to an exploration of original and traditional Montessori educational materials, student work and connections with cosmological, Platonic, Jungian, and Big History themes. As such, the paper suggests both an exemplar and initial framework for an integration of those functions as logical, experiential, and pedagogical emergents from upper elementary and middle school aged students while also providing heuristic value for all other developmental levels.

Keywords: *elementary education, Montessori, pedagogy.*

During the opening moments of the widely popular Public Broadcast series, *The Power of Myth*, journalist Bill Moyers made the following observation of a shift in meaning made by master mythologist Joseph Campbell: 'You changed the meaning of myth from the *search* for meaning to the *experience* of meaning' (Campbell and Moyers 1988: 5, author's italics). Certainly this shift is essential for adults, but perhaps even more so for elementary and middle school aged students. It is equally essential as a context and goal of my work with children and cosmology via the Timeline of Light activities. Children should *experience* meaning.

This paper derives its authority and authenticity from the experiences of 11 and 12 year old children in my upper elementary classes at the Denison Montessori School, a 460 student public magnet program in Denver, Colorado. In short, the children like those experiences and their subsequent insights. It also assumes Brian Swimme's definition of cosmology (Swimme 1996: 31) as both primary and meaningful: 'Cosmology,

though it is consonant with science, is not science. Cosmology is a wisdom tradition drawing upon not just science but religion and art and philosophy. Its principal aim is not the gathering of facts and theories but the transformation of the human'.

Originally designed to fill a relative void in the Montessori approach – the history of the universe and planet prior to the Cambrian period – the approach has been presented locally and nationally at Montessori, holistic education and environmental conferences and workshops.

The work was initially inspired by Brian Swimme and Thomas Berry's (Swimme and Berry 1992) *The Universe Story: From the Primordial Flaring Forth to the Ecozoic Era: A Celebration of the Unfolding of the Cosmos,* a remarkably integral history of our universe and our planet. Not only was the information new when I read it in 1993, but so was the perspective. Both authors insisted on a unique grammatical and ontological perspective: the reader, the author, indeed all of us, are the universe acting. This switch from the typical subject-object relationship was a shift of considerable proportions, a shift made both implicitly and explicitly throughout *The Universe Story*. For a Montessori director, *The Universe Story* clearly was a compelling addition to what Montessori called the idea of the universe (Montessori 1948), a notion that has a distinctly cosmological, trans-disciplinary and integral core. Since Montessori's death in 1952, there have been numerous scientific accretions to cosmological understanding. *The Universe Story* summarized and, more importantly, contextualized many of them. Furthermore, it addressed one of life's pressing questions, a question of which Montessori was well aware, 'What am I?' (Montessori 1948: 10), a concern very similar to the heart of Big History, 'Who am I?' (Christian 2004: 1) and the central concern of Montessori's enterprise as seen by Montessori educators and authors, Michael and D'Neil Duffy (Duffy M. and Duffy D. 2002: 4), with all seeing the question in both variations as central to a life well lived. However, rather than answering the question through a singular mode or perspective, Montessori envisioned an integration of the sciences and humanities as part of a grand cosmic story or plan (Montessori 1948). For Montessori, the perspectives gained from an interdisciplinary approach provided the context for all disciplines and explorations. Not so oddly, her pedagogy is in harmony both with Joseph Campbell's approach to the functions of myth and David Christian's vision of Big History as a 'modern creation myth' (Christian 2004: 6).

Campbell saw myth addressing four human functions (Campbell 1986: 31): the mystical, the cosmological, the sociological, and the pedagogical. Myth therefore functions in all aspects of human experience.

The first, the mystical, opens the participant to enter into a realization of what a wonder the universe is, 'Myth opens the world to the dimension of mystery' (*Ibid.*). Campbell's second function, the cosmological, embraces and magnifies the domain of the empirical sciences, 'showing you what the shape of the universe is, but showing it in a way that the mystery comes through again' (*Ibid.*). The third, or sociological, function validates a certain social order; and the fourth, the pedagogical function, is that which instructs, 'how to live a human lifetime under any circumstances' (*Ibid.*). The mythic and cosmological functions are primary, said Campbell, for they are central to establishing a sense of awe and wonder of opening 'mind and heart' (Campbell 1988: 18) and as presenting nature as an 'epiphany' (*Ibid.*). The Timeline of Light activities are intended to arouse the sense of wonder and awe inherent in the mystical and cosmological functions that Montessori and Campbell so highly valued, while simultaneously addressing the sociological and pedagogical functions.

Montessori took the direction of education one big step into the cosmological dimension when she established the story of the universe as central to her now world-famous approach to elementary education. Writing in 1948, she claimed (Montessori 1948: 9), 'If the idea of the universe be presented to the child in the right way, it will do more for him than just arouse his interest, for it will create in him admiration and wonder, a feeling loftier than any interest and more satisfying. The child's mind will no longer wander but can become fixed and do work'.

The following affords a brief sketch of how Campbell's four functions are welded into the Timeline of Light approach in a Montessori classroom and thus suggests an exemplar for the mythic functions as a truly integral pedagogical approach to the versions of experience that Montessori, Swimme, Campbell and Christian champion. Consequently, it affords an initial framework for Big History at the elementary and middle school levels while providing heuristic value for all of life's other developmental stages.

Context

Before beginning, let us look at the broader context and content of the activities. The initial approach utilized 18 lessons, presenting cosmological principles through an integration of art, story, drama, mathematics, geometry, experimentation, brainstorming, poetry, and song. Thus it follows the cosmological visions of both Montessori and Swimme. While the following presentation highlights some of the earlier and therefore more foundational lessons, it does not and cannot detail the entire framework of activities and images.

The timeline itself is a striking visual presentation of the universe story as seen through my imagination and drawn by artistic friend Tim Hogan. The actual classroom timeline is a 9 feet long, 20 inches wide material and quite striking in color.

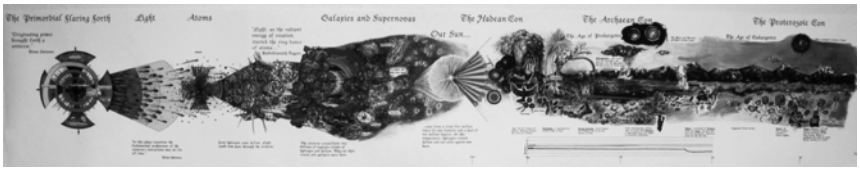

Fig. 1. The Timeline of Light

Regardless, children do not traditionally see this interpretation until, guided by their own activity and experience, their personal story and images have begun to form, usually 11 weeks after the introductory presentation. Prior to that time the children hear stories and respond artistically, complete mathematical and geometric tasks, sing songs and have lessons introducing primary cosmological concepts: the relative size of a hydrogen atom, supernovas, stellar size, and distances between the Milky Way and our nearest neighboring galaxy. All of these concepts are then integrated in the visual presentation of the timeline. The timeline is therefore a visual presentation of a creation myth showing and suggesting all of Campbell's four mythic aspects with which the children have become familiar. Thus, the timeline's imagery and content provides a series of points of departure for various lessons, explorations and researches into geometry, chemistry, astronomy, biology, and other intellectual disciplines.

The Mythic Functions

Jungian Anthony Stevens (Stevens 1993: 63) affords a remarkably clear and concise definition of origin myths 'as an account of human origins that accords with the knowledge prevailing at the time of the myth's emergence into consciousness', a definition compatible with Campbell's definition of mythic functions, Christian's Big History, Swimme and Berry's definition of cosmology and Montessori's vision of cosmic education. Far from myth as a preliminary to science, this definition assumes current science as integral to mythology. Christian provides an important complement to Steven's definition with a simple and important reminder (Christian 2004: 11), 'In their day all creation myths offered workable maps of reality, and that is why they were believed. They made sense of what people knew'. All of the foregoing thinkers are

united in their desire to have children and adults know that we are now able to make numerous new connections. Contemporary cosmology, therefore, provides content for an emergent more internally cohesive and participatory map of reality.

The Mystical Function

Why is there something rather than nothing? Its corollary then leaps out: How, exactly, did that happen? That is *the* mystery of creation mythologies. Imagine your eleven year old self, sitting with a small group invited – in the grand tradition of 'once upon a time' common to children throughout spoken history – to explore the mystery.

> It is impossible to imagine nothing at all and impossible to imagine a time before time. The great mystery of creation, the time when time began, has called throughout the ages wherever great thought occurred. This mystery is ever with us, ever challenging us to look more deeply into life's well of experience in hopes that we, like some likely prospector, find the gold we speak (Fowler 2000: 49).

Through this type of invitation and subsequent introduction children are called to the great questions and their possible solution *as if they matter*. Montessori saw the import of this open-ended approach to discovery and wrote (Montessori 1948: 7), 'No matter what we touch, an atom, or a cell, we cannot explain it without knowledge of the wide universe. What better answer can be given to these questers of knowledge?' In a world trivialized by the media and diversions too numerous to count, children at Denison have leapt to an opportunity for deeper contemplation, as if to say, 'Wow! You thought about this stuff, too?' and thereby establish a deeper rapport and communion with their life, their universe, and their teacher. After hearing an integrated mythic/poetic/scientific story of the creation of the universe, children have responded both artistically and verbally.

The children frequently comment that the story and the setting create a feeling of life, of a living universe of which the children are part, and a desire for more. 'I realize how important it is to have life… the music created a feeling of life', said Alondra (Fowler 2000: 60–61) and added that she desired more. 'I felt desperate for more. I don't know what it is that I wanted. I just wanted. I was just desperate'. In that same vein, Monica once offered, 'I feel relaxed, surprised and incomplete. Relaxed from the music and the darkness, surprised how you said it and the fact that I didn't know, and incomplete because you didn't finish the story. Can we do it again?'

These youthful utterances are strongly suggestive of an awareness at least as old as Plato's eros as detailed in the *Symposium*. The distinguished Oxford Platonist, Francis Cornford interpreted eros as 'the single force or fund of energy' (Cornford 1967: 71), whose objects range from the sensual to the good and the divine. Certainly the children's desires suggest Swimme's allurement – the attraction… the birthplace of philosophy… philo-sophia, the love of wisdom; furthermore, 'love begins as allurement... as attraction' (Swimme 1984: 45), Swimme's Thomas says to a star struck youth. If children do not have that love of learning, that desire for more, there is little reason to go on other than obedience and an adherence to the do-good stereotype, a posture which, after 30 years in the classroom, seems a poor substitute for that love offered by Diotima in Plato's *Symposium* and the allurement suggested by Swimme's sagely Thomas.

The last and in many ways the most striking evidence of the mystical function offered here is Julio's, a child of modest background, whose summary of his initial experience has stayed with me for well more than a decade. It is particularly noteworthy that he was not a particularly religious child when he said, 'I felt like I was there when the universe was being born. And I felt like I was born again at that very same time' (Fowler 2000: 62).

The Cosmological Function

Campbell's cosmological function rests iron dense at the timeline's pedagogical core. It is essential that children *experience* 'the shape that the universe is, but [by] showing it in a way that the mystery comes through' (Campbell 1988: 31). For example, let us explore a hydrogen atom. Shortly after telling two stories of the creation of the universe and the formation of galaxies and hence, but briefly, quarks and the first hydrogen and subsequent helium atoms, the children are invited to physically walk through the dimensions of a hydrogen atom on our school's baseball diamond. Here is a description of their *experience*, originally modeled on Packard's description (Packard 1994: 115–117).

The children are led outside with barely a spoken word. A grain of sand is dramatically gathered, examined, and placed on a red bandana on top of the home plate of our baseball diamond with, again, barely a spoken word. We then begin a slow walk away from the grain of sand, maintaining silence or at least quiet while slowly walking an approximate radius and then arc using that grain of sand as center of our invisible closed curve. The group pauses where the actual radius begins some three hundred feet away from the grain of sand, approximately

the length of a football field. As we walk in that silence the children have a chance to experience space. Occasionally I look curiously and longingly back towards that very soon invisible grain of sand.

After we have reached a point some three hundred feet distant from our now invisible center, the children are told, 'That center is the nucleus of a hydrogen atom, the first atom formed in the history of the universe. We are as far away from it as an electron would be (and I pick up the smallest available particle of dirt) in a hydrogen atom is from its nucleus. It orbits at this distance, more or less, in all directions' and I point up down and at all manner of varied angles. 'The question is … how does the electron know where to go?' This always provokes a variety of answers, but they always seem to center on a type of communication between the two tiny, nay invisible, sub-atomic particles. The key point, however, is the great mystery that atoms, which underlie all that we see, feel, touch, taste, smell, and hear, are so full of empty space. This impressionistic introduction helps the children begin to understand the construction of the physical cosmos as both a way that the mystery Campbell described, and the wonder that Montessori predicted, is fueled. A subsequent story/lesson helps them realize that even though atoms themselves have never been seen but their effects have been recognized.

The Timeline of Light approach is also rife with mathematical challenges and concepts. The notion of infinity, so central to cosmology, is introduced geometrically, when the children construct models of infinity within limits, a standard geometric approach within the Montessori Method as indicated in the following charts.

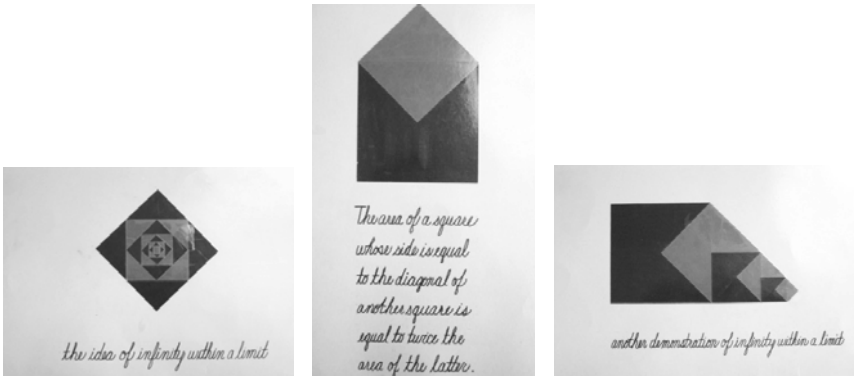

Fig. 2. Art by the author

The first image of infinity within limits is a simple construction, effected by bisecting the side of a square and then connecting the mid-points in successive fashion. Fig. 2, the above middle chart is a construction that involves the bisection of the side of a square and then a line segment equal to the length of the side of the original square used as both diagonals of the resultant next square. The final chart utilizes an extention of the previous principal into a potentially inifinte progression. The experience of constructing these patterns is very engaging and meaningful to the children.

In addition to these geometrical constructions, the approach also uses mathematical problems to determine the approximate age of the universe, the appropriate exponential expression for the time it takes a photon to cross the nucleus of an atom and the range of their teacher's age expressed as a function of the same. Here is a sampling from a challenging set of questions (Fowler 2000: 100–101):

1. The universe is only seconds old, approximately 10^{18} seconds old. How many years old does this make the universe?...

5. Many of you have asked me how old I am. Well, I won't be exact but I am older than 10^{9} seconds. How many years is that?

7. At the other extreme we have the very large. The largest distance we can presently calculate is the radius of the universe. As you can see, the general belief is that the universe is round, like a giant sphere. We take the radius to be 10^{28} centimeters. How many meters is that? Kilometers? Miles?

Discovering the macro and micro principles and aspects of the universe in this way is both challenging and exhilarating and the children love it, even though not all children answer all of the problems correctly. Nevertheless, the search for the fruitful approach is indeed half of the challenge and the children learn greatly through the process.

In addition to a mathematical emphasis, various properties of light are explored, reflection, refraction, the inverse square law for change in surface coverage, and an initial classification of the chemical elements. While story and experiment are used, both are made are contextualized in the universe, and thereby made more relevant and interesting because they are part of a much larger process that strikes the imagination's ability to wonder.

The Sociological and Pedagogical Functions

These two points of consciousness are implicit throughout the course of demonstrations, questions, projects and activities, and derive their strength from both the mystical and cosmological dimensions. As the timeline's imagery and activities address the first 3.6 billion years of

earth's history, the following cosmological and biological points are made clear: 1) the universe comes from *light,* a declaration rich in marvelous scientific, literary, and poetic connotations; 2) vis-à-vis the primordial act of photosynthesis, that light is captured and serves as *primal food*; 3) the bacteria that utilize that food *cooperate* with each other and their environment at a phenomenal rate and degree, sharing their collective memory through DNA transferred from bacterium to bacterium when in close proximity; 4) and, finally, because of that cooperation they evolved, shared, *created complexity*, and eventually transformed their non-nucleated bodies into a nucleated one which allowed for increased growth and communal richness through a diversity greater than possible at the previous bacterial level of organization. This and other examples of cooperation and diversity provide ecological and moral guidelines as these characteristics are presented and seen not merely as human constructs but as patterns necessarily inherent in the evolution of the planet.

So throughout the five or so months of lessons and activities stemming from the timeline, certain sociological and pedagogical implications become ever clearer. If humans follow the path of the universe and the planet of which we are part, it seems wise to cooperate whenever possible, share to the greatest possible degree, and utilize the collective wisdom of the entire cosmological process and learn from the diverse processes which have been essential to the emergence of life on our planet. Accordingly, the societal and the pedagogical merge. The now cosmologically aware child becomes an embodiment of an expanded and better understood idea of the universe, the planet, and its relationships.

A very short story and a child's poem highlight a possible outcome of this process. The story told to the children is entitled 'The Sacrifice of the Sun':

> Each second the Sun gives away four million tons of its helium for light and energy. It has been giving away almost this much for nearly all of its 4.6 billion years life! Our planet uses this radiant energy as the essential stuff of life, the food for photosynthesis. We store it in our bodies and honor it in the glory of each new dawn. This incredible give away of the Sun is at the very center of our life on earth. Without it we would not be here.

Inspired by this brief message, Tara responded with a theme seen frequently, but seldom so poetically, over the years. Let her words conclude the body of this text.

The Giver

Light
Expanding, Radiant,
Rushing, Giving, Receiving.
It burns in all of us,
The Giver.

Concluding Thoughts

Other connections, other thinkers, can easily be drawn into this tale, to support and amplify its messages. Ken Wilber, Jungian archetypes, Einstein, Charles Darwin, great poets *à la* Whitman, come first to mind but surely there are so many more. All of them follow as an easy deduction, for after all, this work is about the creation of everything.

As such, it is, as creation mythologies have always been, both psychologically and scientifically, a starting point, and a door to understanding experience. More importantly, as Tara's poetic insight suggests, there is reason for hope that this timeline will serve the primary integral function of mythology as described by Campbell, 'Indeed the first and most essential service of a mythology is this one, of opening the mind and heart to the utter wonder of all being' (Campbell 1986: 18). That experience has always been a great place to start any exploration or path of discovery. To explicitly or implicitly offer experiences that lead to the union of mind and emotion, is a goal of all true mythologies, all big stories which have shaped cultures and epochs in both conscious and unconscious ways. Then, once both mind and heart are engaged, a new focus can be attained. As Montessori proclaimed, 'intelligence can become whole and complete because of the vision of the whole that has been presented to him, and his interest spreads to all for all are linked and have their place in the universe on which his mind is centered' (Montessori 1948: 9). Hence, a mythology that goes beyond the local folk ideas and into the cosmic idea suggested by a non-sectarian scientific perspective can take both a cultural and psychological center stage. 'The principle can now, however, be developed on a scientific plan and be made far more attractive'… 'modern and complete' (Montessori 1948: 10). Hence, the promise of myth, the pedagogical vision of Montessori, the modern cosmological insight, and the direction of big history now have a model and a common point of light from which to depart.

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19
Big History Beads: A Flexible Pedagogical Method

Jonathon Cleland Host

Abstract

Big History Beads are strings of beads where each bead represents a chronological event in the 13.8 billion year span of our epic journey from the Big Bang to now. Big History beads are a flexible, effective pedagogical tool that supplies a kinesthetic teaching style. Teaching using Big History beads allows many of the more difficult concepts in the field of Big History to be conveyed in ways that are memorable and engaging for students of a wide range of ages. With few subjects as well positioned as Big History is to convey to students the connections between the past, present, and future, a Big History bead set provides an overview of the past that connects students to both the past and future. This paper also supplies information, resources, and descriptions to explore this teaching method, while still leaving substantial room for new innovations.

Keywords: *kinesthetic, active learning, pedagogical tool, Big History Beads.*

1. Introduction

Big History beads are a string of beads in which each bead represents a chronological event in the 13.8 billion year span of Big History, which can be used as a teaching method. As with any class, the amount of learning in a Big History class is strongly affected by the pedagogies used. Because Big History classes face the added challenge of teaching concepts in a wide range of disciplines, as well as difficult concepts like long-term patterns and extremely large spans of time and distance, these issues are even more challenging than they are in classes on many other subjects. Due to the need for effective pedagogical methods in education as a whole, extensive work on how students learn has resulted in many different learning theories (Joyce *et al.* 1997). Of these learning theories, the idea of learning styles has been extensively explored (Hawk and Shah 2007: 1–19).

Many different learning style models are available, so sorting through and understanding all of them can be a daunting task. A detailed review of many of these models, including the most popular systems, has been made (Coffield *et al.* 2004). Though many learning style models exist, a common theme among many of them is the idea that

people learn and teach in different ways, which can be named and classified. Early work focused on the idea that teaching is most effective when the teaching style matches the preferred style of the learner (known as the 'meshing hypothesis'). The meshing hypothesis itself is poorly supported by research (Pashler *et al.* 2008: 105–119; Massa *et al.* 2006: 321–336), and many problems are associated with relying heavily upon the meshing hypothesis, despite its popular and often unquestioned acceptance. Nonetheless, recent studies have shown that incorporating more than one teaching method in the same classroom does help reach those of various learning styles as compared to classes using a single method (Coffield *et al.* 2004). For these reasons, ways of supplying various teaching styles are needed in Big History. Of the many models which have attempted to develop categories of learning/teaching methods, one of the most prevalent learning models in both schools and in business is Fleming's VARK model. Fleming's VARK model gives us the widely known learning/teaching styles of Visual, Auditory, Read/write, and Kinesthetic (Fleming *et al.* 1992: 137–155). Recent models, such as Jackson's Hybrid model, have more empirical support (Jackson *et al.* 2009: 283–312) and also often include kinesthetic and sensory elements in their learning models. Visual, auditory, and read/write teaching styles are commonly incorporated in most classroom teaching environments, especially with the growth of the use of visual media. However, kinesthetic teaching methods are often difficult to incorporate into the average classroom, and Big History classes are no different. Clickers are perhaps the closest many classrooms come to including kinesthetic teaching styles, and by themselves do little to provide actual kinesthetic learning.

The challenges of teaching Big History's difficult concepts have been addressed in a number of ways. Examples of this include the visual and verbal analogies of scaling the time for a commercial jet to fly across well known distances on Earth, then using this same travel rate to compare travel times to different locations in the Solar System, Milky Way Galaxy, *etc.*, in David Christian's Big History class (Christian *et al.* 2005: 55), the visualization of time using Chronozoom by Saekow and Alvarez (Saekow *et al.* 2012), and Carl Sagan's Cosmic Calendar (Sagan 1980). These useful methods supply powerful resources for visual, auditory, and read/write teaching styles. The construction of Big History beads is a kinesthetic method that can complement these other methods with a hands-on approach that is easily accessible in most Big History classrooms. In addition to this benefit when considering learning styles, the flexibility of Big History beads also supplies additional approaches when considering other entire learning theories. In particular, Big History beads may

be well suited to more participatory methods, such as Active Learning in a Constructivist learning theory.

2. Big History Beads

As a pedagogical method, Big History beads are simply a string of beads in which each bead represents a chronological event in the 13.8 billion year span of Big History. From this simple concept, teachers have many flexible options for how they set up Big History Beads in their classroom. Events are usually represented by beads of various shapes and colors, while 'spacer beads' (smaller beads of a uniform size and shape, though often with varied color) are often used between the event beads. These spacer beads can represent other information as detailed below. The basic concept of Big History beads can be adjusted in many ways to fit the situation in which it is being used. For instance, the size (and hence level of detail) of the set of Big History beads can be adjusted to fit the age of the student, ranging from a simple set of 20 or fewer events (beads) to a very detailed set of dozens or hundreds of events (appropriate for college level), as well as being adapted to many different class structures. Big History beads can also be adapted to classes on 'Little Big Histories' – focused on sections of time smaller than the full 13.8 billion years to link a specific subject to larger trends in Big History. These could cover the solar system (~5 billion years), vertebrate life (~ 500 million years), animal tool use from archerfish to computers, or other subjects.

3. Teaching Using Big History Beads

Big History beads are a flexible pedagogical tool that can be adapted to many different class situations. The ability to adjust the overall size and resulting detail of a set of Big History beads allows them to be used in classes of all grade levels, from elementary school age through adult education. This discussion is mostly written with high school to college level instructors in mind. While no formal studies of Big History Bead teaching effectiveness have been done, student and teacher feedback has been positive. In particular, they have been seen to work well in less formal teaching situations, like workshops. It will be interesting to see which aspects are most effective in large classes.

A. Small Group and Individual Instruction

The possible variations help Big History beads adapt to many different classroom settings, including teaching in groups or with individual projects. Group work aids retention by encouraging students to discuss both the events in Big History as well as why or how each chosen bead represents that event, as well as encouraging students to work to-

gether to select beads. Students often report that their discussions and collaborations with other students are a significant part of their learning (Jaques 1991), and the personal element of explaining their reasons for choosing a given bead can help students feel connected and invested in their class group. Further, allowing (or encouraging) students to include beads for themselves and for immediate or important Ancestors can increase their personal attachment to the Big History bead set (in addition to helping see their inclusion in the long term trends of Big History). Either the construction of a single set of Big History beads for each group, or a set for each individual can be conducted in a small group setting. If groups are not used, Big History bead sets can be constructed as individual projects.

B. Timing and Use of Big History Bead Sets

Bead sets made by college students can be a project due at the end of class or have required additions as each section of Big History is covered in class, in order to foster the pacing of study and preventing rushed completion at the end of the semester. A common question asked in class seems to be 'will this be on the test?' Instead of being a distraction, this focus on the test can be utilized with Big History beads by allowing students to bring their Big History bead set to the test. This encourages students to not just study the material but to learn to associate important concepts and events with their Big History beads. As an effective, personal, convenient, and permanent study aid, a set of Big History beads can be used for study in many situations outside of a typical study environment, such as while a student is riding the subway to class. Many students put extra effort into their set of Big History beads to make them not just useful, but beautiful as well, showing a high level of student engagement. A Big History bead set enhances long-term retention because students can keep and refer to their Big History bead string years after the class is over.

4. Big History Bead Planning – Main Concepts

As with any teaching tool, the most important step is planning what one intends to accomplish with the chosen pedagogy. The flexibility of Big History beads allows their use as a tool to convey a wide range of ideas, including the main ideas important for the specific class in which they are being used. As such, beginning with laying out of the main concepts for the class (especially those which are often a challenge to clearly convey) keeps the bead sets focused on the goals of the class. For instance, for a Big History class, several concepts are characteristic of Big History, and thus likely to be important, including connecting the past to the future,

understanding different scales of time and distance, depicting acceleration, understanding increasing maximum complexity, exploring common processes like competition and cooperation, and connecting cases of convergence and interrelation, among others (details on how these can be represented are given below). Big History beads have been used under many names, including 'Universe Story Beads', 'Great Story Beads', a 'Cosmala', and other names.

A. Connecting the Past and the Future

Few subjects are as well positioned as Big History is to convey to students the connections between the past, present, and future, and this is especially true when an overview of the past can be seen using a set of Big History beads. In addition to showing the relevance of Big History in today's world, this can also increase student engagement by helping students see their place in Big History, connecting the past and future. Big History beads can help a student see their own presence in Big History by including beads to represent some recent Ancestors, as well a bead or beads for themselves and/or event in their lifetimes. Long term trends can be seen not just as operating in the past, but as clues to how they might operate in the future, and creating a string of Big History beads can help students imagine how those trends might affect and be affected by human choices today.

B. Different Scales of Time and Depicting Acceleration

Big History beads are usually arranged chronologically (with the Big Bang at one end, proceeding chronologically to the other end, often representing today or the future). Many sets of Big History beads simply present event beads one after another, separated by uniform sets of spacer beads. However, some Big History bead sets adjust spacer beads (or other features) to represent lengths of time. If lengths of time are represented, then a set of Big History beads will likely show that events have been accelerating.

For instance, if the Big History bead set is constructed with a constant value to the spacer beads (where each bead represents, say, 50 million years, giving 274 spacer beads), then events like the appearance of mammals, primates, hominines, humans, agriculture, cities, and writing are bunched together in closer proximity towards the end, while spans of dozens of spacer beads without event beads exist in the time earlier than five billion years ago. These linear sets of Big History beads thus give an overall feel for the comparative time spans involved, along with the increasing rate of new events as today is approached. One example of a linear set of Big History Beads is Kyle Bagnall's Little Big History set of beads, which represents only the most recent 35,000 years of the

history of Michigan, with each spacer bead representing 50 years. However, this same property (of bunching many events towards the end of the bead set) is probably why linear sets of beads are not the most common.

Conversely, lengths of time can be depicted in ways that are not constant by using spacer beads of varying colors – such as: one blue spacer bead represents 100 million years, while one red spacer bead represents ten years, *etc.* Though bead sets constructed in this way do not show the acceleration of change in quite as striking a way, they nonetheless show the acceleration, once the drastic difference in spacer bead value is pointed out. A set of Big History beads with non-constant spacer bead value can have a very large difference in spacer bead value from one end to the other, going from perhaps a billion years per spacer bead to as little as one year or less per spacer bead. In sets like this, the enormity of deep time can be shown by pointing out what the total length would be if only the shortest time value per spacer bead was used, with enough spacer beads to add up to 13.8 billion years. For instance, if a spacer bead value of 5 years per spacer bead is used at the most recent end, and a typical spacer bead size is 3 mm, then:

13,800,000,000 yrs/5 years/bead = 2,760,000,000 beads,
2,760,000,000 beads × 0.003 m/bead = 8,280,000 meters,
or 5,134 miles (similar to the radius of the Earth at 6,400 miles).

Clearly, that is too long to make a practical Big History bead set! This is an illustration that many students can visualize easily.

Though rare, very short timescales can be represented by using the number of spacer beads as a negative exponent. Thus, the time of the formation of hadrons in the Big Bang can be represented following six spacer beads, representing that time 10^{-6} seconds after the Big Bang, *etc.*

C. Increasing Complexity

Another important concept in a Big History course is the increase in maximum complexity over time (while the average complexity might not increase, the complexity of the most intricate entities generally does increase). This can be represented by a marker (a special type of bead or other indicator) denoting beads that represent the most intricate being or system at their time. With beads marked this way, one can easily observe that these 'most complex entities' become progressively more intricate and interconnected as one moves forward in time along the Big History bead set.

D. Competition, Cooperation, and Crisis as Evolutionary Drivers

The relative importance of competition, cooperation, and response to a crisis in driving natural selection is debated among scholars today. An example of competition (which is often misunderstood by the public

as the main or only driver in evolution) is the evolution of taller and taller trees to obtain light in a forest. An example of cooperation is the evolution of chloroplasts in plants from incorporated algae, benefitting both entities. A crisis can foster either or both of these, as well as having other effects. For example, the oxygen crisis around 2.4 billion years ago triggered many changes through competition and cooperation as well as wiping out large numbers of organisms at the time of the impact. These various factors can all be included in a Big History bead set to highlight their roles in evolution. This also makes it easy for the instructor to ensure that he or she is not unconsciously emphasizing one of these more than originally intended. One way to show these different drivers is to have a type of bead (*e.g.*, a small round green bead) to designate times when a given driver (*e.g.*, cooperation) was important and to string a bead of that type next to the event that was driven by it.

E. Convergence, Interrelation, Formation, and Discovery

Convergence and interrelation across large scales are often important concepts in a Big History class, and Big History beads offer useful ways to convey these two concepts. Because they both often require comparisons across great distances and times, Big History beads help them to be visualized by allowing disparate entities to be simultaneously seen in context.

Convergence is commonly seen in biology in the form of evolutionary convergence, where two evolutionary paths lead to similar superficial features due to a common environment. Perhaps, the most commonly used example of evolutionary convergence is the comparison of the outer forms of a dolphin and a shark. Although their most recent common Ancestor (MRCA) is more distant than, say, the MRCA shared by a dolphin and a cow, their outer forms are similarly streamlined and finned due to their mutual aquatic habitat. Big History beads allow this concept to be both demonstrated (by, e.g., having similar beads for both sharks and dolphins) and also greatly extended to areas outside of biological evolution. Similar beads could link other cases of convergence, such as the formation of similar tribute-taking agricultural societies on the separated continents of the Americas *vs.* Asia or the independent formation of Earthlike planets in multiple solar systems.

Big History beads also can show interrelations that can be cumbersome to convey otherwise. For instance, in studying the conquest of the Americas during the sixteenth and seventeenth centuries, Big History beads link disparate causes that are otherwise confined to separate academic departments. At that time, a significant part of the Conquistadors' mission was to find gold for Spain – much of which was needed to

fund the religious wars (linking to the beads for the rise of religions and the Protestant reformation). Why were the Americas geographically separate allowing them to be suddenly 'found'? This can be answered by seeing the bead for the breakup of Pangaea 200 million years ago. Why were there life forms simple enough to be transmitted (diseases)? This can be answered by looking back to the bead for the earliest life forms, over 3.5 billion years ago. Why did metals such as silver and gold exist in the first place? This can be answered by looking to the bead for supernova nucleosynthesis, over 5 billion years ago. These and many other examples can be used to illustrate that many, even most, historical events require the interrelation of factors born in very different times, which each often fall under different classical academic disciplines. If desired, the beads relevant to a given chosen later event can be linked by a common color, small adjacent bead, or another mnemonic.

If the focus of the class includes the human discovery of various phenomena or features of our Universe, then beads for the initial formation of the feature can be linked to the discovery of that feature. An example could be similar phosphorescent beads for the original formation of radioactive elements in supernovae over 10 billion years ago, and the study of radioactivity by Marie Curie around 1900 CE.

Examples of many of these methods of representing major concept information in Big History bead sets are shown in Fig. 1. 'Example Section of a Big History Bead Set'.

F. Including Additional Concepts

Though Big History beads can be used to convey many concepts, the concepts central to a Big History class can be chosen and planned before other aspects of using Big History beads as a pedagogical tool are considered. Other types of information that can be shown using Big History beads are explored below. The relative importance of the various concepts needs to be kept in mind, as trying to include too many concepts can become too complicated to learn all of them. In all of the cases available at this time, only a few main concepts were used in constructing a set of Big History Beads, avoiding excessive complexity. Future uses of Big History Beads may show examples of balancing complexity vs. simplicity, as well as new ways to show Big History concepts clearly.

5. Big History Bead Set Components

After the main concepts to be conveyed are developed, a more direct planning of the Big History bead set can be done. Building on the basic concepts of the class, an overall timeline can be planned, with the overall size of the Big History bead set in mind. While the specific items in

each timeline can be left to each student, items can be picked from the many timelines available in Big History resources, websites, and Big History bead set timelines available online (given in the Resources Section). The timeline, with the list of events to be represented, should be built around the events and methods for conveying the main concepts identified earlier. From observation of people during the construction of Big History bead sets, it seems to be important to first identify major concepts and develop a timeline before choosing (or even seeing) beads. This is to avoid the inclusion of an event simply to include an attractive bead. After all, a Big History bead set is made to convey information, not to collect attractive beads.

Information can be encoded in a Big History bead set in a number of ways. Because the main types of beads in most Big History bead sets are the event beads (representing events) and the spacer beads (to help separate the event beads, as well as sometimes convey additional information), both of these types can be constructed to contain information. Of course, packing many details into a set of Big History beads is often constrained by the availability and cost of the beads.

A. Event Beads

Each of the event beads represents a given event in the Big History bead set. As a result, the event beads are often the most important beads – the focus of the Big History bead set. With the events chosen earlier, the search begins for a bead to represent the chosen event. The chosen event bead can contain information in color, markings, writing, size, shape, composition, and special attributes.

Color can be used to link event beads to others of the same colors (as described above in the 'Main Concepts' section), to designate a general type or class of event (such as, green shaded beads for any plant-related events or black beads to represent mass extinctions), or many other connections. Markings in addition to the background color can be either present when the bead is obtained or added with durable media. These markings can graphically show concepts associated with the bead (*e.g.*, a bead for the publication of the Origin of Species may contain a branching design similar to a phylogenic tree). Abbreviated can add specific information that would be difficult to represent with a simple design. For instance, 'Hm Mts' can be written on a bead for the rise of the Himalayan Mountains, and others. Similarly, beads giving a date or geologic era boundaries can bear a number, letter, or word for that time (such as 'Permian', '299 mya', or 'P').

If a Big History bead set has enough beads that are linked by some conceptual connections (such as the linking of the stellar nucleosynthesis of precious metals with the invention of money) to exceed the number of convenient colors/shapes or other linking features, then numbers

or letters written on the linked beads is an option with nearly unlimited potential. Size or shape can also be used to link beads, or these can be used as part of the mnemonics associated with each event bead. For instance, a rectangular bead can represent the evolution of plant cells, which are often rectangular.

Information can also be encoded by composition and special attributes. After all, every bead has to be made of some material. Examples include a bead of an iron/nickel alloy to represent the solidification of earth's iron/nickel core, a bead for the first coral made from some of that early coral (fossilized), a bead for the Cretaceous extinction made from tektite (rock made during a meteor impact), or beads made from rock from specific locations or time periods. Special attributes include other properties of the bead, such as a change in color upon exposure to ultraviolet light (used to represent the formation of our ozone layer), phosphorescence (mentioned earlier in the Main Concepts Section), a tiny, working flute representing the first construction of musical instruments more than 30,000 years ago as well as other ideas.

In addition to the main concepts of the Big History course, any of the above methods can be used to teach additional important concepts. Otherwise difficult to grasp concepts in biology, such as the founder effect, sexual selection, evolutionary surplus, co-evolution, and the red queen's race can all be represented in Big History beads.

The founder effect – where a small founder population leads to a loss of alleles and possibly speciation – can be coupled with adaptive evolutionary radiations following extinction events. In those cases, small populations may survive, carrying a reduced gene pool. On a Big History bead set, it can be observed how often evolutionary radiations follow mass extinctions or other events which may lead to founder situations.

Sexual selection can be shown both by instances of sexual selection (such as the often-used peacock example), as well as by including a bead for the advent of sexual reproduction. This gap between the first sexual reproduction and the earliest fossilized signs of sexual selection can open discussions about what factors are needed for sexual selection, the low frequency of fossils and fossilizable traits, whether or not sexual selection in species like the tuatara are strong evidence for older sexual selection, and so on.

The longer spans of time conveyed by Big History beads help in teaching the concept of evolutionary surplus. Because natural selection (and hence evolution itself) prepares offspring for the conditions that their parents lived in, it is a 'lagging' force for change. Especially in rapidly changing environments, this can result in organisms which better

fit the past environment than the current environment. Features that were selected for in the previous environment can be helpful, detrimental, or neutral in the current environment. A striking example of this includes the pronghorn antelope's ability to run at speeds of up to 50 mph or more, far faster than any current predators in North America. This speed could be an evolutionary surplus, left over from an earlier time when this speed was needed to escape megafaunal predators (Byers 1998: 318). A contrasting example can be found in the dodo, which evolved in an environment without predators to fly from, and was unable to flee fast enough to escape when discovered by humans. These cases can both be described as having an evolutionary surplus, positive in the case of the pronghorn, and negative in the case of the dodo. Selection, coupled with mutation, drives all evolutionary surpluses toward zero given enough time (though a sufficiently negative evolutionary surplus will result in extinction before that can happen, as in the case of the dodo). In the case of an evolutionary surplus resulting in a phenotype, which does not yield a large difference in selection, mutations over time will still remove the surplus, as in the case of the GULOP gene in primates (Nishikimi *et al.* 1988: 842–846) or the many olfactory genes in whales (Shubin 2008: 146). Big History beads allow many cases of environmental change followed by evolutionary change to be surveyed at the same time, making the concept of evolutionary surplus easier to see.

Often, an organism's environment includes significant interaction with another species. In these cases, the evolution of the first organism is an environmental change to the second species, resulting in evolution in that second species, which in turn causes evolution in the first species, and so on. This co-evolution between two species can often be represented in a single bead, both for cooperative cases (such as the co-evolution of bees and flowers or the co-evolution of fruit and fruit dispersers), as well as non-cooperative cases (such as a Red Queen's Race between predators and prey or a parasite and host). Similarly, the evolutionary situation where one member of a co-evolving pair of species goes extinct (a 'ghost of evolution' [Barlow 2000: 12], such as the pronghorn example above) can be shown with a descriptive bead.

Examples of many of these methods of representing concept information in event beads are shown in Fig. 1 'Example Section of a Big History Bead Set'.

B. Spacer Beads

Additional information can be represented by spacer beads, as described above. Because spacer beads are often added to separate the larger event beads anyway, using them to encode additional information need not add to the overall size of the Big History bead set.

The small size of space beads usually means that information is encoded by their size and/or color. A color not used to represent time can be used for geologic time periods or lineages. For instance, if colors in order of the spectrum (r.o.y.g.b.i.v.) are used to represent successive time periods or time values, then a white spacer bead on either side of a bead with a letter can show the boundary between geologic time periods (such as a white spacer bead on either side of a bead with a 'D' at the start of the Devonian). Similarly, a chosen lineage can be made easier to follow by putting another color spacer bead (perhaps a clear spacer bead) on either side of any event bead representing member of that lineage. The lineage leading to humans is probably chosen most often, but this approach works just as well for any other extant or extinct species. Examples of many of these methods of representing concept information in spacer beads are shown in Fig. 1.

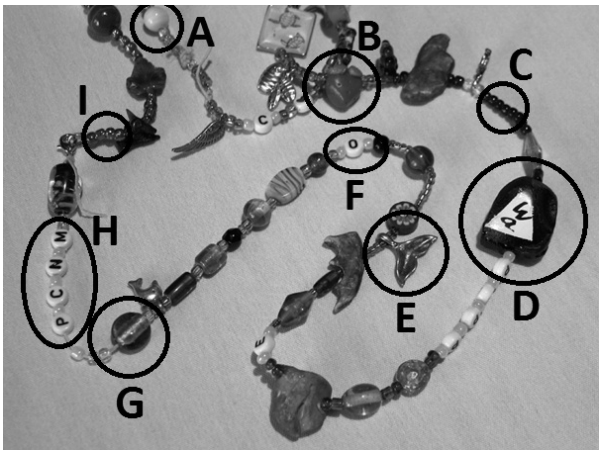

Fig. 1. Example Section of Big History bead set

Fig. 1 shows several of the ways of encoding information. A – event bead flanked by clear spacer beads, indicating an Ancestor of humans – in this case the first mammal to produce milk. B – event bead for co-evolution of fruit and fruit dispersing animals in the Cretaceous period. C – blue spacer beads, here representing two million years each. (Note that some events are generalized to the epoch of occurrence, and often represent gradual changes anyway.) D – event bead for the extinction marking the end of the Cretaceous period, made of tektite (solidified impact ejecta) and signed by Dr. Walter Alvarez, the co-discoverer of the Alvarez theory (Alvarez *et al.* 1980: 1095–1108). E – event bead for the return of early whales to the water. F – bead indicating the begin-

ning of the Oligocene epoch, flanked by white spacer beads to indicate a geologic marker. G – event bead for the evolution of proconsul, an early ape (Leakey 1963: 32–49) flanked by clear spacer beads, indicating an Ancestor of humans. H – geologic marker beads indicating that within the Phanerozoic, within the Cenozoic, within the Neogene, the Miocene begins – all flanked by white spacer beads. I – green spacer beads. All colored spacer beads since the start of the Cenozoic represent 1 million years each.

6. Resources for Big History Bead Set Construction

Though resources are described here, the open ended nature of Big History beads gives the opportunity to find many solutions that are not included here. It is also likely that items listed in this article will become outdated over time.

A. Timelines

Depending on the class goals, timeline needs can vary significantly. As a result, the needs of most classes will not be met exactly by any given timeline available online. However, some timelines may come close, and with only a little adjusting, can fit well. Some sources of free, online timelines are below (with URLs for each in the Reference Section), though additional examples can likely be found as well.

- 45 events in a Sagan Cosmic Calendar (Sagan 1977: 14–16);
- a 100 event timeline (Schick *et al.* 2013);
- a 216 event timeline (Barlow *et al.* 2002);
- a 248 event, time proportional timeline (Cleland-Host 2009);
- Chronozoom (Saekow *et al*. 2012);
- a list of many timelines to draw from (Levinson 2013);
- additional examples are available at the Great Story site (Barlow *et al.* 2002).

B. Beads

Another important variable is the source of the beads. A large amount of different beads can be easily obtained in variety packs of bulk beads, which are often inexpensive, even for glass or other higher quality beads. While bulk variety packs provide a lot of variation and often provide beads that are well suited to represent given events, often some events still have no bead that obviously matches. For these cases, many additional sources can provide beads with more specific information. Also, the properties described in the Event Beads Section above can all be things to look for in choosing beads. A wide variety of specific beads is often available at craft stores, specialty bead stores, or on eBay. In addition to these, beads can be constructed by drilling a narrow hole in chosen objects, such as a large seed, a small bone, a small ammonite

fossil, a stone arrowhead, a coin, a computer chip, or any other object which works well to represent the chosen event. If none of those produces a bead fitting the chosen event, then clay (skulpt or conventional) can be used to fabricate the bead (see Fig. 2). Note that so called 'permanent' markers often fade over time, so paint covered by a clear coating is preferred for longevity. For longer Big History bead sets, clasps (such as barrel clasps, lobster claw clasps, wire wrapping, or others) can be included at points along the string. This makes it easier to add, remove, or replace beads nearby by allowing a break point to access the local beads, avoiding the need to remove and restring the entire set of Big History beads. Also, many options for cord exist for stringing the beads. The most durable option is stranded bead stringing wire available at many craft stores. Copper wire, fishing line, and many kinds of thread should be avoided because they tend to break over time. Thin hemp or other plant fiber cord is a useful option if an intentionally weaker bead strand is desired (e.g., members of households with small children may desire a weaker strand to avoid a strangulation hazard).

Fig. 2. Beads Hand-Made Using Clay

In Fig. 2, the two larger beads here were hand-made using clay. The top bead represents the formation of the Pangaea supercontinent approxi-

mately 300 million years ago, with modern continent boundaries shown by dotted lines ('SA' = South America, etc.). The bottom bead represents the evolution of *Tiktaalik rosae* (Daeschler *et al.* 2006: 757–763) ~ 380 million years ago.

7. Summary

Big History Beads have been used in hundreds of diverse settings to teach Big History to students from 5 to 90 years old at locations across the United States. This teaching tool can provide a clear depiction of otherwise difficult concepts characteristic of Big History such as increases in complexity, acceleration, convergence, and others. At the same time, Big History beads increase student enjoyment and engagement through personalization and the connection of the past and future through by representing long-term trends. Big History bead sets provide an accessible kinesthetic teaching method that engages students who might not otherwise fully explore the topic through other pedagogies, and can be adapted to a wide range of class goals, classroom settings, and grade levels. Resources and descriptions in this paper provide information and resources to investigate this teaching method, while still leaving substantial room for new innovations. While students report loving this activity and teachers enjoy using this method, controlled studies of their effectiveness in comparison to more conventional pedagogies are an area of opportunity in Big History research.

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David Christian has taught for most of his career at Macquarie University in Sydney (Australia). Between 2001 and 2008, he taught at San Diego State University in California (USA), and he also teaches at Ewha Womans University in Seoul (Korea). He was originally a historian of Russia, specializing in the history of material life. In 1989, he began teaching a course on the history of everything. In a 1991 article, Dr. Christian coined the phrase 'big history' to describe this project. In 2004, he published *Maps of Time: An Introduction to Big History* and, in 2007, he recorded a set of 48 lectures on Big History for the Teaching Company. In 2010, he was elected founding President of the International Big History Association, and also began work on the construction of a free online syllabus in Big History for high school students throughout the world.

Michael and D'Neil Duffy have been involved in Montessori education for 35 years, since their daughter entered a Montessori school at age 2 1/2. D'Neil, who had been a teacher in the traditional public and private schools for 12 years before gravitating to Montessori, has Association Montessori International certification at the 3–6 level and American Montessori Society certification at the 6–12 level. She founded her own Montessori school in Georgia in 1979 and was the school's administrator for 21 years, teaching at every level but toddler. Michael, who had been a journalist by profession, was AMS-certified at the 6–12 level in 1990 and taught lower and upper elementary classes. Both joined the faculty at the Center for Montessori Teacher Education (New York), and they have trained Montessori teachers in New York, Phoenix, Boston, Toronto, Vancouver, and Puerto Rico. Recently they helped establish the Montessori Elementary Teacher Training Collaborative. The Duffys have given workshops at national and international Montessori conferences, and they gave a presentation at the first conference of the International Big History Association in 2012. They have authored three books on Montessori education, including *Children of the Universe: Cosmic Education in the Montessori Elementary Classroom*. Both have master degrees in education, D'Neil with a specialty in Guidance and Counseling, and Michael with a specialty in Media Education. They retired from the classroom in 2001 to devote more time to teacher training, writing and educational consulting, and they currently live in the mountains of Virginia.

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Ken Gilbert has been a pioneer of Big History ever since his undergraduate days at MIT in the Sixties. A synchronistic series of defining moments and fascinating insights were initiated at that time ultimately transforming his perspectives. These experiences inspired his lifelong project and quest for creativity in scholarship and education. Ken has been fortunate to enjoy many years researching a transdisciplinary synthesis of Big History, benefitting both from a wealth of expert guidance and the freedom of independent scholarship. His background includes Master's degrees from the California Institute of Integral Studies and Wayne State University, plus postgraduate research at the University of Edinburgh and Emory University on a Woodruff Fellowship. He introduced Big History at the World History Association of Texas 2012 Conference, and has participated in conferences sponsored by the Templeton Foundation. Ken passionately believes in the prospects for Big History contributing towards a timely transformation of our collective learning through two interconnected developments: a Grand Unified Theory of evolution throughout history, and a meaningful Grand Unified Story for research and education at all levels. To this end, he is currently working on expanding and deepening the initial elements proposed in his IBHA Inaugural Conference paper for constructing a new Integral Evolutionary Synthesis in the context of Big History. Ken seeks to teach at the college level, and work towards introducing a Big History program, based on the wonderful precedent underway at Dominican, at a local university.

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Esther Quaedackers has been teaching Big History at the University of Amsterdam, Amsterdam University College, and the Eindhoven University of Technology since 2006, alongside Fred Spier. She is also working on a PhD that has a thesis topic about the 'Little Big History' of Tiananmen Square. Ms. Quaedackers became interested in Big History while studying architecture at the Eindhoven University of Technology. She suspected Big History might be able to provide some answers to the large architecture questions she had been thinking about, such as why our built environment looks the way it does, why people built it the way they did, and why they built it in the first place. When, after obtaining her Master's degree in architecture (with honors), she got the chance to study and teach Big History, she changed her plans to become an architect into plans to become a Big Historian of building instead.

Barry H. Rodrigue was born and raised on the eastern borderlands of Canada and the United States. He worked in Alaska for 20 years as an ethnographer, field biologist, journalist and commercial fisherman. While there, he founded the international journal, *Archipelago*, and collected songs, stories and music for the legendary Folkways Records (available through the Smithsonian Institution's *Global Sound* series). A Fulbright Scholar and graduate of The Evergreen State College (Washington) and L'Université Laval (Québec), Dr. Rodrigue works as a geographer and archeologist on projects pertaining to ethnicity and global networks – both as a scholar and as an active world citizen. His efforts focus on the local, regional and global linkages between issues as diverse as indigenous adaptation in the Appalachian Highlands and peace initiatives in the Caucasus. He has produced a variety of award-winning articles and books, individually and with others, such as *L'Histoire régionale de Beauce-Etchemin-Amiante* (2003), which was runner-up for the Canadian Historical Association's Sir John A. MacDonald Prize for most significant contribution to Canadian history. He is presently a professor at the University of Southern Maine (USA), where he founded The Collaborative for Global & Big History (for more information, visit their website at http://www.usm.maine.edu/lac/global/bighistory/). He also serves as International Coordinator of the International Big History Association (IBHA).

Ekaterina Sazhienko was born in Gubakha, a small industrial city in the Ural Mountains, in the center of Russia. She is a postgraduate student and studies at the International University of Humanity and Nature, which is located in Dubna, one of the Russian 'science cities'. The subject of her MA thesis was the mega-historical model for forecasting and regulation of global social processes. She continues to work on this subject now.

Tracy Sullivan is Education Program Leader for the Big History Institute, Macquarie University and manages the Australian portion of the Big History Project. Trained as a secondary History teacher Tracy taught in Australian classrooms for eight years before moving to the tertiary sector, lecturing in History Education at the University of Sydney and the University of New South Wales. A former Churchill Fellow and Westfield Premiers Teachers scholar Tracy is currently completing a PhD in Education at Macquarie University exploring the transformative impact of Big History as a vehicle for interdisciplinarity learning at the secondary level.

Joseph Voros started out as a physicist, and has a PhD in theoretical physics. During this time he worked on mathematical extensions to the General Theory of Relativity. This

was followed by several years with internet-related companies, including the legendary Netscape Communications Corporation in Silicon Valley (California), before becoming a professional futurist. For over a decade he has taught courses on thinking seriously about the future. Wherever possible – whether in formal teaching or in popular speaking – he endeavors to emphasize an expanded perspective on our place in the Universe, which includes cosmic evolution and Big History. His interests are broadly multidisciplinary and include the emerging field of 'integral inquiry', theories and models of social change, the long-term future of humankind, astrobiology/SETI, and the broad sweep of cosmic evolutionary history as a framework for conceptualizing the human knowledge quest and futures research. Three of his research articles have won excellence awards, including an Outstanding Paper Award in 2010. He is a member of the World Futures Studies Federation, a professional member of the World Future Society, and is a founding member and current board member of the International Big History Association.

Sun Yue is an associate professor, who works at the College of Foreign Languages and the Global History Center, School of History of Capital Normal University in Beijing. Meanwhile, he edits the *Global History Review*, the first such academic publication in China. Dr. Sun's doctoral dissertation deals with the *Malleus Maleficarum* and the Early Modern European Witch-Hunt. Now he is intent on widening his perspective, to get a clearer picture of human undertakings on planet earth or even in the universe.