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EVOLUTION

A Big History Perspective

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'Evolution' Almanac

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The rapidly globalizing world needs global knowledge and a global overview. That is why the ideas of universal history or Big History, which cover all of the Universe's existence, from the Big Bang to the present human networking of the planet, are becoming more and more popular. This volume includes a number of the exciting works in this relatively new field that, along with a macroevolutionary approach, seek to develop an inclusive view of the Cosmos, Earth, life and humanity by erasing boundaries between disciplines.

This volume is the second in a series of almanacs that has *Evolution* as its general subject and title. This volume is also a special edition with the subtitle: *A Big History Perspective*. We have tried to collect a wide variety of contributions by very different authors – not only from different countries, but also authors who have very different educational backgrounds (historians, astrophysicists, biologists, sociologists, geologists, psychologists, archaeologists and others). All of them have come to the shared understanding that we need a unified picture of the evolution of the Universe.

The first section of the Almanac ('Evolution and Understanding of Big History') presents articles analyzing the evolution of views on the development of the Universe and the Big History concept itself. The second section ('Big History's Trends and Phases') analyzes major phases of Big History (cosmic, geological, biological, social), including some possible forecasts. The third section ('Essays on Big History') considers literature, art and poetry, as well as the teaching of children and personal views of the world – all through the prism of Big History.

This Almanac 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. More than that, this edition will challenge and excite your vision of your own life and the exciting new discoveries going on around us!

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Introduction

Evolution and Big History: From Multiverse to Galactic Civilizations

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A macroevolutionary approach and the new field of Big History seek *to develop an inclusive view of the Cosmos, Earth, life and humanity* by erasing boundaries between disciplines. Big History is a versatile study that brings together constantly updated information from Astronomy, Physics, Geology, Biology, Chemistry, Anthropology, Psychology and other scientific disciplines, and then merges it with the contemplative realms of Philosophy and the Humanities. Big History evolved from the academic need to transcend the straightjacket of university disciplines in the early 20th century, beginning with subjects like Biochemistry and Astrophysics (Christian and McNeill 2008; Rodrigue and Stasko 2011).

The need to see this process of development holistically – in its genesis and growing complexity – is a fundamental characteristic of scientific and human cognition (see David Christian's article in the present Almanac for more detail about this). The growth of scientific specialization and the immense amounts of information in different realms of science hinders the capacity for inclusiveness, but, paradoxically, it amplifies the need for it too. This aspiration for integrated vision is especially salient among those scientists who would like to see beyond their narrow field of specialization. One can also see the growth of such interest in the framework of individual disciplines, as well as in interdisciplinary research. As we have already mentioned on a number of occasions, the rapidly globalizing world needs global knowledge and global generalizations (see Grinin, Korotayev, Carneiro, and Spier 2011; Grinin and Korotayev 2009). Indeed, globalization itself becomes a vehicle for this Big History expansion of awareness.

Cybernetics pioneer W. Ross Ashby noticed that the range of systems is enormously wide (1958). Nonetheless, it makes much sense to represent the history of the Universe (and even the Multiverse) as a single process. Without this, we are fated to live within a fragmented, endlessly shifting intellectual universe, deprived of the philosophical and ethical anchors of a more unified vision of how things came to be (again, see Christian's article). That is why the ideas of universal history (that is, covering all of the Universe's existence) never died, whereas the idea of Big History (under various names) emerged almost simultaneously and independently in different countries (Australia, the Netherlands, Russia, the United States).[1]

Such an aspiration towards a unified paradigm (or, at least, toward a unified evolutionary narrative) is interdisciplinary by its nature. Simple dialectical thought will not resolve the problems of our world today. It is not about resolving a few opposing questions, such as religion *versus* science or technocrats *versus* humanists. The problems are multivalent. It is a dilemma of antique, irrational perspectives hidden in modern, logical reasoning. A central issue is that people think in 'silos', in which a narrow focus masquerades as a holistic solution.

This is an administrative problem as well, one in which a confusing, vertical array of state agencies, private businesses, academic departments, federal ministries, public NGO's and all their personnel develop policies and carry them out in isolation from each other – not only duplicating each other's efforts but often in competition with them. This is nowhere more in evidence than just after a sharp, focused crisis: be it an earthquake, a military attack, a hurricane, the bursting of an economic bubble, or any other kind of natural or social catastrophe.

So, how do we develop holistic and cooperative models of existence, yet still maintain the humility of on-going enquiry? How do we implement and encourage such open models on a global scale? Part of the solution is to adopt wider views of existence, ones that transcend the silos and promote communication between all segments of societies. This quest is addressed in our present edition of the Almanac *Evolution*, which highlights approaches that could guide us out of the maze in which we seem to be trapped.

That is why we have tried to collect in this volume contributions by very different authors – not only from different countries, but also authors who have very different educational backgrounds (historians, astrophysicists, biologists, sociologists, geologists, psychologists, artists, poets and so on). All of them have come to the understanding that we need a unified picture of the evolution of the Universe in their own ways. Those ways are described in the many contributions to this Almanac (especially in its first Section).

The interdisciplinarity that is necessary for the development of such major theories may provide opportunities for a fruitful synthesis of ideas. There are a number of potential ways to develop a paradigm for the study of the history of the Universe. In general, those ways share a unified view of the process of evolution.

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[1] Big History was also a child of the Cold War and the Space Race, as scholars sought to collaborate beyond their national boundaries and ideological divides (Rodrigue and Stasko 2011: 36–38).

As we have already mentioned in the first issue of the Almanac *Evolution* (Grinin, Korotayev, Carneiro, and Spier 2011: 7), this shared vision is remarkable, given the fact that the application of the evolutionary approach to the history of nature and society has remained one of the most effective ways to conceptualize and integrate our growing knowledge of the Universe, society and human thought. Moreover, we believe that without using mega-paradigmatic, theoretical instruments such as the evolutionary approach, the scientists working in different fields may run the risk of losing sight of each other's contributions.

This process may be denoted as *megaevolution* or *metaevolution*, *Universal History*, *Cosmic Evolution*, or *Big History.* The term 'Big History' has become especially popular, is used more widely than other terms, and has become the name of an academic movement. That is why we have decided to merge these two similar and basic concepts in the present Almanac: Evolution and Big History. This enables us to bring together people who are close to each other intellectually. Furthermore, this has made it possible to assemble a very comprehensive collection of views by Big Historians. In addition, it fulfils the task set up in the first volume of *Evolution:* The scientists working within the evolutionary *mega*paradigm should have an opportunity to know more about each other, to see and understand who does what, and to get enriched with the experience of scientists working in different fields of evolutionistics.[2]

It is not by accident that several founders of Big History came from organizations that were already seeking to bridge the gaps between disciplines. In addition to the laboratories and centres of many key scholars, several academic societies stand out for their contribution to and encouragement of Big History. These include the World History Association, the Historical Society (USA), and the Russian Academy of Sciences. As a result of such collaborative efforts, the International Big History Association (IBHA) was founded during a field seminar at the Coldigioco Geological Observatory in the Apennine Mountains of Italy in August 2010 (Rodrigue and Stasko 2011: 41; Osservatorio Geologico di Coldigioco [see http://www3.geosc.psu.edu/~dmb53/OGC/index.html]).[3]

A very important theme among all of us is the connection between the Universe's past, present and future. In this regard, it appears possible to agree with the point that the Big History movement is an important bridge between scien-

[2] 'Big History' is a simple and elegant term coined by historian David Christian that tends to be used in the English-speaking world by scholars in the Humanities and Social Sciences (Rodrigue and Stasko 2011: 37). However, it is hardly surprising that some contributors use alongside Big History other terms as synonyms.

[3] This cross-disciplinary cooperation continues, as shown by the World History Association conference in Beijing in July 2011, which includes 6 Big History panels, 2 roundtables and several individual presentations. The first conference of the International Big History Association is in Michigan (USA) in August 2012.

tific understanding of this past, varied views of humanity's place in Earth history, and practical environmental issues that affect our daily lives.

As has already been mentioned above, Big History ideas did not appear from out of nowhere. They have deep roots in philosophy and science; those roots ascend to the approaches of evolutionists and holistic thinkers of the past, such as Compte and Spencer. This can also to some extent be said about some Marxists and Hegelians, as well as Neokantians (see Grinin, Korotayev, Carneiro, and Spier 2011: 5–7; Grinin, Markov, and Korotayev 2011 for more detail). In his contribution to this edition, Eric Chaisson points out that:

> Other researchers have addressed life and complexity in a cosmic setting, among them Chambers (1844), who anonymously wrote a pre-Darwinian tome of wide interdisciplinary insight, and Shapley (1930), who pioneered 'cosmography' that classified all known structures according to increasing dimensions. Henderson (1913) regarded the whole evolutionary process, both physical and biological, as one and the same, Whitehead (1925) sought to broaden scientific thinking with his 'organic philosophy', von Bertalanffy (1968) championed a systems theoretic approach to physical, biological, and social studies, and Shklovskii and Sagan (1966) popularized the idea of intelligent life in the cosmos.

However, the theme of 'Big History' predecessors still needs much work, and we hope that we will be able to publish new articles on this subject in forthcoming issues of our Almanac.

The aspiration to embrace the evolution of the Universe from its 'beginning' up to the present is based not only on the needs of a cognition that seeks a certain order and completeness. The world, notwithstanding all its immense diversity, is also a single entity – not only epistemologically but also ontologically. There are many ways to describe this unity scientifically. One way is suggested by Eric Chaisson, according to whom 'specific energy flow (*i.e.* energy rate per unit mass) constitutes a useful complexity metric and potential evolutionary driver for all constructive events throughout universal history' (see his contribution to this volume).

We may also base ourselves on the idea that each subsequent phase of Big History is accompanied by the emergence of new mechanisms of evolution; however, the preconditions of these new mechanisms may be detected within the previous phase. The emergence of new mechanisms of evolution and the canalization of the Big History movement at certain phases does not abolish evolutionary mechanisms that appeared at earlier phases. As a result, one can observe the emergence of a complex system of interaction by various forces and mechanisms that determine the evolution of new forms. Biological organisms act in the framework of the laws of Physics, Chemistry and Geology; social systems and humans behave in the framework of biological limitations. The unconscious 'search' for new forms of evolution goes in various directions, as a result of which basically similar forms emerge – not only at the point of a macroevolutionary breakthrough but also at what may be called 'evolutionary blind alleys'. This 'search', however, finally leads to the transition to a new phase of Big History.

We have already written that one may find contradictions between the world and its sentient beings within evolutionary theories, perhaps even more so than with other theories. And, the wider the scope of research, the sharper this contradiction.

We view the boundless Universe (let alone Multiverse) in different ways. That is why our Almanac brings together contributions in various formats and styles. They reflect our perceptions of enormous scales and incredible complexities in different ways. These differences in perception are also an important feature of our world, and the contributions to this volume throw light on its various aspects. That is why the contributions to the present Almanac display a representative panorama of our ideas of the Universe, life and human society.

This Almanac is divided into three sections.

* * *

Section 1 ('Evolution and Understanding of Big History') provides a wide-ranging overview of this new field, including articles by astrophysicists, historians and philosophers. These articles analyze the evolution of views on the development of the Universe that led to the emergence of a paradigm that is capable of describing that mega-process known as "Big History" (the authors also provide rather interesting accounts of the evolution of their own views). On the other hand, most articles in this section convey the authors' understanding of Big History: its possibilities, goals and tasks. Naturally, as within any other scientific paradigm, one may find discussions and different views. One can even observe a difference in respect to the simple tradition of writing its very name – as 'big history' or 'Big History'.[4] This is good and normal. Hence, in this section, Big History is represented in its evolutionary and epistemological aspects.

In his brief but bright contribution ('The Evolution of Big History: A Short Introduction') **David Christian** demonstrates that Big History represents a modern, scientific form of an ancient effort: that of constructing unified, coherent and universal accounts of reality. Such efforts can be found within the origin stories of most human societies. But in the late 19th century, universalistic efforts tended to disappear within both the Humanities and the Sciences, as scholars in field after field coped with the modern tsunami of information by narrowing

[4] The style of using capital letters or lower case letters in the name of Big History might appear a simple issue, but actually is very complex. It touches on disciplinary and interdisciplinary perceptions, political etiquette, academic tradition, linguistic perception and others.

the scope of their research. The Sciences began to return to larger and more universalistic perspectives from the middle of the 20th century, as new unifying paradigms emerged in field after field, and physicists even began talking of 'Grand Unified Theories' of everything. New information and new dating techniques made it more reasonable than ever before to attempt scientifically grounded universal histories, and such attempts began to re-appear in the 1980s. But not until the first decade of the 21st century has that effort really begun to take off.

Fred Spier ('Big History Research: A First Outline') provides a first outline of how to define Big History research, including an overview of the types of research that could be profitably undertaken. Practical issues are also discussed, such as how to obtain funding, where to publish the results, and whether the research results might have practical applications. Because this contribution is, to our knowledge, the first attempt to outline Big History research, Spier's observations should be considered preliminary. We hope that they will stimulate a healthy discussion about Big History research, one that will lead to formulating a Big History research agenda.

Eric J. Chaisson ('Cosmic Evolution – More Than Big History by Another Name') offers simultaneously a broad description of the Big History panorama and the history of his own intellectual pursuits. As with many other contributors to the present Almanac, this history is tightly connected with the search for the most adequate ways of teaching Big History to students. Chaisson suggests that evolution – ascent with change of Nature's many varied systems – has become a powerful unifying concept throughout the Sciences. In its broadest sense, Cosmic Evolution, which includes the subject of Big History, comprises a holistic explanatory narrative of countless changes within and among organized systems, extending from the Big Bang to humankind. Chaisson presents his principal working hypothesis in Cosmic Evolution: Mass-normalized energy flow, termed 'energy rate density' and denoted by Φ_m, is possibly the most universal process capable of building structures, evolving systems, and creating complexity throughout the Universe. This theory allows us to quantitatively account for the ranked order of increasingly complex systems across the many successive phases of Big History. One may agree with Chaisson's conclusion that better metrics than energy rate density may well describe each of the system categories – within the more restricted domains of physical, biological and cultural evolution – but no other single metric seems capable of uniformly describing them for Cosmic Evolution as a whole.

Alexander Mirkovic ('Big History and the End of History') situates Big History in the context of the rise of religious fundamentalism in the last twenty years. While Francis Fukuyama in his 'The End of History' (1989) argued that the end of the Cold War would produce the end of grand narratives, as well as the triumph of democracy and liberal capitalism, in reality the world saw a resurgence of religious fundamentalism that orchestrated a resolute attack on science and thereby came into conflict with Big History. Mirkovic argues that Big History emerged in opposition to resurgent and often politically sustained religious fundamentalism. This oppositional stance presents some dangers for Big History. For example, the concept of a modern creation myth, while useful in the debate with religious fundamentalism, hides the true character of Big History. Big History should not endorse the once fashionable triumphalism of science. As Thomas Kuhn warned, science goes through paradigm shifts and is not immune to shift in power/knowledge relations. The author argues for understanding of Big History as a branch of the history of science. The strength of science is that it is able to change and survive a paradigm shift. Mirkovic also points out some inconsistencies in the fundamentalist challenges to Big History. While fundamentalists reject human evolution, they also advocate the ideal of ever-increasing economic prosperity extending into the limitless future. This question of the future is something to which Big Historians do not pay enough attention. In this context, Mirkovic calls attention to Peak Oil theories. If some of the predictions made by Peak Oil 'doomers' were to come true, major chapters of Big History would need to be re-written. Big Historians should, in the author's opinion, seriously analyze various kinds of possible futures, as the future is also a major part of the 'map of time'.

Barry H. Rodrigue ('The Evolution of Macro-History in the United States') points out that the inclusion of large-scale studies in the world's educational systems is of great importance for resolving the most serious problems that humans face today. A problem encountered by today's scholars is how to reconcile competing visions of existence, not only for our global benefit but for our very survival. One suggestion is to continue moving with the current trajectory and adopt a model of macro-studies, such as the example provided by Big History. He argues, however, that evolutionary beliefs have come to provide almost as much comfort to ordinary people as religion. As a result, the belief in an external agency (*deus ex machina*) that will 'take care of us' has continued. There are many examples illustrating the flawed consequences of such faith, examples that demonstrate how unquestioning faith in a higher power – be they god or computers – has resulted in serious consequences for our species and our planet. The related belief that particular groups of humanity have been chosen to fulfil a pre-ordained 'mission' is just as prevalent and just as dangerous, perhaps nowhere more obvious today than in central Eurasia. This problem of misunderstanding the world around us and acting in unintentionally lethal ways is perhaps one of the most mortal conundrums we face today.

Akop P. Nazaretyan ('Mega-Evolution and Big History') maintains that Big History – an integral conception of the past from the Big Bang until today – is a relatively novel subject of cross-disciplinary interest. The concept was construed in the 1980s–1990s simultaneously in different countries, after relevant premises had matured in the Sciences and Humanities. Various versions and traditions of Big History are considered in the article. Special attention is paid to the comparison between the Russian and the Western approach to Big History. Most Western authors emphasize the idea of equilibrium, and thus reduce cosmic, biological and social evolution to mass-energy processes. As a result, the informational parameter, involving mental and spiritual aspects, are seen as epiphenomena derived from the increasing complexity of material structures – epiphenomena that do not play their own role in evolution (on this subject, see David Hookes' article in this issue). In the Russian tradition, sustainable non-equilibrium patterns are more frequently used. This implies attention to pan-material sources, including the evolution of mental capacities and spiritual culture (as basic anti-entropy instruments), as well as to humans' growing intervention in the material processes on Earth and outside of it. The non-equilibrium approach, in the context of modern control and self-organization theories, alters the portrayal of the past, and still more dramatically, the estimation of civilization's potential.

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Section 2 ('Big History's Trends and Phases') looks at particular aspects of Big History, such as analogies between biological and social evolution, information as a defining aspect of cosmic evolution, and exo-humanitarian connections in our meta-galaxy. Contributions to this section analyze major phases of Big History (cosmic, geological, biological, social) including some possible forecasts. The detection of separate trends, and analysis of evolutionary mechanisms allow for a more comprehensive understanding of the general principles and mechanisms of Big History. This is very important for the development of a general Big History paradigm.

G. Siegfried Kutter ('Big History: A Personal Perspective') gives a personal perspective on the history of the Universe, from the Big Bang to the origin of life on Earth, and life's evolution towards the enormous diversity that we witness today. His perspective is based in part on writing the college-level text, *The Universe and Life*, published in 1987, which influenced the creation of the multi-disciplinary field of Big History. Kutter begins by describing the circumstances that motivated him in the mid-1970s to start writing *The Universe and Life.* He continues by giving a brief, updated summary of the text's content about physical and biological evolution, asking, 'Where do We Go from Here?', and discusses the philosophical and pedagogical challenges that he confronted.

These are issues that characterize Big History as well. He concludes by commenting on some of Big History's unique challenges, due to the field's broad, multi-disciplinary nature, and suggests that we consider these as an opportunity to jointly move the field forward.

One of the articles of this section, the contribution by **Tom Gehrels** ('The Chandra Multiverse') extends the already colossal time horizons of Big History in a truly fantastic way. While reading this article, it is difficult to avoid exclaiming something like: 'This is a really BIG history!' Of course, this is a hypothesis, with which many might not agree. But this is a very bold hypothesis that extends the Big History horizon by many orders of magnitude. According to Gehrels, equations of Planck and Chandrasekhar lead to the conclusion that our universe is a member of a quantized system of universes, which he calls the 'Chandra Multiverse'. It is a trial-and-error evolutionary system. All universes have the same critical mass and finely tuned physics that our universe has. The origin and demise of our universe is described. In our astronomical environment, everything ages and decays; even the proton may have a limited half-life. The decay products of all the universes expand into the inter-universal medium (IUM), clouds form in the IUM, from which new universes are started. When the density at the center of our proto-universe cloud reached proton density, then photons, protons and neutrons were re-energized. A Photon Burst marks the beginning of our universe at 10^{-6} sec (10^{37} Planck times) later than a Big Bang, and the evolution of forces, sub-atomic particles and finely tuned physics occurs in the Chandra Multiverse. This theory of the multiverse also makes identification of dark energy and dark matter possible.

Walter Alvarez, Alessandro Montanari and David Shimabukuro ('*Ex Libro Lapidum Historia Mundi:* Reading History Written in Rocks') indicate that, in the emerging conception of Big History, the largely contemporaneous regimes of Earth and life occupy the middle ground between cosmos and humanity. As part of the bridging of disciplinary boundaries, historians and astronomers will need to learn how geologists and paleontologists read history written in rocks. This was the goal of a workshop held at the Geological Observatory of Coldigioco, in the Marche Region of Italy in August 2010, that led to the founding of the International Big History Association. The Observatory is in a part of the Apennine Mountains that has extensive outcrops of deep-water or 'pelagic' limestones, which carry the best record of Earth history, covering an interval of about 200 million years. Especially in the remarkable outcrops at Gubbio, geologists and paleontologists have recovered records of the evolution of microfossils, the reversals of the Earth's magnetic field, the giant impact that caused the mass extinction in which the dinosaurs perished, and have dated parts of this record with volcanic ash layers that give numerical ages. The integrative stratigraphy obtained from the Italian pelagic limestones has been very important for the development of the geologic time scale, and new developments in cyclostratigraphy hold the promise of dating these rocks back to about 100 million years ago, with a resolution of about 1,000 years.

Leonid E. Grinin, Andrey V. Korotayev and Alexander V. Markov ('Biological and Social Phases of Big History: Similarities and Differences of Evolutionary Principles and Mechanisms') demonstrate that the comparison of biological and social macroevolution is a very important issue; this issue, however, has been studied insufficiently. Yet, its analysis suggests new, promising possibilities to deepen our understanding of the course, trends, mechanisms and peculiarities of the biological and social phases of Big History. Even though there are very important differences between biological and social macroevolution, it appears possible to identify a number of fundamental similarities. At least three fundamental sets of factors determining those similarities can be singled out. First of all, we are dealing with very complex non-equilibrium (but rather stable) systems whose principles of functioning and evolution are described by General Systems Theory, as well as by a number of cybernetic principles and laws. Secondly, we do not deal with isolated systems but rather with complex interactions between both biological and societal organisms and their external environments. Thirdly, there is a direct 'genetic' link between the two types of macroevolution and their mutual influences. This article analyzes similarities and differences between two phases of Big History at various levels and in various aspects. It compares biological and social organisms, mechanisms of evolutionary selection, transitions to qualitatively new states, processes of key information transmission, and fixation of acquired characteristics. It also considers a number of pre-adaptations that contributed to the transformation of the Big History biological phase into its social phase; it also analyzes some lines of such a transformation.

This article is the continuation of the authors' contribution to the previous issue of the Almanac. It appears appropriate at this point to remind our readers the basic ideas of the authors' first article. According to them, it appears reasonable to consider biological and social macroevolution as a single macro-evolutionary process to at least some extent. This implies the necessity to comprehend general laws and regularities describing this general process. An important notion that may contribute to our understanding of the differences and similarities of these two types of macroevolution is the term *social aromorphosis.* This term was developed as a counterpart to the notion of biological aromorphosis, which is well established within Russian evolutionary biology. Grinin, Korotayev, and Markov regard social aromorphosis as a rare qualitative macro-change that increases in a very significant way complexity, adaptability and mutual influence of social systems, and thus opens up new possibilities for social macro-development. In their contribution, they discuss a number of regularities that describe biological and social macroevolution by employing the notions of social and biological aromorphosis, including such regularities as rules of 'module evolution' (or the evolutionary 'block assemblage'), 'payment for arogenic progress', *etc.*

David Hookes ('The Evolution of Information Systems: From the Big Bang to the Era of Globalisation') shows the importance of the evolution of information systems for the emergence of life and the trajectory of human history. It locates this development in the widest possible context, that is, the history of the Universe as a whole. One can view the development of the Universe from the Big Bang to the present social existence of our species as a series of revolutionary/evolutionary stages, with each stage associated with the development of a new information system. The present form of globalization is made possible, in part, by the development of modern Information and Communications Technology (ICT). In this context, the change in character of the working class is examined. It is argued that information workers are the dominant category in advanced economies, and that one of their sub-groups, the knowledge workers, can play an especially important role in resolving the crises of both the socio-economic system and the physical environment.

Alexander D. Panov ('Post-singular Evolution and Post-singular Civilizations') discusses how the ability of the world civilization to overcome a singularity border (a system crisis) determines important aspects of that civilization during an intensive, post-singular phase of development. A number of features of a post-singular civilization can stimulate its 'strong communicativeness', which is a prerequisite for the formation of a 'galactic cultural field'. Post-singular civilizations – carriers of the cultural field – are considered as potential partners in interstellar communication and in our own potential future.

* * *

There then follows ***'Essays on Big History' (Section 3)*** that considers literature, art and poetry, as well as the teaching of children and personal views of the world – all through the prism of Big History. This is an exciting assemblage of thinking from around the world on what promises to be the defining paradigm for the survival and continued evolution of our global civilization. It is very important to show the connection between Big History and various aspects of human life, such as poetry and ecology, art and architecture. It is even more important to develop methods of Big History teaching so that it can be understood by children and adolescents – our next generations.

Nigel C. Hughes ('The Change We can Believe in: Ten Facts about the Evolution of the Earth-Life System and their Relevance to Current Global Environmental Change') emphasizes that what we believe about the past of the Earth, for the first time in human history, has direct implications for our future. If we are to make responsible choices about global environmental change, we must understand what Earth history says about how the planet and its inhabitants have coevolved, and be able to relate these insights to our current conditions. The Big History movement is an important bridge between scientific understanding of this past, varied views of humanity's place in Earth history, and practical environmental issues that affect our daily lives. If Big History is to gain serious traction, the movement must emphasize the linking of lessons from the past to the choices we must make as a global society today. This article presents ten facets of Earth history that contextualize some current issues concerning global change and species extinction within a Big History perspective. Hughes argues that, although extinction has played an important role in shaping the evolutionary history of life and although we are here partly because of it, the fact that almost all species that have ever lived are extinct cautions against a passive response to global climate and environmental change.

Jos Werkhoven ('Once upon a Time… There was a Story to be Told...') was a teacher for more than thirty years. The article starts with the story of a teacher: the story of everything! For a while, we follow the story in the classroom. But it is a 'long, very long story'. So we leave the classroom and he writes about his approach to telling this story of Big History to children of the age of 6+. He calls his story 'questioning' – questioning of space and time. He helps the children with three frameworks, which is the core of the article. For the framework of space, he uses the concept of the *Powers of Ten*, which was developed by Kees Boeke. For time, he uses a framework that he himself developed: *The Lines of Life*, a set of four timelines for use in primary school. For questioning, he uses the material for sentence analysis developed by Dr. Maria Montessori.

Erika K. H. Gronek ('And Then There Was You…: A Children's Story of Science and Emotion') describes the background to the writing of the children's book, *And Then There Was You...* In addition, the multiple layers of the story that go beyond a child's initial comprehension are deconstructed. The book in question hits upon many of the themes of the Big History movement in academia.

The objective of the article by **Paula Metallo** ('Brain Stretching: Art and Big History') is to express the ways that Art can serve as a means to describe patterns and encourage openness to 'stretching' the brain. Such a process helps us comprehend inter-connectivity and shows how Big History can help to implement a whole-picture, interdisciplinary approach to learning. She quotes author Richard Shelton, who wrote twenty-five years ago: 'Somebody must integrate and synthesize what we know about ourselves and the world in order to prevent social, cultural, and even personal fragmentation'.

Gary Lawless ('Big History and Bioregions') demonstrates that Bioregionalism and Big History are part of the new way of looking at our homes and the Cosmos that is unfolding around our planet Earth today. Bioregionalism is Big History in action. This essay shares some views about Big History by a bioregionalist poet from his home in Maine, relating them to other bioregional poets like Gary Snyder in California and Nanao Sakaki in Japan.

Esther Quaedackers ('A Little Big History of Tiananmen') aims at demonstrating the usefulness of studying small-scale subjects such as Tiananmen, or the Gate of Heavenly Peace, in Beijing – from a Big History perspective. By studying such a 'little big history', previously overlooked yet fundamental explanations for why people built the gate the way they did can be found. These explanations are useful in their own right and may also be used to deepen our understanding of more traditional explanations of why Tiananmen was built the way it was.

Roland Saekow ('From Concept to Reality: Developing a Zoomable Timeline for Big History') emphasizes that Big History is proving to be an excellent framework for designing undergraduate synthesis courses. A serious problem in teaching such courses is how to convey the vast stretches of time – from the Big Bang, 13.7 billion years ago, to the present, as well as how to clarify the wildly different time scales of cosmic history, Earth and life history, human pre-history and modern human history. Inspired by a series of printed timelines that had been created by Professor Walter Alvarez at the University of California Berkeley, a time visualization tool called 'ChronoZoom' was developed by Saekow and Alvarez through a collaborative effort between their Department of Earth & Planetary Science and Microsoft Research. Work on the second version of ChronoZoom is presently underway with the hope that it will be among the first in a new generation of tools to enhance the study of Big History.

Finally, **James Tierney** ('Two Themes Inherent in Big History') ties together the Big History components of collective learning and complexity-building within the long term perspective of the evolution of the Universe and the shorter term perspective of human culture. Since human culture is at the leading edge of complexity-building, it is appropriate to wonder where that process is taking us and whether there are ways by which it might be influenced. Tierney suggests that the pace of cultural evolution is significant in terms of the heavy investment in war technology over the past 10 thousand years, while the more leisurely and cooperative pace of human development from 35 thousand years ago may hold better lessons for human sustainability.

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So, you hold in your hands an almanac that has been assembled with the cooperation of local, regional and international organizations. It features editors and authors from different parts of the planet. It is a concept that builds bridges over the antiquated fortifications of the Cold War. It is an interdisciplinary and international effort. And now it transcends the boundaries of 'mere' global existence: Big History.

This very publication is an example of the process – in Marshall McLuhan's words: 'The medium is the message'. Think about it… Many of the ideas expressed in this edition are derived from thoughts that – until recently – have been sequestered behind artificial barriers of ideology, language, class and profession. We are on the threshold of a new era of advancement.

There is a certain point at which evolution leads to revolution. This certainly was the case when our universe coalesced, when blue-green bacteria created an oxygen-rich atmosphere on Earth, when hominids developed symbolic logic that could be communicated through generations, and when human society deployed carbon-combustion engines throughout the world. Although none of these evolutionary steps inevitably led to the next stage, each evolutionary step did lead to a revolutionary stage of activity. We are at a point where there is the need for yet another evolutionary revolution, this time in the realm of scholarship and pedagogy. We embrace the challenge and welcome you to our new world!

Technical Note

Many of the articles are accompanied by photographs and images that cannot be inserted into the printed edition of the Almanac *Evolution* for technical reasons. Following the example of journals, such as *Nature* and *Science,* as well as other paper-published volumes, we provide an online edition of the Almanac at its website (www.socionauki.ru/almanac/evolution_en/evol_2_en/). There, you can find full texts, together with all the photographs and images sent by the authors. Some figures and diagrams mentioned in the articles, but which are available only in the online version, have linked references to the online publication.

Acknowledgement

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I. EVOLUTION AND UNDERSTANDING OF BIG HISTORY

1
The Evolution of Big History: A Short Introduction

David Christian

Abstract

Big history represents a modern scientific form of an ancient project: that of constructing unified, coherent and universal accounts of reality. Such projects can be found within the origin stories of most human societies. But in the late 19th century, the universalistic project vanished within both the humanities and the sciences, as scholars in field after field coped with the modern tsunami of information by narrowing the scope of their research. The sciences began to return to larger and more universalistic perspectives from the middle of the 20th century as new unifying paradigms emerged in field after field, and physicists even began talking of 'Grand Unified Theories' of everything. New information and new dating techniques made it more reasonable than ever before to attempt scientifically grounded universal histories and such attempts began to reappear in the 1980s. But not until the first decade of the 21st century has that project really begun to take off.

The website of the International Big History Association defines Big History as 'the attempt to understand, in a unified, interdisciplinary way, the history of Cosmos, Earth, Life, and Humanity' (http://www.ibhanet.org/). It seems likely that most human societies have tried to construct unified histories that embrace all areas of knowledge. We often refer to these as creation myths or origin stories. Such stories, or cycles of stories, can be found within all religious traditions. They could even be found within the more secular intellectual traditions of Europe as late as the 19th century, within attempts such as those of Hegel or Marx to construct unified and coherent accounts of how the world had evolved to be as it was.

Origin stories are powerful precisely because they aim at a sort of completeness. They attempt to link all areas of knowledge into a more or less

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complete account of how things came to be as they are. The result of such projects is the creation of a sort of a map within which individuals and societies can identify their place in time and space, and to which they can tether their deepest intuitions and convictions about existence, meaning and ethics. Without origin stories, we are fated to live within a fragmented, endlessly shifting intellectual universe, deprived of the philosophical and ethical anchors of a more unified vision of how things came to be. We can think of Big History as a modern form of this ancient project. Big History returns in a sense to the old tradition of 'universal histories'.[1] What gives the idea such salience right now is the fact that universalist accounts of the past vanished from serious historical scholarship in the late 19th century. They have been absent from serious scholarship and teaching for over a century.

Instead, historical scholarship and teaching have been contained within more fragmented intellectual and institutional structures that divided the histories of humanity from those of the natural world, and divided the histories of humanity itself into multiple regional or national histories. Because these were normally based on written evidence, modern histories were also fractured by the presence or absence of literacy, so that they excluded large areas of human history for which no written evidence existed. Sharply focused scholarship of this kind appeared in field after field, in both the humanities and the natural sciences, and its achievements have been immense. Furthermore, there can be no doubt that scholars had good reasons to eschew the more grandiose visions of the 19th century universal histories, because in most fields of study, particularly in the humanities, the available information was too thin to discipline large speculative theories, so that all too often ideology overwhelmed hard fact. Social Darwinism was merely the most obvious expression of the dangers of attempting overly grandiose accounts of the past in an era of limited information and nationalist or imperialist ideologies.

But a lot has changed since then. Careful empirical scholarship within many different scholarly disciplines has generated vastly more information than was available late in the 19th century. And particularly in the natural sciences, scholars from different disciplines have begun once again to explore unified, inter-disciplinary accounts of the past. These accounts have been associated with the appearance of powerful paradigms within geology (plate tectonics), biology (the idea of natural selection reinforced by a modern understanding of genetic mechanisms), and – perhaps most spectacularly of all – in cosmology. Big Bang cosmology arose from a unification of nuclear physics (the study of the very small) and cosmology (the study of the very large). So powerful was the resulting synergy that cosmologists and physicists began to speculate quite

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[1] I have developed this argument more carefully in *The Return of Universal History* (Christian 2010).

seriously about the possibility of constructing 'grand unified theories', theories that would encapsulate most of physical reality within one grand account of how the Universe works.

The Humanities disciplines remain more fragmented. But the field of Big History is based on the assumption that the time may now have come even for historians to return to large, unifying questions about the past. One reason for saying this is that new dating techniques developed since the 1950s, beginning with C^{14} dating, have made it possible to construct chronologies embracing the whole of time. When H. G. Wells tried to construct a universal history, at a time when such projects were frowned on by professional historians, he had to concede that he had no reliable absolute dates reaching back more than a few thousand years, because absolute dates still relied on the presence of written evidence.

Today, we have a whole range of new techniques for dating events in the remote past, so we can construct reasonably precise absolute chronologies dating back, literally, to the origins of the Universe. Such chronologies allow us to form narratives of the Universe's history that run the gamut from cosmology to geology, to biology and, eventually, to human history. It is possible, as a result, to see human history not as something separate from the history of the Earth and biosphere but rather as a part of that larger history. This, of course, is a narrative that aligns very well with the growing awareness of the ecological embeddedness of human history that has evolved since the middle of the 20th century.

Another factor that may have encouraged more expansive accounts of the past is the sheer pace of globalization in the late 20th century, accompanied, as it has been in many fields of scholarship, by the creation of genuinely international communities of scholars. The rise of world history is one expression of a growing awareness among historians that, in a more globally interconnected world, global interconnections need to be taken very seriously indeed. No longer does it make sense to think that the history of each nation can be understood adequately without seeing how it is embedded within a wider world. Increasingly, world history is a project undertaken and shared by historians from many parts of the world; the 2011 conference of the American-based World History Association will meet in Beijing.

It may be that the extreme fragmentation of scholarship as it evolved since the late 19th century has generated a counter-reaction. There were, after all, good reasons for thinking that an over-rigid breaking up of knowledge into separate disciplines was philosophically incoherent. After all, the very idea of reason seemed to imply an underlying unity between all forms of knowledge. The alternative, after all, was to suppose that reality was itself criss-crossed by arbitrary epistemological chasms that made the knowledge of one discipline incoherent beyond that discipline's borders.

These may be some of the factors that explain why from the 1980s, scholars in a number of different specialist areas began attempting large, unified, and even 'universalist' accounts of the past. Interdisciplinary anthropologist Fred Spier has shown that modern attempts to return to some form of universal history, either in written works or in university courses, appeared from the 1980s within a number of disciplines, and mainly in the USA.[2] Scholars who attempted such syntheses included Preston Cloud, G. Siegfried Kutter and Eric Chaisson, while the first attempt to develop a modern *theory* of Big History was probably Erich Jantsch's *The Self-Organizing Universe*, published in 1980. From the late 1980s, several historians undertook similar projects, including John Mears and myself, both of whom began to teach undergraduate courses in Big History.

Like many other historians who have become interested in Big History, I came out of a traditional scholarly specialization, in my case Russian history. As an admirer of Fernand Braudel, I had always been interested both in the idea of material life as a sort of 'sub-stratum' to conventional historical scholarship and also in the closely related idea of the importance of the *longue durée*. And it was these questions that encouraged me to study Russian material life over long periods. But, over time, I began to wonder about the limits of Braudel's *longue durée*. After all, how *longue* is *longue*? If we learn something of value by surveying trends over many centuries, is it possible that we will learn even more if we stand even further back and attempt to survey the past at scales of millennia? This was, of course, a very slippery slope and once embarked on it, it did not take long to ask similar questions at scales of millions or even billions of years, scales that took me well beyond conventional historical scholarship and into the territory of biologists, geologists and, eventually, cosmologists.

I am not at all sure how typical this path to Big History was. In the early 1990s, the sociologist, Johan Goudsblom, and the biochemist and anthropologist, Fred Spier, began teaching a Big History course at the University of Amsterdam. Goudsblom had always been interested in the sociology of the *longue durée*, particularly as developed in the work of Norbert Elias. And Spier had long been struck by the way that pictures of the Earth from space suggested the importance of a more global and interdisciplinary vision of today's world. In 1996, Fred Spier published a pioneering attempt to theorize Big History in *The Structure of Big History: From the Big Bang until Today* (Spier 1996), in which he identified distinct 'regimes' within many different realms, from those studied within astronomy and geology to those studied within biology and the humanities.[3]

[2] See 'A Short History of Big History' in Fred Spier's *Big History and the Future of Humanity* (2010).

[3] In 2010 he published an expanded version of this work in *Big History and the Future of Humanity* (Spier 2010: 9–16).

In the natural sciences, in an environment increasingly friendly to the idea of grand unified theories, such projects may have seemed ambitious but not unreasonable. However, in the humanities, they were generally treated with deep suspicion. Even world history has had to fight for respectability within the history profession. The conventions that had created modern disciplinary boundaries, with their built-in career structures, criteria for judging success, journals and academies, proved remarkably powerful, and interdisciplinary scholarship remains extremely difficult. As E. O. Wilson pointed out in *Consilience*, a powerful plea for more inter-disciplinary study, the largest of these divides remains today where C. P. Snow found it in the 1950s, between the natural sciences and the humanities (Wilson 1998). Wilson argued that one of the main scholarly projects of the near future had to be the search for unifications that could cross this border, and integrate the human sciences more firmly within modern scientific scholarship as a whole.

Then, somewhat to the surprise of those committed to the project of Big History, in the first decade of the 21st century, these barriers began to fall. Barry Rodrigue and Daniel Stasko have tracked the rapid evolution of college level courses in Big History, and they have also compiled a substantial bibliography of published scholarship in the field (Rodrigue and Stasko 2010; Rodrigue and Spier 2010). In April 2011, a formal scholarly association was created to support scholarship and teaching in Big History: the International Big History Association. And just a month earlier, the 'Big History Project' was launched, which will build a free online high school syllabus in big history in order to try to develop Big History education in secondary schools.[4]

And what should the field be called? These various projects have attracted several different names, including 'cosmic evolution', 'the evolutionary epic', 'universal history' and 'Big History'. I first used the phrase, 'Big History' in an essay I wrote just three years after I started teaching a Big History course at Macquarie University in Sydney (Australia) (Christian 1991). I used it because it was simple, catchy, not too solemn, and seemed, by echoing the notion of the 'Big Bang', to capture something of the scale of the course I had begun to teach. The label has acquired broad currency particularly in the humanities, but other labels, such as 'cosmic evolution', may be preferred within the sciences. The labels do not matter too much. What is important is that we seem to find ourselves at a very exciting moment in the evolution of modern scholarship, one in which for the first time in over a century the project of constructing unified, coherent and scientific accounts of the whole of the past is back on the agenda again. Whatever we call the project, it holds the promise of re-creating, now on a firm scientific basis, the unified visions of reality that have

[4] See the IBHA web site at http://www.ibhanet.org/ and the Big History project web site at http://www.bighistoryproject.com/

been so powerful in most human societies. As E. O. Wilson argued in *Consilience*, there are immense intellectual synergies awaiting those who start bringing together the insights, the information, the methods and the paradigms of today's major scholarly traditions within a more coherent, less fragmented vision of our universe.

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2
Big History Research: A First Outline*

Fred Spier

Abstract

This contribution provides a first outline of how to define big history research, including an overview of the types of research that could profitably be undertaken. Practical issues are also discussed, such as how to obtain funding, where to publish the results and whether the research results might have practical applications. Because this contribution is, to my knowledge, the first attempt to outline big history research, my observations should be considered preliminary. I hope that they will stimulate a healthy and vigorous discussion about big history research, the one that will lead to formulating a big history research agenda that will successfully be pursued worldwide.

General Outline: What is Big History?

For a fruitful discussion of big history research we first need to address the question of what 'big history' is. In September 2010 a group of big historians defined big history as 'the attempt to understand, in a unified and interdisciplinary way, the history of the Cosmos, Earth, Life, and Humanity'. This joint formulation was a part of the effort in founding the International Big History Association (IBHA).[1]

The word 'unified' is extremely important, because it means that big history is more than the sum of its parts. This is by itself not at all exceptional. All academic fields are more than a sum of their parts. In other words, these fields exhibit a distinct type of complexity that legitimizes their existence. Usually this includes a theoretical approach that holds the promise to successfully tackle a set of research questions, questions which cannot be investigated equally successfully by looking only at the parts. This is very much the situation, for instance, in the fields of astronomy, geology and the social sciences, although in the latter case there is no consensus yet about core theories. But even if a disci-

* This essay has benefitted from insightful commentary by Jonathan Markley, Robert King, Esther Quaedackers, Barry Rodrigue and John de Vos.

[1] Big historians who took part in the discussion about how to define big history included: Walter Alvarez, Craig Benjamin, Cynthia Brown, Lowell Gustafson, David Christian, Barry Rodrigue and myself. These big historians constituted the provisional board of the International Big History Association. More about this may be found at the IBHA website: www.ibhanet.org.

pline does not yet have a shared general theory, the idea of employing a theory for mapping and explaining its field is usually not contested.

However, there are some exceptions within the walls of university life. The academic study of history as well as other branches of the humanities, such as the study of art and literature, have established themselves without a core theory and are very reluctant to use any such theories. This is usually explained by saying that these fields are too complex or subjective for any general theory to be useful. To be sure, individual humans, human societies, and their expressions, are among the most complex subjects that are studied in academia. However, it seems to me that the main reason of why these fields continue to exist without a core theory is that they are dealing with identities. Histories written by academics historians, for instance, are mostly local, regional and national in scope, while for the European Union members this now also involves the history of their nations within the context of European history. The academic histories about nations and regions outside of what is seen as one's own society often deal with the period that these societies began to interact with the own society. In fact, the interactions during such a period often helped to shape the identity of the society that performs these studies. Historical studies that do not bear any direct relation to the identity of the academics that produced them are actually rare. It seems to me that they form only a tiny minority of all academic histories.

Furthermore, the results of academic histories are sometimes meant for consumption by larger numbers of people that make up their own society. This especially pertains to the history taught at schools or shown in documentaries. In such situations, story-telling usually works the best. Yet there are limitations to story-telling. While the sources on which the story is based can be checked, it is not usually made explicit what the criteria were for deciding what to include in the story and what to omit, as well as how to tell the story. Sometimes even the research questions that led to the story may be unclear. As a result, many academic histories stimulate virtually endless discussions, which reinforce the impression that these objects of study are extremely complex.

Most, if not all, historical research tends therefore to be impressionistic in nature. It may have a central thesis, but it almost always lacks a core theory that could be used to structure and test such a theory. In other words, the traditional approach to history is not unified.[2] If this is an accurate description of academic history, one may wonder how we could possibly achieve a unified approach in big history, within which human history only constitutes a small sub-field.

Yet, if big history is to become fully-fledged academic field that includes research, big historians must be able to show how, and to what extent, big history is unified. In other words, what type of results could big history research

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[2] This is not at all a new point of view. In the 1960s, German sociologist Norbert Elias argued along these lines, first in German (1969) and later published in English (2005).

contribute that are both valuable and different from the results that are already being obtained within its sub-fields, most notably astronomy, geology, biology, climatology, archeology and human history? What is it that might unify big history and thus would legitimize a big history research agenda?

The Need for a Big History Theory

In my opinion, the unification of big history requires a viable theory, or a set of theories, that helps to structure, summarize and explain big history in a unifying way. If this sounds very abstract, let us consider some of the advantages that a core theory of big history might offer, if it could be found.

First of all, such a core theory would allow us to systematically structure the historical narrative along its theoretical lines. The theory would thus help to clarify why the story is told the way it is. It could also help to discover deficiencies, as well as to find indications for how our story could be improved. The theory could also illuminate in a systematic fashion why certain aspects were selected to become part of the story while others were omitted.

In the second place, a theory-driven approach to big history would make practitioners aware, in a systematic fashion, of important aspects that are missing. Furthermore, such a core theory could be applied to aspects of big history that have not systematically been examined yet. This also could include testing whether the core theory is applicable to these aspects. If the theory failed to be useful in such circumstances, even after a long and careful investigation, it would be in deep trouble. This type of research might therefore lead to a better understanding of both the research subject and its theory.

In the natural sciences, theories are often tested by predicting either the outcome of new experiments or the occurrence of certain phenomena. If these predictions fail, the theory may be in jeopardy. Because it is impossible to do systematic experiments while studying history, historians lack this predictive power. But that does not mean that theories of history cannot predict anything. Instead of predicting the outcome of experiments, or the ways natural processes have evolved, good theories of history should be able to help us predict the past of circumstances that have not yet been examined but may be similar, ranging from the development of galaxies to the ways human societies have changed over time. I encountered such examples during my research in Peru on religion and politics. For instance, a general theory about the emergence of early priesthood in human history helped to throw new light on the development of the early Inca state, while a general theory about the dynamics of the Catholic church that was developed for the Southern Netherlands allowed me to recognize similar processes in colonial Peru.[3]

[3] For my Peru research see Spier 1994.

If all of this is correct, big history research should to a considerable extent be based on an agenda that is driven by a core theory. This makes one wonder whether such a theory may already exist. Although a few proposals have been made, most recently in my book – *Big History and the Future of Humanity* (2010) – it seems fair to say that no consensus has emerged yet about such a core theory. But this does not mean that the goal of achieving such a synthesis is elusive. Until today, only very few academics have devoted time and energy to formulating such a theory. It may well be that, while the big history field expands, more scholars will make such efforts, which will more likely than not lead to the successful formulation of such a theory.

In Search of a Big History Theory

Let us now explore in very general terms how we might proceed in search of a big history theory. While looking for a unified view of big history, the first thing to do is to look for components of the theory that are shared by all aspects of history. For instance, in my big history theory, the main players are matter, energy, complexity and disorder, as well as favourable ('Goldilocks') circumstances. These aspects can be found in all historical studies.

In the second place, we could systematically compare certain portions of big history, such as the division of labor in human societies with what happens within and among biological cells. Such detailed comparisons are rarely made today, as a result of academic specialization.[4] We could look for similarities and difference, while we could also examine whether the current biological and social theories share certain aspects. If that were to be the case, we might be on our way to constructing a more general theory. We could then extend our comparison to lifeless objects such as galaxies and solar systems, and examine whether our theory is also relevant in those cases. If that did not happen, our theory would not be a general big history theory. Yet it might be applicable as a specific theory for certain levels of complexity with their associated emergent properties. But perhaps, while extending our comparisons, we might stumble into unexpected similarities that all these portions of big history share. If that were to be the case, we would be on our way to construct a theory of big history.

Let me now summarize my own approach, as outlined in chapter one of my book *The Structure of Big History* (1996). Then, I argued that a general theoretical framework for big history must be applicable to the entire range of phenomena that have occurred in cosmic history, from the smallest particles to the most complex configurations. As a result, we can expect that such a theory will exhibit, by necessity, a very high level of generality. This is very similar to the level of generality that currently exists in the natural sciences. For each lev-

[4] For such comparisons, for one of such exceptions see, *e.g.*, the contribution by Grinin, Korotayev, and Markov to this issue of the Almanac; see also Grinin, Markov, and Korotayev 2011.

el of emerging complexity we may well need additional theories, such as the theory of natural selection for life or plate tectonics for geology. Yet all these additional theories must fit within the general theory.

Finally, let us not forget that all the divisions that we see in big history, such as the distinction between life and non-living nature, are to some extent mental constructs invented by humans. However different these fields may be, they are never entirely unconnected or separated by unbridgeable abysses. For instance, although life is surely different from rocks or stars, they all consist of matter and energy, and thus share certain aspects. A similar argument can be made for all aspects of big history.

If all of this is correct, then the search for general principles outlining how big history works, and thus unifying and simplifying the entire story as much as possible, must stand out as a primary goal. A considerable part of big history research efforts must, therefore, be aimed at, or at least be connected to, the development of big history theories. These theories can then be utilized and tested while trying to find new, and better, answers to particular questions. This is similar to how currently biological research is linked to the theory of evolution; geological research to plate tectonics; and astronomical research to big bang cosmology. In our case, the general big history theory must overarch all of these specialized theories, which, in doing so, would become special cases of the general theory.

All of this may sound very ambitious. Yet this ambition is not new. It was already formulated by Alexander von Humboldt more than 150 years ago in the introduction to his series of books *Cosmos*, in which he tried to summarize all of nature and its history. Von Humboldt may not have succeeded at the time, but that does not mean that achieving such a synthesis is totally impossible. Baron von Humboldt was restricted in his efforts by the much more limited scientific knowledge about the past that existed at that time. Today, by contrast, we can build on more than 150 years of research into many different fields of history, which has yielded so many wonderful fruits, while we have virtually instant access to large portions of this knowledge, thanks to the emergence of the Internet. I think, therefore, that the time is now ripe to pick up this unfinished task and challenge each other to see whether we can do better.

Types of Big History Research

If the above thesis is correct, then the first and most important subject of big history research is:

1. Big 'big histories': exploration of big history theories.

This involves finding general patterns and mechanisms in big history that help us to understand it better, and thus explain it in more simple ways. Such research could be both descriptive (qualitative) and quantitative. All these studies could be undertaken in the form of interdisciplinary projects. All the theories employed must be connected to empirically observable reality. I see several areas of potential interest:

1a. Make an inventory of all the theories that have been used in large-scale approaches to history and select those that hold the greatest promise. Such decisions should always be open to revision. Yet, if we were able to agree temporarily on a common theoretical paradigm, or just on a few common principles, this would greatly strengthen our research position. If such decisions cannot be made, we must point out what the weaknesses are of the current theories, while seeking to develop new and better ones.

1b. Critically examine existing theories of big history. In the case of my big history theory, this would include refining the analysis of how energy flows through matter, while it is producing certain effects (in our personal case, how food is keeping us alive while enabling us to do the things that we do). This refinement is important, because the outflow of energy that can be seen as waste, from the point of view of the regime through which it is flowing (for example, our bodies), is often useful for other regimes. For instance, solar energy is a waste product for the Sun but high-quality energy for us in the form of energy captured by plants and transformed by animals. In addition, many microorganisms thrive on our waste products. In fact, the entire food pyramid can be considered in terms of such energy flows. This requires much more systematic attention.

1c. Systematically compare theories in different fields of big history, such as comparing the process of human collective learning with natural selection in biology, as suggested by David Christian. This may enrich both fields and, perhaps, also general big history theories.

2. Use big history theories and insights for interdisciplinary research projects.

Areas of interest might include:

2a. A research project based on my emerging theory of big history of combing the existing literature for numerical and descriptive data on matter and energy flows, the generation of entropy, and 'Goldilocks circumstances', all the way through big history and systematizing the results, in the hope that this will show the emergence of new unexpected patterns. I am convinced that a large amount of such data already exists, scattered throughout the academic literature. The results could also be used to improve the theory. Such a project would preferably include collaboration with US astrophysicist Eric Chaisson (Tufts University and Harvard University), who is the major pioneer in the field of energy flows in big history.

2b. Form small interdisciplinary big history teams, while dealing with specific problems. While considering the origin of humans, for instance, or our current situation concerning the use of natural resources, we could form teams with specialists from many different fields, including unusual choices such as cosmologists, psychologists, paleoanthropologists and cultural anthropologists, to see whether this would add extra value to the analysis. My strong suspicion is that in most cases there will be such an unexpected added value.

We should, however, not underestimate the extent to which such interdisciplinary efforts may already have started, most notably, perhaps, in System Earth science, including long-term climate studies. In all such cases, we should first carefully consider what has been achieved already before making any grand plans ourselves.

2c. One wonders whether there might be a role for big historians as research counselors for interdisciplinary projects of many kinds, including the business world, thus contributing our wide-ranging knowledge to provide unexpected, and hopefully productive, new angles on how to tackle certain more limited research questions. I have experienced such productive situations quite often in informal settings over the past fifteen years, during a great many meetings with scholars, ranging from astronomers to anthropologists. We may want to establish this on an institutional basis.

3. Little 'big histories'.

3a. Placing a certain research subjects within a big history perspective, preferably, but not always, all the way back to the big bang, and see whether this enriches our understanding of that particular subject. In the Netherlands, we require our students to do this during our big history courses.[5] They may pick any object of their choice, the history of which they must trace back all the way to the big bang. Their choices range from iPhones to 'my little brother because he is so funny'. Some students are puzzled in the beginning, but the great majority of them produce essays that are often enlightening and sometimes very entertaining. This approach clearly helps them to better understand both big history and their subject. I understand that this approach is going to be a major component of big history teaching at Dominican University in San Rafael, California (USA), where Cynthia Brown is the leading inspiration.

Little big histories are not only useful didactic tools but can also become serious research projects. The study by Jonathan Markley (2009) on the history of grass offers such an example. But more Little big histories exist, such as the book *Lima* (1992) by Juan Gunther Doering and Guillermo Lohmann Villena, which begins with a short explanation of how plate tectonics had formed the landscape on the Peruvian Pacific coast and how that had in turn influenced the entire ecology as well as its human habitation during all of its history. The work by Alfred Crosby on the Columbian exchange is a much better known example, which explains how plate tectonics led to the current configuration of continents, which deeply influenced the biological resources available to their inhabitants. Another recent example is British geologist Jan Zalasiewicz's book *The Planet in a Pebble: A Journey into Earth's Deep History* (2010), in which he traces

[5] For the Dutch big history courses, this idea was first proposed by Esther Quaedackers and Marcel Koonen. This idea emerged independently elsewhere also.

the history of one little pebble through the eons of time as part of changes of the environment it found itself in during its entire existence. This contribution provides a first outline of how to define big history research, including an overview of the types of research that could profitably be undertaken. Practical issues are also discussed, such as how to obtain funding, where to publish the results and whether the research results might have practical applications. Because this contribution is, to my knowledge, the first attempt to outline big history research, my observations should be considered preliminary. I hope that they will stimulate a healthy and vigorous discussion about big history research, the one that will lead to formulating a big history research agenda that will successfully be pursued worldwide.[6]

3b. It might be a good idea to make an inventory of the already-existing studies of this kind. I would not be surprised to find that many more such studies already do exist.

4. Study of the history of big history.

This could include the following research questions:

4a. How did our current big history field emerge? Who were important players and forerunners? In which ways has big history been used, and by whom?

4b. What have been the various approaches (theoretical, regional, thematic, style of narrative, *etc.*) to big history and how was their reception? How can we explain this?

4c. Have similar approaches to history also emerged elsewhere in the world?

5. Reinterpreting traditional origin stories from a big history perspective.

How and to what extent can we reinterpret origin stories of traditional cultures in the light of big history – by analyzing them as answers to big questions that people have posed in such societies? Why were some of these answers codified and are known to large numbers of people today, while many other origin stories became marginalized and were partially, or sometimes almost entirely, lost? What does this tell us about the history of both those societies and our own society?

Funding

How to obtain funding for big history research will, in all likelihood, very much depend on the type of big history research that is proposed. Because big history is not yet an established discipline, its practitioners will find it hard to apply for grants in established scientific organizations, because these are usually organ-

[6] Little big histories: Crosby (1972, 1986), Markley (2009), Zalasiewicz (2010), Doering and Lohmann Villena (1992); for a recent illuminating summary by Juan Gunther Doering see http://www.usmp.edu.pe/webingles/novedades/index.php?pag=ivuc.

ized along established academic lines. As a result, we must be creative in how to obtain funding and seek new venues, including perhaps wealthy sponsors, business corporations or other individuals and organizations willing to support big history research. Of course, we should try to apply for grants at established academic organizations also, if only to make clear that we exist and have a novel, and hopefully exciting, research agenda. The IBHA might serve as a major platform for promoting such a research agenda, for instance, by posting exciting research results on its website on dedicated research pages.

Perhaps, we could add a contact page on the IBHA website from where potential sponsors could send us a message showing interest in potentially supporting IBHA members' research proposals. A further dialogue might lead to productive forms of collaboration. Such a discussion would involve building and maintaining contacts with all these different types of sponsors. The IBHA members must be able to make very clear what type of research they want to undertake so that sponsors can decide whether it would be worthwhile for them to fund such types of big history research.

Doing the Research

Most, if not all, big history research should preferably be initiated and executed within universities and across disciplines, hopefully with a global orientation and participation, in the form of PhD projects and beyond. In addition to the research results, an important objective for this focus is to make sure that we train new generations of big historians. We should also look for opportunities to forge cooperation with business corporations or any other organization that may be interested in performing portions of the research.

An important outcome of the research should also be raising the profile of young talent, who hopefully may become eligible for big history university positions. In order to achieve such an objective, it is extremely important that such candidates also gain sufficient experience in teaching big history, because teaching is primarily what universities want their faculty to do.

All of this will involve building contacts with universities, independent academics and business corporations worldwide. The IBHA may help to foster such global contacts.

Reporting Results

We are basically starting from scratch, and thus have the opportunity to use the latest technology for reporting our research results. However, we should not ignore the existing ways of reporting them either. More traditional venues for reporting research results include established academic journals and books. In addition, the IBHA is planning to start its own journal, which may become a place where big history research is reported.

But we may also consider other options, most notably the IBHA web site. It might very much enhance spreading the results of big history research and scholarship, if we could place at least the summaries of our results on the IBHA web site on dedicated pages. This would be very effective in spreading such knowledge worldwide and may attract potential sponsors, especially when we indicate very clearly who had sponsored successful types of big history research.

All of this will involve building contacts with publishers as well as constructing a big history research section on our web site. Furthermore, we would promote big history research at conferences, both the IBHA conferences and panels during other conferences that we find appropriate. This will involve organizing such panels as well as obtaining the necessary funding.

In addition, we may consider presenting the results of big history research via Internet media such as Twitter and Facebook, online video sites and audio presentations, as well as encouraging interactions with interested persons and organizations, through Skype or similar channels. And, more likely than not, there may be a great many other options on the Internet that may evolve somewhere in the near future. All of this will involve a continuing exploration of new media. I see this as particularly important.

Practical Applications

Many sciences have practical applications. One may wonder, therefore, to what extent big history might also offer more than only general insights into how things have gone the way they went. While it is often said that history repeats itself, it remains difficult to draw clear lessons from history. But, perhaps, our more general theories, if we can find them, might come to the rescue. Perhaps, we will be able to offer more than impressionistic insights. Perhaps, we will uncover mechanisms in history that may help people to make better decisions in specific situations in daily life. If we could achieve such results, it would represent a major added value to our research projects. As always, the proof of the pudding will be in the eating. Right now, we have barely begun preparing the pudding of big history research. Let us start doing that first and then decide how it tastes.

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3
Cosmic Evolution – More Than Big History by Another Name

Eric J. Chaisson

Abstract

Evolution – ascent with change of Nature's many varied systems – has become a powerful unifying concept throughout the sciences. In its broadest sense, cosmic evolution, which includes the subject of big history, comprises a holistic explanatory narrative of countless changes within and among organized systems extending from the big bang to humankind. This interdisciplinary scenario has the potential to unite physical, biological, and social sciences, thereby creating for people of all cultures at the start of the new millennium a consistent, objective, and comprehensive worldview of material reality.

Historians

A few years ago, while having lunch in the Harvard Faculty Club with a group of science colleagues, I overheard a dispute among scholars at the table next to us. Several famous historians were squabbling about a frivolous territorial issue in their ancient and honorable discipline: Who studies history further back in time? The Greco-Roman expert maintained that the roots of his subject went way back, at least several thousand years. The Egyptian scholar argued that her studies involved events that were surely older, perhaps predating those of ancient Greece by a thousand years or more. And the Sumerian specialist tried to trump them all by claiming that his subject starts even earlier, maybe as long ago as 7000 years.

As they heatedly volleyed their arguments back and forth with growing indigestion, I could not resist interrupting the historians – an intrusion they did not appreciate, for what right did I, as a scientist, have to say anything of use or interest to them. When I asserted, as an astrophysicist who looks out into space and thus back into time, that I was a 'real historian' whose studies extend into the past to nearly the beginning of time some 14,000,000,000 years ago, they became visibly upset. Their statements had been rendered nonsense, their subject matter reduced to minutia in the larger scheme of all history. At least one of those distinguished historians has not spoken to me since.

Big Historians

The recent onset of the new and exciting subject of big history has brought forth an outgoing and refreshing breed of historical scholars. Their stories are inspiring, their outlook is uncommonly broad, and their attitudes open to new ideas, big ideas, indeed ideas central to fields well beyond their own. Big historians are helping to show that history writ large comprises many, diverse, yet related events that transpired well before those of recorded history, often extending back virtually to the beginning of time. This is not to say that I concur with all the words and assertions of the big historians. As a natural scientist, I often experience a mild reaction to their subjective inquiry, indeed I have been trained in quite different methods of scholarship that emphasize objectivity. My scientific work needs to be confirmed with empirical data, or at least be based on statements that are experimentally or observationally testable. Skepticism and validation are my central dogmas.

Nonetheless, it is easy for me to admire the emergence of Big History, whose practitioners are willing and able to cross disciplinary boundaries and whose subject name is simple, clear, and unpretentious. By studying past events that gave rise to humanity on Earth, indeed to Earth itself among the stars and galaxies, big historians naturally address Nature; to be sure, big history was once historically called just that – natural history, which is usually defined as 'the study of natural objects and their evolution, origins, description, and interrelationships'. And since I have always regarded natural history expansively as a long and continuous narrative from the early Universe to the present time, not only incorporating the origin and evolution of a wide spectrum of systems and structures but also connecting many of them within an overarching intellectual framework, it is intuitive for me to relate favorably to their important work.

That said, even big historians' work is limited. Big History, as most often defined – 'human history in its wider context' (Christian 2004) or 'an approach to history that places human history within the context of cosmic history' (Spier 2010) – pertains mostly to the meandering cosmic trek that led specifically to us on Earth. As such, it mainly concerns, in reverse order of appearance, changes that led to humankind, the Earth, the Sun, and the Milky Way Galaxy. Scant treatment is given, or need be given, to other galaxies, stars, or planets throughout the almost unimaginably vast Universe, for the goal of Big History is to place humanity itself into a larger cosmic perspective. Furthermore, big historians especially need not be burdened with claims of multiple universes on macro-scales unimaginably larger than even those conceived by most physicists today, or of string theory and extra dimensions on micro-scales fully twenty orders of magnitude smaller than anything we can now measure – least of all that we and everything around us are cyberspace avatars in an alien computer simulation running an infinity of parallel worlds and implying that all possible histories conceivable are occurring somewhere, and maybe even everywhere an infinite number of times – none of which mathematical notions currently have any empirically supporting evidence whatsoever (Penrose 2010; Greene 2011).

In declaring these caveats, I wish neither to belittle Big History nor to critique those colleagues who prefer to speculate about the life and times of meta-events beyond the confines of our 14-billion-year-old Universe. Rather, I seek to make clear that most natural scientists still embrace the definition that 'the Universe is all that there is: the totality of all known or supposed objects and phenomena, formerly existing, now present, or to come, taken as a whole', and to suggest that if big historians are to make headway, indeed to be accepted by traditional historians, they ought to ground their research agenda on empirical facts and tested ideas, where possible, and to focus their subject matter on the role of humanity in the one and only Universe we know.

Cosmic Evolution

Big History is not new, although one might not realize it by reading its current (March 2011) Wikipedia entry; the impression given is that this subject was invented hardly 20 years ago by traditional historians who began realizing that history actually reached well back beyond the onset of civilization. Broad, interdisciplinary explications of natural history have been researched and taught by natural philosophers since Renaissance times, and the specific big-bang-to-humankind story of special interest to big historians has been championed in recent decades largely by cosmologists, who arguably think more broadly than anyone else on Earth. It is the latter astronomers, who in modern times have christened their subject 'cosmic evolution', but which is alternatively known within various academic disciplines as macroevolution, universal history, and the epic of evolution. (My original, qualitative book exposition Chaisson 1981, was updated in 2006 and made quantitative in 2001; a recent readable summary and a technical review can be found at 2009a and 2009b, respectively – all referenced at the end of this paper.[1])

Cosmic evolution is the study of the sum total of the many varied developmental and generational changes in the assembly and composition of radiation, matter, and life throughout the history of the Universe. These are the physical, biological, and cultural changes that have generally produced galaxies, stars, planets, and life-forms – specifically, regarding Big History and its more limited coverage, the Milky Way, Sun, Earth, and life on our planet, especially human life. The result is an inclusive evolutionary synthesis bridging a wide variety of scientific specialties – physics, astronomy, geology, chemistry, biology, and anthropology – a genuine scientific narrative of epic proportions extending from the beginning of time to the present, from the big bang to humankind.

Nor is the general study of change itself new; its essence extends back at least 25 centuries when the philosopher Heraclitus arguably made the best observation ever while noting that 'everything flows ... nothing stays'. This remarkably simple idea is now essentially confirmed by modern scientific reasoning and much supporting data – indeed the notion that change is ubiquitous in Nature is at the heart of cosmic evolution. Other researchers have addressed life and complexity in a cosmic setting, among them Chambers (1844), who anonymously wrote a pre-Darwinian tome of wide interdisciplinary insight, and

[1] Most of my recent journal publications including those in the Reference can be downloaded from my research page: http://www.tufts.edu/as/wright_center/eric/ericrsrch.html.

Shapley (1930), who pioneered 'cosmography' that classified all known structures according to increasing dimensions. Spencer (1896) also broached the idea of growing complexity in biological and cultural evolution, Henderson (1913) regarded the whole evolutionary process, both physical and biological, as one and the same, Whitehead (1925) sought to broaden scientific thinking with his 'organic philosophy', von Bertalanffy (1968) championed a systems theoretic approach to physical, biological, and social studies, and Shklovskii and Sagan (1966) popularized the idea of intelligent life in the cosmos. Later in the 20th century, several independent efforts came forth virtually simultaneously, as Sagan (1980), Jantsch (1980), Reeves (1981), and Chaisson (1981) all advanced the idea of complex systems naturally emerging with the pace of natural history.

Fig. 1 sketches Nature's different kinds of evolution atop the so-called 'arrow of time'. These three evolutionary subsets constitute the whole of cosmic evolution: physical evolution → biological evolution → cultural evolution, each describing how, in turn, 'islands' of growing complexity emerged to become ordered systems, whether massive stars, colorful flowers, or busy cities. Regardless of its shape or orientation, such an arrow symbolizes the *sequence* of events that have changed systems from simplicity to complexity, from inorganic to organic, from chaos in the early Universe to order more recently. That sequence accords well with a long and impressive chain of knowledge linking seven major epochs in time – particulate, galactic, stellar, planetary, chemical, biological, and cultural – wherein each changed chronologically:

- elementary particles into atoms,
- atoms into galaxies and stars,
- stars into heavy elements,
- elements into organic molecules,
- molecules into life,
- life into intelligence,
- intelligence into cultured and technological civilization.

Despite the extreme specialization of modern science, evolution marks no disciplinary boundaries; cosmic evolution is a truly interdisciplinary topic. Accordingly, the most familiar kind of evolution – biological evolution, or neo-Darwinism – is just one, albeit important, subset of a broader evolutionary scenario stretching across all of space and all of time. In short, what Darwinian change does for plants and animals, cosmic evolution aspires to do for all things. And if Darwinism created a revolution in understanding by helping to free us from the anthropocentric belief that humans differ from other life-forms on our planet, then cosmic evolution extends that intellectual revolution by treating matter on Earth and in our bodies no differently from that in the stars and galaxies far beyond.

Anthropocentrism is neither intended nor implied by the arrow of time; the arrow is not pointing at humankind. Anthropic principles notwithstanding, no logic supports the idea that the Universe was conceived in order to produce specifically us. Humans are not the pinnacle or culmination of the cosmic-evolutionary scenario, nor are we likely the only technologically competent beings that have emerged in the organically rich Universe. The arrow merely provides an archetypal symbol, artistically conveying the creation of increasingly complex structures, from spiral galaxies to rocky planets to thinking beings.

Note, finally, that time's arrow does not imply that primitive, ‘lower’ life-forms have biologically changed directly into advanced, ‘higher’ organisms, any more than galaxies have physically changed into stars, or stars into planets. Rather, with time – much time – the environmental conditions suitable for spawning simple life eventually changed into those favoring the biological origin and evolution of more complex species. Likewise, in the earlier Universe, the physical evolution of environments ripe for galactic formation eventually gave way more recently to conditions conducive to stellar and planetary formation. And now, at least on Earth, cultural evolution dominates, since our local biospheric environment has once more changed to foster robust, societal complexity. Change in surrounding environments usually precedes change in organized systems, and the resulting changes for those systems selected to endure in Nature have *generally* been toward greater amounts of diverse order and inherent complexity.

Cosmic Evolution

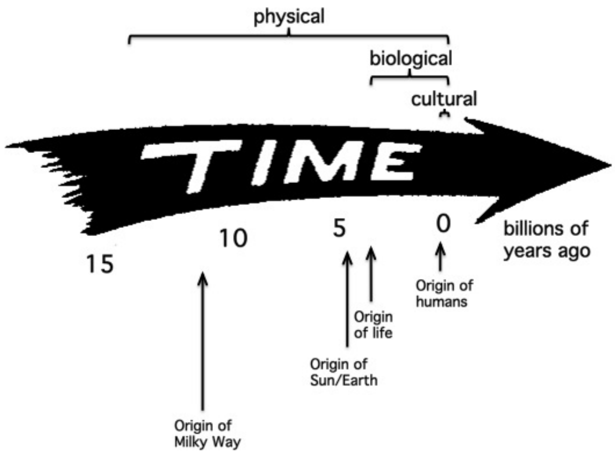

Fig. 1. An arrow of time symbolically chronicles the principal epochs of cosmic history, from the beginning of the Universe ~14 billion years ago (at left) to the present (at right). Labeled across the top are three major types of evolution (physical, biological, and cultural) that have produced, in turn, increasing amounts of order and complexity among material systems observed in the Universe. Cosmic evolution, as a general and inclusive term, comprises all of these subset evolutionary types and temporal phases

Energy Flows and Complexity Rises

Of special interest to big historians are the origin and evolution of the many diverse systems spanning the Universe today, notably those that sequentially and eventually gave rise to humanity on Earth. Particularly intriguing is the increase in complexity of those systems over the course of time, indeed dramatically so (with some exceptions) within the past half-billion years since the Cambrian period on our planet. Both theory and experiment, as well as computer modeling, suggest that islands of increasingly ordered complexity – namely, open, non-equilibrium systems that mainly include galaxies, stars, planets, and life-forms – are numerically more than balanced by great seas of growing disorder elsewhere in the environments beyond those systems. All emergent systems engaged in the cosmic-evolutionary scenario agree quantitatively with the valued principles of thermodynamics, especially its entropy-based 2^{nd} law (Chaisson 2001). Yet what has caused the emergence of systems and their rise in complexity over time, from the early Universe to the present? Is there an underlying principle, general law, or ongoing process that creates, organizes, and maintains all complex structures in the Universe?

Briefly stated and while keeping technicality minimized, I have suggested for at least a quarter-century that energy flows are at the heart of the cosmic-evolutionary story (Chaisson 1987, 2001, 2004). In particular, specific energy flow (*i.e.* energy rate per unit mass) constitutes a useful complexity metric and potential evolutionary driver for all constructive events throughout universal history. Energy does seem to be a common currency among all such ordered structures; whether living or not, all complex systems acquire, store, and express energy. Energy flow may well be the most unifying process in all of science, helping to provide a cogent explanation for the onset, existence, and complexification of a whole array of systems – notably, how they emerge, mature, and terminate during individual lifetimes as well as across multiple generations.

The chosen metric, however, can be neither energy alone nor even merely energy flow. Life on Earth is surely more complex than any star or galaxy, yet the latter utilize much more total energy than anything now alive on our planet. Accordingly, I have normalized energy flows in complex systems by their inherent mass, thus better enabling more uniform analysis while allowing effective comparison between and among virtually every kind of system encountered in Nature. This, then, has been and continues to be my principal working hypothesis in cosmic evolution: mass-normalized energy flow, termed energy rate density and denoted by Φ_m, is possibly the most universal process capable of building structures, evolving systems, and creating complexity throughout the Universe (Chaisson 2003).

Fig. 2 summarizes much recent research on this subject (Chaisson 2010, 2011), depicting how physical, biological, and cultural evolution over ~14 billion years have changed simple primordial matter into increasingly intricate and complex structures. (For specific power units of W/kg, divide by 10^4.) Values plotted are typical for the general category to which each system belongs, yet as with any eclectic, unifying theme in an imperfect Universe – especially one like cosmic evolution that aspires to address all of Nature – there are variations. And it is likely that from those variations arose the great diversity among complex, evolving systems everywhere.

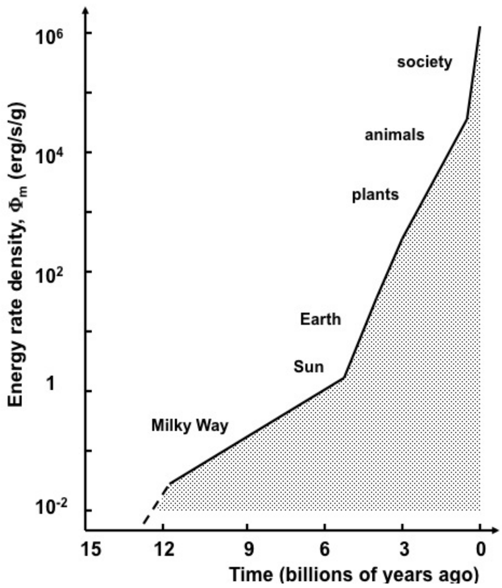

Fig. 2. Energy rate densities, Φ_m, for some complex systems of special interest to big historians, plotted here semi-logarithmically at the time of their origin, display a clear increase during the ~14 billion-year history of the Universe. The shaded area includes an immense array of changing Φ_m values as myriad systems evolved and complexified (data are from Chaisson 2010, 2011, and 2012)

Following the graphed trend in Fig. 2, which addresses complex systems of greatest interest to big historians concerned with the specific evolutionary path that likely led to our human society, I have found systematic increases in the energy rate density (expressed here in the metric units of erg/s/g, evaluated against time in billions, millions, and thousands of years ago, Gya, Mya, and kya, respectively).

Within physical evolution:

- The Milky Way Galaxy evolved from protogalactic blobs > 12 Gya ($\Phi_m \approx$ $\approx 10^{-3}$ erg/s/g), which became widespread dwarf galaxies (~10^{-2}), then a mature, normal galaxy ~10 Gya (~0.05), and currently our galaxy's present state (~0.1).
- The Sun evolved from a protostar ~5 Gya ($\Phi_m \approx 1$ erg/s/g) to become a main-sequence star currently (~2), and will continue evolving to subgiant status ~6 Gya in the future (~4), eventually terminating as an aged red-giant star (~10^2).

Within biological evolution:

- Plants evolved from microscopic protists > 470 Mya ($\Phi_m \approx 10^3$ erg/s/g), to seedy gymnosperms ~350 Mya (~5×10^3), to flowering angiosperms ~125 Mya (~7×10^3), and to highly efficient C_4 plants ~30 Mya (~10^4).
- Animals evolved from fish and amphibians 370–500 Mya ($\Phi_m \approx$ $\approx 4\times10^3$), to cold-blooded reptiles ~320 Mya (~3×10^3), to warm-blooded mammals ~200 Mya (~4×10^4), and to flying birds ~125 Mya (~9×10^4).

Within cultural evolution:

- Human society evolved from hunter-gatherers ~300 kya ($\Phi_m \approx 4\times10^4$ erg/s/g), to agriculturists ~10 kya (~10^5), to industrialists ~200 ya (~5×10^5), and to technologists of today (~2×10^6).
- Machines evolved from primitive devices ~150 ya ($\Phi_m \approx 10^5$ erg/s/g), to the invention of automobiles ~100 ya (~10^6), to the development of airplanes ~50 ya (~10^7), and to modern jet aircraft and their computers (~5×10^7).

Or, for those readers who prefer words devoid of numbers, a simple 'translation' of the above technical summary suggests a ranked order of increasingly complex systems across the many successive phases of cosmic evolution:

- mature galaxies are more complex than their dwarf predecessors;
- red-giant stars are more complex than their main-sequence counterparts;
- eukaryotes are more complex than prokaryotes;
- plants are more complex than protists;
- animals are more complex than plants;
- mammals are more complex than reptiles;
- brains are more complex than bodies;
- society is more complex than individual humans;
- machines are more complex than societies.

Better metrics than energy rate density may well describe each of the system categories within the more restricted domains of physical, biological, and cultural evolution that combine to create the greater whole of cosmic evolution, but no other single metric seems capable of uniformly describing them all. The significance of plotting on a single graph one quantity for such an enormously wide range of systems observed in Nature should not be overlooked.

I am unaware of any other single quantity (Φ_m) that can characterize so extensively and uniformly so many varied complex systems spanning ~20 orders of magnitude in spatial dimension and nearly as many in time.

What seems inherently attractive is that energy flow as a universal process helps suppress entropy within increasingly ordered, localized systems evolving amidst increasingly disordered, wider environments, indeed a process that arguably governed the emergence and maturity of our galaxy, our star, our planet, and ourselves. If correct, energy itself is the mechanism of change in the expanding Universe. And energy rate density is an unambiguous, objective measure of energy flow enabling us to gauge all complex systems in like manner, as well as to examine how over the course of time some systems evolved to command energy and survive, while others apparently could not and did not. The optimization of such energy flows might well act as the motor of evolution broadly conceived, thereby affecting each of cosmic evolution's subset domains of physical, biological, and cultural evolution.

Teaching Cosmic Evolution

My philosophy of approach firmly grounds my research in empiricism, mines data from a wealth of observations, and aims to synthesize history in a seamless story that unifies much of what is actually known to exist in Nature. Fig. 2 contains a huge amount of data, computations, and modeling, summarizing many years of effort to interpret, at a quantitative level, my original exposition of the modern cosmic-evolutionary scenario (Chaisson 1981). Cosmic evolution has become a natural way for me to cross stultifying academic boundaries and to understand – at some level, in chronological order, and in a unified way – many of the complex, organized systems in the known Universe. To be honest, it has been a personal intellectual journey to learn about who I am and whence I came.

My interests in interdisciplinary science are deeply rooted in my earlier career, extending back several decades when I first arrived as a student at Harvard. It was then that I aimed to enroll in the course that I had always wanted to take, but found that it did not exist. I was seeking a broad survey course that cut across the boundaries of all the natural sciences, not only because I was unsure which of the sciences I might like later to study in depth but also because I was personally seeking an overarching, integrated worldview. I was eager to make sense of all that I saw around me in the air, land, sea, and sky, and I was especially struggling to place myself into the big picture of Nature writ large.

Sadly, nearly everyone I met 40 years ago – much as still the case today – was into 'their own thing'. Peers studied narrow disciplines, faculty researched specialized domains, and few people showed much interest in others' fields of knowledge. That universities are so lacking in universal learning and teaching was my biggest disappointment at the time, and still is. There had been a few earlier exceptions: Observatory director Harlow Shapley had taught a wide survey on 'cosmography' from the 1920s to the 1950s, and (my predecessor) Carl Sagan had taught 'life in the universe' to big crowds in the 1960s; but by the time I arrived as a student, Shapley was dead, Sagan banished, and the broad course I sought was nowhere to be found in the Harvard curriculum.

Less than a decade later, when I was appointed to the Harvard faculty in the mid-1970s, I was fortunate to be able to co-(re)create that broad survey course along with a senior professor, George Field, who had also long wanted to teach the sciences in integrated fashion. We called the course 'cosmic evolution' and we resolved to make it intentionally 'a mile wide and an inch deep', regardless of expected criticism. This would be a true survey of the sciences from big bang to humankind – an interdisciplinary sweep across physics, astronomy, geology, chemistry and biology, with social studies included as well. We were unsure if any students would show up.

Within three years, Cosmic Evolution had become the largest science course on the Harvard campus, limited only by the fire codes of the biggest lecture hall. Its immediate acceptance and rapid growth were partly due to our having taken the art of teaching seriously, but mostly because students 'voted with their feet'. When asked, the students were quick to reply that they, too, were seeking the bigger picture – trying to grasp a larger perspective of all else studied at college, and especially trying to create for themselves a grand system of understanding.

I have now taught cosmic evolution at Harvard for 28 of the past 35 years since its creation, almost all of those years (as now) alone. For the first few years, I imported many guest speakers, including Steve Jay Gould, E. O. Wilson, George Wald, and several other experts outside my own expertise of physical science. The guest talks were fine as individual appearances, but together they lacked educational continuity. So, when I received a Sloan Fellowship in the 1980s, I surprised my colleagues by using those funds to take a year's leave to learn for myself all the science needed to teach the epic myself. Solo teaching of the course has led to much greater satisfaction personally as it has forced me to keep abreast of advances in a wide spectrum of subject areas; and it has provided much richer pedagogy and continuity for attending students by having a single person present the bulk of the course content. This course's syllabus and multi-media web site are freely accessible: http://www.tufts.edu/as/wright_center/cosmic_evolution.

A few years ago, after many unsuccessful attempts to inaugurate a course in cosmic evolution at Tufts University (owing to the usual turf battles with specialized faculty members), I finally succeeded while co-conspiring with a senior scientist, David Walt, provided that the course was team-taught by representatives from each of the science departments. Today, 'From the Big Bang to Humankind' is a popular offering at Tufts, where I co-teach it with an organic chemist, glacial geologist, developmental biologist, and cultural anthropologist. Such a team effort does lack educational continuity from speaker to speaker, but its decided advantage is that students meet a variety of leading researchers, each of whom has substantial expertise in their respective disciplines.

Our principal reason for creating this broad survey course at Tufts is that a distinct minority of students there studies natural science. Although about a third of incoming freshman each year indicates intent to major in math/science, less than 10 % graduate with a degree in it. It is not much different on many college campuses across the nation – Americans are opting out of science in droves. My contention has been – to the distress of many colleagues – that the science faculty is the main problem here. Blame need not be placed on elementary-school teachers or high-school curricula; rather, it is more likely that college professors, having shirked our duties to teach well, to teach broadly, indeed often to teach at all at the introductory level, have abrogated our responsibilities to disseminate the excitement and enthusiasm that we have for our subjects.

Even so, the hope was that such a survey that sweepingly integrates many science disciplines would renew student interest in science – and it most certainly has. The numbers are rising, the students once again voting with their feet. And they are very much inspired by the big picture, as witnessed this past semester when, after one of my lectures, a young woman paid me high tribute while remarking with tears in her eyes, 'Thank you for helping me remember the love I once had for science'. That is the kind of sentiment that makes teaching this stuff for 35 years worthwhile!

Summary

The subject of cosmic evolution has been at the core of my entire academic career. It is the only thing I know – yet fortunately it includes vast facts, ideas, and implications. As I built the course at Harvard over decades (along with its extensive suite of online-supporting materials), my scholarly research agenda gradually shifted from mainstream astrophysics to fully embrace this interdisciplinary topic, and the science-education program that I direct at Tufts' Wright Center has adopted it as our intellectual theme. What started out as a search for a single course by a wandering student displaying hardly more than persistent curiosity became a life-long pursuit to understand our world, our universe, and ourselves.

Even after decades of researching, teaching, and writing about the epic of evolution, I am still unsure if I know who I am or how I really fit into the larger scheme of things. But I have found a lifetime of satisfaction exploring the general theme of cosmic evolution, publishing quantitative science to bolster the big-bang-to-humankind story, and especially sharing the details, excitement, and significance of that awesome story with countless people eager to discover their own worldviews. It has been, for me, the best of all scholarly endeavors: I have selfishly sought to know myself, yet in the process I have apparently helped myriad others to explore themselves and their sense of place in the amazing cosmos.

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4
Big History and the End of History

Alexander Mirkovic

Abstract

I situate Big History in the context of the rise of religious fundamentalism in the last twenty years. While Francis Fukuyama in his 'The End of History' (1989) argued that the end of the Cold War would produce the end of grand narratives, the triumph of democracy, and liberal capitalism, in reality the world saw a resurgence of religious fundamentalism orchestrating a resolute attack on science and thereby coming into conflict with Big History. I argue that Big History emerged in opposition to the resurgent and often politically sustained religious fundamentalism. This oppositional stance presents some dangers for Big History. For example, the concept of modern creation myth, while useful in the debate with religious fundamentalism, hides the true character of Big History. Big History should not endorse the once fashionable triumphalism of science. As Thomas Kuhn warned, science goes through paradigm shifts and is not immune to shift in power/knowledge relations. I argue for understanding of Big History as a branch of history of science. The strength of science is that it is able to change and survive a paradigm shift. I also point out some inconsistencies in the fundamentalist challenges to Big History. While fundamentalists reject the human evolution, they also advocate the ideal of ever-increasing economic prosperity extending into the limitless future. This question of the future is something to which Big Historians do not pay enough attention. In this context I also call attention to Peak Oil theories. If some of the predictions made by Peak Oil 'doomers' were to come true, major chapters of Big History would need to be re-written. Big Historians should, in my opinion, analyze seriously various kinds of possible futures. Future, ironically, is also a major part of the map of time.

One thing I like the most about history is that it puts everything in a perspective, a historical perspective. As a historian, I noticed that I look at things differently than the majority of non-historians. Take most trivial examples, when I shop for chocolate, coffee, or sausages, I wonder, what are the historical origins of this particular brand? What ingredients were put into it, where did they come from, and what is their history? Why should it be different with Big History? Can we put Big History also in the historical context? I believe we can.

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The context that we need to put Big History in is the end of the bipolar world represented by the Cold War and the triumph of global neo-liberalism as the only (remaining) collectively accepted grand narrative of history. In other words, if the Cold War era was a period when two grand narratives struggled, Karl Marx' grand narrative with Adam Smith's grand narrative, the post-Cold War era witnessed the end of the Marxist grand narrative and the triumph of liberal capitalism, the dominant economic doctrine of globalization and financial capitalism. At least, this was what Francis Fukuyama's famous article 'The End of History' announced in 1989. According to Fukuyama, once there were conflicting paradigms, but now the neo-liberalism paradigm has won. What happened in reality was something quite different and that requires to be put in a historical context, especially if Big Historians would like to avoid the triumphalism of Fukuyama and its consequences.

The end of the Cold War brought about many surprises. With the end of Soviet Marxism, we were led to believe that what triumphed at the end of the Cold War was the idea of progress achieved through democracy and free market competition, the victory of evolution over revolution, victory of Darwin over Marx, and the victory of Jefferson over the dictatorship of the proletariat. Again this was what Francis Fukuyama promised in his 1989 essay, 'The End of History'. While we were promised the triumph of the liberal ideas and ideals, what actually happened in the two decades following the fall of the Berlin Wall was the reactionary backlash, comparable to the Age of Reaction after the Napoleonic Wars. There was a resurgence of religious fundamentalism, which assumed a distinctly conservative, even a reactionary form. This post-communist religious fundamentalism attempted not only to counter the effects of Soviet official atheism, and the general indifference toward religion in the West, but also to roll back modern scientific achievements. This conservative moment was not just another religious revival such as many similar movements that the Western world experienced occasionally, movements which tried to rekindle popular interest in religion. The movement was global and its effects dramatic as it wanted to roll-back the clock of secular modernism (Marty and Appleby 1997: 1). For example, religion dramatically increased its appeal in the Islamic world. It also revived in the post-communist countries, as exemplified by the quick rebuilding of the Moscow's Christ the Saviour Cathedral in the 1990s, previously dynamited by Stalin in 1931. Most importantly, there was a religious revival in the Anglo-American world and this is important because of this worlds' global economic and cultural preponderance. All of these religious movements attacked classical Western secular and liberal values formed during the Enlightenment. It should be noted that these values were guarded carefully by both the Capitalist West and the Socialist East even during the Cold War period. Ironically, during the Cold War both the East and the West saw themselves as 'modernizing' political forces, advocating different paths, but having the same goal of modernization in mind (Huntington 1998: 19–21). However, this changed, and after 1989, like never before, many Anglo-American politicians felt that the fall of communism was an apocalyptic moment. Not only was it the triumph of democracy *vs.* dictatorship, or of free market *vs.* controlled economy. It was a triumph of good *versus* evil and God *versus* the Devil. Guided by these apocalyptic ideas so common among Anglo-American fundamentalists, and propelled by the ever increasing power of the radical right, many politicians stepped into the scientific debate over the details and mechanisms of the evolutionary process, arguing over human, cosmic, and social evolution. In particular, the main target was the idea of human evolution, what we commonly call Darwinism. After a century or more of scientific debates on the human evolution, and comparably long debates on the cosmic evolution, suddenly politicians wanted to force scientists to treat creationism and intelligent design as legitimate scientific theories. One of the way to exert political pressures on the scientific community was to attach the so-called intelligent design amendments to various pieces of legislation. For example, the Santorum amendment to the 'No Child Left behind Bill' of 2001 was interpreted as a federal requirement to teach the opposing view, both the evolutionary account and the so-called scientific creationism.

The main purpose of this paper is to analyze the Big History in the context of resurgent religious fundamentalism in the Anglo-American world. Not all aspects of Big History are equally challenged by religious fundamentalists. Cosmic evolution is the least problematic. Geology and earth formation are a bit more controversial; biological and human evolution even more. The most controversial is social evolution, since Fukuyama and his followers advocated the abolition of all paradigms not compatible with notions economic liberties. Therefore, in the following pages I will review these controversies, beginning with the cosmic evolution and astronomy, continuing with geology and Earth formation, then with biology and the theory of evolution, and finally concluding with the social evolution of humankind. When this is accomplished, I will look into the future, focusing on the ideas of possible futures which in most accounts of Big History are given as an appendage. However, some methodological remarks are due in the beginning.

Postmodernism, with its rejection of the objective truth and arguing that the scientific narrative was just another meta-narrative, unwittingly, unlocked the door for the onslaught of reactionary religious fundamentalism. This was especially ironic because many practitioners of philosophical postmodernism were not favorably inclined toward either religion or free-market capitalism and were generally located on the political left. Post-modernists were considerably surprised and enraged when Fukuyama and other neo-conservatives announced the end of history, or as I would put it here, the end of competing paradigms in history (Derrida 1994: ix). For postmodernists, the religious narratives of origins were just another example of culturally constructed grand narratives, whose purpose was not to be true or false, but 'to establish powerful, pervasive, and long-lasting moods and motivations in men' (Geertz 1993: 93). Yet, with their highly original works, the postmodernists managed to dethrone many modern sciences from the politically advantageous position of philosophical objectivity. Anglo-American politicians were quick to exploit this weakness of modern sciences, by cleverly arguing that human evolution is 'just a theory' or as Thomas Kuhn would put it, just a 'paradigm' of normal science that could easily be overturned by a scientific, or in this case a political revolution. Postmodernism gave an opening to the religious 'counter-revolution' that many conservative politicians were advocating without ever them wishing to do so.

It is little known that postmodernism was not only studied at American departments of liberal arts, but also in many religious and divinity schools across the nation. For example, the curriculum of Fuller Theological Seminary, in Pasadena, California, arguably the most influential theological seminary in the US in terms of the number of ministers produced, shows to what extent the fundamentalists have engaged certain relativizing aspects of postmodernism. A good example of this theological postmodernism is also a book often used in many departments of religion and divinity schools all over the country. Called *To Each its Own Meaning* the book places the Bible at the unquestioned center of interpretation, and then allows all other interpretation to follow from the Bible itself as equally valid reading of various dimensions of the text (Mckenzie and Hayes 1999: 183–185). Such a radically relativistic version of postmodernism was never advocated by its founders, such as Derrida, Lacan, de Man, and others. In fact, the main point of philosophical deconstruction was to dislodge the text from its central place in hermeneutics. Theological postmodernism argued exactly the opposite. That is why President Ronald Reagan, who was always well-briefed, and who had substantial contacts with religious leaders, skillfully exploited this newly found vulnerability of sciences. During a 1980 press conference, then presidential candidate, Reagan was asked if he thought the theory of evolution should be taught in public schools. He answered that evolution is, 'a theory only, and it has in recent years been challenged in the world of science and is not yet believed in the scientific community to be as infallible as it once was believed' (*Science Magazine* 1980: 1214). This attitude was not limited to the politicians from the right. During the controversial 2000 presidential campaign, Albert Gore supported teaching both creationism and evolution, his running mate Joe Lieberman asserted that belief in a creator is instrumental to 'secure the moral future of our nation, and raise the quality of life for all our people' (Paul 2005: 4).

In reaction to this kind of religious fundamentalism propagated from the bully pulpits of power, there appeared a small but spirited movement often called New Atheism. Scholars such as Sam Harris and Victor Stenger wrote vigorously in defense of human and cosmic evolution, and against the rising tide of creationism. Later they were joined by many other scientists, as well as public figures, such as Richard Dawkins, Sam Harris, Christopher Hitchens, and Michel Onfray. Breaking a long standing consensus of the Anglo-American culture that religion was to be tolerated but not debated, these scholars rose up in defense of science, and against claims that scientific grand narrative was just 'a theory only'.

I would, therefore, like to situate the emergence of Big History more precisely in this struggle between the 'scientific counter-revolution' advocated by religious fundamentalists and the new atheism of some scientific circles, which emerged as a reaction to religious fundamentalism of the last two decades. This is not to say that Big Historians are all atheists in the mould of Richard Dawkins. Yet, Big Historians firmly believe that the scientific account of the world and of history at the grand scale is not on the same epistemological level as the Biblical account of creation in the Book of Genesis. Big History was conceived from the beginning as the modern creation myth. In other words, Big History answers all of the question that were traditionally posed by religions, namely, the origins of the Universe (as in the Big Bang theory), the origins of the stars and planets, the Earth and life, human beings and societies. Like a typical religious narrative Big History ends with speculations about our cosmic future (Hughes-Warrington 2002). In short, Big History covers everything from Genesis to the Apocalypse.

This new branch of history, the Big History, represents an answer to the challenges presented by religious fundamentalist to modern natural and social sciences. In a convenient form of a one-semester-long course, historians, helped by other natural and social scientists, present a scientific version of the creation myth. The Big History, according to David Christian, the most influential practitioner of the genre, integrated cosmic evolution (or history if you prefer), evolution of the Earth, biological and human evolution, as well as, social evolution, emphasizing environmental history, and social history on the grandest scale. Therefore, Big History includes what sciences, such as astronomy, geology, biology, anthropology, economics, and history can tell us about the origins of everything, beginning with cosmos, and ending with human society. That is why many supporters of Big History, such as Bill Gates, underline the current crisis in scientific and humanistic education in the US, and see the Big History as one of the antidotes to the emergent religious fundamentalism which, encouraged by 'the end of history' apocalyptic ideology, pushes for more and more control over the school and university curricula.

Such religious dimensions of Big History involve some pitfalls. The main hazard for Big History is the danger of dogmatism and over-simplification. Such danger can only come from the lack of historical understanding of the Big History narrative. Strictly speaking, Big History is not the scientific narrative of 'creation', as it is often asserted, since such an approach would put Big History on the same epistemological plane as any other narrative of creation. To use the words of President Reagan, Big History would, in that case, be just ‘a theory’. In order to avoid these risks, Big History should, first and foremost, be a history of various sciences, not the final account of origins. Therefore, the sobriquet that Big History is a ‘modern creation myth’, often repeated by many Big Historians, is somewhat unfortunate. Though quite understandable in the context of the conflict between Big History and contemporary religious fundamentalism, the usage of the phrase ‘modern creation myth’ hinders the cause of Big History. First it tends to take us back to postmodern relativism, where all myths are constructed, all equally true, or all equally false. This is not what Big Historians argue. Big Historians acknowledge their narrative is a construct, but they also point to the enormous difference between the Big History narrative and the traditional narratives of origins, namely that Big History grand narrative is supported by the enormous amount of evidence accumulated in the last several hundred years. If not objectively true in the traditional sense, the Big History narrative is much more sophisticated than traditional religious grand narratives.

Thus, Big History is not just a survey of what sciences know about origins of the world, human beings, and society. It is, or should be, a history of science, thematically organized around the macro time-scale. This is a very important point. Sciences, especially natural sciences, have often been guilty of triumphalism, similar to the triumphalism espoused by Fukuyama. Before Thomas Kuhn's epochal work *The Structure of Scientific Revolutions* (1996), the dominant narrative in natural sciences was the narrative of perpetual progress, the same kind of progress that was advocated by Fukuyama in his ‘The End of History’ (1989) for social sciences and humanities. Kuhn turned this logic of progress around and said that we call all the disciplines that actually make progress sciences. Those that do not, such as literature, we do not call sciences (Kuhn 1996: 160–173). Yet, in spite of Kuhn, science textbooks are still full of heroic narratives of progress through science and technology and I am afraid that it could spill over into Big History. Such triumphalism is not needed in Big History and actually would hinder its development. The greatest strength of natural sciences has been their ability to change course, achieve a paradigm shift, as the scientific crisis become apparent and as scientific revolutionaries do their critical work. Postmodernists have also often pointed out to the shifting character of science and further developed this kind of analysis by advancing the concept of discourse and the power/knowledge relationship. To put it simply, dry dogmatic objectivity is a trap for Big History.

While postmodernists, specifically postmodernist theologians who were eager to adopt a simplified version of postmodernism, had gone too far in equating the scientific grand narratives with religious grand narratives, they were right in pointing out to the power/knowledge relations in the history of modern sciences. I will not re-hash here the well-known accounts of history of medicine put forward by Michel Foucault and his followers. Instead I will put forward an argument on why have natural sciences declined in power after the Fukuyama's end of history, that is, after the end of the Cold War. As Fukuyama pointed out in his essay, the end of the Cold War was not just the demise of the Soviet Union, but a triumph of liberal capitalism and the consumer society that accompanies it. The form that the triumphant capitalism assumed was the financial capitalism and not the industrial capitalism Karl Marx was talking about. For the financial capitalism, branding is more important than producing. Financial capitalist focuses on investment in market speculations, not in investments in industrial production, which can now conveniently be done in the regions with lower wages and in the absence of union agitation for higher wages. Consequently, the role of natural sciences is diminished in the society based on financial capitalism in comparison to a society based on industrial production. For the last two decades, the industrial West, in particular Great Britain and the United States are going through a very rapid process of de-industrialization and this process has enormous social and cultural consequences. While during the Cold War, natural sciences were fostered and showered with funds to 'keep up with the Soviets', now this is no longer necessary. It is not even desirable, since scientist now have to 'advertize' and 'brand-name' their research in order to compete for the diminishing pool of funds. For example, Richard Dawkins is not just an atheist who out of personal conviction debates religious fundamentalism. As an Oxford Chair for the public understanding of science, he is a successful fund-raiser for science who can stand up to conservative and reactionary politicians who make decision on the funds for science. Therefore, the attack on natural sciences and their spirited defense, which is one of the main features of the 'end of history' period, should not be surprising. It was to be expected, since the power/knowledge dynamics have shifted away from natural sciences and toward finances, advertising, and management. Just a brief look at the salary survey in various academic disciplines should be enough to illustrate, if not prove the point. A newly hired assistant professor in business now earns more than a full professor in either natural or social sciences (CUPA-HR 2009–2010).

After this prolonged methodological digression, let us go back now to survey of all sections of Big History, cosmology, geology, biology, and economics, from the standpoint of their conflict with resurgent political conservatism and religion fundamentalism. Fukuyama believed that the era of Scientific Revolutions and paradigm changes was over. For Big History this means that sciences that underpin it, such as cosmology, geology, biology, and economics, should show no signs of an impending crisis. The readers should be reminded that, according to Thomas Kuhn, a crisis within a science is an indication of an impending paradigm change. Such a change could and would seriously affect Big History. For example, if some of the major theories that underpin Big

History, such as General Theory of Relativity, or the Gene Theory were to be proven wrong, and replaced with a different theory, this would have major consequences on Big History. In fact, I would here argue that all of these sciences – cosmology, historical geology, evolutionary biology, and macro-history – are, and have been for some time, in a state that Thomas Kuhn described as normal science, a kind of science that is focused on 'puzzle solving' and not on changing the basic presupposition of the scientific paradigm. It is this state of modern science, where paradigms are not being challenged, that actually made it possible for Big History to appear. However, I also believe that this 'normal science' period is mistakenly identified by Fukuyama as 'The End of History'. This is above all obvious as we move away from natural sciences into social sciences and economics in particular, where one can see more signs of an impending crisis.

The fact that cosmic evolution does not present a significant challenge to religious fundamentalism is, at least in part, due to the moderating influence of Albert Einstein. Einstein is today simply understood as the greatest scientist who also believed in god. This popular image of Einstein, sometimes quite different from 'real Einstein', was in fact created during the Cold War when religious circles willingly overlooked Einstein criticism of revealed religions and focused entirely on Einstein's 'belief in a god'. Thus Einstein's creation, the science of Cosmology is fairly safe from attacks from religious fundamentalism. Niceties about the non-anthropomorphic god of Spinoza, or his comments about the foolishness of revealed scriptures are seriously downplayed today. Popular culture and popular theology barely, if at all, mention the conflict between Georges Lemaître and Albert Einstein. Monsignor Lemaître, a catholic priest, offered a particular solution of Einstein's Field equations of General Relativity that we now call the Big Bang Theory, and for a while Einstein rejected that solution out of hand, for no apparent reason (Deprit 1984: 370). Similar controversies no longer plague modern cosmology. After the departure of Einstein, and with the demise of the Steady State Theory of the Universe, the Big Bang paradigm has been firmly established since the 1960s and has not been seriously challenged. Steven Hawking famously said that the discovery of background cosmic micro-wave radiation in 1965 was the last nail in the coffin of the Steady State Theory, the last serious challenger of the Big Bang cosmology (Hawking n.d.). It is also significant to mention that all three founders of the Steady State Theory, Fred Hoyle, Thomas Gold, and Hermann Bondi, are gone now. Reader should here be reminded that, according to Kuhn, the sure sign that the old paradigm has been replaced by the new paradigm is when the die-hard practitioners of the old paradigm literally die out, leaving the field open for the complete dominance of the new.

In the context of cosmology, I should also mention the so-called string theory, an attempt currently being made to unify the special relativity, quantum mechanics, and the atomic standard model. If the attempt to create a unified theory of everything, as the string theory is often called, becomes successful, should that affect the teaching of Big History? I am convinced that this is not the case. Again, according to Kuhn, new paradigms only emerge as a result of a crisis and none of the three theories involved, special relativity, quantum mechanics, or the standard model show signs of a major crisis. The string theory seeks to unify these three separate areas, and, therefore, it seeks to incorporate previously mentioned theories into a single grand theory. According to Kuhn, the new paradigm replaces the previous paradigm; it does not just harmoniously unite the previously divergent parts. As it is currently conceived, I believe that the string theory does not offer much promise in terms of paradigm shift. Even if completed, it would represent the continuation of normal science. In order to represent the paradigm shift, the string theory would need to claim that Einstein's Theory of Relativity, Quantum Mechanics were 'wrong' in same way. One should not forget that Einstein's theory and Quantum Mechanics had shown that Newtonian physics was 'wrong' when applied to large speeds and on the atomic scale. The goal of the string theory is to harmonize, not to overturn previous scientific theories. Thus, by definition, it cannot represent a paradigm shift.

The evolution of the Earth presents more challenges to the practitioners of Big History. Currently historical geology is dominated by a single paradigm, the theory of plate tectonics, the theory that became commonly accepted in scientific circles in the 1950s and early 60s. However, the theory of plate tectonics can only reconstruct the history and geography of the Earth in the last several hundred million years, far short from the actually 'age' of our planet. For the rest of the geological past, we depend on the theories of planetary formation, which are currently in a state of flux. In addition, the theory of Milankovitch's cycles, that reasonably-well reconstructs the climate of our planet, takes us only several hundreds of thousands of years back in time. Furthermore, Milankovitch's cycles only work as long as we know and can calculate the moments of inertia of a particular configuration of the Earth's tectonic plates. If we do not know the position of the tectonic plates, we also do not know the position of the Earth's axis of rotation, and, therefore, cannot reconstruct the climate.

The theories of planetary formation had been formulated only on the basis of our growing knowledge of our solar system. This is obvious since the scientist only had access to the information about our solar system. The so-called 'nebular hypothesis', initially formulated several centuries ago by Immanuel Kant and Pierre Simone Laplace, with many changes and refinements accumulating over time, is still the main paradigm of historical geology. The discovery of many planetary systems in our galaxy, due to the powerful space telescopes, such as Hubble and Kepler, is bound to bring many surprises not only to astronomers, but also to geologists. In short, the geological evolution of the Earth is not generally challenged except by a small fringe even among the fundamentalists that we call the proponents of the Young Earth theory. The greatest challenge for the history of the Earth comes from the discovery of new solar systems and new planets in our galaxy. It is the area that Big Historians should watch carefully, in order to keep their narrative of Big History up-to-date.

Furthermore, while the Young Earth theory is only a minority view even among the proponents of creationism and intelligent design, this does not mean that the theory that our planet is only a couple of thousands of years old does not engender support among the general public. There was always a gap between what scientist teach and what general public believes and one of the main goal of Big History is to somewhat bridge this gap. A recent Gallop poll suggests that 40 % of American believe in strict creationism and identify the Biblical 'day' in Genesis as one thousand years (Newport 2010). One can only expect that politicians, usually very sensitive to Gallop polls, will find a way to accommodate the views of the large portion of their constituencies. This kind of strict Biblical literalism was always strong in the Anglo-American cultural milieu and will continue to present a challenge to both Earth scientists and Big Historians.

Biological and human evolutions were always a very controversial subject in the Anglo-American world. One should be reminded of not only the controversies surrounding Charles Darwin and his writings in the nineteenth century, but also of legislation which prohibited or restricted the teaching of evolution in many states of the union following the so-called Monkey Trials in 1925. By 1927, 14 states, both in the North and the South, debated or introduced some kind of an anti-evolutionary laws (Halliburton 1964: 280). The opponents of the biological and human evolution changed their strategy in the 1960s and moved away from actually banning the teaching of evolution. As the government of the United States, after the Sputnik humiliation, began to push for increased spending on scientific education, in order to 'keep up with the Soviets'. Subsequently, however, after the Cold War ended, the proponents of fundamentalist Christian values suggested Creationism and later Intelligent Design as alternatives to Darwinian evolution.

As in the case of Earth sciences, the creationists are divided into moderates and radicals, in the so-called Old Earth and the Young Earth creationists. The Young Earth creationists, such as late Henry M. Morris, the founder of the Creation Research Society and the Institute for Creation Research, with their literal belief in the 6 days of creation, really represent a fringe in the creationist community, even though they often build 'museums' that are quite popular among the general public, and run 'graduate' courses in Christian apologetics and creation science. For example the creation museum in Petersburg, Kentucky, run by the Answers in Genesis religious ministry group, opened its doors in 2007 and, according to its web-site, it celebrated the one millionth visitor in 2010 (Answersingenesis 2010). In contrast, when American Museum of Natural History, an institution of considerable prestige in New York and nation-wide, organized the Darwin exhibition in 2005, it, allegedly, had trouble finding corporate sponsors and had to rely on individual donations and the sale of merchandize. This was never officially confirmed by the American Museum of Natural History, but reports about it widely circulated in the press (Wapshott 2005). Having in mind that 68 % of Republicans and 40 % of Democrats do not believe in evolution, one might justifiably say that Darwinian evolution is very seriously challenged by the public opinion in the United States (Newport 2007).

The most sophisticated and, in my opinion, the most dangerous challenge to the Darwinian evolution comes from various relatively moderate creationist groups that are often lumped together as Intelligent Design. Important organizations such as Seattle-based Discovery Institute or Dallas-based Foundation for Thought and Ethics are fairly successful in their fund-raising activities and in seeking public support among politicians. These Intelligent Design organizations apply the so-called ‘Wedge Strategy’ the main goal of which is to drive the wedge ‘into the heart of scientific materialism’ (Mooney 2002). This strategy is tailored to the split of the public support for Darwinian evolution by portraying the scientists who support evolution as radical atheists, while at the same time offering a moderate ‘alternative’ theory which accept many points of the theory of evolution, but does not engender atheism. One of the strategies of the Intelligent Design groups was to publish textbooks, such as *Of Pandas and People: The Central Question of Biological Origins,* and then send copies to public and school libraries, hoping to have the books removed for inaccuracy, or because of the protests by the American Civil Liberties Union. In that way the proponents of the Intelligent Design could claim that they are a prosecuted minority, victims of a vicious campaign by radical atheists. The campaign has failed to convince the American Library Association to declare *Of Pandas and People* the Banned Book of the Year, but this had not dissuaded ID group to continue pursuing the same ‘Wedge’ strategy (West 2006).

Other initiatives of these kind was the Discovery Institutes' ‘Teach the Controversy’ campaign, presented as an action fostering freedom of speech and civil liberties allegedly curtailed by atheist scientists. Many initiatives, especially of the Discovery Institute, are very sophisticated public relations campaigns, and have drawn attention of the politicians. For example, as a candidate in the 2008 presidential election, John McCain made a high profile visit to the Discovery Institute, which is quite understandable, since the institute was founded by the former president Reagan's advisor Bruce Chapman and covers not only the issues of Intelligent Design but also is a major advocate of a libertarian free-market oriented economic policy (Discovery Institute 2007). Because of this mixed advocacy for Intelligent Design and free-market economy, the Institute has been called, somewhat ironically, 'the intellectual love child of Ayn Rand and Jerry Falwell' (Wilgoren 2005).

One of the most sophisticated lines of attack on Darwinian evolution was to attempt to link it with the rise of Nazism. Considering the consequences of such a link, especially if the public opinion becomes convinced that the Darwinian evolution somehow generated Nazi racial policies and the Holocaust, one must admit that this is a very serious challenge. In a book called *From Darwin to Hitler* Richard Weikart attempted to show an intellectual connection between Darwin and Nazism, and to document 'the influence of naturalistic evolution on ethical thought, euthanasia, militarism, and racism – and ultimately Hitler's ideology' (Discovery Institute n.d.). Weikart's work is also a part of the effort directed by the Discovery Institute, in particular the branch of the institute called 'Center for Science and Culture'. In the book Weikart tries to show that Darwin and Darwinism were responsible for the rise of 'scientific racism' which was a quite popular phenomenon in the late 19th and early 20th century, but does not make a sufficient distinction between the positions of Darwin and his more racially minded followers, such as Leonard Darwin and the famous eugenicist Francis Galton, who was also Darwin's cousin. Both of these men were among the founders and active members of the British Eugenics Society, founded in 1908. While making connections in the intellectual history of the late 19th and early 20th centuries, the book is unfair to Darwin, since it blames Darwin and Darwinism for all the excesses of the 19th century moment called Social Darwinism. The book has generated quite a controversy, including some excellent studies on Darwin's views on slavery, which convincingly argued that Darwin was a persuaded abolitionist and by no means a racist (Desmond 2009).

Common sense should convince the most observers that Darwin should not be held responsible for Darwinism. The fact, however, remains that there was a movement called 'scientific racism' or 'Social Darwinism' and that it had considerable influence in Europe and in the Western hemisphere in the late 19th and early 20th centuries and that it has generated important intellectual links leading to the Nazi movement. What is often forgotten here is that neither Darwin nor early Darwinist had a clear model of evolution until the re-discovery Gregor Mendel's work in the early 20th century by three biologists, Hugo de Vries, Carl Correns, and Erich von Tschermak and their firm establishment of the laws of heredity. If one is to summarize this quite complicated history, one would say that Darwinists really did not understand mechanisms of the evolution, namely heredity, before Hugo de Vries' discovered genes, and many evolutionary scientists working before de Vries were prone to offer various suggestions that were often widely off the mark, including the aforementioned racial theories. In other words, Darwin and his immediate supporters, in order to disprove Lamarck's theory of the inheritance of acquired characteristic were often suggesting quite speculative theories before the establishment of modern genetics.

Theory of evolution does not have a goal toward which all life is evolving and it is no secret that many people find Darwin's theory quite disturbing. People in general find it difficult to operate in a cultural system which moves in no particular direction. Religion as a cultural system gives meaning to the chaotic Universe; the theory of evolution does not. Darwin and people after Darwin often borrowed the idea of progress from the contemporary culture and consciously or unconsciously applied it to the evolutionary process. In fact, the term 'survival of the fittest' was not even Darwin's. It was introduced by Herbert Spencer, who was comparing his own social theories with Darwin's. Herbert Spencer writes, 'This survival of the fittest, which I have here sought to express in mechanical terms, is that which Mr. Darwin has called "natural selection", or the preservation of favoured races in the struggle for life' (Spenser 1896: 444). In sum, Weikart's book *From Darwin to Hitler* is a fairly tendentious account of the development and the influence of Darwinism on European culture. Not only he often equates social Darwinism with socialism and Nazism, but more importantly, he never considers 'imperialism' as a context in which social Darwinist racial theories developed. Furthermore, his assertions that Darwinism necessarily leads to the lack of respect for human life, and that the only alternative is Christian ethics based on the sanctity of life, are unwarranted and untenable. There are many ethical systems that were not Christian and did not lead to racism and genocide.

Weikart's book raises some serious, and often unanswered, questions about the relations between the theory of evolution and social sciences. In this way we can seamlessly transition into the fourth part of our discussion of the fields of Big History, namely, the social evolution. Some practitioners of the field of Darwinian evolution have often tried to cross-over into the domain of social sciences. Darwin never showed such a tendency, even though he did write a book called *The Expression of the Emotions in Man and Animals*. This threshold between biological and social sciences was crossed by Francis Galton, Herbert Spencer, Madison Grant, and most recently by Richard Dawkins with his idea of memes, the cultural equivalent of genes. Meme is a cultural belief that is transmitted from one person or group of people to another (Dawkins 1976: 189). There is, of course, an obvious overlap between biology and social sciences, after all we, human beings, are animals, and we follow the laws of evolution as we must follow the laws of gravity. The crucial question is here as follows: can human and social behavior, what we in general call culture, be explained only by biology, or do we need a separate scientific field called social sciences. For example, population biology, a branch of biology that studies populations of organism, has serious influence of the study of society and culture. I will take here economic history as an example, since economic history is at the heart of the last segment of Big History, social evolution that I am considering here.

The same religious fundamentalists, who often have serious trouble accepting biological Darwinism, have no trouble advocating what I would call here the Malthusian economic model when it comes to economic history. By Malthusian economics I here mean the advocacy of the extreme form of the *laissez-faire* economy implemented without regard for the human cost, in particular the views that poverty and hunger are ultimately beneficial for the society, since they motivate the poor to work harder (Malthus 2008: 158). Naomi Klein has called this version of neo-liberal predatory capitalism 'the disaster capitalism' (Klein 2007: 355). Again, a good example is the Discovery Institute, which through one of its branches advocates Intelligent Design and opposes Darwinian evolution, but though the other branch, geared more towards economy and politics, advocates what I called above the Malthusian economics. I am here, of course, caricaturing the economic platform of the Discovery Institute, but not in order to create a straw-man argument, but in order to make a more subtle point. Namely, if according to Weikhart, Darwinism is responsible for the emergence of Nazism, how come the predatory imperialist capitalism, equally based on the principle of 'the survival of the fittest', is to be absolved of all responsibility?

Economic history is probably the most complicated part of Big History, because, as it is usual in social sciences, there is no single paradigm, but rather they are competing theories. However, this flies in the face of Fukuyama's suggestion that this struggle of paradigms in social sciences has ended with the triumph of liberal democracy and free-market capitalism. Without going into details about what capitalism is or should be, I would start with a very simple description. Capital needs to grow, or circulate, and at the end of the circle, there should be more capital then at the beginning. Adam Smith called this process 'the progress of opulence'. Therefore, unless there is growth, there cannot be any capitalism. In the last two hundred years there has been a persistent average growth that we call the industrial revolution. Fukuyama never specifically said that this growth would continue forever and ever, but his point is that democracy and free-market are now triumphant in the larger part of the world. The new democracies will continue to grow much like the old democracies grew in the 19th and 20th centuries. Implicit in his argument is a vision that eventually the whole world will in terms of economic development and democracy will look like the West. This is actually a very noble vision of ultimate equality of the whole world that Fukuyama advocates. However, the question might be asked, what if this does not happen? Simply put, does our planet have enough resources to support this growth to its idealistic conclusion? Can this Earth sustain the life style of the whole world if everyone starts consuming natural resources like the West does?

For the relationship between economic history and Big History, especially interesting is the notion of complexity, so wonderfully explained by Eric Chaisson in his book *Cosmic Evolution: The Rise of Complexity in Nature* (2002). Human civilization is one of the most complex phenomena in the natural world, and therefore, it consumes the largest amount of energy per unit of mass. It is, therefore, inevitable that at some point in the future the capitalist economy will consume all the available energy resource of our planet. Consequently, there are only two possible futures here. In one we discover a new source of energy, and continue doing what we are doing now. Various science-fiction scenarios have been suggested here, including expansion of the human race to other planets, or even other solar systems. In this case, there is no end to human progress and Fukuyama's vision of free market capitalism and liberal democracy continues for ever. In the other possible future, we do not discover a new source of energy supply and then the human race would need to adjust to existing and limited energy resources. We should be under no illusion that such an adjustment would be achieved by negotiations and by general consensus.

Economists connect growth with energy consumption, and this can easily be seen by comparing two graphs that compare the growth of the world's economy and the increase in energy consumption. Both curves linger in low ranges for centuries, if not millennia, and then rapidly jettison upwards in the last two centuries. In fact, economic historian Gregory Clark in his *Farewell to Alms* made an argument that there are only two periods in the whole history, the period of industrial revolution, and the period of Malthusian trap before the industrial revolution (Clark 2008: 1–18). The difference between the two is the lack of growth, pre-industrial economies did not grow for extended periods of time, claims Clark, because when they did, it was only for a short period of time, and even if they did, the growth was immediately reversed by the Malthusian trap, a biological mechanism of the evolution, which reduces the population numbers, and therefore, brings down the economic growth. The key to industrialization in England, claims Clark, is that England managed to grow, and yet it also reduced the population numbers. In particular the least desirable parts of the society were eliminated, namely the poor. This allowed for the accumulation of wealth to happen in tandem with the suppression of the population growth and it ushered in the second period in history, the period of growth.

Clark argument is fairly cruel towards the losers in the economic game, and represents in effect the old idea of the survival of the fittest now revived. I will not offer here criticism of this argument, but let us follow this argument further, because this is basically the same economic model that Fukuyama advocates for the whole world, free-market capitalism, or as Adam Smith had put it, 'the system of perfect liberty.' Presumably what is meant here is the system of perfect economic liberty. In order to achieve Fukuyama's vision of world economic prosperity, the world economy need to grow, the developing countries, such as China and India, need to grow more than the developed world in order to catch up. This is exactly what is happening. In fact, after Nixon's historic visit to China in 1972 and the death of Mao in 1976, Chinese Communist Party under the leadership of Deng Xioping has also adopted the free market economics of the West. Fukuyama claims that the end of history it not just about adopting values of liberal democracy, which he foresees happening in the future, but also about adopting of the 'winning' paradigm in economics. Namely, Fukuyama claims that in the 1980s, both Russia and China embraced 'the "Protestant" life of wealth and risk over the "Catholic" path of poverty and security'.

What does Fukuyama mean by 'Protestant' and 'Catholic' economic paradigms? Fukuyama's 'Protestant' economy is what we normally call the neo-liberal, *laissez-faire*, or I would even call it the Darwinian model of economy. Each economic player, each individual, pursues his or her selfish goals. These conflicting interests are then balanced on the open and free market. Each producer is free to choose what to produce, and each consumer is ideally free to choose what to consume, but in the end the needs and the demands are all perfectly matched by the so-called 'the invisible hand of the market'. The key to understanding economic models is to always have in mind that they are extreme simplification. Like in the case of the invisible hand, the model envisions that all the players in the market are of the same size. Furthermore, not only are the all players of exactly the same size before the market is balance, but there is no growth at all in this economic model. Since all the needs and the demands are met, there is no real increase in wealth. The system is perfectly balanced. Somebody's gain is other person's loss, so that the overall amount of wealth in the system is constant.

How is then wealth created according to this 'Protestant' economic model? Here I would go back to Clark's book, the *Farewell to Alms*. Clark's argument is perfectly clear; the wealth is created by eliminating the poor (Clark 2008: 272). This is how it works in an idealized model: all the subjects pursue their selfish goals; some are successful, while others are less successful; the big fish grow bigger, and the small fish grow smaller. This, however, does not create growth yet, no increase in average prosperity for the whole society, since the system is still in balance. The overall wealth increases only when some of the small fish, the less successful individuals, are no longer able to meet their needs, and according to the principles of natural selection, when they die out. Once they are eliminated, the overall average wealth of the society increases. Actually, that is one of the reasons why Clark's book is called *Farewell to Alms,* because if the system is taken seriously, points driven to their logical conclusions, giving food to the starving poor actually just prolongs their agony, while, at the same time, it does not increase the prosperity of the society as a whole. Clark's argument is really that only a society such as England, which was able to eliminate its own poor, was able to create sufficient economic growth to propel itself into a stage of the prolonged economic growth and the accumulation of wealth, moving decisively beyond the mere balanced equilibrium of needs and wants.

Before I get into the second kind of economy mentioned by Fukuyama, the 'Catholic' one, I would first like to point out that this 'Protestant' economic model is intrinsically anti-democratic. This is obvious from the model itself and is actually supported by historical evidence. The reader will remember that the neo-liberal system starts with the often unstated presupposition that 'in the beginning' all the market subjects were equal, that is, of equal size. As the exchange of goods and services proceeds, some players become bigger, and some smaller. Yet, in Fukuyama's vision, the system is also supposed to be democratic, that is, to be governed by the principle one person, one vote. In this way, an imbalance is created between the wealth of individuals and their economic weight. Naturally, the economic big fish will try to limit the political influence of the small fish, since, according to Clark, the small fish will want alms, while the big fish would like to increase its wealth. This can only be achieved by eliminating the political influence of the small fish, reducing their demands for alms, thus hastening their elimination. In this way, one can better understand why during the nineteenth century the industrialized England consistently lagged behind less industrialized France, in terms of the universal male suffrage. It is a well-know historical fact that while France allowed universal male suffrage, albeit intermittently, from the times of the Revolution to the times of the Third Republic (1871), England only allowed universal male suffrage by the Representation of the People Act of 1918 adopted under a threat of a Bolshevik style uprising. This anti-democratic nature of the Darwinian economic system can also explain that from the standpoint of the Chinese Communist Party, the decision to abandon planned economy and adopt the *laissez-faire* system, was the right decision. The adopting of the *laissez-faire* business model actually prolonged the Chinese Communist Party's grip on political power. Fukuyama's assertion that the free market capitalism would eventually lead to the greater democratization of China is wrong, since most Chinese businesses are led by the Communist Party officials who now control them as business managers, not as party ideologues. Deng Xioping correctly reasoned that political freedoms do not mean much as long as the Party is in the managerial control of the economy. This is actually a point where Adam Smith and Karl Marx agree, lack of organized labor guarantees higher profit margins (Palast 1999). Even though most Western analysts predicted that the shift to the managerial style free-market economy in China would lead to greater political freedoms, it has not happened, even though over 20 years have passed since the end of history began in 1989. Capital investment will only come in a developing country if it is provided with a docile and compliant workforce.

Let us move not to what Fukuyama had in mind when he was talking about 'Catholic' economic model of 'poverty and security'. While the Protestant economic model promises wealth and risk, the Catholic offers poverty, but security. Fukuyama has in mind here various kinds of planned economy, where wants are planned in accordance with the needs. In the US, the most popular such model is the 'systems theory' introduced to the political sphere by the advisors to the Kennedy administration. For example, the economist Alain Enthoven, one of the pioneers of systems analysis worked on the particular problem of the increasing cost of military equipment and, later on, the increasing cost of pay-per-service medical plans. In a book called *How Much is Enough* Enthoven (2005) asked some serious and unanswerable question about the 'Protestant' wealth and risk model. National defense and health care are areas in which we as a society are willing to pay any cost in order to provide security for the country and health for ourselves. In these two areas, Enthoven argued, neo-liberal economic model failed to bring down the cost. Outside political pressures on the economic system are just too big. We will pay any price to keep our country safe, and similarly pay for any procedure that will save our lives. The problem is that we cannot afford what we want. As a consequence, the United States is devoting higher and higher percentage of its income to defense and healthcare. These ever increasing pools of money are the sacred cows in the government budget, since no politician can afford to be perceived as vulnerable to accusations of jeopardizing national security and rationing health care. What is happening in the United State is exactly what Clark described in his *Farewell to Alms*. People who can afford to buy into the pay-per-service system are receiving technologically the most advanced health care available. People who cannot afford it are receiving no health care and are, therefore, consigned to the losing end of the evolutionary struggle for existence. Enthoven suggests a simple solution. Instead of trying to fulfill our every wish when it comes to defense and health, we should simply ask, what are the needs? We should analyze those needs and come up with the system that best meets those needs.

This particular logic has been expanded to the economy in general, above all by the so-called Green Movement. It is a well known fact that if the whole world is to achieve economic prosperity currently available to the citizens of the West, there will be not enough resources on our planet. Analysts estimate that the world will run out of some metals, for example, zinc in 2025 (Cohen 2007). Various peak-oil theories suggested that the production of oil in the world, has or it is about to reach its maximum, and after that moment it will only decline. The peak-oil theory, suggested first by Marion Hubbert in 1956, accurately predicted that the production of oil in the continental US would peak around 1970, and would thereafter fall into an inevitable decline (Hubbert 1956). There are many theories related to this issue of the depletion of Earth's resources by an economy that favors wealth and risk. Studies have been done on peak-gas, peak-uranium, peak-copper, peak-lithium, and even peak-cod fishing. There is little doubt that Earth's resources are limited and the question asked by Enthoven, how much is enough, is a very relevant question not only for Big History, but also for the future of the humanity. These issues are being discussed, and Big Historian, as historians of science should follow them closely. There might be some interesting paradigm changes in this area, in spite of Fukuyama's prediction. It is interesting to note that in 1992, twenty years after Enthoven published his book *How Much is Enough?* Alan Durning published a book with the same title *How Much is Enough: The Consumer Society and the Future of the Earth* (Durning 1992). In this book Durning calls for a 'society that lives within its means'. This is, I guess, what Fukuyama called the 'Catholic' economic model of poverty and security.

This debate is not going to be easy, particularly in the United States. Protestant fundamentalists take their beliefs in the 'Prosperity Gospel' very seriously. A great number of popular fundamentalist and evangelical churches teach the prosperity gospel as the core living principle. The teaching is fairly simple and has its deep roots among the more radical streams of the Protestant Reformation. It argues that God blesses the believers with riches. In a typical Calvinist fashion, those who are rich are those who are blessed. For many fundamentalists this teaching is as important as the doctrines that we most commonly associate with Protestant fundamentalism, such as the inerrancy of the Bible, or the substitutionary atonement of Christ on the cross. It is highly ironic that Anglo-American fundamentalists, while opposing Darwinism in biological sciences, endorse the crudest possible Darwinian economic model, thus condemning the poor not only to the margins in this world, but to a place of eternal damnation. In fact, these attitudes toward economy became so pervasive in the last twenty years that some journalist questioned whether or not such attitudes were ultimately responsible for the economic crash of 2008. Hanna Rosin in her December, 2009 article in the *Atlantic Magazine* directly asks the question, 'Did Christianity Cause the Crash?' There Rosin described an immigrant church in suburban Virginia, full of Latinos who converted to fundamentalist Protestantism, eager to fit in the Prosperity Gospel ideology. There the minister tells his parishioners, 'God is the Owner of All the Silver and Gold, and with enough faith, any believer can access the inheritance. Money is not the dull stuff of hourly wages and bank-account statements, but a magical substance that comes as a gift from above' (Rosin 2009). Even in these hard times, it is discouraged, in such churches, to fall into despair about the things you cannot afford. 'Instead of saying I am poor, say I am rich', writes Rosin as she continued to describe this phenomenon of American culture (*Ibid.*). It is hard to see how to argue with this kind of dogmatic thinking.

In fact, Fukuyama recognized that his logic of the end of history, as it manifested itself in the prevailing Anglo-American fundamentalism, was a mistake. He recently condemned politically active religious fundamentalism, of which he was an active part for over two decades. To a surprise of many, he compared Anglo-American neo-conservatism to Leninism, saying, 'Leninism was a tragedy in its Bolshevik version, and it has returned as farce when practiced by the United States. Neo-conservatism, as both a political symbol and a body of thought, has evolved into something I can no longer support' (Fukuyama 2008). Fukuyama should be applauded, in my opinion, for his honest change of mind. It is dangerous to try to impose 'paradigms' on sciences by the might of political and economic power. I believe that was exactly what was going on in the last twenty year and various aspects of Big History clearly illustrate it. Fukuyama's comparison of neo-conservatism with Leninism is, I believe, very appropriate. A group of influential, religiously motivated, political leaders, backed by some tycoons of the economy, tried to impose uniformity in the areas of human investigation that we call natural and social sciences. They not only opposed the idea of human evolution, but also attempted to impose a single 'true' paradigm of free-market capitalism onto social and economic sciences. These imposed paradigms could or are already becoming so entrenched that there might be very few further challenges to them. Social structures could be built around the victorious paradigm which could possess mechanism to eliminate any inside or outside challenge. This is what is mean to have a paradigm which is victorious forever. This is why Fukuyama compared neo-conservatism with Leninism.

In the light of this fairly pessimistic review of contemporary politics, I would like to say that Big History represents a ray of hope. Historical understanding of the fundamental cultural concepts of human society, such as who we are, where do we come from, and where are we going, can only enrich our understanding of what is going on around us. That is why I argued in this paper against the notion of presenting Big History as the modern scientific creation myth. Quite to the contrary, Big History should be historical understanding of the basic notions of science. It is interesting that now, in the 'end of history' period, it is historical understanding that can serve as a guide on how to proceed forward, in the light of the financial crisis, and the growing environmental problems. Historical understanding of science, I believe, should be at the core of Big History. It is our only weapon against forceful imposition of uniform paradigms from the outside.

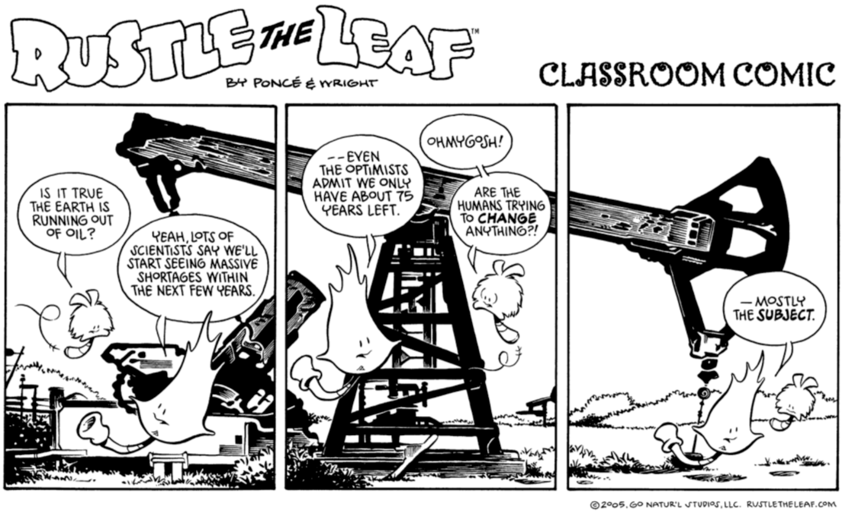

Fig. Is the peak oil a possible end of history? (URL: http://ictlessons.wikispaces.com/Environment+with+cartoons+and+comics)

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5
The Evolution of Macro-History in the United States

Barry H. Rodrigue

Abstract

The inclusion of large-scale studies in the world's educational systems is of great importance for resolving the most serious problems that humans face today. In the United States, the development of such macro-historical studies began with courses in Western Civilization a hundred years ago. Global studies came to be increasingly offered in universities after World War II and evolved in two directions. The first developed into Globalization Studies, a hierarchical model that was discipline-based and focused on power-relationships in regions and markets. The second was a 'mondialisation' or horizontal model, which was interdisciplinary and used the entire world as a reference point. Similar academic models also came into existence around the world that paralleled this U.S. experience in macro-history. A problem that today's scholars face is how to reconcile these two visions, not only for global benefit but for our very own survival. One suggestion is to continue moving with the current trajectory and to adopt a model of macro-studies, such as the example provided by Big History.[1]

A pervasive problem that historians face in the United States is that we lack an appropriate point of reference from which to adequately address today's global issues. The source of this problem is an antiquated model of society that is still taught in our universities, one that largely reflects the society that existed in the United States a century ago.[2] Many have been struggling to adjust this

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[1] A version of this paper was originally presented at the Russian Academy of Sciences' Fifth International Conference on Hierarchy and Power in the History of Civilizations in Moscow (Russian Federation) on 23 June, 2009. A brief version of this paper was published in the National Education Association journal, *Thought & Action*, in December 2010.

[2] Maine is the most northeastern of the United States and is surrounded by Canada on three sides. It has a largely resource-based economy, consisting of farms, timber and fish. Indeed, 90 % of the state is forested. It is similar in size, population, ethnic diversity and economy to Pskov Oblast in Russia. Maine is 86,542 km² in size and has a population of 1,316,456 people; Pskov Oblast is 55,300 km² and has 760,810 people. Both are border-states that were locations of violent warfare in the early modern period and have populations reflecting this frontier status: Maine is adjacent to Canada, while Pskov is adjacent to Estonia. Both are on the major waterbodies: Maine is on the Gulf of Maine (Atlantic Ocean), while Pskov is on the Lakes Peipus (Pskov system that empties through the Neva River into the Baltic Sea).

problem, but it is only recently that some success has been achieved, primarily through the introduction of *Big History* as a new paradigm.

Antique Education

When I began my job at the university, I was asked to teach a course called *Western Civilization*. This is one of the two most widespread and fundamental historical studies in the United States today. 'Western Civilization' was created as an academic study about 100 years ago and embodied the concerns of elite Americans for that time.[3] In that period, around 1910, the United States had grown into its present boundaries and was involved with incorporating overseas territories into its domain. The administrative challenges were enormous.

This expansion had resulted from the conquest of millions of kilometers of Native American territory and half of Mexico, boundary adjustments with Canada, purchase of Louisiana from France and Alaska from Russia, and seizure of the island kingdom of Hawai'i, as well as the Philippines, Cuba and Puerto Rico. A variety of peoples had been brought into the United States by this territorial expansion, but they did not share the elites' English-American heritage. Among others, these new citizens included French Canadians in Maine, Spanish Mexicans in Texas, Indigenous peoples in Kansas, and Russians in Alaska.

As a result, these varied peoples joined millions of newly freed African-American slaves to form the United States' social underclass. Moreover, this process had taken place during the Industrial Revolution, when millions of new immigrants were also arriving into the United States from Eurasia. The elites certainly wanted the new lands and the new workers, but found themselves encumbered by an unwanted diversity of cultures that included 'radical' ideas about equality, as well as the sharing of power and wealth. In response, educators developed a course of study that they called *Western Civilization*.[4]

The goal of *Western Civilization* was to provide cultural and historical legitimacy for the United States by showing that the young nation was derived from Greek democracy, Roman administration, the Protestant Reformation and English property rights, all of which had been carried to the Americas by colonial expansion. Its central message was that 2000 years of western European institutions had been brought to perfection in the United States.

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[3] Courses in *Western Civilization* do not commonly exist elsewhere in the 'western' world. However, there has recently been a move towards something similar to it in Europe, reflecting development in the European Union. For example, a course of study that is called the 'Dutch Canon' was submitted to the Netherlands' government in 2007. It is essentially Dutch History couched in a European context, along with overseas colonial history (Indonesia) (De canon van Nederland 2009). Fred Spier, University of Amsterdam (Netherlands), personal communication e-mail to Barry Rodrigue, Lewiston, Maine (USA), 1 June 2009. Also, four universities joined together, in 2008, in order to offer a two-year graduate program in 'European Civilization' in Greece, France and Italy (Marseilles 2008).

[4] *Western Civilization* was more than just a single course. It developed into an entire sub-curriculum that involved the study of art, literature, politics, religion, *etc.*

By teaching the superiority of western European society and its colonial offshoots, educators expected that U.S. residents could be convinced to support elite institutions. In other words, *Western Civilization* developed into a tool of acculturation and assimilation, as well as the academic base for the study of *United States History*.[5] Over the next century, its instruction became required at almost every college and university in the United States, while its themes trickled into elementary schools, high schools and public culture.[6]

Although *Western Civilization* has been liberalized over the years, a 'culture war' developed between its supporters and those who believed that the concept of a 'Western Civilization' was exclusionary.[7] While I very much enjoyed teaching Western Civilization, I also saw it as an inappropriate reference point for a modern university, especially since the United States has become a much more diverse nation than it was a century ago – with our citizens coming from every part of the world.[8] So, I made a deal with my Dean: I would teach *West-*

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[5] The present course description for *Western Civilization I* at the University of Southern Maine reads: 'A basic survey and introduction to the heritage of Western society from ancient to early-modern times. Particular attention is given to the ancient civilizations of Egypt, Greece and Rome. Medieval civilization is explored with a focus on the institutions it bequeathed to the modern world. The Renaissance and Reformation and the rise of the great nation-states are studied. Throughout the course important individuals are considered such as Alexander the Great, Caesar, Charlemagne, Michelangelo, and Elizabeth I'. That for *Western Civilization II* reads: 'A basic survey and introduction to the heritage of Western society from early modern times to the atomic age. Particular attention is given to the Enlightenment, the French Revolution, the rise of the industrial era, the growth of nationalism, and the World Wars. Personalities such as those of Napoleon, Hitler, and Stalin are studied' (University of Southern Maine 2008: 167).

[6] The spread of the concepts of *Western Civilization* in the United States was furthered by schooling being made increasingly mandatory for children in the early 20th century. Although *Western Civilization* was a course of study primarily for colleges and universities, its message filtered into parallel and lower venues of education, such as government-run Indian Schools for Native Americans, Settlement Houses for immigrants and Adult Education programs for workers, as well as into courses in elementary and high schools. In this way, concepts of 'the West' became pervasive long before the Cold War popularized them. Certainly, the content of *Western Civilization* has been liberalized over the years, as many of its negative aspects began to be discussed, from the Inquisition to the Holocaust, while its perimeters were expanded beyond just Western Europe to include Russia, North Africa, Greenland and other 'fringe' areas.

[7] Selma Botman, a scholar of modern Egypt and President of the University of Southern Maine, notes: 'We may all take this [the acceptance of a global context] for granted now, but it has taken a whole generation for western historians to appreciate the significance of placing the west in a context that respects and acknowledges the contributions of others'. Selma Botman, University of Southern Maine, Portland, personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 16 June 2009.

[8] Debate about the appropriateness of *Western Civilization* as a core study in higher education in the United States is active and open (Stearns 2003). Broad-ranging assessments of history courses seem to indicate that use of either Western Civilization or World History as a base course of study are about equal in today's universities (Townsend 2004). Peter Stearns, George Mason University, Fairfax, Virginia, personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 12 June 2009. Matthew Keough (and Robert Townsend), American Historical Association, Wash-

ern Civilization for two years, but then would replace it with *World History & Geography*.[9]

We succeeded in this transition, as *World History & Geography* is now an established course at our college, but I came to appreciate that this is not a generally accepted trend, even in the other colleges of our own university.[10] Nonetheless, there is a campaign to make it a more general requirement in the United States, such as through the work of the World History Association.[11]

ington, D.C., personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 12 June 2009.

[9] World Studies have been prevalent in other nations to varying degrees, but – as in the United States – it often can be a form of *Western Civilization* in disguise: although a course title might say 'World History' or 'World Artistic Culture', its content might be largely drawn from European cultural areas. On a German perspective: Professor Michael Heine, University of Western Ontario, London, Ontario (Canada), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 2 June 2009. On a Russian perspective: Professor Alexei Gusev, Moscow State University, Moscow (Russian Federation), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 10 June 2009. A student entered one of my Western Civilization courses and was surprised that it was not about the history of California and the other western states (she actually did well in the course).

[10] My two-course sequence in *World History & Geography* is a requirement for our major in *Arts and Humanities* at the University of Southern Maine's Lewiston-Auburn College. My course description for *World History & Geography I* reads: 'This is the first in a series of two courses that are designed to not only develop an understanding of and an appreciation for world history and geography, but also to help students become more knowledgeable participants on today's rapidly changing planet. The goal is to provide students with a humanistic background from which to better comprehend global complexities, as well as to make links between historical events and current events. In other words, it is a primer in 'global citizenship'. This course will cover the period from Prehistory to the Age of Modern Expansion – from about 50,000 to 500 years ago'. That for *World History & Geography II* reads: 'This is the second in a series of two courses that are designed to not only help students develop an understanding of and an appreciation for world history and geography, but also to become more knowledgeable participants in today's rapidly changing world. Its goal is to provide a humanistic background that can be used to unravel complexities of the modern world – by helping to make links between historical materials and modern world situations, as well as find locations on a map! In other words, it is a primer in 'global citizenship'. This course covers the modern period from the Age of World Exploration to the Present – from c 1500 to 2009 CE' (University of Southern Maine 2008: 361).

[11] Ironically, although many high schools (for students from 14–18 years old) teach courses in *World History & Geography*, many colleges and universities still require *Western Civilization* and feel that *World History & Geography* is 'exotic'. An example of a book on *Big History* that is oriented towards this younger group of students is *What on Earth Happened?: The Complete Story of the Planet, Life, and People from the Big Bang to the Present Day* by C. Lloyd (2008). A hindrance to the establishment of *World History & Geography* or any macro-study as a base in our colleges and universities is that many of our students are driven by the focused desire of professional certification in a particular job, which often precludes non-required electives. In order to encourage more global reference points for students, I have also widened the parameters of other subjects that I teach. For example, my course in *World Indigenous and Native Studies* discusses more than just 'American Indians', incorporating materials on the Basques, Chechens and Kurds as indigenous peoples, as well as the indigenous origins of Europeans. Likewise, my course on *International Labor* considers more than just the American Federation of Labor, as

A Redirection of Macro-Studies

One may ask: 'Don't American universities teach international studies?!' Yes, they do. But these courses are often taught in an old-fashioned style of 'us' *versus* 'them'. This polarization is the result of centuries of nationalist discourse supercharged by decades of the Cold War and, more recently, by the so-called 'War on Terror'. There has been change, but it is often not necessarily for the better. For example, in the study of macro-economics, nationalism might recede into the background, but the orientation is still conflictual – focusing on 'our profits' *versus* 'their profits'. The results of such binomial education can then be seen in the highly competitive life of today's 'real world', from stock market meltdowns to leveraged buyouts.[12]

This dichotomy of 'us' *versus* 'them' can be highly nuanced. Professor Sharman Haley, a scholar at the University of Alaska in Anchorage, describes how issues of pan-Arctic social science are not played out so much by nation, but by Northern residents *versus* Southern centers of political, economic and cultural power. She also describes how, despite an internationalist intention, researchers tend to use their own familiar national models as international paradigms, which can be just as polarizing. Furthermore, since the end of the Cold War and the start of the recognition of the catastrophic effects of climate change, she notes the opposing tendencies to seek international solutions but also to establish new national claims in a melting Arctic seascape.[13]

Nonetheless, there is a movement in the United States towards a more humanistic and ecological globalism, which many French activists distinguish as *mondialisation*.[14] Professors are offering new courses that use the entire globe as their basic reference point. In addition, academics are creating new global networks and are interesting university administrators in such reform.[15] I believe that biased history is not usually intentional. Rather, it is the result of gen-

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the students also study the Third International, the Catholic Worker Movement and the African National Congress. In this way, the residual provincialism in higher education in the United States is slowly broken down – in a process that is similar to that by which *Western Civilization* was established.

[12] Some of the issues about how global studies are dealt with in today's universities in North America are discussed in Knight 2009.

[13] Sharman Haley, University of Alaska, Anchorage (USA), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 8 June 2009.

[14] Professor Eric Waddell, a geographer from Laval University (Québec), eloquently described the Mondialisation Movement as it developed in the Causses region of interior France, especially in the area of Larzac. Eric Waddell, Le Vigan, Languedoc-Roussillon (France), personal communication (conversation) to Barry Rodrigue, 2002. One of the intellectual sources of this movement came from the French philosophers, Gilles Deleuze and Félix Guattari, who used the horticultural metaphor of a rhizome to describe horizontal and multifaceted links within and between societies (Deleuze and Guattari 1987, 2004). Eric Waddell, Québec, Québec (Canada), personal communication (e-mail) to Barry Rodrigue, 16 August 2009.

[15] There are a number of good examples of the new movement towards a truly 'globalized' view in higher education in the United States. These are reflected in geographer Denis Wood's *Five Billion Years of Global Change* and historian Michael Cook's *A Brief History of the Human Race*.

erations of people thinking in traditional ways. It is our job as academics to begin transformation towards new models.

However, during the process of promoting *World History & Geography*, I came to appreciate that an even larger paradigm shift was needed. In the last decade, we have become more aware that entire species of life are vanishing, along with fresh water supplies. Pollution makes parts of the world uninhabitable. Nonrenewable resources are being exhausted. Global warming is impacting the entire planet, from the melting of the world's ice sheets and permafrost to the related rise in sea levels and changing storm patterns. Local agriculture and business are destroyed by competition from multinational industry, resulting in the vast concentration of people in urban areas, as more and more residents are dropped to the lowest rungs of society. Unlike past crises, the scale of this situation could lead to the end of life as we know it. Regardless of what happens, the world will be a much different place in fifty years, as a result of depleted petroleum resources and its impact on the world economy.

As I became aware of the enormity of this crisis, I also came to understand that *World History & Geography* does not sufficiently address these challenges, because of its human-centered and nation-based approach. Fortunately, I came across a few articles about the subject of *Big History*, soon followed by the good fortune of meeting several Big Historians at a conference in the State of Maine.[16] There, I learned about the pioneering of this discipline in the 1980s and 1990s by an international group of interdisciplinary scholars that included Fred Spier, Eric Chaisson, John Mears, David Christian, and others.[17] It appeared that *Big History* might be the academic vehicle for which I was searching, so I designed a course in this new discipline.

Mega-Studies and Big History

Big History is a holistic and scientific survey of existence from our origins in the 'Big Bang' to the present – and beyond. It considers how humans fit into the vast expanse of the universe (or multiverse), instead of orienting the universe around humans. *Big History* also considers the challenges of modern globalization, with an important theme being on the quest to develop sustainable lifestyles. The overall focus is on what such knowledge might mean in our everyday lives and how we should – as responsible individuals and a responsible species – conduct ourselves on this planet and off of it.[18]

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16 The Fourth Conference of the Historical Society: *Reflections on the Current State of Historical Inquiry*, Boothbay Harbor, Maine (USA), June 2004.

17 See a photograph by Kim Dionne in the electronic version of the Almanac at http://www.socionauki.ru/almanac/issues/evolution_2_en/#rodrigue

18 Feminists, particularly eco-feminists, have also strongly criticized the human-centric vision of course offerings in the university. Diane Wood, George Mason University, Fairfax, Virginia (USA), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 11 June 2009. Big History is also referred to as 'Megahistory' in some areas. Akop Nazaretyan, personal communication (discussion), Moscow, Russia, 23 June 2009.

In this new course on *Big History*, students get exposure to quantum mechanics, plate tectonics, evolutionary biology and social development. They consider the emotional landscape of a philosophy without organized religion. They study environmental problems and solutions, as well as ecology movements around the world. They meet with workers on farms and at production sites, in addition to communicating with scholars on the Internet and through telephones. Their capstone event is an Earth Day or other celebration that brings together citizens of our region in central Maine. The message is that these disciplines all are linked together and students need to be engaged participants in changing human activity.[19]

It is surely a special circumstance when us, educators, put a course together and have it work the way that we intended the first time. When I read the papers of my students, I wept. They all got the point – we are but one life form in the known universe and we are responsible for whether our species or, at least, our civilization persists or becomes extinct. One student, Amanda Munroe, wrote:

> When I was first asked to consider my role in the universe four months ago… I do not think I fully realized there was even a living community around me, never mind an Earth full of other humans and an entire universe beyond…But after this long, incredible voyage of exploration… I have a newfound sense of what the universe is. I have learned… that we are all part of the Global Future, and I can make a difference in my life as well as the lives of others. I feel honored to have been a part of the big history movement, along with the University of Amsterdam and a few others. I know that I am a better, more wholesome being because of this experience. My role is now to change my ways and respect this beautiful planet that granted us life, and to get others to join me.[20]

[19] Earth Day is celebrated on 22 April. Surprisingly, my students say that they get little exposure to the very serious problems facing the world in other university courses, which, in part, reflects the problems associated with professional career education. This educational gap does not bode well for public awareness of the planet-shaking issues that we face today and the need for citizens to deal with them. Ecologist Michael Morrison, who has worked on the Greenland Ice Cap and who participates with both our Earth Day celebration and *Big History* development, writes about their inter-connection: 'Since we discovered the dramatic shifts of which climate is capable, I have a sense of how protected and safe we are here in our 'Stable Climate Era' beginning about 12,000 years ago. Recently, I have begun to think about how so much of the Universe is an extreme version of Earth's climate: most of it is profoundly uninhabitable with enormous energies, on the one hand, or almost none at all, on the other. Even just a few miles up, radiation becomes destructively intense. I have begun to think of Earth as remarkable for, among other things, its stability and for the protection it provides us from a truly inhospitable Universe. It is, of course, because of this rare, pleasant and hospitable circumstance that we are here to appreciate it!' Michael Morrison, Falmouth, Maine (USA), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 26 April 2009.

[20] Amanda Munroe, University of Southern Maine, Final essay, LCC 350 Global Past, Global Present, Saco, Maine (USA), 19 May 2009.

Even more surprising, each student pledged to change their life and work towards the greater shared good of the world. You have to realize that this self-generated commitment is a shocking result in the context of the selfish, consumer-driven society of the United States. I have never seen this result from another course.

Certainly, macro-studies are not new, either in academia or in popular society. Indeed, *Western Civilization* itself is a macro-study, but one loaded with ethnocentric bias. The difference with *Big History* is that: 1) it uses the entire Universe and Earth as reference points, and 2) it uses the scientific process. Indeed, the motto for my course comes from the U.S. writer, Philip K. Dick: *Reality is that which, when you stop believing in it, doesn't go away*.[21]

Our college at the University of Southern Maine is interdisciplinary in its orientation and was adopting an entirely new core curriculum just as I was developing my course in *Big History*. Indeed, Lewiston-Auburn College is one of the first post-secondary institutions in the United States to implement such a sweeping change in general education. This new core curriculum integrates arts, natural sciences, humanities and social sciences in a global perspective that emphasizes social consciousness and is titled: 'How, then, shall we live?'[22] This opportune change of direction for our core curriculum made it an excellent home for *Big History*, which is now included in it under the name: *Global Past, Global Present*.

Our students have embraced these transformations. They have created Facebook sites, in order to promote worldwide networking among students of *Big History*. The course has been so successful that I made it 'hyperflexible', in which students may sign up to take it in the classroom or online. As a result, our online students have participated from as far away as Germany and Korea.[23] I am now designing a sequel course that is called, *Global Futures*, which has already happened at the University of Amsterdam.[24]

[21] Phillip K. Dick was author of scientific and philosophical fiction that was also produced as popular films, such as *Blade Runner*, *Total Recall* and *Minority Report*.

[22] A core curriculum in the United States consists of those courses that all students are required to take; it is also called 'general education'. Most of the core curriculums that are being taught today date from the 1960s or 1970s and have problems of relevancy that are as challenging as those of courses in *Western Civilization*. Indeed, *Western Civilization* is often part of old general education requirements. Academics acknowledge that revision is needed, but disagree about course content, which has stalled general education reform at many institutions. The new core curriculum at the University of Southern Maine's Lewiston-Auburn College was collectively developed by its faculty members from 2005–2007 (University of Southern Maine 2009: 381–384).

[23] In many ways, and despite its drawbacks, online course delivery is a productive way for us to reach a wider audience and, for macro-history, perhaps this kind of outreach is most appropriate – since it is global and democratic, at least in its best forms.

[24] The content of courses in *Big History* tends to vary somewhat from instructor to instructor. What they all have in common is a 'big' context that is keyed to the large-scale and thematic aspects of the natural and social sciences. Most of the courses presently offered are survey courses that

Big History has been the high point of my academic career. I feel as if I am doing something that changes lives and changes society. It transcends national boundaries, religious disputes and economic systems. It serves as a new, unifying reference point for the world.[25]

A Challenge and a Proposal

This is much more than just a question about pedagogy and curriculum. It involves life and death around the world. When an American president takes his country into a war in Central Eurasia, calls it a 'crusade' and is then surprised by global criticism – that is an example of the far-reaching consequences of educational deficiency. I argue that such antiquated curriculums not only prevent citizens from making informed decisions on matters of elected officials and their policies, but actually encourage them to act in jingoistic and selfish ways that profit national and corporate leaders – all under the delusion that it somehow benefits their nation.

I regularly get active-duty soldiers and military veterans from Iraq or Afghanistan in my courses on World History and Big History. It is a visibly moving experience, as they relate their personal experiences to global events about which they had never before heard. Many suffer from Post-Traumatic Stress Disorder (PTSD) and Traumatic Brain Injury (TBI). In contrast, Vice President Dick Cheney and his corporate colleagues at Halliburton made billions of dollars from the wars in Central Eurasia because American citizens thought that a 'crusade' was a good thing. Guards at Abu Ghraib Prison in Baghdad tortured, raped and killed detainees, in part, because they considered themselves on a 'crusade' against a lesser people. As reprehensible as all of this is, it pales in comparison to the ecological tragedies underway, such as massive industrial pollution from Bhopal to Chernobyl.

For this reason, these issues of curriculum are issues of present-day life and death for us as individuals and for our civilization. We, as scholars and educators, must find ways to address global problems using global linkages between

cover the whole of existence in one or two semesters, while some focus on aspects of the whole, such as macro-sociology or Earth studies (Barry Rodrigue 'A Directory of Big History, 2009'). The sequel course in *Big History* at the University of Amsterdam is called *Big Futures*, and the text it uses is Lucas Reijnders, Bert De Reuver and Egbert Tellegen (editors), *Toekomst in het Groot* (Amsterdam: Amsterdam University Press, 2007). Fred Spier, University of Amsterdam (Netherlands), personal communication (e-mail), Barry Rodrigue, Lewiston, Maine (USA), 25 May 2009. There is also a philosophical aspect of Big History, which has tended to be emphasized in Russia and is linked to Cosmist philosophy (Nazaretyan 2005).

[25] Educator James Moulton's response to the concept of Big History was: 'Why should we stop at "Big History"? – Why not Big Education and Big Political Science!' James Moulton, Bowdoinham, Maine (USA), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 2 February 2009.

ourselves, our students and our communities. It is commonly reported that when our cosmonauts and astronauts went into space, they saw no political boundaries on the Earth and came back confirmed internationalists and activists.[26] It is in this spirit of global endeavor that we need to ignite world change by empowering our world citizens with new ideas – in a process that English physicist David Hookes calls 'Global Enlightenment'.[27] There is a need for such wide views today in every field and subject. It is something that we can do right now. The survival of our species and our world civilization is at stake.[28]

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[26] Likewise, when our nations went into space, people around the globe said that 'We did it', meaning all of humanity, not just one nation.

[27] David Hookes, Liverpool, Merseyside (England), personal communication (e-mail) to Barry Rodrigue, Lewiston, Maine (USA), 19 June 2009.

[28] I appreciate the sharing of thoughts for this paper that came from my wife, Penelope Markle, who is the best editor I have ever met, my students (especially John Kimball and Kessi Watters-Kimball who established the Big History Facebook site), as well as Professor Fred Spier (University of Amsterdam, Netherlands); Professor David Hookes (University of Liverpool); Professor Eric Waddell (Laval University); Professor Sharman Haley (University of Alaska, Anchorage); Professor Michael Heine (University of Western Ontario); Professor Akop Nazaretyan (Moscow State University); President Selma Botman, Professors Mark Lapping, Christy Hammer, Roxie Black and David Harris (University of Southern Maine); Provost Joseph Wood (University of Baltimore, Maryland); Provost Peter Stearns and Professor Diane Wood (George Mason University, Virginia); Dr. Victor Berezhnoy (Moscow, Russia); Michael Morrison (Falmouth, Maine); and James Moulton (Maine Learning Technology Initiative, Bowdoinham, Maine).

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6
Mega-Evolution and Big History

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Abstract

Big History – an integral conception of the past, from the Big Bang until today – is a relatively new and unique subject of cross-disciplinary interest. The concept was construed in the 1980–90s simultaneously in different countries, after certain basic concepts had matured in the Sciences and the Humanities. Various versions and traditions of Big History are considered in this article. In general, most Western authors emphasize the idea of equilibrium, and thus reduce cosmic, biological and social evolution to mass-energy processes. Furthermore, they view the information parameter, involving mental and spiritual aspects, as mere epiphenomena of increasing complexity – only adjunct to material structures, ones that do not play their own role in evolution. In the Russian tradition of Big History, however, sustainable non-equilibrium patterns are used. This implies attention be paid to pan-material sources and evolution of mental capacities and spiritual culture (as basic anti-entropy instruments) and humans' growing intervention in the material processes on Earth and off of it. The non-equilibrium approach, in the context of modern control and self-organization theories, alters the portrayal of the past, and even more dramatically, the estimation of civilization's potential.

Mega-evolution is the chain of transformations that have taken place in the Universe over a period of 13.7 billion years. As we study this subject, we can find how more and more complex forms of organization, mechanisms of activity, and systems of reflection have been arising, and perhaps will continue to rise. This highly intricate subject requires new interdisciplinary paradigms and methodologies for us to integrate all the data about the physical Universe, the Earth, the biosphere, society, culture and mind into a single model.

From the 1970s into the 1990s, an assemblage of such holistic knowledge was developed by scholars from various academic backgrounds in North and South America, Australia, Western Europe and Russia. Initially, these scholars worked independently and without much contact, but new networks developed by the end of the 20th century, as work on mega-evolution gained acceptance in the world's academic community. Indeed, in November 2005, an international conference in Dubna (Russia) paraphrased the slogan from the Communist Manifesto: 'The Specter of Big History is Roaming the Earth'.[1]

Big History is one of the names for the study of mega-evolution. It is a research program aimed at the synthesis of Natural Sciences, Social Sciences, and the Humanities. Through Big History, we try to identify megatrends, mechanisms and regularities in evolution, the specific character of processes at each stage of development, and the peculiarities in phase transitions. It is worth mentioning that the interest of professional historians in this interdisciplinary field has lately been increasing.

As recently as the 1980s, most historians in the West (unlike their Russian colleagues) disdainfully treated research exceeding three generations as 'sociology', while 'middle level conceptions' in sociology were referred to as 'philosophy'. Since 2000, however, researchers have been paying attention to the growing interest in historical generalization (McNeill and McNeill 2003) and relate it to efforts at global modeling of social trends. Big History's retrospective outlook also has been provoking interest from social historians.

This acceptance of the study of mega-evolution has been in reaction to the inertia of mono-disciplinary thinking, on the one hand, and insufficient methodology for integration of heterogeneous studies, on the other. Therefore, it is symptomatic that a growing number of historians are recognizing the value of using the telescope and the microscope as instruments for assessing the past. And, since 2005, the World History Association has increasingly included Big History panels at its conferences.

The Constructs of World, Global and Big History

The medieval historians were, in J. Le Goff's (1977) expression: 'great provincials'. Each described the events they observed as the center of human history and had no reason to reflect on the differences between separate civilizations' stories. Geographic discoveries, colonial conquests, geologists' and archeologists' findings, and especially a new mentality broadened the Europeans' space and time horizons.

Formation of nations, nation states, and national ideologies resulted in discrimination and conceptual confrontation between local histories. In the 18th

[1] The projects and courses known as Big History in English have different names in other national traditions: *Universalnaya Istoria* in Russia, *Weltallgeschichte* in Germany and *mega-historia* in Latin America (Christian 1991, 2004; Spier 1996, 2010; Chaisson 2001, 2005, 2006; Hughes-Warrington 2002; Brown 2007; Velez 1998; Moiseev 1991; Nazaretyan 1991, 2004, 2008, 2010a, 2010b; Neprimerov 1992; Fedorovich 2001; Panov 2005, 2007). They had also particular denominations from the 1970s to the 1990s, like *Cosmic Evolution* (E. Chaisson in the USA, see in this issue) or *The Universe* (N. Neprimerov in Russia). In Russian universities, inter-faculty Big History courses are sometimes taught under the heading of 'The Conceptions in Modern Science', which fits under the standards of the Ministry of Education. Recent formats in Big History can be seen in Rodrigue and Stasko 2010 and at http://usm.maine.edu/lac/global/bighistory/.

and 19th centuries, a conception of *world history* appeared with national histories and was based on the idea of pan-human progressive development. Current versions of it have divisions into periods, ascending from prehistory to modern times.

Originally, world history was Eurocentric, which was strongly criticized by adherents of the 'civilization approach' in the 19th and 20th centuries, such as Nikolay Danilevsky, Oswald Spengler, the early Arnold Toynbee and others. Later, historical particularists, post-modernists, and religious and national fundamentalists joined the debate. Together with Eurocentric ideology, the idea of pan-human history was denied. Spengler (1980) even proposed to consider *humankind* as merely a zoological concept.

In the 21st century, the world-history concept is still not yet shared by all historians or sociologists. Nonetheless, archeological, anthropological and historiographical discoveries disavowed two key arguments by Danilevsky and Spengler: 1) There had been no continuity between the developments of regional civilizations; and 2) There had been no meaningful events for all of humankind. Since we now have abundant evidence for the mainstream of human history and prehistory in a scientific (as opposed to ideological) discussion, one may question certain interpretations, but not world history as a subject matter.[2]

Moreover, in the first half of the 20th century, the profound mutual influence of geological, biological and social processes was revealed. As a result, a novel cross-disciplinary field took shape – *global history:* The planetary story seen as the successive formation, evolution and interaction of the structures in which first biota and then society turned out to be the leading agents.

Russian biochemist Vladimir Vernadsky, French anthropologist Pierre Teilhard de Chardin, and philosopher Édouard Le Roy were among the discoverers of global history. They showed that human history was a phase in the evolution of the Earth, which they predicted would culminate in a 'Noosphere' – the sphere of maximum intellectual control over planetary processes. Among those who contributed to the global history approach were (Golubev 1992; Snooks 1996, 2002, 2005; Iordansky 2009; Grinin, Markov, and Korotayev 2011; Lekiavičius 2011). Particularly, the Australian global scientist Graeme Snooks has developed and applied a general dynamic theory of life and human society.

It is curious that when Vernadsky (1978) wrote in the 1930s, although he did not pass over the question of evolutionary standpoint existing beyond Earth and the Solar System, his answer was in the negative. Not being a specialist in theoretical physics, he ignored relativist cosmological models, and – like most

[2] We have singled out five mainstreams of consecutive global transformations for millennia: *increases of world population, of technological power, of organizational complexity, of mental information capacity*, and *perfection of cultural regulation mechanisms*. The first three vectors are inferred as 'empirical generalizations' that can be easily illustrated by figures. The fourth and the fifth ones require particular arguments (Nazaretyan 2004).

of his contemporaries – shared the idea of a stationary, isotropic and infinite universe. That idea, which descended from Giordano Bruno, obviously contrasted with universal evolution: Eternity cannot have a history! Since the Russian scientist did not see an alternative to a Brunian view of the Cosmos, he had to recognize that the evolutionary processes on Earth were nothing but an ordinary local fluctuation, which was doomed to dissolve with time in the infinite universe, like an ocean wave. As to the universe as a whole, he argued, it had always remained and would always remain exactly as we find it.

Before Vernadsky, many outstanding thinkers (Francis Bacon, Nicolas de Condorcet, Charles Fourier, Friedrich Engels and others) had been racking their brains over the problem of concordance between a philosophy of progress and a naturalist vision of reality. All of them, more or less explicitly, came to the same discouraging conclusion: No infinite perspective for life and spirit is thinkable, if the destinies of the Earth and Sun are limited. At best, it was assumed that eternal matter was regularly producing splashes, like evolution on Earth, in various points of cosmic space; any continuation or progression between those local stories were external to the discussion.

Only the most reckless of the German and Russian 'Cosmists' dared to argue that human intelligence would lead its bearers from their cradle planet far into cosmic space, guaranteeing infinite progress to Earth's civilizations. The first proponents of these Cosmist views were Johann Gottlieb Fichte, Nikolay Fedorov and Konstantin Tsiolkovsky. These visionaries were considered a laughingstock by many of their contemporaries. Yet, even the Cosmists had a limited vision – they extended their evolutionary outlook into the future but not backwards on the past: The pre-human Cosmos remained outside their view of history.

As to 'respectable' science, the only reason it could be assumed to have adopted a universal mega-trend up to the 20th century is through the second law of thermodynamics. Its rational corollary stated that, if the world was a single whole, it would continually degrade from maximum organization to absolute entropy. The heat-death theory of physics harmonized with the biological theory of catastrophes that was argued by the father of Paleontology, Georges Cuvier: New living forms cannot spontaneously emerge and their original diversity has successively decreased because of geological and cosmic cataclysms. The concept of social and spiritual decay constituted the roof over this theoretical building, which had been raised well before the building's walls and groundwork appeared!

While the idea of a descending trend had powerful alternatives in 19th century sociology and biology (Auguste Comte, Herbert Spencer, Charles Darwin, Karl Marx), Physics could set off against the heat-death theory only a thesis that the infinite universe was an open system and therefore free from thermodynamic laws, *ergo*, from history. However, empirical data testified to the consecutive evolution of life and society, while relevant conceptual conclusions strongly contrasted with thermodynamic generalizations. In philosopher Roger Caillois' (1976) words: 'Clausius and Darwin cannot both be right'.

Big or Universal History is a concept that considers evolution from the Big Bang to modern society. It took shape from about 1980 into the 1990s. At least, two crucial achievements in the 20th century science influenced this trend.

First: Relativist evolutionary cosmology models had been mathematically deduced and then received indirect empirical support from discoveries, such as the red-shift effect, cosmic background radiation and others. Historical methods deeply penetrated into Physics and Chemistry: All material objects, from nucleons to galaxies, proved to be temporal products of a certain evolutionary stage, which had their histories, pre-histories and naturally restrained futures.

Second: A set of natural mechanisms were discovered by which open material systems could spontaneously move away from equilibrium within their habitats and – using the environment's sources for anti-entropy work – sustain their non-equilibrium conditions. Self-organization patterns became a subject of interest in the Sciences and the Humanities.

All the above-mentioned factors reveal that we can distinctly trace progressive vectors or mega-trends, which enter into social, biological, geological and cosmo-physical histories as a single and continual process. Moreover, although no direct contradictions with the laws of physical irreversibility have been found, the mega-trends' orientation conflicts with the classical natural science paradigm. Some astrophysicists (Chaisson 2001) describe this as the disparity between two 'arrows of time' – the thermodynamic and the cosmological ones.

Indeed, available data allows us to observe evolution from the quark-gluon plasma up to star clusters and organic molecules, from the Proterozoic cyanobacteria up to the higher vertebrates and most complicated ecosystems of the Pleistocene, and from *Homo habilis* with pebble chips up to post-industrial civilization. Thus, as far back as our view reaches, the Universe has been evolving from the more probable or 'natural' states, from an entropy point of view, to the less probable (or 'unnatural') ones.

True, the cone of evolution has been tapering. Most matter of the Universe (the so-called *dark matter*) has avoided evolutionary transformations and remained apart from atomic structures. A tiny portion of atomic structures has formed organic molecules. Living matter has apparently emerged in extremely rare and limited parts of cosmic space, and only one of hundreds of thousands of biologic genes on Earth has reached the social stage. Thus, we may agree with Eric Chaisson (2001) and David Christian (2004) that complexity and rarity go together. Still, the appearance of a qualitatively higher structure imparts a novel attribute of the Universe as a single whole. As Albert Einstein once noted, the state of the Universe is probably altered by a mouse just looking at it.

These new qualities are fraught with further development. Hence, an opposite trend to the cone of evolution is traced after a certain stage: The field of the mind's influence has been growing as human activity has manifested a more profound physical effect. These effects are now spreading beyond the Earth, and there is no reason to see limits to this expansion (see below).

The Russian physicist Alexander Panov (2005) added a new trait to this model when he confronted the time intervals between the qualitative leaps in the evolution of Earth, nature and society. By using geo-chronological tables and human-induced global crises since the Lower Paleolithic, he found that the time spans decreased over the course of 4.5 billion years in conformity with a simple logarithmic formula.[3] This result, reported to the State Astronomic Institute (November 2003), was recognized as a scientific discovery by the participants. Panov's equation was conceptually pre-empted by Graeme Snooks (1996), who had formulated the 'law of cumulative genetic change': each great transformation of life was one-third the duration of its predecessor. This independent discovery offers complementary evidence for the unity of the Universal History, and a new context for global forecasts.

In order to give it a sharper graphic form, the pivotal evolutionary mega-trend may be drawn as a consecutive distancing, or 'digression from the natural (the most probable) condition'. On our whole retrospective view (about 13.7 billion years), our world has been getting 'stranger and stranger'. In fact, this conclusion is nothing but an empirical generalization deduced by simply comparing evidence from different disciplines. In spite of human-free choice, wrong actions, countless social fractures and 'civilization cycles', a bird's eye view of world history reveals its progressive ascent, which is a continuation of the mega-trends.

An obvious (or seeming) contrast between the two 'arrows of time' looks like *the pivotal paradox in the current scientific worldview*, which leaves open a wide range of conceptual interpretations. A question at the heart of the matter is why evolution has gone in such an odd direction.

The Versions of Big History

There is a temptation to explain universal evolution's paradoxical 'digression from the natural condition' by adopting an *a priori*, theoretical view focused on a final state. As soon as we do this, the most acute questions (beginning with 'why?') disappear and are replaced by relatively elementary ones (like 'for what?' and 'how?').

A vivid example of such a teleological argument in modern Cosmology can be seen in the 'strong anthropic principle'. This view implies that a very precise balance of physical conditions in the Universe made the emergence of living cells possible. In other words, humans are an artificial composition derived from the initial parameters in the giant laboratory of our Metagalaxy. Indeed,

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[3] Panov used the first edition (2001) of the book (Nazaretyan 2004); see also (Nazaretyan 2010a, 2010b).

English astrophysicist Fred Hoyle said that interpretation of the facts from Physics, as in Chemistry and Biology, leads us to presume that they have been the result of a Super-Intellect's experimentation (Hoyle in P. Davies 1982).

In Biology, we find a similar argument represented by theories of nomogenesis and ortogenesis. To emphasize their essential idea, the outstanding Russian biologist Lev Berg (1977: 69–70) quoted from his predecessor, another enthusiast of nomogenesis Karl Bar: 'The final goal of the whole animal world is the human species'.

A similar teleological idea is metaphorically expressed in Karl Marx's famous words that 'the anatomy of humans is the key to the anatomy of monkeys'. Such a view still has deep roots in Sociology. Almost all progressionist theories in the 18th to the 20th centuries held to the belief that historical process consisted of ascent toward an ideal model. This argument generated severe criticism from its opponents. In the early 20th century, for example, Russian philosopher Nikolai Berdyaev advanced a strong anti-progressionist argument: The idea is immoral, he wrote, for it represents all previous generations as nothing but foot-steps on the way to the final aim (and thus deprives them of self-value) and the future generation of 'lucky-guys' as vampires reveling on the graves of their ancestors (Berdyaev 1990).

Classical and modern Philosophy includes more teleological doctrines than other disciplines. However, they all are exotic topics in Big History courses at the university level, and as far as I know, are hardly even mentioned. What prevails are *a posteriori* interpretations. This means that most scholars deduce evolutionary effects as consequences of actual interactions, so that a sequence within a certain mega-trend is seen as a *problem*, which needs a scientific solution.

For their part, though, *a posteriori* versions of evolution are not homogeneous either. In order to see the difference, we need to consider the recent history of the question. If we exclude myths and legends, as well as classical religious and philosophical doctrines concerning the beginning and the end of the world, then Erich Jantsch's paper, *The Self-Organizing Universe* (1980), seems to be the first that could be unconditionally referred to as Big History.[4]

Jantsch had emigrated from Austria to the United States, so his brilliant book was published in German and English, but it drew little interest from Western European or American scholars. Soon afterwards, he committed suicide (people living a hard life often write optimistic texts, and *vice versa:* Psychologists call it *compensation*). In my contact with Western colleagues in the 1990s, I was surprised to discover that none of them had even heard of Jantsch. *The Self-*

[4] Alexander von Humboldt, Herbert Spencer, Karl Marx, Friedrich Engels and other great European 19th century philosophers who tried to integrate the history of humans and the history of nature could not see the Universe as it is viewed after Albert Einstein and Alexander Friedman. Like Vernadsky, they had to limit their portrayal of evolving nature (or Cosmos) to the Earth and Solar System. Therefore, those books were not properly 'Big History' as we use the term.

Organizing Universe might have sunk into oblivion if it were not for a series of accidental circumstances.

Ironically, although Jantsch's book was never published in Russian, it had a stronger impact on Soviet readers than in Europe or America. In order to trace the reasons for this, we need to remember that the Russian physician and philosopher, and one of system theory's founders, Alexander Bogdanov, had focused on the study of *non-equilibrium systems* in the 1910s (Bogdanov 1996). In the 1930s, Soviet biophysicist Ervin Bauer first used the concept of *sustainable non-equilibrium*, which was further developed by the Russo-Belgian chemist, Ilya Prigogine. This concept was then philosophically adopted by Jantsch, who dedicated his book to Prigogine. As a result, the concept of non-equilibrium systems was more familiar to Russian scholars than their Western colleagues. In contrast, systems-thinking in Western Europe had almost exclusively focused on the idea of equilibrium (Ludwig von Bertalanffy, W. Ross Ashby and others), so Western scholars still used equilibrium patterns when they developed their forms of Big History in the 1990s.

This explains why Big History in Western universities has mostly ignored psychological considerations. In Prigogine's words, 'equilibrium is blind' and non-equilibrium gives a system sight (Prigogine 1981). In order to sustain a far-from-equilibrium condition, an organism must work in opposition to the environment's pressure. This work requires free energy to be extracted from other systems. So, in order to continually tap energy from outside and escape from itself becoming a source of energy for its enemies, an organism needs *information:* It has to orientate itself in the habitat, forecast events and organize its activity in conformity with a dynamic situation. In other words, it must construct anticipative world models.

Without this purposeful and highly sensitive anti-entropy activity, neither long-term, far-from-equilibrium conditions, nor the progressive building up of stages in living matter's non-equilibrium would be possible. For its own part, competition for matter and energy resources has served as an immutable motive for the perfection of modeling procedures, so that the specific weight of information *versus* matter/energy has been increasing with time. It is on the social stage that the mind became more and more the determinant cause of material evolution.

So, as we like to get rid of teleology, or the 'drive to evolution' assumption, we still have to assume living matter's drive to sustain highly improbable, far-from-equilibrium conditions. This occurs in a manner similar to Henri Bergson's *élan vital*, but, in order to avoid the French philosopher's dualism, we must seek the evolutionary premises of living organisms' immanent attribute.

As far as Big Historians in the West have used equilibrium patterns, they have tended to confine themselves to discussions of matter/energy interactions and underestimated the information processes. As a result, the history and prehistory of subjectivity, as well as mental and spiritual reality, are viewed as epiphenomena (side effects) of material structures that do not play a role in evolution. In this way, the psycho-physical problem raised by René Descartes was simply removed.

This problem has moved from the 'philosophical' to the 'scientific' realm, as mathematical theories of communication and control have been developed. This move was highlighted when mathematician Norbert Weiner (1950) indicated that information was neither matter nor energy. Accordingly, after the basic question of Big History's methodology (teleological *versus* causal approach) is solved in favor of *a posteriori* arguments, attention to the last constitutive in the triad of 'matter – energy – information' will come to the fore. Properly, the question is whether information is a significant factor in evolutionary processes or if matter and energy are alone sufficient.

In a strict physicalist version, evolutionary mega-trends in the Universe are nothing but an irreversible growth of entropy in which the emergence of qualitatively higher organizations like life and society serve to accelerate the destructive processes (Huzen 2000). A moderate physicalist view, which is more popular among scientists insofar as it denies a creative role to intellectual agents, also leads us to the conclusion that the prospect of civilization is strictly constrained by natural laws (Nazaretyan 2004).

It is not an accident that interdisciplinary scholar David Christian follows the professional astrophysicists' usual estimation of the distant future. Entities as complex as modern human society, he suggests, arise close to the limit of our Universe's capacity to generate complexity, and so we cannot expect dramatic further development. After the Universe's youthful period ends, stars will flicker out and die, the Universe will get colder and colder as it ages, and there will be no more energy to conjure up or sustain such miracles as living and thinking matter. Apparently, this textbook scenario is a slightly modified wording of the heat-death theory (see a similar scenario in Spier 2010).

In Russia, the influence of Cosmist philosophy remains strong among many of the most qualified astrophysicists and mathematicians, including those who actually work outside of Russia. We find its influence even extending to those who reject its naturalist scenario but still relate the potential future of the Metagalaxy with the increasing intervention of civilization (Novikov 1988; Linde 1990; Lefevre 1996). Not only Russian physicists come to similar suggestions, but also others. For instance, the eminent American specialist in quantum theory, David Deutsch (1997), who seems to had never heard of Cosmist philosophers, distinctly expressed the same idea: The future story of the Universe depends on the future story of intelligence, which will progressively enhance its control over cosmic space as completely as it is dominating the Earth's biosphere (see also Nazaretyan 2010b).

Although this suggestion looks amazing on the surface, it becomes reasonable when we observe the long trend over billions of years. Looking back, first at the millennia of social history, we note how ‘virtual’ events like novel ideas and values, religious and philosophical doctrines, poetic, artistic and musical images, technological and scientific findings, all have exerted – via human activities – stronger and stronger impacts upon the Earth. Ultimately, their far-reaching effects surpassed the ones of spontaneous geological and climatic cataclysms full of blind power.

Going back far beyond human history, we again find that living matter's growing capacity to use energy flows is related to its growing ‘cleverness’, although in this case the fact is less obvious. To argue it, Vernadsky has used the concept of a ‘coefficient of cephalization’ – the anatomic correlate for the intellectual quotient of vertebrate species. If we take modern fauna's aggregative index for 1, then the index for the Miocene (25 million years ago) would be 0.5 and for the beginning of the Cenozoic (67 million years ago) would equal 0.25. This outstanding Russian evolutionist did not read the words by Norbert Weiner (they were written after Vernadsky's death in 1945), but he was also puzzled by numerous facts that demonstrated the independent role of information: How can mind, which is surely not a form of energy, influence material processes?

We will consider some approaches to this question. As to the *growing* capacity of intelligence-induced regulation, modern Psychology offers some suggestions. As gestalt-psychological experiments have shown, parameters of the objective situation, which are *uncontrollable constants* within an accepted mental pattern, prove to be *controllable variables* as soon as we find a conceptual meta-system to reflect more extensional causal links. Having assumed our world is infinitely complicated, no absolutely control-proof attributes of it should be theoretically imposed, and no correctly formulated technical problem should be recognized as radically solution-proof.

In fact, the history of the development of social technologies shows us that any major problem has been resolved as evolution required it. Most technical achievements in the 20th century seemed to be theoretically forbidden by the natural laws of the 19th century. Indeed, the outstanding thinkers of that earlier age did formulate worthy interdictions against the possibilities of these new advances. Although no law of classical Physics had been dramatically disavowed, multiple additions, modified definitions, and specifications made possible quite a different conceptual and technological reality. Looking further back in human history, or into the evolution of pre-human biological ‘technologies’ (living matter's expansion from the sea onto land, conquest of the air by vertebrates, *etc.*), we find a slower but essentially similar succession.

The post-physicalist view of Big History's empirical evidence supplements the evolutionary portrayal with a new determinant. The relationship between structural complexity and the amount of energy consumed has been brilliantly shown by Eric Chaisson (2001): The more complex the order is, the denser the energy flows that pass through it. Our caveat to this principle is that the denser energy flows take place because complex systems get 'cleverer' and thus perfect their control capacities. The relationship between a system's capacity for energy control and the volume of its information has been singled out as 'one of the fundamental laws of nature' by Russian system theorists (Druzhinin and Kontorov 1976; Nazaretyan 1991).

It has also been indicated that as soon as we include the information-control parameter, the *futuribles* (potential futures) of civilization, as well as that of the Metagalaxy, look radically different. This is related to the various perspectives of the mind's development. The cosmic Universe can be influenced by intellectual development of the Earth's civilization (if it survives) or some other planet's civilizations, which manage to survive longer. This raises specific problems, including ethical ones (Nazaretyan 2010a, 2010b).

The differences between adherents of the *a posteriori*, experiential approach admit to having a scientific debate about the Universe's patterns. In contrast, the discrepancies between the *a posteriori* and the *a priori* (teleological; theological) approaches are mainly a subject of 'philosophy', which being 'eternal' questions, cannot be solved by the scientific method. As far as post-classical, model-oriented epistemology excludes final and exhaustive solutions, gaps in any theoretical worldview may be filled by an appeal to the purposeful (and thus anthropomorphic) Actor. This mocking phantom is perpetually soaring over science and evolving together with it from the Biblical Creator to the Watch-Master, and further, to the Computer Engineer, Exo-Planet or even Exo-Galaxy Intellect, and so on, to create complementary impulses to scientific and philosophical reflection.

Nevertheless, as we have mentioned, modern scientific method accepts a telic approach as much as it is introduced in the context of actual interactions (the task of preservation). Taking this into account, we will conclude the article by a brief outline of one of the synthetic patterns that helps us to interpret Big History's mega-trends.

Big History, Cybernetics, and Self-organization Theory

The mutual relationship of causal and telic mentalities has had its own faraway and fanciful story, and has essentially influenced both official ideologies and ordinary worldviews in various epochs (Nazaretyan 1991). Non-classical science implies a synthesis of approaches that is embodied in the interdisciplinary patterns of cybernetic system theory and synergetics.[5]

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[5] Self-organization patterns were named *synergetic* in Germany (H. Huken), *non-equilibrium thermodynamics*, or *theory of dissipative structures* in Belgium (I. Prigogine), *theory of autopoesis*

In cybernetics, the goal is considered to be the 'system-making factor' (Anokhin 1974). The primary kinds of goal for interacting systems is not a final condition but conservation of the parameters of all outer and inner structures. Combination of the two basic attributes – immanent activity of matter and physical conservation laws – is manifested in 'the struggle of organization forms' (Bogdanov 1996), or *competition of controls* for preservation of current movement condition by each of the interacting agents.

Some patterns of classical Physics, such as variational principles and Onsager Law, organically conform to the metaphor of regulation, control, telic causality and competition. Ultimately, as the Russian physicist Nikita Moiseev put it: 'Any inert matter law ... is in fact a mechanism of selection of real movements' (Moiseev 1986: 70).

The cybernetic and ecological metaphors put together the questions beginning with 'why?', 'how?' and 'for what?' Molecular biologists are aware that ferment synthesis, at any particular moment, is regulated by the cell's actual needs. Geologists apply telic functions in order to mathematically describe landscape processes. Having asked for what purpose nature needs several kinds of neutrino or lambda-hyperons, theoretical physicists refer to system-dependencies. The search for the 'missing elements' has more than once led to important discoveries. Conceptions based on categories like control, self-organization, competition and selection demonstrate continuity between 'inert' and living matter, the evolutionary roots of apparently aim-oriented behavior by living organisms.

In particular, cybernetic system theory accentuated the functional essence of material *reflection*. As Russian chemist and philosopher Yuri Zhdanov has indicated: 'Self-preservation against outside coercions is an essential function of reflection as an immanent material faculty' (Zhdanov 1983: 73). Compare this to Prigogine's words about 'blind equilibrium'. Therefore, the philosophical category of *reflection* is similar to the interdisciplinary category of *modeling* as an instrument of control.

Provided all interaction agents have comparable capacities of reflection and control, the outcome is a kind of 'compromise of coercions'. Still, even in this case, equilibrium conditions are only a virtual aspect of non-linear processes (like a perfect gas or a geometric point).

Since self-organization effects have been discovered, we can better understand how a highly improbable, far-from-equilibrium condition spontaneously emerges. The combination of self-organization and control patterns makes it clear why a non-equilibrium condition is preferable and purposefully defended

in Chile (U. Maturana), *dynamic chaos theory* in USA (M. Feigenbaum), and *non-linear dynamic* in Russia (S. Kurdyumov). Recently, a general term, *complexity theory*, has become popular. The linguistic diversity and competition for priority must not conceal the fact that these are various readings of a single scientific paradigm.

by complex systems. We see why feedback and modeling mechanisms have been progressively improving together with structures' complexity and behavior capacities for billions of years (Nazaretyan 1991, 2004).

In the 1940s, Erwin Schrödinger showed that anti-entropy work can be done only by means of 'order consumption' from outside – at the cost of the increasing entropy of other systems (Schrödinger 1969). When and if the environment is abundant, open non-equilibrium systems increase the volume of their anti-entropy work, and expand as much as they can. Sooner or later, this exhausts the available resources, and, as a result, a specific crisis in system-environment relations follows.

Crises of this type are called *endo-exogenous* in ecology. The system – an individual, a population or a human society – runs up against unfavorable environmental transformations provoked by its own activity. Endo-exogenous crises, including all of the anthropogenic (technogenic) ones, play a special role in evolution. As previous anti-entropy mechanisms turn counter-productive – being fraught with catastrophic entropy growth – a bifurcation phase develops. If migration is impossible, there are only two further possibilities. Either the system returns to equilibrium – it degrades (what is called a *simple attractor* in synergetics) – or it diverges, owing to the development of advanced anti-entropy mechanisms. The latter is usually caused by a higher inner diversity and structural complexity, resulting in a more dynamic model with higher resolving power and sensible feedback mechanisms.

The new, non-equilibrium response to crisis is known as a *strange attractor* (Arnold 1992). It looks like a 'quasi-aim' situation, since the actual self-preservation task has turned with directionality to a phase transition (a qualitative leap). Indeed, a highly developed society can give this crisis-coping effort deliberate projects that result in technological, organizational and psychological reconstruction. Retrospectively, the sequence of successful solutions that are accompanied by dramatic collapses, over a long passage of time, is seen as overall biological and social 'progress'.

Self-organization patterns in anthropology include the evolution of spiritual culture, which is usually mediated by anthropogenic crises. It has been shown, for example, that instrumental intelligence, like any other anti-entropy vehicle, led early hominids into dangerous situations: The Olduvai artifacts broke the ethological balance between animals' natural weapons and instinctive intra-species aggression-inhibition (Lorenz 1981). Stone weapons came to supplement muscle and teeth. In this new and unnatural situation, in which the proportion of intra-group deadly conflicts became incompatible with existence, perhaps very few *Homo habilis* groups could have survived.

Archeological, anthropological and neuropsychological data on confrontation brings us to the conclusion that hominid survival was due to specific neurotic condition. Necrophobia (fear of the dead) seems to have been the first artificial factor that balanced the killing-power of extra-natural weapons: It restrained in-herd aggression. Necrophobia was displayed in the care for their dead, sick and crippled conspecifies. So, the groups affected by necrophobia, which implied higher mental lability, suggestibility and unnaturally developed imagination, were the ones to create proto-culture and start a new evolutionary spire with different selection mechanisms (Nazaretyan 2005).

Since that time, the existence of hominids, including *Homo sapiens*, has not followed a natural course but has, to a great extent, been enabled by the balancing of technological power through cultural regulation. Disparities in the development of instrumental and self-regulative hypostases of culture caused outbursts of ecological and/or geopolitical aggression, which most often resulted in the destruction of society. The mechanism by which internally sustainable social systems are selected and unbalanced ones – discarded has so far enabled the preservation of humankind. As calculations show, although killing power of weapons and demographic densities have been successively growing for millennia, the ratio of human killings to population numbers has been non-linearly decreasing (Nazaretyan 2008, 2009, 2010a).

Those calculations (and some others) have been conducted to check a corollary of the hypothesis, which arises from quite different empirical evidence, namely, the history of anthropogenic catastrophes and the following cultural revolutions since the Paleolithic. Summing up diverse information from cultural Anthropology, History, historical Psychology and current Ecology concerning anthropogenic crises, I suggest that there was a regular relationship between three variables: technological potential, cultural regulation quality, and society's internal sustainability. This pattern is called *The Law of Techno-Humanitarian Balance: The higher the power of production and war technologies, the more developed behavior/regulation means are required for self-preservation of society*.

Following this pattern, we can observe the progression of pan-human history, in spite of successive and dramatic replacement of leading cultures and continents. We see how one after another social organism fell into evolutionary deadlock, but humanity as a whole managed to find a way out. This was achieved by successive and irreversible leaps forward that included technological innovations, increasing information volume of the individual and social mind, complexity of social structures, and improvement of cultural values.[6]

[6] The hypothesis for Techno-Humanitarian Balance is consonant with Lawrence Kohlberg's (1984) idea of the correlation between humankind's intellectual and moral development, which is still a subject of criticism, even by social evolutionists. In fact, Kohlberg applies classical evidence by Jean Piaget and his followers concerning individual development to social history, as well as the 'conflict-enculturation hypothesis' of anthropologists: the downward course of violence with

Seven wide-ranging anthropogenic crises and their resultant revolutions since the Lower Paleolithic have been considered. Each solution led to the next growth phase of the social system. On the whole, this process led to the distancing of society (the society/nature system) from the natural (wild) condition. This becomes clearer when we contrast, for example, hunting-gathering to agriculture (Neolithic Revolution) or farming to industry (Industrial Revolution), or industry to modern information economy (Information Revolution). Each of the revolutions broadened and deepened the human ecological niche, as well as furnished a new demographic transformation, new opportunities, new ambitions and new consumer demands. It thus led to overall improvement until a subsequent anthropogenic crisis began.

In synergetic (complexity theory) terms, human history is the story of one 'self-similar' system that exists on the scale of a couple of million years and has been successively transforming itself to conserve sustainability (Christian 1991, 2004). From there, we may see the universal roots of human intelligence and morality without appeal to 'God's Providence'. What we call biological or social 'progress' is neither an eternal purpose (a divine program) nor a movement 'from worse to better'. It is *a means of self-preservation* by which a complex, far-from-equilibrium system responds to the challenges of reduced sustainability and to the effects of its own chain of successful adaptations.

Thus, the informational parameters of world development bring a relevant 'moral' or self-regulation view to the evolutionary stage. Taking a bird's eye view of World History along with the context of Big History helps us to develop reliable scenarios for the future and distinguish between forecasts and projects that are realistic *versus* those that are utopian. Hence, planetary civilization's prospects in the 21st 'bifurcation century' are concerned either with a global fracture or a next drastic 'digression from the natural condition' spiral. This conclusion, which is based on long-term historical observations and analysis of relevant mechanisms, discredits numerous 'back to nature' claims and projects. The creativity of the mind gives civilization unlimited potential for advancement, but the mind's inner imbalance rather than natural laws may turn with lethal menace on civilization in the future (Nazaretyan 2010b).

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increasing time has been revealed both in Western and primitive cultures (Chick 1998; Munroe *et al.* 2000).

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II. BIG HISTORY'S TRENDS AND PHASES

7
Big History: A Personal Perspective

G. Siegfried Kutter

Abstract

My objective is to give a personal perspective on the history of the Universe, from the Big Bang to the origin of life on Earth, and life's evolution towards the enormous diversity that we witness today. My perspective is based in part on writing the college-level text The Universe and Life published in 1987, which – according to the founders of Big History – influenced the creation of this multi-disciplinary field. I begin by describing the circumstances that motivated me in the mid-1970s to start writing The Universe and Life. I then continue by giving a brief, updated summary of the text's content about physical and biological evolution; ask 'Where Do We Go from Here?'; and discuss the philosophic and pedagogic challenges that I confronted. These are issues that characterize Big History as well. I conclude by commenting on some of Big History's unique challenges due to the field's broad, multi-disciplinary nature and suggest that we consider these as an opportunity to jointly move the field forward.

Introduction

Last September I received the preprint of an article 'Changing the Future with the Past: Global Enlightenment through Big History' by Barry Rodrigue and Daniel Stasko, both at the University of Southern Maine (Rodrigue and Stasko 2011). In the accompanying e-mail, Barry referred to me as 'one of the legendary founders of Big History' (pers. com., e-mail 5 Sept. Rodrigue to Kutter, 2010). I was rather surprised, to put it mildly.

I am an astrophysicist, but spent the latter part of my active career in administrative positions at the National Science Foundation, at NASA Headquarters, and in industry. Thus, I must admit that when I received Barry's e-mail I had not even heard of 'Big History'! As I read on, I learned that the interdisciplinary text *The Universe and Life: Origins and Evolution* (Kutter 1987), which I wrote in the 1970s and 1980s, was the cause of his attribution.[1]

[1] Some of the citations for Dr. Kutter as a forerunner of Big History can be found in Christian 2004; Spier 2010.

Barry and I have been friends since the early 1970s, when he was a student and I was a faculty member at The Evergreen State College, a small liberal arts college in Olympia, Washington (USA). Evergreen distinguishes itself by giving its students an interdisciplinary education via broadly designed programs taught by teams of faculty with diverse backgrounds. In addition, from its beginning in 1971, Evergreen lowered the traditional barriers between students and faculty by encouraging first-name interactions between them. It was in this informal but educationally rigorous setting that I got the idea to write *The Universe and Life*.

Barry serves as International Coordinator of the International Big History Association and invited me to write an article for a special edition of the Almanac, *Evolution*, which is devoted to Big History. I felt honored by the invitation and accepted.

Motivation to Writing *The Universe and Life*

As I said, I am an astrophysicist. From the late 1960s to around 1990, my research focused on investigating the structure and evolution of stars via computer simulations – in particular the hydrodynamic events that stars of solar-mass experience as they age, such as pulsations and mass loss, either slowly and gently as planetary nebulae or suddenly and violently as nova explosions (selected references: Kutter and Sparks 1972, 1974; Sparks and Kutter 1987; Starrfield, Truran, Sparks, and Kutter 1972).

Upon arriving at The Evergreen State College in 1972, I team-taught with colleagues whose backgrounds were in chemistry, biology, geology, anthropology, the social sciences and the humanities. Once again, I became a student and began concerning myself seriously with fields beyond my own, learning from my colleagues and through seminar discussions with my students. This was the most fascinating, broadening and, yes, challenging education that a curious young PhD could hope for!

I began searching for the threads that tie diverse disciplines together. I asked myself: 'What are the similarities and differences in the *evolution* of stars, galaxies and the Universe, on the one hand, and the *evolution* that we witness in the Solar System, in the geology of our planet, in the life that flourishes on it and, in particular, in our hominid lineage, on the other?' I also asked: 'How are these different *evolutionary pathways* related?'

These questions prompted me to research the relevant literature, develop written notes, and request teaching assignments on the subjects of physical and biological evolution, and the origin of life. Before long, I became totally consumed by this 'Big History' and began writing *The Universe and Life*.

I learned rather quickly that when we venture beyond our disciplines, we step into a minefield of potential misunderstandings, omissions and blatant errors. I had the good fortune that several of my Evergreen colleagues, in particular Burton Guttman and David Milne (both biologists), as well as Elizabeth

M. Kutter (biophysicist, geneticist and founder of Evergreen's Laboratory of Bacteriophage Research), were willing to help me again and again when I had difficulties with concepts in their fields. They pointed me in the right direction when I went astray, and read and critiqued large parts of the manuscript. My wife, Sheryl Kutter (anthropologist), put up with my single-minded focus and was always ready for discussions, in addition to proof-reading the entire manuscript. I also got support from the College deans by giving me relevant teaching assignments and, towards the end of the project, a one-year leave of absence. Additionally, the publishers Jones and Bartlett solicited reviews of each of the chapters from recognized authorities in the respective disciplines.

Despite all of this support, Lynn Margulis, a biologist and professor at Boston University, wrote in the text's foreword: 'I cannot help but notice that Kutter as a biologist still has some learning to do. I am sure that any anthropologist, zoologist, geophysicist, organic chemist, *etc.* will see small errors and differences in interpretation'. She then continued: 'My response to this *inevitability* is that all of you specialists, students and teachers using this tome celebrate the magnitude of Kutter's effort by bringing to his attention your criticisms'.

Summary of the Content of *The Universe and Life*

The Universe and Life is divided into two parts: *Physical Evolution* and *Biological Evolution*.[2]

Part I. Physical Evolution

Long before the formation of the Solar System, a series of cosmic events took place that set the stage for the eventual origin of life on Earth and its evolution toward the enormous diversity we witness today. These events began roughly 13.7 billion[3] years ago when time and space, energy and matter (dark and baryonic[4]), as well as the laws of physics 'emerged' during one gigantic explosion, the *Big Bang*. Chaos reigned everywhere. Energy was largely in the form of

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[2] The following descriptions of physical and biological evolution are in part based on sections from the preface of *The Universe and Life*, but have been expanded and updated to reflect current understanding.

[3] In this paper I am using the US convention for billion: One billion = 1000 million = 10^9.

[4] *Baryonic matter* is the kind of matter we, the Earth, the Sun and the rest of the visible Universe are made of. In contrast, *dark matter* cannot be seen. It makes itself felt only via the gravitational effect it has on baryonic matter and electromagnetic radiation. To date dark matter has not been detected on scales of planets and stars, only on scales of galaxies and larger structures. Dark matter's mass exceeds that of baryonic matter by roughly a factor of five.

In addition to baryonic and dark matter, cosmologists hypothesize that the Universe is permeated by an energy they call *dark energy*. Dark energy differs from the energy associated with baryonic matter, such as kinetic energy, potential energy (*e.g.,* gravitational), chemical energy, heat energy, *etc.* Dark energy is thought to be a property of space itself and postulated to be responsible for the observed current acceleration of cosmic expansion. Interpretations of the cosmic microwave background (see Fig. 1) suggest that today dark energy amounts to ~72.8 % of the total mass-energy of the Universe, while baryonic and dark matter amount to ~4.6 % and ~22.7 %, respectively (Jarosik 2011).

high-energy electromagnetic radiation; and, after a brief period of primordial nucleosynthesis, baryonic matter consisted almost entirely of gaseous, ionized hydrogen and helium plus electrons. The heavier elements had not yet appeared. The radiation and matter were nearly homogeneously distributed throughout the Universe, except for very weak fluctuations in frequency distribution and density, respectively, which both had inherited from the Beginning – the so-called *Planck Era*. Furthermore, the radiation and baryonic matter were strongly coupled because the latter was ionized (radiation interacts with electric charges). The temperature was extreme.

The Universe was expanding furiously, due to the enormous amount of energy released during the Big Bang. Gradually, the expansion lowered the temperature; and by the time the Universe was roughly 400,000 years old, it had dropped to below 3,000 K. Now hydrogen and helium were able to capture electrons and keep them bound. Baryonic matter became neutral; and the initially strong coupling between it and radiation ceased. Radiation and matter decoupled. Each was now able to do its own thing.

Not much has happened to radiation since decoupling, except that its wavelengths got stretched by roughly a factor of 1,000 due to cosmic expansion. Today we observe it as the *Cosmic Microwave Background* (CMB) radiation. The CMB radiation is the same from every direction, except that it still possesses the weak fluctuations in frequency distribution.

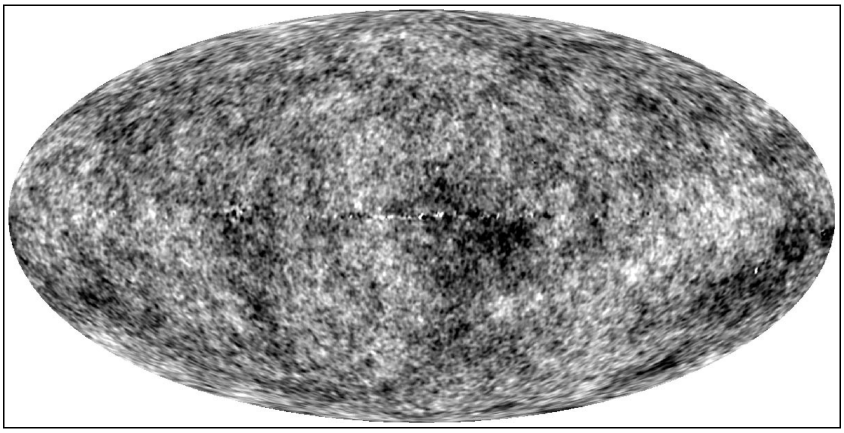

Fig. 1. All-sky map of the Cosmic Microwave Background radiation, the 'oldest light' in the Universe, dating to when the Universe was roughly 400,000 years old, and characterized today by a black body temperature of ~2.7 K. The radiation is isotropically distributed across the sky, except for weak fluctuations in temperature, amounting to about 1 part in 10^5. (Source: NASA / WMAP Science Team.)

Matter, too, followed its own evolution; but it has been far more interesting than that of radiation. Regions that had inherited above-average dark-matter densities possessed above-average gravity. They succeeded in locally slowing cosmic expansion and then began contracting via self-gravitation. Regions that had inherited lower-than-average densities had weaker gravity and, therefore, lost matter to higher-density regions. Baryonic matter followed these developments. In the course of some hundreds of millions of years, baryonic matter coalesced into the first generations of stars and proto-galaxies, followed by the formation of galaxies, galaxy clusters, and galaxy superclusters. Today, the galaxy superclusters and clusters form enormous walls, filaments, and bridges that crisscross the Universe, with huge voids between them. Some of these structures are many hundreds of millions of light-years in length (Bromm, Yoshida, Hernquist, and McKee 2009; Springel *et al*. 2005).

In the cores of the newly formed stars, nuclear reactions fused hydrogen and helium into heavier elements, such as carbon, nitrogen, oxygen, silicon, *etc.* As the most massive stars reached the ends of their lives, they exploded as supernovae and ejected newly synthesized elements into interstellar and intergalactic space. There, the elements intermingled with primordial hydrogen and helium. From this enriched mix new generations of stars were born, some of which also exploded and further contributed to the gradual buildup of heavy elements in the Universe.

Fig. 2. The *Southern Pinwheel galaxy*, *Messier 83*, at a distance of ~15,000 light-years. If we could view our galaxy, the *Milky Way*, from afar, it probably would resemble M 83, with a similar, bar-like central bulge and graceful spiral arms; plus star-forming regions, bright nebulae lit up by recently formed stars, and dark, light-absorbing dust lanes. (Source: S. Lee, C. Tinney, D. Malin, and the Australian Astronomical Observatory.)

Among the billions of galaxies populating the Universe, one was the *Milky Way*. In an interstellar cloud, located in one of its spiral arms and enriched with heavy elements, the *Sun* and its planets formed approximately 4.5 billion years ago.[5] The third planet from the Sun was *Earth*. During its formation, Earth lost most of its hydrogen, helium, and other volatiles. What remained was a gravitationally differentiated globe consisting of an iron-nickel core surrounded by a rocky, silicate-rich mantle and, initially, a magma 'ocean'. As the Earth cooled, this ocean hardened into a solid crust, probably within the first 100 to 200 million years of its existence (Hawkesworth and Kemp 2006).

During the first billion years, Earth and the other terrestrial planets were repeatedly bombarded by bodies, large and small (some were 1000 km and larger in size), called *planetesimals*. Their equivalents today are asteroids and comets. In fact, the Moon is thought to have been formed when a planetesimal roughly the size of today's Mars impacted on the nearly formed Earth, some 30 to 50 million years after the origin of the Solar System. Some of the material blasted into space by the giant impact went into orbit around the Earth and accreted to form the Moon. Impact scars from the later phases if this interplanetary bombardment, the so-called period of *late heavy bombardment*, between roughly 4.1 and 3.8 billion years ago, are still in evidence today on the surfaces of such geologically inert bodies as Moon and Mercury[6] (Kleine *et al*. 2005).

The cometary planetesimals came from the outer regions of the Sun's planetary system, probably perturbed in their orbital paths by Jupiter and the other giant planets. These cometary bodies consisted largely of water ice and frozen volatiles rich in biogenic elements, such as carbon, nitrogen, oxygen, phosphorus, sulfur, and other elements, as well as simple organic molecules, necessary for the eventual origin and evolution of life. These freshly delivered materials covered the Earth with oceans and an atmosphere.[7] From the Sun, Earth received a steady supply of radiation, which provided warmth and light.

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[5] The interstellar matter from which the Sun and its planets formed consisted approximately of 71 % hydrogen, 27 % helium, and 2 % heavier elements (by mass).

[6] The bombardment of Earth by interplanetary debris continues today, but at a much reduced rate. Most of today's bodies, arriving from interplanetary space, are extremely small compared to those early in our planet's history. The vast majority is roughly of the size of sand grains, though some have dimensions comparable to boulders. We call them *meteors* or *shooting stars* when they pass as fiery streaks across the night sky, or, if they are very bright, *bolides*.

[7] The early terrestrial ocean and atmosphere were anoxic. Molecular oxygen began accumulating on Earth only after the appearance of cyanobacteria, the earliest known aerobic (O_2-releasing) photosynthesizers, around 2.8 billion years ago. The oxygen level in the atmosphere began increasing measurably about 2.3 billion years ago (Olson 2006).

Fig. 3. Earth as seen from NASA's Apollo 8 Command Module, orbiting the Moon 110 km above its impact-scarred surface (December 1968)

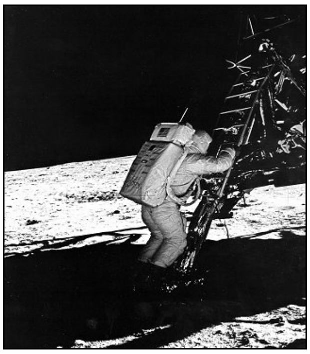

Fig. 4. The first landing by humans on a planetary body beyond Earth (Apollo 11, July 20, 1969), attesting to our species' indomitable spirit of exploration and adventure

Fig. 5. Human footprint in Lunar soil (Source: Figs 3, 4, 5 NASA/ Apollo Program)

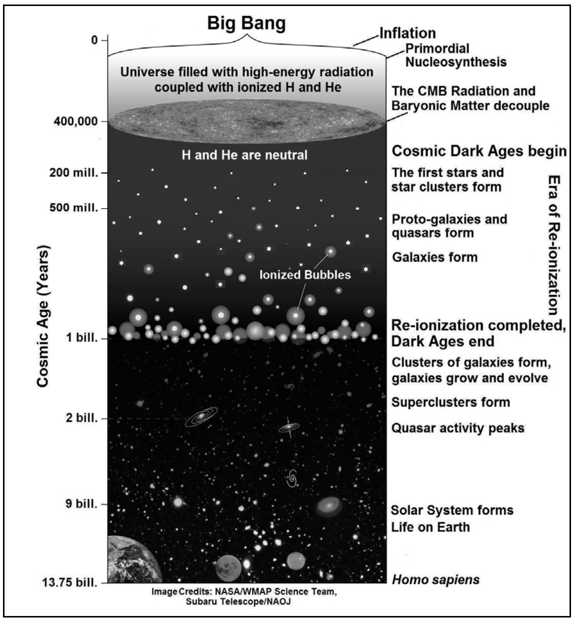

Fig. 6. Major events in the physical evolution of the Universe – from the Big Bang to today (Source: National Astronomical Observatory of Japan, Subaru Telescope, Press Release, 24 Feb. 2009.)

Part II. Biological Evolution on Earth

As the young Earth acquired, via cometary bombardment, an ocean consisting of water, along with biogenic elements, we may assume that locally conditions arose that were well suited for the occurrence of a multitude of different kinds of chemical reactions. Many of these reactions were probably driven by such energy sources as heat from lava eruptions, lightning, shocks from impact events, and solar UV radiation, and catalyzed by the physical environment (*e.g.,* mineral surfaces). The result was the creation of a great variety of simple organic molecules. Over time, the molecules became larger and more complex. Amino acids, nucleic acids, sugars, fatty acids, and other small organic molecules, and polymers composed of them accumulated in the ocean, became locally concentrated, and created what is often referred to as the 'prebiotic soup'.[8]

[8] There currently exist two principal theories for the origin of life on Earth – the *prebiotic soup* theory (a cold, oceanic origin) and the *autotrophic metabolic* theory (a hot origin, mainly energized by geothermal sources). The former theory links early terrestrial biochemistry with the preceding cosmic chemistry; while the latter links it with geochemistry. In the above description of how life might have originated on Earth, I favour the prebiotic soup theory, though I also

The interactions between the molecules increased in diversity and eventually some sort of order emerged. This order must have included the first primitive means of both storing information and carrying out catalysis, functions required for biological reproduction that today are performed by *deoxyribonucleic acids* (DNA) and *proteins*, respectively. It has been suggested that early on this dual function was performed by a polymer that is related to but predates DNA, namely *ribonucleic acid* (RNA) or a precursor of RNA. However, to date attempts to experimentally create such a polymer under prebiotic-soup-conditions (*i.e.,* abiotically) and thus to confirm the so-called 'RNA world hypothesis' have not been successful (Powner, Gerland, and Sutherland 2009). In any case, according to our current understanding, within possibly a few 100 million years of the formation of Earth, the initially relatively simple chemical and physical interactions led to the origin of self-maintaining chemical systems – the first *protocells* on Earth.

Of course, there may have co-existed numerous different 'species' of protocells, competing with each other, probably inhabiting a range of different environments, and co-evolving. Furthermore, 'species' of protocells may periodically have become extinct when large planetesimals impacted on Earth, particularly during the period of late heavy bombardment; and new 'species' arose subsequently. But based on the biochemical and structural similarities of modern cells, it is believed that all of today's life evolved from a single protocell lineage – the *last universal common ancestor* or *LUCA*. The other protocell lineages died out (Forterre and Gribaldo 2007).

The LUCA cells lived in the juvenile ocean and resembled today's bacteria, though they probably were considerably less complex. They were capable of neither photosynthesis nor respiration, but obtained their nourishment by the anaerobic process of fermentation of organic molecules synthesized in the soup. Furthermore, they did not reproduce sexually, by the mating of males and females, but by direct asexual cellular division. However, natural selection – the maintenance of genetic diversity and the preferential survival of those individuals best adapted to the prevailing conditions in the environment – exerted itself right from the beginning. Over time, the LUCA cells became more complex; metabolic pathways became more efficient and versatile (*e.g.,* photosynthesis developed); and by roughly 2 billion years ago, the three domains of modern cells had evolved: the bacteria and archaea, which are prokaryotes (cells without nuclei), and the eukarotes. Subsequently, the eukaryotes evolved into protists, fungi, plants, and animals, including humans.[9, 10]

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took some elements (*e.g.,* catalysis on mineral surfaces) from the autotrophic theory (Bada *et al*. 2007).

[9] In addition to archaea, bacteria, and eukaryotes there exist viruses, which are microscopic parasites possessing genes, but by themselves cannot reproduce. Therefore, traditionally they have not been classified among living organisms. Viruses reproduce by infecting appropriate host cells and subverting their reproductive machinery to produce offspring viruses. Recent research has shown that viruses probably have played and are still playing major roles in the evolution of cellular organisms; and their place in the universal tree of life has become an active topic of discussion.

The human phylogenetic lineage goes back about 5 to 7 million years in Africa to the last common ancestor of today's humans and chimpanzees. That ancestor was an arboreal animal who lived in the tropical forest. For roughly one million years after this speciation, our early ancestors retained anatomical features that allowed them to live as both climbers in the arboreal environment and upright bipeds on the ground. Gradually, as the climate became drier and more seasonal, our ancestors began moving from the receding forest out into the grasslands of the surrounding savannah; and their dual adaptation shifted more and more toward habitual bipedalism. It was an adaptation that allowed them to walk over great distances and to quickly escape predators. An example of this adaptation is found in fossil records of the *australopithecines* (meaning 'southern apes'), who appeared around 4.2 million years ago and survived for close to three million years.

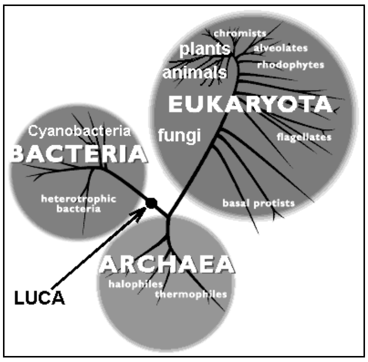

Fig. 7. The phylogenetic tree (simplified) showing the three domains of terrestrial life: Bacteria, Archaea, and Eukaryota. The organisms of the three domains are thought to have evolved from a single 'last universal common ancestor' or 'LUCA' (Source: Carl Woese, University of Illinois.)

[10] It was the accumulation of molecular oxygen (O_2) in the terrestrial ocean and atmosphere that made possible the evolution of eukaryotes, which are obligatory aerobes. Molecular oxygen offered the potential of developing metabolisms that combine oxygen and hydrogen (the latter typically obtained from organic materials, such as sugars and fats) to form water (H_2O), a reaction that liberates far more energy than anaerobic reactions. However, O_2's high reactivity makes this molecule potentially lethal to life. Two evolutionary 'inventions' were required to counteract this danger. First, 'escort' molecules had to evolve that bind with O_2 and make it harmless while circulating within the cytoplasm of cells. Second, metabolic pathways needed to evolve that ensure that the reaction of $O_2 + 2\ H_2 \Rightarrow 2\ H_2O$ does not occur suddenly (as it does, for instance, in burning wood), but in a series of small steps, so that the reaction energy is released gradually and, hence, safely. The evolution of cyanobacteria, the first aerobic photosynthesizers on Earth, was accompanied by both inventions. All subsequent aerobic life adopted, with various adaptations and improvements, this two-step strategy of the early cyanobacteria, allowing evolution to take the great multitude of paths it has and creating the enormous biodiversity that characterizes our planet today.

Roughly 2.4 million years ago the genus *Homo* evolved from the australopithecines; and by 250,000 to 200,000 years ago *H. sapiens* (meaning 'wise' man) or modern man appeared, still in Africa, who possessed a large brain, language, sophisticated stone tool technologies, and fire, and, we may assume, was capable of abstract thought and developed social structures and culture. Earlier members of the genus *Homo*, such as *H. habilis, H. erectus*, and several other Homo species possessed some of these characteristics, too, but not to the same degree.[11] By about 100,000 to 50,000 years ago – the timing is currently a matter of considerable debate among physical anthropologists – tribes of *H. sapiens* migrated out of Africa and began spreading across the globe.

Figs 8, 9. The Laetoli footprints, left about 3.5 million years ago by three people of the extinct hominid species, *Australopithecus afarensis.* The prints clearly show the raised arch, rounded heel, pronounced ball, and forward-pointing big toe of individuals who were habitual bipeds. The prints were discovered in 1976 in the Laetoli Beds of Northern Tanzania, Africa, by an international team of scientists. They are preserved in powdery volcanic ash that became compacted by gentle rain, and in time was covered by additional ash deposits. (Source: Figs 8, 9, Bob Campbell, National Geographic Society.)

[11] Our closest relatives were the now extinct members of *H. neanderthalensis*, with whom we share a last common ancestor that goes back about 500,000 years in Africa. In fact, some anthropologists think that the Neanderthals were not a separate species from us, but a subspecies – *Homo sapiens neanderthalensis*. Early on, the Neanderthals left Africa and settled in Asia and Europe, where they survived until about 50,000 and 30,000 years ago, respectively. Genetic evidence indicates that humans and Neanderthals interbred about 60,000 years ago in the Eastern Mediterranean and, more recently, about 45,000 years ago, in eastern Asia. Of course, there probably were other interbreeding events that we may never know about. As a result, approximately 1 to 4 % of the genome of Eurasian people derives from *H. neanderthalensis*; but to date, no evidence exists of interbreeding in the genomes of African people (Dalton 2010).

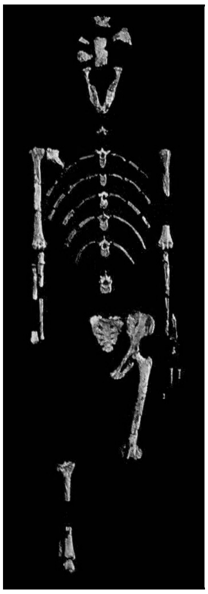

Fig. 10. Fossil hominid, Lucy
Like the Laetoli people, 'Lucy' was a member of *Australopithecus afarensis* and lived roughly 3.2 million years ago in today's Hadar region of Ethiopia. The fossil skeleton was found in 1974 by the international Afar Research Expedition, whose members named her after the then popular Beatles song 'Lucy in the Sky with Diamonds'.
The skeleton, which is nearly 40 % complete, indicates that Lucy was an adult female about 25 years old who, like her contemporaries, was rather small – a little more than one meter in height, with a weight of about 30 kg. The ratio of the length of her arms to that of her legs is less than that of modern chimpanzees, but greater than that of modern humans, suggesting that even though Lucy was a habitual biped, she still retained some arboreal adaptations. (Source: Cast from the Museum national d'histoire naturelle, Paris.)

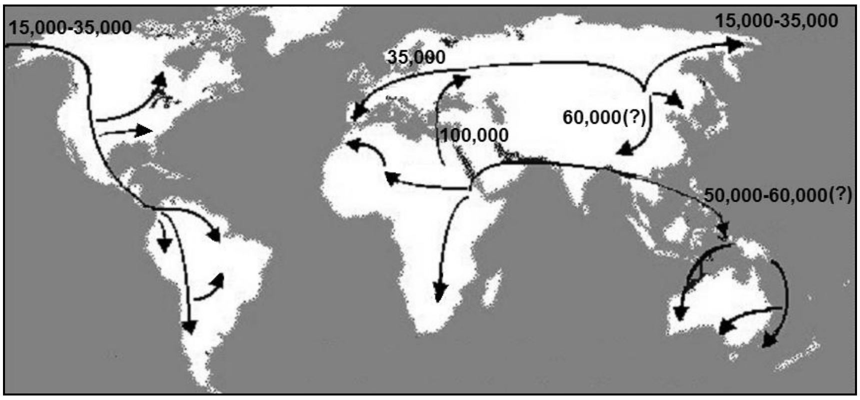

Fig. 11. Major human migration paths out of Africa and across the globe, with estimates of their timing (years ago)[12] (Source: Cavalli-Sforza, Menozzi, and Piazza 1994.)

[12] This map gives a good overview of human migration paths, but is slightly dated. For a more up-to-date and detailed map see: National Geographic Maps, *Atlas of the Human Journey*, URL: http://www.utexas.edu/features/2007/ancestry/graphics/

Fig. 12. Watch tower, Jericho, ca. 7000 BC

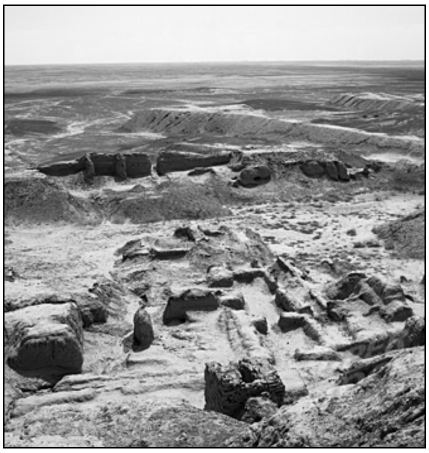

Fig. 13. Ruins of Uruk, ca. 3000 BC

Early human populations were hunters and gatherers. They lived off the land, eating the fruits, grains, and vegetables that were in season and following herds of wild animals in their yearly migrations. But by about 10,000 years ago, as the last ice age was coming to a close and the climate grew milder, some groups of *H. sapiens* were beginning to cultivate plants and domesticate animals; and they began building villages and (later) towns. They were gaining independence from the vagaries of nomadic life. The earliest known signs of human settlements and an agricultural way of life are found in the Fertile Crescent of the Middle East, which arches from the Jordan Valley and Syria through eastern Turkey to Iraq and Iran. Here we find stone ruins of houses, walls, and watch towers nearly 10,000 years in age. Examples are Jericho and (later) Uruk. Jericho, on the west side of the Jordan River valley, had a more than 5000-year-old history when biblical writers made reference to it, and at one time is thought to have had a population 2000 to 3000. Uruk (Erech in the Bible) was located on the banks of the Euphrates River in today's Iraq and was one of the principal cities of ancient Sumer. It was enclosed by brick walls about ten kilometers in circumference, built by the mythical king Gilgamesh. At the height of its development by around 2900 BC, the city is estimated to have had a population of some 50,000.[13] (Source: Figs 12, 13, Casa Editrice Scode, S.p.A., Italy.)

[13] It is worth noting that protective city walls and towers have a long history, signifying that conflicts, wars and conquests go back a long way and attesting to the aggressive nature of our species.

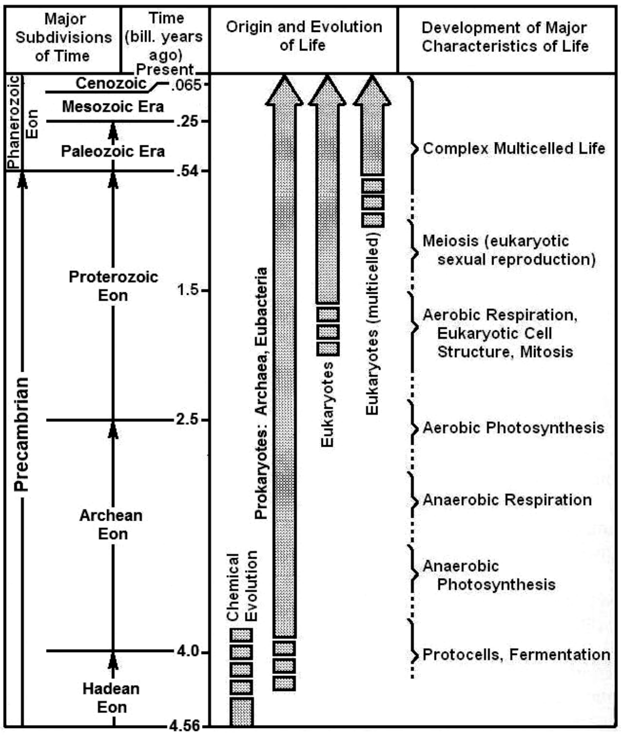

Fig. 14. Major events in biological evolution on Earth (Source: Kutter 1987, updated.)

Where Do We Go from Here?

The images below illustrate the huge divide that exists today between the subsistence living of people in the underdeveloped world, on the one hand, and the materialistic life styles, wanton pollution of the environment, and excessive military spending in at least parts of the industrialized world, on the other. Unless we, the people of the Earth, manage to narrow this divide; take the wide-spread degradation of the environment, including the human contribution to global warming, seriously and begin counteracting it; preserve the planet's biodiversity; recognize that the world is finite, which places limits on population, economic growth, and availability of natural resources; reduce military spending and weapons arsenals; and learn to live in harmony with our environment and with each other; humankind will surely be marching toward an abyss.

In my view, to avoid a catastrophe, we must set aside our prejudices; make use of our scientific and technological knowhow; and, as I wrote in *The Uni-*

verse and Life, 'we must learn to combine the two seemingly contradictory attitudes – modern man's reliance on science and technology and the nomad's maxim of adaptation to the environment' (O'Neill, Dietz, and Jones 2010; Victor 2010; Kutter 1987: 546).

Fig. 15. Akha couple in northern Thailand. The husband is carrying the stem of a banana-plant, which will be fed to their pigs (Source: Manuel Jobi Weltenbummler84, en.wikipedia.org)

Fig. 16. Evening rush hour, Times Square, New York City (Source: Institute for the Future of the Book)

Fig. 17. Industrial smoke stacks (Source: blogcity.org)

Fig. 18. Nuclear submarine armed to capacity with nuclear warheads (Source: Military-Today.com)

Physical *vs.* Biological Evolution

According to our current scientific understanding, the evolution of the inanimate Universe is governed by the laws of physics that humans have deduced, over the course of centuries, via experiments in terrestrial laboratories and by observing events in the Solar System (*e.g.,* orbital motions, star light making grazing passages of the Sun's limb) and the Universe beyond.

On macroscopic scales, the classical laws of physics from Newton's mechanics; Carnot's, Joule's, Clausius', and Lord Kelvin's thermodynamics; Faraday's and Maxwell's electricity and magnetism; *etc.* to Einstein's theories of special and general relativity are *deterministic*. This means that if the initial state of an isolated system is known, the laws allow a competent theoretician with sufficient computer power to predict all future states of the system.

On the microscopic scales of molecules, atoms and elementary particles, Heisenberg's, Born's and Schrödinger's quantum mechanics rule. Quantum mechanics is a *probabilistic* theory because there are limits to how well the state of a microscopic system can be known, today or in the future. The probabilistic nature of quantum mechanics is embodied in Heisenberg's uncertainty principle and confirmed by measurements, according to which it is impossible to determine simultaneously and with arbitrary precision both the position and momentum of electrons, protons and other particles.

These laws – both classical and quantum mechanical – are consistent with nature's conservation laws: the conservation of mass-energy, linear momentum, angular momentum, electric charge, and several other physical characteristics that evidence themselves on the sub-atomic level.

Moving on now to biology, we believe that all of its processes – from the biochemical and physical processes of individual organisms to biological evolution – are also consistent with the laws of physics, because organisms are made of the same kind of baryonic matter that we find in the inanimate Universe. But even though organisms and their internal processes, as well as their interactions with their environments, are subject to the laws of physics, they do distinguish themselves from inanimate objects in a number of fundamental ways:

1) Organisms possess unique structural organizations – on both microscopic and macroscopic scales – that are enormously complex and give rise to a range of physical processes more or less optimized for the organisms' survival and reproduction. It is these organizations and processes that give them the quality we call *living*.

2) Organisms cannot survive on their own. They all are dependent on and part of ecosystems, typically consisting of a great many components, both biotic and abiotic, as well as ranges in size, that dynamically interact with each other in a multitude of ways and via complex feedback loops. Nothing quite comparable is found in the inanimate world.

3) However, the most profound difference between organisms and inanimate objects is the fact that the former reproduce according to genetic informa-

tion encoded in long molecular strands – *deoxyribonucleic acids* or *DNA*. Inanimate objects do not. Over time, the genetic information of members of a population changes in a two-step process of *chance* and *selection*:

In the first step, *random* mutations and their recombinations gradually alter the genetic information of a population from generation to generation, thereby contributing to and maintaining a *large degree of variation* in the genetic makeup among the population's individual members.

The second step results from the fact that some members of a population are, because of their particular genetic makeup, more competent – due to biochemical, anatomical, and/or behavioral traits – than others in finding food and shelter, defending against predators, resisting disease, and dealing with changes in climate and geophysical conditions. These more competent members are more likely than others to survive, reproduce and pass their genetic makeup on to the next generation.

This inequality among members of a population in the likelihood of passing on genetic information constitutes a *selection process*. It continually pushes the genetic makeup of a population in directions that better adapts them to changing biological and climatic/geophysical environments and increases the likelihood of survival of the population. The result is *Evolution by Natural Selection*, as first recognized independently in 1858 by two British naturalists, Charles Darwin and Alfred Wallace.

This two-step process of *chance* and *selection* is also the driver of *speciation,* the evolutionary process by which new biological species arise.

Philosophic and Pedagogic Challenges

In writing *The Universe and Life,* I used the chronologic approach, which presented two challenges that characterize Big History as well – one *philosophic,* the other *pedagogic*.

The *philosophic* challenge arose from the chronologic order of the presentation of the topics, which might mislead the reader into thinking that there is purpose to evolution, namely the making of humankind. This view is not warranted, at least as far as is known from science. The laws of nature came into being, along with time and space, energy and matter, during the Big Bang, and they have governed the evolution of the Universe and all it contains ever since. The appearance of life on Earth, including humankind, is a consequence of these laws, just as the formation of stars and their planetary systems, galaxies, and galaxy clusters is. Science does not accord any special status to life or to humankind. This conclusion had already been reached by 17th century philosopher Benedict de Spinoza, when he wrote in his influential metaphysical treatise *Ethica*: 'Nature has no particular goal in view, and final causes are only human imaginings'.

The *pedagogic* challenge arose from the fact that the *Universe and Life* is written on the introductory level, yet, because of its chronologic approach, starts with complex and difficult topics. For example, Chapter One deals with the Big Bang, during which conditions were far from simple and as different from our experiences as can be imagined. Likewise, theories of the emergence of the earliest organisms on Earth and the eventual evolution of some of them toward complex multi-celled life based on the eukaryotic cell structure, aerobic respiration, and sexual reproduction are topics with which most students are probably not familiar, and that to a considerable degree are still controversial. Clearly, a chronologic approach did not allow me to start with the familiar and simple and then develop the subject matter in a systematic manner, as is common in traditional texts.

In order to minimize the difficulties that a chronological approach presents, I wrote introductions to Parts I and II that establish essential background information. Furthermore, each chapter contains numerous comments, short essays, and tables that are boxed to set them off from the main text. They offer additional information that, if included in the text, would interrupt the flow of the presentation.

Looking back today, from the perspective of more than two decades since the publication of *The Universe and Life*, I recognize yet another challenge, or put more positively, an opportunity, which at the time I did not appreciate fully. This opportunity reveals beauty, as well as new insights to the subject of Big History. It was articulated by the English sculptor Henry Moore, when he was asked by Nobel Prize winning Indian-American astrophysicist Subrahmanyan Chandrasekhar: 'How should one view sculptures: from afar or from nearby?' Henry Moore replied: 'The greatest sculptures can be viewed – indeed should be viewed – from all distances, since new aspects of beauty will be revealed on every scale' (Chandrasekhar 1979).

Likewise, I believe that the Universe and its contents should be viewed and studied on all scales accessible to our telescopes and, here in our Solar System, more directly through space missions; and so should terrestrial life, by direct observations and with the aid of microscopes, from the scale of ecosystems to that of individual organisms, cells, viruses, and their contents. At every scale we will find new insights, surprises, and beauty, and new interconnections and complexities.

Conclusion

I would like to conclude by asking you to re-read Lynn Margulis' words above, pointing out that, 'I as a biologist still have some learning to do', and then suggesting that the 'specialists, students, and teachers using the text bring to my attention their criticisms'. In this spirit, I would like to propose that we, who are participants in the development and teaching of Big History, recognize that our intellectual endeavour is so immensely broad that no single individual or even members of a single academic institution can likely be experts in all that the field entails.

As we advance Big History, 'errors and differences in interpretation' are inevitable. But let us not be disheartened by this fact. Instead, let us use the challenges of Big History as our guiding principle to generously communicate with each other; collaborate and constructively critique each others' contributions, particularly at the interfaces of different disciplines; and patiently, but resolutely, move the field forward toward the common goal: '…to understand, in a unified and interdisciplinary way, the history of Cosmos, Earth, Life, and Humanity' (see International Big History Association website at http://www.ibhanet.org/).

Aknowledgement

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8
The Chandra Multiverse

Tom Gehrels

Abstract

Equations of Planck and Chandrasekhar lead to our universe being a member of a quantized system of universes, the 'Chandra Multiverse'. It is a trial-and-error evolutionary system; all universes have the same critical mass and finely tuned physics that our universe has. The origin and demise of our universe are described. In our astronomical environment everything ages and decays; even the proton may have a limited half-life. The decay products of all the universes expand into the inter-universal medium (IUM), clouds form in the IUM, from which new universes are started. When the density at the center of our proto-universe cloud reached proton density, photons, protons and neutrons were re-energized. A Photon Burst marks the beginning of our universe, 10^{-6} s, i.e. 10^{37} Planck times, later than a Big Bang; the evolution of forces, sub-atomic particles, and finely tuned physics, occurs in the Chandra Multiverse. This paper is based on 30 observations, 8 previous papers, and 2 books; the multiverse makes the identification of dark energy and dark matter possible.

To leave the earth's surface was the desire of Leonardo da Vinci – in 1783, the first balloonists left the earth! There were *four* flights that year, from the squares of Paris, in full sight of thousands of people who had come out to see the miracle: 'If we can do that, what can we *not* do?' The French Revolution began soon after that. Of the next step, to the moon, President John F. Kennedy spoke to the US Congress in 1961. It sounds like poetry when you read it aloud:

I believe that this nation
should commit itself
to achieving the goal
before this decade is out,
of landing a man on the Moon
and returning him safely to Earth.

It was done, and had the same effect on the world population as on the people of Paris before. The trials and failures, and ultimately the flights and walks on the moon were shown on international television, in newspapers and magazines, watched and discussed by millions on Earth: '*If we can do that, we can do anything!*' The astonishing feat of people leaving Earth may have spurred the surge of activity and questioning that took place during the 'Great Sixties' all over the world.

These two examples of broadening the horizons stimulate the Chandra Multiverse[1] to solve old problems and open new disciplines ('Chandra' was used by his colleagues and for the Chandra X-Ray Observatory spacecraft). There was an inkling of high expectations in 1954 when I was a student in the class of Subrahmanyan Chandrasekhar (1910–1995) at the Yerkes Observatory of the University of Chicago. There were many equations and derivations, but his cosmic-mass equation was exceptional because of its unified operation of quantum, relativity, gravity, and atomic physics. He hinted the possibility of deeper relations between atomic theory and cosmogony.

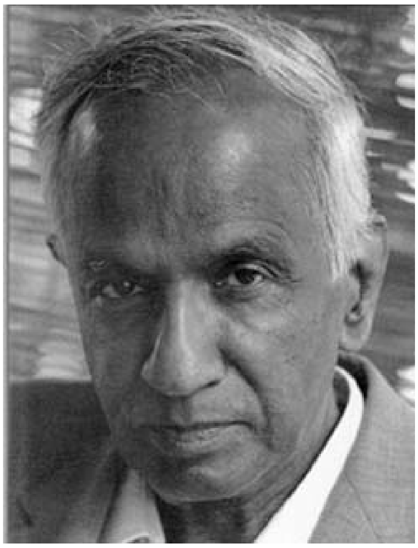

Fig. 1. Chandra

It took me years of preparation, but when I finally dared to use that equation, it pointed to our universe not being alone but being a member of the Chandra Multiverse with many others, each with the same mass and physics. I published that in 2007, and thought I was done, because others would surely jump to such a basic change in our worldview. No one stirred, so that I proceeded with various papers; www.lpl.arizona.edu/faculty/gehrels2.html presents them readily, and there two books (Gehrels 2011, 2012). This is a beginning, a sketch to show possibilities, while expansion by specialists is needed for all parts.

[1] This notion is explained further in this article.

Better understanding of the vast dimensions of the Chandra Multiverse follows from changing scales, using various measuring sticks. We use centimeters or inches for small distances on the desk, but it would be silly to use the large number of centimeters for going home, so that we switch to kilometers or miles. Beyond the Earth and Moon, the astronomical unit (AU) is used, which is the average distance of the Earth from the center of the sun. To the outer edges of the solar system that becomes a large number again – 100,000 AU. So, beyond that to the stars and galaxies we use the lightyear, which is the distance light travels in a year, $\sim 10^{13}$ km.

In order to help you visualize the multiverse, consider the next larger grouping after planets and stars, which is a galaxy, the ensemble of at least a thousand million stars, and then the next step, another thousand million galaxies to populate our universe. Having come to the end of our universe, as far as we can observe it, we ask: 'Why would our universe be the only one?' Some theoreticians have already made models regarding the existence of other universes, but this article is about a specific set of universes. It is based on the mass equation of Chandrasekhar (1951) and is therefore called the 'Chandra Multiverse'; it has nothing to do with any previous usage of the word 'multiverse'.

This paper has 8 introductory context sections followed by 11 technical sections; the latter begins with 'The Cosmos has a Single Unified Physics'. It is all assembled for historians who call themselves 'Big Historians' for wanting to go back all the way in time. The evolution in the Chandra Multiverse is now the earliest we can go back to – there never was a Big Bang – and the early evolution is now properly taken care of in the multiverse.

Big Bang, Planck Time, Inflation and Strings

The words 'Big Bang' are commonly used for the beginning of our universe. As it is conceived, a supercharged explosion created the basic matter and energy that evolved over the course of 13.7 thousand million years into what we perceive to be our universe today. These Big Bang words are also used in a presently accepted theory called the 'Standard Model'. In this model, our universe is generally believed to be the only universe... this is *it* for the Cosmos.

There are problems with this concept. The usual thinking is to reverse the *expansion* of our universe as a *contraction* back in time. A problem arises when one continues the contraction, without stopping, until all of the mass of our universe is in nearly zero space and compressed into nearly infinite density. That infinite condition is called a 'singularity', which has caused theoreticians to write a large amount of literature in papers, books, and encyclopedias. The Big Bang is believed to be confirmed by three observations, but these were made at ages of minutes and much later, applying nicely to the Chandra-Multiverse model.

The Big-Bang starting time for the Standard Model is $t = 10^{-43}$ sec and all of *our basics* would have had to be produced during the very beginning of our universe. The earliest stages after the Big Bang would have had to be able to evolve quantum mechanics, relativity, gravity, and atomic physics, as well as fundamental forces.

The Standard Model includes that the volume of the universe must have stayed small for a while because of the condition that *interaction must have flourished*; in other words, everything could interact with everything else in such confinement. This requirement emerged when the background radiation between the stars was observed by the COBE spacecraft to have the same temperature of 1.728 K in all directions – the universe is *uniform* on its largest scales. However, this leads to that impossible early condition, because in order to interact, the components must be close enough. All of the quantum fluctuation components, with a total mass equivalent to 10^{21} solar masses, would have had to be confined in a volume so small that all their components could interact with all others at the velocity of radiation. Their density would have had to be as high as the Planck density of 10^{96} kg/m^3, which does not seem realistic.

At this point of reasoning, *inflation theory* seemed to solve the problems in the 1970s, with a complex homogenizing and processing between 10^{-43} sec and 10^{-32} sec, removing a variety of uncertainties in the understanding of the early stages for our universe. (That interval is hard to imagine, and looks brief, while it is actually long for the fast subatomic actions. The usage of the *second* as a unit of time is better replaced here for sub-atomic action by the *Planck time*, which is about 10^{-43} sec. That interval is then $[10^{-32} – 10^{-43}] / 10^{-43} \sim 10^{11}$ PT.) Anyway, the inflation theory has in that interval a fast increase in the size of the universe, an inflationary expansion, with thorough interaction of components, explaining the uniformity of our universe found by COBE. This fast expansion was confirmed in later observations by the WMAP spacecraft (Spergel *et al*. 2007).

Such confirmation has not yet happened for *string theories*, which have no observations supporting them; they may be too small and energetic. String theories consider sub-atomic particles as one-dimensional curves called ‘strings’. The strings all differ in order for their vibrations to represent the variety of properties of sub-atomic particles. They facilitate storage of information by having those particles replacing the infinitely small point-particles of quantum theory. The theories are mathematically expressed and are powerful because they can describe atomic forces and fields; the strings are imagined to be embedded in space-time. They come in various sizes and shapes for storing the various properties; they may be curled and imperceptibly small. The variety of particle properties is a reflection of the various ways in which a string can *vibrate*: electrons vibrate in one way, quarks in another, *etc.* Several *dimensions* are added, at least seven, to the four we are used to (which are up-and-down, close-and-far, left-and-right, and time). The seven higher dimensions are not defined; no one seems to be able to describe them other than by making a comparison with the four (Randall 2005, 2007; Smolin 2007).

There are many string theories, Smolin gives their number as 10^{500}, and the name ‘M-theory’, M for Many, is therefore used for the ensemble. There is some collaboration of inflation and string theorists, while there seems to be a general acceptance that some combination of inflation and strings is what happened at the beginning of our universe. Large physics departments have at least one inflationist and a string-theorist in their faculty; hundreds of physicists work on these theories in international collaboration.

Physicist Brian Greene has provided an overview of string theories and their history, and he revels in an analogy with vibrational patterns of music, how the strings orchestrate the evolution of the world into a cosmic symphony (Greene 1999).

Physicists Paul Steinhardt and Neil Turok criticize inflation theories, while presenting a string theory that has our universe pulsating, expanding ↔ contracting; they do not believe inflation theories (Steinhardt and Turok 2007). Physicists Peter Woit and Lee Smolin do not believe in string theory (Woit 2006; Smolin 2007). Steinhardt specifies why he finds inflation theory deeply flawed (Steinhardt 2011). Such is the state of affairs for understanding the early stages of our universe before $t \sim 10^{-6}$ sec, the beginning time of our universe in the Chandra-Multiverse model, which has the earlier sub-atomic evolution in its multiverse.

Parallel Universes and Anthropic Principles

In the large literature about other multiverses, some of it seems to be *anthropic* (from the Greek *anthropos*, human being), *i.e.* based on human interpretations of physics. The anthropic principle has the idea that nature is the way it is because we are here to observe it – it was created for people. For example, physicist Hugh Everett (1971) adopted the wave interpretation of quantum mechanics held by Schrödinger and others (Bitbol 1995), but he also felt that this picture makes sense only when observation processes are treated within the theory. He favored an interpretation of quantum theory by which reality is brought through observation or measurement. Some of the literature about the multiverse is therefore based on an interpretation of quantum mechanics in which *observations* bring *reality*. I cannot help thinking of that when crossing a major street on the bike, ‘Perhaps if I just do not observe an oncoming car, it would not exist’, but I have not tried it yet. Books and articles describe various multiverses; some have ‘parallel’ universes with identical copies of us reading this paper at this time (Everett 1971; Vilenkin 2006). In contrast, the Chandra-Multiverse model is free of anthropics.

Expansion of 100 % Space

The word 'space' is a most frequently used word, while we actually do not know what it is, in a physical sense. The best feel for space can be obtained by a thought experiment: Imagine that the outer perimeter of the hydrogen atom with its electron shell is as large as the longest outer dimension of an Olympic stadium. How large is then the proton nucleus of the atom on center field? As the size of the stadium is roughly three times the length of a soccer or football field (100 meters or 300 feet), take the long dimension to be about 1000 feet, which is 10^3 x 12 (in/foot) x 2.54 (cm/in) = 3 x 10^4 cm. Divide that by the known factor between the radii of the hydrogen atom and the proton, 10^5, and it follows that the nucleus would be 0.3 cm, the size of a pea. All around inside that stadium is modeled as space. Furthermore, the proton is a structure of space as well. So, the answer to the question of how much of this atom is 'space' is 100 %. The most astonishing conclusion is that this applies to all atoms, to our entire visible world consisting of 100 % space.

You might protest that the objects around us are solid and we experience our mass and weight – how can that be if we are 100 % space? The answer is that space has an abundance of particles with their properties. The word 'particle' is confusing because it reminds us of a solid grain. When physicists use the word, however, they do not mean anything like the Greeks did (an inert grain of dull matter), but rather that *a particle is a point in space that produces a phenomenon, like mass.* By what it does, *a particle is something that provides action and an effect, like electricity.* Both sentences together may help us understand the particles as forms of space and waves by which they produce and interact with gravity, electromagnetism, *etc.* It is because of the properties of particles and photons that we experience weight and all other characteristics of nature.

There is also in this paper much discussion about the expansion of space. It is simple to understand by the galaxies having been pushed apart and still moving because there is little to stop them. It may be helpful to imagine a cake in the oven, which expands as the temperature increases. Imagine yourself to be one of the raisins and you see the others drifting away... that is the expansion. A raisin twice as far away will seem to expand at twice the speed.

The First Minute of our Universe

As of the notable event in the Standard Model that we mentioned at 10^{11} PT after the Big Bang, high-energy particle physicists begin to understand the physics involved at this time, just barely, and make proposals for the forces and subatomic particles that subsequently evolved. A feature of the theories indicates that particles formed symmetrically with their anti-particles of opposite properties. The two would then have largely annihilated each other. However, it was apparently not a total annihilation; one of the two types would have prevailed a little, and that survivor is what we now call a 'particle'. It will be interesting to see if this feature of the theory survives in the evolution of the Chandra-Multiverse.

The next milestone came at 10^{31} PT with the emergence of four nuclear forces: the weak, gravitational, electromagnetic and nuclear forces. The forces and their laws began to be recognized in physicists' modeling of the temperature and pressure of that time.

At 10^{37} PT, protons and neutrons were made; a large amount of radiation was produced. We will see later that this is the beginning time for the Chandra-Multiverse model, t = 0 for that model, and from here onwards the Chandra-Multiverse model adopts and follows the Standard Model. The evolution during the earlier 10^{37} PT is however in the multiverse; that is not an *ad hoc* assumption, but based on the realization that the early evolution, the natural selections, could not have happened in a single universe with fast changes in their environment, while in the multiverse there are many samples and long times like Darwin had for his finches and people. An example of natural selection is in Fig. 2, that is of course for millions of years later and still happening today.

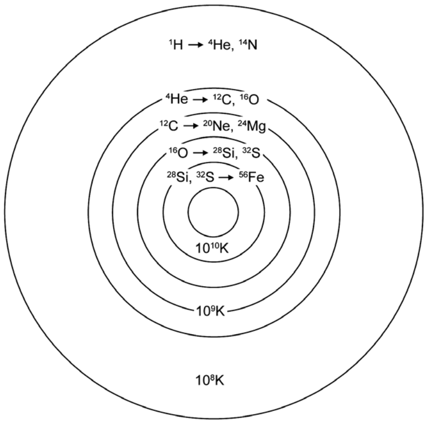

Fig. 2. An example of *natural selection* but at a much later time in our evolution. Increasingly heavier atomic nuclei are formed in increasingly energetic environments in massive stars of spectral types O and B

Neutrinos appear at t = 1 sec, electrons fifteen seconds later, and helium nuclei one minute later. At about that one minute of age, the Standard Model shows a spell of a few minutes during which the conditions were right for the assembly of the nuclei of helium, plus traces of heavier nuclei. However, the change towards less dense conditions still happened fast in that expanding universe; such that the conditions of pressure and density for the combination of nuclei heavier than protons lasted just a few minutes. Therefore, only a limited number of helium nuclei were formed. However, the numbers computed for these conditions are confirmed by the numbers of helium nuclei that are presently observed in the universe. Here lies a success for the later times in the Standard Model.

About the following millennia we know little, other than that the universe consisted of photons being scattered around by protons, electrons, *etc.* – a noisy and energetic mass in expansion, too dense for light to escape (except perhaps an early Photon Burst, we shall see). Not much was happening except this *multiple scattering* of light, somewhat similar to what happens inside the sun, where it takes a million years for a newly made photon at its center to be bounced to the outer levels and then onwards to Earth. All we can do with the present models is to consider the plasma 380,000 years later.

The Universe at Age 380,000

Finally, at t = 380,000 years, came the last remarkable event of the Standard Model for the Big Bang. A great transition took place when the temperature and pressure reached a level at which the scattering diminished, resulting in less density such that the photons were knocked about far less violently and frequently. As a result, the nuclei (of protons and neutrons) and the electrons no longer had enough collision energy to stay free, so they coalesced into hydrogen and helium *atoms*, which are widely spacious to let the photons pass through them, as we saw two sections before.

By the time the expanding universe had reached the temperature of about 3000 Kelvin, it resulted in the separation of matter and radiation. The radiation from that stage is still observed today. It is all around us, observed far away between the stars to where it has expanded since $t \sim 10^{-6}$ sec. By now, the cloud has cooled to almost absolute zero. It is called *the 3-degree-Kelvin radiation*, 3 K being its approximate temperature. The COBE and WMAP spacecraft confirmed this. WMAP also derived that the detailed formation of galaxies and their stars began some 200 million years after the beginning of the universe. The galaxy formation peaked about 5,000 million years after the beginning, which is at 5×10^9 years of age for the universe, compared with the present age of 13.7×10^9 years (Spergel *et al*. 2007). The epoch of 5×10^9 years will return in the history of our universe, when the *acceleration of the expansion* was discovered.

Galaxies

Here is another thought experiment. Imagine that you are a galaxy in space... rather lonesome because space is so large and dark... but still, your gravity will make you move towards whichever galaxy wins over the gravitational tugging by all the others, because it may be closer or more massive. That is how the Andromeda Galaxy is moving towards our Milky Way Galaxy. Such gravitational *interaction* causes the galaxies' motion, groupings, clusters, and collisions.

Although nearly all galaxies expand away from us, they themselves do not expand (nor do we): galaxies have their own gravitational regime. The expansion takes place between the galaxies, and is therefore properly referred to as *expansion of intergalactic space*.

With the naked eye we can see at a certain place in the sky a 'Milky Way' band encircling the sky with the multitude of stars in the galaxy (Fig. 4). We see that because our solar system lies in the flat galaxy that from the outside would be seen in the shape of a discus (Fig. 3). The solar system is also about halfway from the center to the outer rim, and so we see more stars in the direction towards the galactic center than in the opposite direction. Now, if we look in the third direction, away from the plane of the Milky Way, up and down in the paper of Fig. 3, we see fewer stars that belong to our own galaxy and more of the dark sky because we look deep into space where there are few disturbing stars in our own galaxy or its halo. Now we can see other galaxies in the distance.

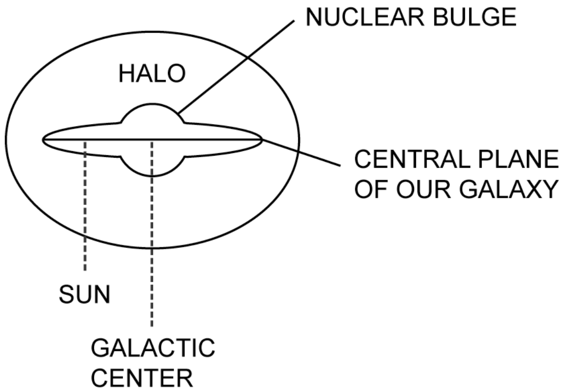

Fig. 3. An edge-on sketch of our Galaxy. The central plane is at the middle of the Milky Way seen in Fig. 4. The Halo is exceedingly faint

The detailed studies of our galaxy require a rich variety of *observational facilities* such as infrared instruments and radio telescopes, along with *theoretical studies* for the formation of star systems and for the dynamics of moving objects. Our galaxy has about 10^{11} bright and faint stars and a great variety of clouds consisting of gas and dust; it all moves through endless turbulence and dynamics.

How large is our galaxy? At the speed of light, it takes about 26,000 years to travel to its center, from the sun to the right in Fig. 3. We are roughly 24,000 lightyears away from the outermost visible stars in the other direction, to the left;

this is approximate, because there is no sharp edge to the galaxy. We therefore are located a little more than halfway from the center to the edge of our galaxy; the diameter of the galaxy is about 100,000 (10^5) lightyears.

Galaxies occur in groupings. Outside of our Milky Way, we first encounter others of our *Local Group,* which has about 30 members and is about three million lightyears in size. The local groups are members of *clusters*, which have a million or so groups, and they in turn may be parts of *superclusters*, having some ten-thousand clusters.

The Interstellar Medium (ISM)

Experts study the characteristics of whatever floats through interstellar space by observing its interaction with starlight, and they find scattering properties in different colors at different wavelengths. Classical studies have made use of such observations with special instruments such as spectrometers and polarimeters at large telescopes.

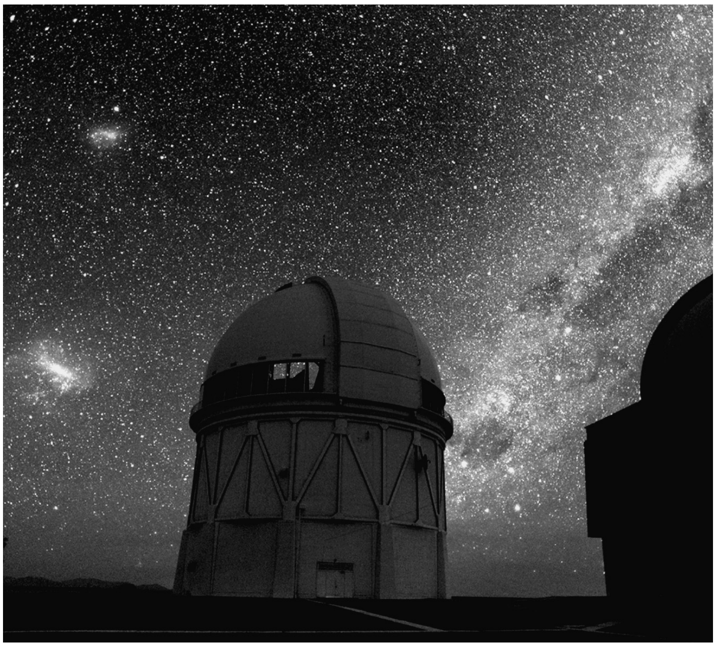

Fig. 4. View of the Milky Way with its dark dust clouds, the two Magellanic Clouds, and telescope domes at the Cerro Tololo International Observatory in Chile (Copyright: Roger Smith, NOAO/AURA/NSF)

Interplanetary and perhaps even interstellar grains have been collected by high-altitude aircraft and balloons, and made available for investigation with microscopes and other instruments in the laboratory. In this way, the 'Stardust' spacecraft flew through interplanetary space to collect samples, as well as grains near Comet Wild 2 in 2004, dropping them off in a capsule for a parachute landing on the Utah desert in 2006. It was a great success; other comets had been studied from spacecraft, but this was the first return of a sample.

Another branch in astronomical science studies molecules that are either drifting freely in space or are attached to interstellar grains. Faint glows emitted by hydrogen molecules sometimes show clouds of interstellar gas. The reason for emphasis on this interstellar medium of gas and dust is that they play a primary role in the formation of the stars. The reason for mentioning the ISM here is that we use it for the study of the inter-universal medium (IUM).

Introduction to Dark Energy and Dark Matter

There is a special challenge in astrophysics and cosmology, which is to understand the physical nature of dark energy and dark matter observed and called by these names, but not understood until now. They are the dominant contents of our universe. You will see the miracle occurring when we switch from our sole universe to considering the multiverse; both problems will then be solved in an elegant manner.

Observable matter, which is called 'baryonic', from the Greek word *barys*, or heavy, accounts for only 4.6 % of the total mass in the universe, while neutrinos equal less than 1 %. The rest is 'dark' or not observed: 23 % of dark matter, while 72 % of the total is in some form of dark energy, believed to be the cause of the acceleration of the intergalactic space expansion.

It was not always so. The abundances were not the same when the universe was young as they are now, and that may be a clue for origins. When the universe was young – age 380,000 years – the observable universe was made up of 12 % atoms, 15 % photons, 10 % neutrinos. What was not observable but otherwise derived to be present was 63 % dark matter and a small amount of dark energy.

The Cosmos has a Single Unified Physics

Young Chandrasekhar showed such promise at the age of 19 at school in Madras (now Chennai), India, that he was accepted for PhD studies at Cambridge University in England. During his long sea voyage to Britain, he did much of his work on stellar structure, which he would further develop throughout the 1930s, and for which he would receive the Nobel Prize in 1983. He moved to the Yerkes Observatory of the University of Chicago in 1937 and to the Chicago campus in 1956.

His equation for masses I referred to at the start of this paper is

$$M(\alpha) = (hc/G)^{\alpha}\, H^{1-2\alpha}, \tag{1}$$

in which *h* is the Planck constant, *c* is the velocity of radiation, *G* is Newton's gravitational constant, and *H* is the mass of the proton; positive exponents α identify the objects shown in Table 1. The derivation takes seven pages, and there was some awe about it, that Chandrasekhar (1951) was aware of – he did publish the equation four times – but he thought it was too early to use it to explore '...deeper relations between atomic theory and cosmogony...' Shu (1982) referred to it in his classical textbook as '...one of the most beautiful and important formulae in all of theoretical astrophysics...' Max Planck had already expressed the possibility for *extraterrestrial* application of constant *h*:

> …the possibility is given to establish units for length, mass, time and temperature, which, independent of special bodies or substances, keep their meaning for all times and for all cultures, including extraterrestrial and non-human ones, and which therefore can be called 'natural measurement units'… (Planck 1899)

He wrote that more than a century before the present time, when we had not as yet discovered any society on a planet of another star. What he probably surmised is that the Cosmos has a single physics that is nearly perfect; it is that physics we consider in the Chandra-Multiverse model.

At the time, however, no one *did* anything with Chandra's equation. The time was not ripe; one had to wait for large telescopes and powerful spacecraft to deliver essential information about our own universe. This began in 1989 with the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP) that followed (Spergel *et al.* 2007).

I started working with Chandra's equation in 2001. The only purpose of the term $H^{1-2\alpha}$ is to be able to use any unit for the mass, such as kilograms and solar masses. But these would be useless in a multiverse; other planetary cultures would have their own units. For a truly *universal* mass, the obvious choice of unit is that of the proton. If all masses are expressed in terms of proton mass H = 1 and $H^{1-2\alpha} = 1$ for all values of α, such that:

$$M(\alpha) = (hc/G)^{\alpha}. \tag{2}$$

It appears to be a concise and powerful combination in terms of the Cosmos' physics, which would encompass perfect versions of quantum, relativity, gravity, and atomic physics (the latter because all masses are expressed in terms of the proton mass, *H*).

The next excitement was to see what happened for various values of exponent α, and that is in Table 1. Chandra had already published these values for the mass for the 'primordial stars' that provide our heavier atomic nuclei (spectral type O) at α = 1.5, and the mass of our universe at α = 2.0. The values under 'units shown' were computed with his Eq. (1); s.m. = solar masses. Each step of $\Delta\ \alpha = 0.50$ is a factor of 3.3×10^{19}. The last column has observations presented in values of α, for comparison with the first column. It is remarkable that the proton mass, determined in laboratories, would occur in Table 1, alongside the stupendously large structures of the cosmos, all by using the same equation. Observations became the predominant feature of this model, in the end as many as 30 have been used; this is unusual in cosmology.

Table 1. Computed and observed masses

Computed α	Proton mass	Units shown	Type of object	Observed α
2.00	1.13×10^{78}	9.52×10^{20} s.m.	Primordial universe	1.998–2.008
1.50	3.47×10^{58}	29.179 s.m.	Primordial stars	1.49–1.53
0.50	3.26×10^{19}	5.46×10^{-8} kg	Planck mass	0.500
0.00	1	1.67×10^{-27} kg	Proton	0.000

At this point, I was not rushing forward, but checking the quantization and the enormity of its consequences, because this modeling was clearly going outside of our universe. A correlation with Max Planck was found. On the last pages of his classical paper that initiated quantum mechanics, he has a derivation of units. For mass it is:

$$M(\alpha) = (hc/G)^{0.5}, \quad (3)$$

which is what we now call the 'Planck mass'. He found the units from dimensional analysis of the cosmological constants *h, c,* and *G.* Chandra's analysis now provides the numerical calibration of the Planck mass. Equation (3) looks like the Planck mass with a variable exponent; it might be called 'the universal Planck mass', and it is used in Table 2, below.

It is easy to do a dimensional analysis as a trial-and-error until getting a mass; for instance the Planck mass in kilograms is $(m^2\ kg\ s^{-1}\ m\ s^{-1}\ m^{-3}\ kg\ s^2)^{0.5}$. The numerical values of the constants are being improved all the time (except for *c*); modern values for it are published yearly by Mohr and Taylor (2005). In 2005, their numerical values for the constants and their dimensions were $h = 6.626{,}0693(11)\times10^{-34}\ m^2\ kg\ s^{-1}$, $c = 299{,}792{,}458\ m\ s^{-1}$ (in a vacuum, exact by definition), $G = 6.6742(10) \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$.

The treatment of the present paper indicates that the Planck constant is *h*, not $\hbar = h/2\pi$, as is now used in most of the literature; it is easily seen that the values in the Tables would be off unrealistically for ħ. Three of Planck's units are:

$$\text{Planck mass} = (hc/G)^{0.5} = 5.455{,}55(40) \times 10^{-8}\ \text{kg}, \quad (4)$$

$$\text{Planck length} = (Gh/c^3)^{0.5} = 4.051{,}31(30) \times 10^{-35}\ \text{m}, \quad (5)$$

$$\text{Planck time} = (Gh/c^5)^{0.5} = 1.351{,}38(10) \times 10^{-43}\ \text{s}. \quad (6)$$

The Planck temperature and charge are also considered members of the basic set, and there are derived units; the entire set is called 'the Planck domain'.

Theoreticians prefer to have quantization in steps of whole units rather than fractions, and Table 2 shows a form of Eq. (3) for statistics with whole numbers for N. The key equation of cosmic masses is then,

$$M(N) = (hc/G)^{0.5N}, \quad (7)$$

where the exponent gives the values of N shown in Table 2. N = 2 may be for the mass of the planetesimal; this needs checking by an expert. The constant quantization factor of 0.5 in the exponent yields the same factor 3.3×10^9 as before; for instance, the Local Group has 3.3×10^{19} universes. Note the arrow pointing up as α is not restricted so that there may be other steps of universes; the quantization topic needs expert study too. A theoretical challenge for future work may be to explain the mechanism of quantization. Such a solution seems to resort to the basic studies of quantum physics, with its connection to Planck's constant *h*. The cosmos has a quantized distinctness, without which it would be an amorphous brew.

Table 2. Masses in steps of Planck mass

No	Proton mass	Type of object
5	3.7×10^{97}	Local Group of universes
4	1.1×10^{78}	Universe
3	3.5×10^{58}	Original star
2	6.7×10^{38}	Planetesimal
1	3.3×10^{19}	Planck mass
0	1	Proton

The numbering of the alphas in M(α) and of N in M(N) is, however, an *anthropic curiosity* because we think of our universe as having α = 2.00, while another culture in another universe will at first do the same for its own universe. Imagine another culture elsewhere, with its intelligent beings seeing a hierarchy as we do, within and outside of their universe. They too start with their symbols for *h, c, G,* and *H,* which are measured in their laboratories, and they consider that their 'α values' are from 0 for the proton mass to 2.00 for their 'universe', and onward out into 'the multiverse'. Their universe is then imagined by them as we do for ours, as a member of an assembly of 3.3×10^{19} universes at α = 2.50, which is a member of 3.3×10^{19} assemblies at α = 3.00, *etc.* However, while their universe is at their α = 2.00 and is followed by their 2.50 outside, for us these two may be at our α = 7.50 and 7.00, for example.

The fact that the equations are open – that α in Eq. (2) and N in Eq. (7) are unrestricted – has brought us the multiverse; I believe that an expert study is needed to establish whether it is an infinite multiverse. In any case, the equations set this multiverse apart from other models in having several characteristics of the universes. To begin with, we know their number at each step, with 3.3×10^{19} in the Local Group, the next step in the quantization being 3.3×10^{19}

larger, *etc.* The *h, c, G,* and *H* cosmic physics is the same for all; the universes therefore are the same in their grand design, except for age (having started from inter-universal clouds at different times), and perhaps for some small effects of evolution.

This is such an important point that it bears repeating in different words. If our universe resulted from, and is decaying back into the inter-universal medium, the IUM must have the *h, c, G, H* physics we know for our universe. The IUM has uniformity through mixing of debris from a large number of universes, and they all emerged from the IUM as well, such that all universes surviving from the medium have that same physics.

Another characteristic is the *critical mass.* 'Critical' is defined as being not too large, or the universe would gravitationally collapse under its own weight; and not too small, or lack of gravitational pull would let the universe quickly expand into nothingness. The mass for N = 4 is indeed near that critical mass for our universe, and thereby for all others in the multiverse. Any universe with a mass different from this critical limit would simply not have survived; it would have collapsed or blown apart.

The interaction between the universes is by their expansion. The effect is seen from a bridge over a quiet pond on which raindrops fall. The rings on the water expand and travel through each other. The result in three dimensions is a thorough mixing of the debris from old universes. The resulting new universes will then be the same in composition because the mixing brings material together from many old universes.

The multiverse *endowed the universes with their mass, energy, physics, and evolution.* Each universe is thereby capable of doing all that we observe in our universe. That may include evolution going as far as having cells and chromosomes for its tools, and making beings who claim to be intelligent as one of its species, depending on local conditions such as the right distance of their planet from the central star. Comet and asteroid impact is also an uncertain factor.

The time scale of the multiverse is estimated by using the scaling factor of the Tables, 10^{19}, times the lifetime of our universe, $\sim 10^{11}$; the resulting 10^{30} seems consistent with the observations of the half life of the proton. This is probably a real average, as some universes may have longer times, and others shorter, to come to the epoch of their formation through random cloud accretion.

The predominant characteristic of the multiverse is, however, that it is an *evolutionary* system (Gehrels 2012). It has the abundance of time and possibilities for change, just as Darwin and Wallace's evolutionary model for life had long times and much trial and error. The physics, the forces and components more basic than photons and protons are established and maintained during the long times and through many universe-samples in the multiverse. Universes that do not succeed end back in the inter-universal medium.

This intense and extensive evolution explains the fine-tuning of the nuclear transactions in stars that Fred Hoyle used to point out, how the selections and combinations could not have occurred if the physical constants of the elements had been even slightly different (Hoyle 1999, originally 1987, is actually on a discrepancy he had with Darwin's theory). The fine tuning, or any evolution, could not have happened if ours had been the *single* Big-Bang universe unfolding *fast* in the times before t ~10^{-6} sec, 10^{37} PT on the standard clock.

The Aging and Decaying of our Universe

We now begin a history of our universe, discussing its decay and demise first because we are in that stage at present so that we can identify the components of debris that are spreading into the multiverse. The major concepts of evolution include birth and demise; that we must die is therefore an evolutionary predicament.

Not only people and animals die, but inorganic substances age and decay as well. Even the protons may have a limited half-life, predicted at greater than 10^{50} years, but they are observed to be at least 10^{33} years old. This model then becomes useful right away because these two large numbers have been puzzling in comparison to the lifetime of our universe, which is some 10^{11} years. Why would the proton have evolved to live that long? The large numbers now are nicely in perspective with the timescale of the multiverse, ~10^{30} years.

In summary, our universe is slowly dying with aging stars and galaxies. The dying of universes is a basic process in evolution, because the debris of radiation, atomic particles and other masses are used in the accretion for new universes.

Debris of Photons, Protons and Everything Else

Photons emerge from stars, supernovae, gamma-ray bursters and other energetic sources. Their aging is in terms of moving out, cooling steadily. Their radiation is observed 3,000 K at age 380,000 and 3 K at present. On the time scale of 10^{30} years, the old photons must be near zero degrees during most of their time in the multiverse. The situation near 0 Kelvin, –273.15 degrees Celsius, ‘absolute zero’, needs to be studied by experts, including the common understanding that all thermal activity stops. I use the term ‘near 0 K’ for what seems to be the ground state of photons, protons, *etc.*

The *protons* cool in the expansion as the photons do; other particles such as neutrons and electrons, they all are part of our universe's decay debris, as are old stars and brown dwarfs. Whole galaxies expand outwards too – and clusters of galaxies – while they internally keep their gravitational ensemble together for whatever is aging inside; these mass configurations, as decayed as they are, appear conserved in the multiverse because they are recognized with the Wilkinson Microwave Anisotropy Probe (WMAP) in our early universe. Dark matter and dark energy must be included in the discussions too because they are abundant in our universe, 23 % and 72 %, as we saw above.

The Acceleration of the Expansion

In the late 1990s, two teams of observers went to two different but large telescopes on the prevailing prediction that the expansion of our universe is *de*celerating, such that a shrinking and collapse would be its fate. Because of their competition and interesting goal, the astronomical world seemed to be travelling with them. The two used the same techniques and made the same opposite discovery: of an *ac*celerating universe as of age 5,000 million years after the beginning, which is at 5×10^9 years of age for our universe (Goldhaber and Perlmutter 1998; Riess *et al.* 1998).

The discovery is crucial for the Chandra-Multiverse model because a *de*celerating expansion, leading towards collapse of our universe, would have made it impossible. We speak of *accelerated* expansion of intergalactic space, and now see how all the debris of a decaying universe proceeds on the accelerated expansion into the inter-universal medium in which our universe is imbedded.

Furthermore, the cause of the acceleration was interpreted to be dark energy (Riess *et al.* 1998), and we will use this as the key to the physical interpretation of dark energy, below.

The Inter-Universal Medium (IUM)

The description of the IUM uses the extensive knowledge and understanding of the interstellar medium (ISM) between our stars and galaxies. The ISM is tenuous in most places while in others there are extended clouds of hydrogen and other molecules. The ISM clouds have lifetimes of $\sim 10^9$ years, there always is motion in the universe so that they encounter, combine and grow. Concepts from the ISM may be used in this modeling because the same types of processes are bound to happen in the IUM, albeit over much larger cosmological scales of time, $\sim 10^{30}$ years. The comparisons must, however, be made with care because the conditions of size, density, radiation environment, *etc.* of the two media differ greatly.

Anyway, the space density in the IUM will be as uneven as it is in the ISM, with huge clouds accreting. The clouds grow by sweeping the material up during their motion through space. Eventually, self-gravitation will become dominant by its increasing gravitational cross-section, speeding the sweeping and contraction of the cloud towards making a new universe.

The principal difference of the IUM is in its *composition*, now no longer the young and active material of hydrogen and other atoms but, instead, the above old and cold decayed debris objects that had come long before from dying universes. This is *energy seeking* material. Gravitational energy of the contracting cloud is now being used internally. The growing proto-universe can therefore increase in mass without getting as hot as a proto-star would do, because the gravitational energy is used to re-energize the old cold photons and to re-energize and re-constitute the atomic particles into regular photons, protons, and neutrons.

That this actually happens is seen in observations of the preservation of characteristics, for instance the clustering of galaxies coming from old universes being recognized for our young universe, as was mentioned above. In other words, the characteristics have *not been melted away.*

Now we are ready to consider the cloud of the IUM that made our new universe. The spherical gravitational mass is of overall *uniform* composition because the debris from many universes is mixed together, with all the above components of old photons, subatomic parts of protons and neutrons, and of dark mass and dark energy. This is the uniformity found by the COBE spacecraft till the third decimal of 2,728 K.

Characteristics of Photons

Cooling is the prime characteristic of this decay, and it is here connected with the expansion whereby the density of the material diminishes as a cooling mechanism. We then speak of old cold photons, of old cold protons, *etc.* COBE discovered them to have 3,000 K at age 380,000 and 3 K at present. At the 10^{30}-years time-scale of the multiverse, they all spend most of their existence near absolute zero. Their *ground state* is therefore near 0 K; the energy equation of photons has a zero-point energy term (Lamb 1995). Only occasionally may they be scooped up to proto-universal duty, and only a very few will serve the most complex and capable form of evolution known to us as *life*.

Photons are even more important than the protons because there are at least 10^9 more of them; this enormous ratio may become better understood with the role the photons play in the birth of universes in the present model. The characteristic most needed here is their radiation pressure. It depends on the *fourth power of the temperature*, such that it will be strongest for re-energized photons, rather than for the old cold ones.

The Proto-Universe and Photon Burst

We are now ready to pursue the cloud that started our universe, the *universe's nebula*, towards the more advanced form that is called the *proto-universe*. We recall that the IUM *composition* is totally different from that in the ISM, namely of decayed energy-seeking debris. This is the *first reason* why the growing proto-universe did not become impossibly hot and the galaxy clustering was observed; 10^{13} K will be its maximum temperature, as the standard models indicate. The mass of our baryon universe is equivalent to 10^{21} solar masses, but it consisted at this time mainly of energy-absorbing material, and may therefore not have collapsed into a black hole during accretion.

The *second reason is the radiation pressure* of photons, which provides counter-action to gravity. Imagine a box in IUM space, with radiation from many photons pushing in all directions, but at the periphery of the box the pressure is outward. That results in direction opposite to that of gravity in the proto-universe cloud; it will have negative sign if and where one uses a positive sign for gravity.

It is noted that the maximum temperature of 10^{13} K makes it unnecessary to do a computer modeling at this time. Before a detailed modeling, an outline like this is needed, so we proceed with the history of our universe on first principles.

The rate of accretion was first controlled by the geometrical cross-section of the cloud, but gradually the larger gravitational cross-section would accelerate it. Already then, the cloud would gain outward force due to radiation pressure. During the accretion this build-up of pressure *lagged behind* the gravitational force of the cold photons. It brought about the appropriate temperatures, from near 0 to 10^{13} K, as density increased from the start at $\sim10^{-28}$ to 10^{18} kg m^{-3}, but that would take time for the heat to penetrate, and cause a delay. The gravity thereby prevailed and the accretion continued.

The fourth-power dependence of the radiation pressure on the temperature must have caught up to end the accretion phase. The remarkable epoch would be reached for the completion of re-energizing the photons, namely at 10^{18} kg m^{-3} and 10^{13} K, at the time of t $\sim10^{-6}$ sec on the old clock at which we know these three conditions from the Standard Model for Big Bang as well as the one for atomic physics.

An increasingly enormous number of old photons reached their full radiation; in other words, an *inferno* flared out. It must have increased from a small to a maximum central volume; the maximum depends on the total mass and on the percentages below. That central region of sizeable volume was converted from old photons to re-energized radiating photons in a Photon Burst. The one-but-last paragraph of this paper has more information about this stage.

The Photon Burst may have been detected by WMAP as a shell beyond that of the 3-K radiation; *i.e.* of greater radius than that of the 3-K radiation. Analysis of that WMAP observation would confirm that a flaring occurred like thousands of Super Novae!

Another observation may support this reasoning, in addition to the percentages observed uniformly and of a WMAP verification, namely that we do not observe a center for our universe. This confirms that the enormous Photon Burst brought passage and thereby *mixing* of baryons with the non-baryons throughout the whole universe. This explains that '12 % atoms, 15 % photons, 10 % neutrinos, 63 % dark matter and little dark energy' were observed by COBE and WMAP *everywhere the same* in our early universe.

Continuing in the central volume is the re-energizing of the protons *etc.*, which took longer than that of the photons because they were more complicated. They however encapsulated the inferno by holding the photons back through multiple scattering, which sustained the expansion; now the appropriate temperature from 10^{13} K to 3,000 K was *lagging behind* the decrease of the density from 10^{18} to 10^{-19} kg m^{-3}, because the cooling took time. The multiple scattering thereby prevailed and the expansion continued.

At t = 380,000 years, the space density had become low enough for the electrons, protons and neutrons to combine, to make atoms. Atoms have internal space to let photons pass through them; remember the 'stadium experiment' in the beginning parts of this paper. This blast would also have a pressure blowing the IUM material further away from the completed universe. The expansion continued for there was nothing to affect it, until age 5×10^9 y when the acceleration occurred.

The Identity of Dark Energy

We have seen in the previous section that at age 380,000 years there was only a small amount of dark energy left. The dark energy was apparently mostly used up in the accretion and birthing processes and so were most of the old, cold photons. A discovery thereby occurs: *dark energy is the energy of old photons*; *causing* the expansion has the same physical action as *accelerating* the expansion, which was mentioned above as being due to dark energy (Riess *et al.* 1998). In other words, the conclusion is that the original expansion was caused by dark energy, which also caused the later acceleration.

There appears an indirect but powerful reasoning to confirm this interpretation of dark energy. The evolution in the multiverse could not have left unused the major part of what each decaying universe contributes to the IUM, the old, cold photons (or, in the second interpretation, the 72 % dark energy). They must have been fitted into the evolution of universes and their survival. If they would have been left unused, the ever-increasing number of old-photon debris (*i.e.* dark energy) would have overwhelmed the cosmos.

The Identity of Dark Matter

The Chandra-Multiverse model might also provide a confirmation of the solution to the problem of the physical nature of dark matter, for which there is already a large literature. Astronomer Bernard Carr (2001) has a critical discussion of both baryonic and non-baryonic dark matter. Physicist Padmanabhan (2002) concludes: '*both baryonic and non-baryonic dark matter exist in the universe, with non-baryonic being dominant'*. His general rule is: '*There is not an a-priori reason for the dark matter in different objects to be made of the same constituent*'. He also discusses baryonic and non-baryonic matter such as protons, WIMPs, axions, neutrinos and massive astrophysical halo objects. Their results support that old, cold protons and other particles, such as neutrons and electrons, are part of our universe's decay debris, as are whole galaxies (each gravitationally holding its debris), clusters of galaxies, and whatever other debris such as old stars. As a short name for all these we use ‘protons *etc.*’

The dark-energy actions for multiple scattering and expansion have a counterpart in the dark-matter actions – the one gives and the other receives the kinetic energy of the photon. In other words, while dark energy is the kinetic energy of photons, old or new, dark matter may be the name for the ensemble with which these photons interact, old protons *etc.*

This view of dark matter has the same simple but firm confirmation as dark energy. The evolution in the multiverse could not have left unused the major part of what all decaying universes contribute to the IUM, namely their 23 % dark matter (old protons *etc.*). If this matter had been unused, the ever-increasing amount of dark matter would have overwhelmed the Cosmos.

The Cosmological Constant

The cosmological constant is sometimes held responsible for the acceleration of expansion at the universe's age of 5×10^9 years. The previous scenario applies just as well as the cosmological constant for the physical acceleration action by old photons. There is a certain form of logic in it: That the multiverse evolved the properties of the photons, in order to get the cycle of decay and rebirth accomplished, for expansion and survival of the system. In the equations, that is expressed as a cosmological constant.

A refined support of the model appears in the fact that the cosmological constant is exceedingly small, because its theory entails *fine-tuning* of physics and nature to ‘bizarre’ accuracy (Padmanabhan 2002). Hoyle (1999 [1987]) used similar strong words alike ‘bizarre’ for extreme fine-tuning of the nuclear constants inside stars. The evolution of the universes in the multiverse has indeed bizarre long times: $\sim 10^{30}$ years, and numbers of samples, $>10^{19}$ universes. That is how the Chandra Multiverse accomplishes extreme fine-tuning for all parameters and characteristics of the universes.

Schwarzschild’s Confirmations

In conclusion of this paper is a warning that there was no Big Bang by Schwarzschild (1873–1916), which also confirms the Chandra-Multiverse model. He was a well known and versatile physicist in Germany who had volunteered for duty during World War I. He caught a serious illness on the Russian Front, but worked on elucidating one of Einstein's equations until the end of his life (Schwarzschild 1916). It included a discussion that can be illustrated as follows.

Light can escape only when its kinetic energy is greater than its potential energy,

$$GMm\ R_S^{-1} < ½\ mc^2, \tag{8}$$

such that there is a limiting radius of the body,

$$R_S > 2GM\ c^{-2}, \tag{9}$$

which is 3×10^8 lightyears; that is the radius of our universe at age 380,000 when the radiation did escape. Table 3 shows the comparison of R_S with radius $R = (3M/4\pi\sigma)^{1/3}$ for a sphere with uniform space density σ; $M = 1.13 \times 10^{78}$ proton masses.

The first line applies for the above case when the universe's radiation did escape, $R/R_S = 1$. The Schwarzschild limit does not seem precise because standard theories predict that density to be $\sim 10^{-19}$ kg m^{-3} at that time, not 10^{-23}. However, the precision of these predictions is low and the effect is small, because if 10^{-19} were used in the calibration of R_S, the following ratio is still rounded off to 10^{-14}, and the next is 10^{-38} instead of 10^{-40}.

Table 3. Radii and Schwarzschild radii

R/R_S	t	σ	R(ly)
1	380,000 y	10^{-23}	10^8
10^{-14}	10^{-6} sec	10^{18}	10^{-5}
10^{-40}	0	10^{96}	10^{-31}

The second line is for the above starting time of our universe, $t \sim 10^{-6}$ sec, using proton density of 10^{18} kg m^{-3} to derive R. Because $R/R_S = 10^{-14}$ is so very negative, the Schwarzschild radius indicates a giant black hole, but our entire universe is not a black hole. Furthermore, for photons to escape at age 380,000, they must have been *generated much earlier*. In the case of the Sun, it takes a million years for a photon generated at its center to escape; physically that is a different situation, but it serves this comparison. The shorter time of 380,000 years may be appropriate, even though the body is much larger than the sun, because the medium is *expanding*. The photons' scattered journey was increasingly speeded up because it went through diminishing density, eventually as low as the above 10^{-19} kg m^{-3} (which was the density of the whole universe).

In the third line, the Planck density of 10^{96} kg m^{-3} is used for obtaining R and thereby R/R_S. Under these conditions, the Schwarzschild limit calls resoundingly for a giant black hole of our whole universe. Our universe was not a black hole, and neither radiation pressure nor dark energy is available to save the modeling (this is not to say that our universe would not have smaller black holes, of course). The Table confirms the Chandra-Multiverse model.

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9
Ex Libro Lapidum Historia Mundi: Reading History Written in Rocks

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Abstract

In the emerging conception of Big History, the largely contemporaneous regimes of Earth and life occupy the middle ground between the Cosmos and humanity. As part of the bridging of disciplinary boundaries, historians and astronomers will need to learn how geologists and paleontologists read history written in rocks. This was the goal of a workshop held at the Geological Observatory of Coldigioco, in the Marche Region of Italy in August 2010. The Observatory is in a part of the Apennine Mountains with extensive exposures of deep-water, or 'pelagic', limestones, which carry absolutely the best record of Earth history we have, covering an interval of about 200 million years. Especially in the remarkable outcrops at Gubbio, geologists and paleontologists have recovered records of the evolution of microfossils, the reversals of the Earth's magnetic field, the giant impact that caused the mass extinction in which the dinosaurs perished, and have dated parts of this record with volcanic ash layers that give numerical ages. The integrative stratigraphy obtained from the Italian pelagic limestones has been very important for the development of the geologic time scale, and new developments in cyclostratigraphy hold the promise of dating these rocks back to about 100 million years ago with a resolution of about 1,000 years.

Introduction: The Emergence of Big History

Universal history, the attempt to make sense of all of the human past, fell into disrepute some decades ago, in part because the need to understand particular historical episodes in detail has led to extreme specialization, and in part because previous attempts sometimes led to deplorable results, like the glorification of 'Aryans' by the Nazis. At the present time, history is studied mostly in tiny chunks by specialists, but this does not seem like a healthy long-term situation. There is already a reaction to this situation with the rise of World History, looking at the entire human past.

An even more ambitious approach is Big History, developed in the 1990s by the Anglo-Australian historian David Christian. Big History seeks to unify the study of all of the past, both human and pre-human, thus bringing together the work of historians and other humanists, and of historical scientists, including cosmologists, astronomers, geologists, paleontologists, paleoanthropologists and archaeologists (Christian 1991, 2004). The Dutch sociologist Fred Spier proposed the usefully vague term 'regime' to refer to 'a more or less regular but ultimately unstable pattern that has a certain temporal permanence' (Spier 1996: 14). No standard set of regimes has been agreed upon, but one useful set would be (1) Cosmic history, (2) Earth history, (3) Life history and (4) Human history, while a more detailed subdivision would be (1) Big-Bang history, (2) Cosmic history, (3) Earth History, (4) Life history, (5) Human prehistory and (6) Human written history (Alvarez *et al.* 2009). It is only now becoming possible to construct a serious account of all of the past, because of the discovery and invention of a wide variety of techniques for dating historical events in all of the regimes (Hedman 2007). Christian (2008a) has reviewed this chronometric revolution. Other recent book-length treatments of Big History have been published by Brown (2007), Christian (2008b), and Spier (2010).

The Role of Geology and Paleontology in Big History

In either of the sets of regimes mentioned above, Earth history and life history are fundamental parts of the unified understanding of the past that Big Historians wish to develop.

Earth history began with the origin of the Earth, 4.567 billion years ago, and runs to the present time. Life probably appeared not long after the origin of the Earth, perhaps about 4 billion years ago, so the regimes of Earth history and life history are largely coextensive in time.

Earth history and life history fall largely in the domain of geology and paleontology, and in both of these fields of study, much of the historical record comes from sedimentary rocks. The study of sedimentary rocks is called 'stratigraphy', and although the procedures of stratigraphy are fairly straightforward, they are largely unfamiliar to most historians, although much has been learned about human history through the work of archaeologists, who use stratigraphic techniques in their excavations.

The August 2010 Coldigioco Workshop

In order to bridge the gap between the techniques used by historians and those used by geologists and paleontologists, a workshop was held in Italy, at the Geological Observatory of Coldigioco, in August, 2010. The goal of the workshop was to demonstrate – in the field, in the laboratory and using maps – how geologists and paleontologists extract historical information from sedimentary rocks.

The workshop was taught by the three authors of the present paper, all of them practicing geologists, and was attended by six Big Historians who come from humanistic and social science backgrounds – Craig Benjamin, Cynthia Brown, David Christian, Lowell Gustafson, Barry Rodrigue and Fred Spier – as well as Daron Green and Michael Dix of Microsoft, who are involved in developing tools for Big History teaching and research. The workshop was extremely successful in crossing the disciplinary barriers that separate historians and geologists, and in addition it provided the opportunity to plan what has since become the International Big History Association. The present paper summarizes the concepts and techniques of reading Earth and life history from rocks that were demonstrated at the workshop (Fig. 1).

Fig. 1. Participants in the August 2010 Workshop on geology in Big History, at the Geological Observatory of Coldigioco in the Apennine Mountains of Italy

Ex Libro Lapidum Historia Mundi

The central concept of stratigraphy – that history is written in rocks – is conveyed by the motto, *Ex Libro Lapidum Historia Mundi,* – 'Out of the book of rocks comes the history of the world'. Of course, there are all kinds of rocks, and different kinds of rocks record different kinds of history. Metamorphic rocks, which have been subjected to high temperatures and high pressures, carry a record of events deep in the Earth's crust, and thus they are critical for understanding the origins of deformed mountain belts like the Alps, which resulted from collision between the continental crust of Europe and that of Italy. Igneous rocks, which are produced by the cooling of molten magmas generated under conditions of very high temperature, again tell us more about the conditions deep within the Earth than about the history of the Earth's surface, except in cases where volcanic ash has buried and preserved surface features like Pompeii and Herculaneum, or forests and river valleys (Alvarez 2009: part II).

Most of the information we have about the history of the surface of the Earth and of life on that surface, comes from the stratigraphic study of sedimentary rocks. There are many kinds of sedimentary rock, and different kinds carry different types of historical information. Clastic, or fragmental, rocks like conglomerates, sandstones, and shales tell us about the erosion of ancient highlands, the transportation of the resulting debris by rivers, glaciers, winds and submarine gravity flows, and their deposition in low areas or oceans.

Evaporitic rocks like halite (rock salt) and gypsum tell us about the chemical conditions in shallow seas in hot dry regions, where so much water evaporates that the dissolved salts are left behind as sedimentary deposits. A spectacular example is the evaporite layer that lies beneath most of the floor of the Mediterranean Sea – the result of the evaporation of that sea about 5 million years ago when the inlet at the Strait of Gibraltar was blocked by uplift, so that the entire floor of the Mediterranean became a desert, 2–3 km below sea level (Hsü 1983).

Limestones, composed primarily of the mineral calcite ($CaCO_3$) are made largely of the shells of what were once living organisms, and as a result, they tell us directly about the history of life. Most limestones formed in shallow ocean water where, sadly, their record of the history of life has been disturbed or even partly removed by waves, currents, and storms. Fortunately some limestones are deposited in deeper water, below the depths where those disturbances can reach. These are the pelagic (deep-water) limestones, and they carry absolutely the finest record we have of many aspects of the history of the Earth, and of life.

Pelagic Limestones

Pelagic limestones are deposited under rather unusual conditions. Their site of deposition must be deep enough to avoid scouring by currents, waves and storms, but shallow enough to avoid the dissolution of $CaCO_3$ that occurs in deep, very cold water. In addition, they must somehow be out of reach of clastic sediments, which can be deposited very rapidly, overwhelming the slow accumulation of limestone. That accumulation rate is very slow, because pelagic limestones are made of tiny shells and skeletons that were secreted by organisms that floated in the shallow surface waters, and which, after death, have drifted down very slowly onto the deep-sea floor beneath them.

There are quite a few places on the floor of the modern ocean where pelagic limestones can be sampled by deep-sea drilling ships, but very few places where they have been uplifted above sea level and are exposed on the surface of the land. Absolutely the best of these places in the entire world is in the Italian Apennine Mountains of the regions of Umbria and Marche. These splendid exposures of pelagic limestones have yielded a vast treasure trove of historical information about the Earth, and it was to study these limestones that the Geological Observatory of Coldigioco was founded in 1992.

The Geological Observatory of Coldigioco

Since the importance of the Apennine pelagic limestones was recognized in the 1960s, geologists and paleontologists have come from all over the world in increasing numbers to study the remarkable historical record in these rocks. In 1992, the Geological Observatory of Coldigioco was founded by two of us (AM, WA), together with Paula Metallo and Milly Alvarez, as a center that can be used both for research and for teaching. In the nearly 20 years since its founding, Coldigioco has hosted a large number of researchers, geological field courses and international conferences.

The workshop of August, 2010, for the first time brought a component of Big History into the activities of the Observatory. It was here that the first steps were taken toward the now-completed organization of the International Big History Association. We anticipate that Coldigioco will continue to play a valuable role in the growth and development of the new field of Big History. Scholars and scientists from any discipline relevant to Big History are urged to contact Director, Dr. Alessandro Montanari, about possibilities for collaboration or conferences at the Observatory (sandro.ogc@fastnet.it).

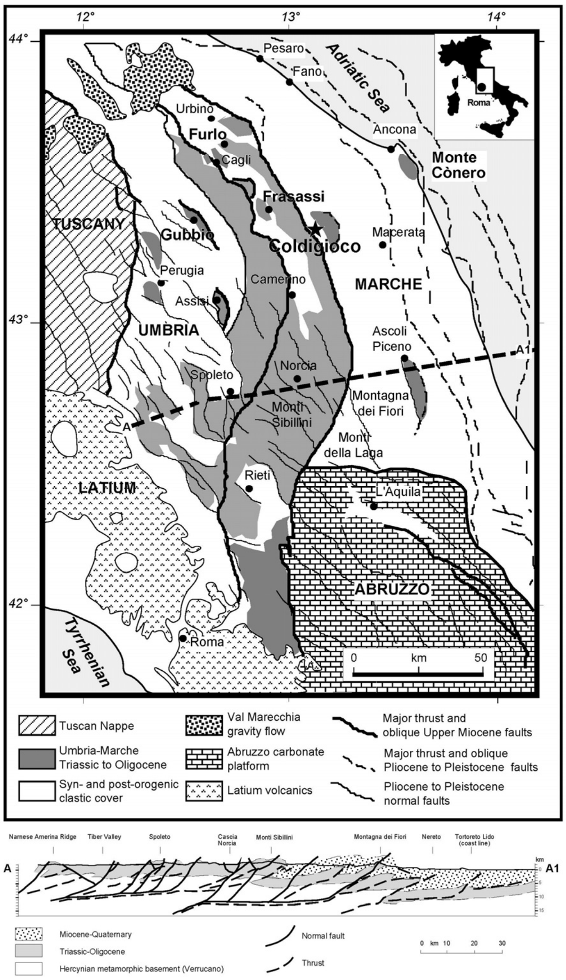

Fig. 2. Coldigioco and its setting in the Apennine Mountains of Italy

Nicolas Steno and the Origins of Stratigraphy

The Danish anatomist, Nicolas Steno (1638–1686), discovered the principles of stratigraphy in Tuscany in the 17th century (Cutler 2003; Alvarez 2009: ch. 5). The fundamental principle, which seems obvious today but was not obvious in the 17th century, is that what is on top is younger, unless there has been some still younger deformation or some other kind of complication. A second principle of Steno is that sedimentary rocks are laid down in roughly horizontal beds, so that if we now see inclined, vertical or even overturned beds, we can infer that there has been a deformational event after the deposition of the rocks that has tilted them. Thus, in order to understand the rock record in the pelagic limestones of the Apennines, we need to tilt the beds mentally back to their original horizontal orientation.

Paleontology and the Rock Record of Evolution

Writing in the 17th century and pioneering the study of history written in rocks, Steno had no way either to date or to interpret his rock history other than on the basis of the account in Genesis. Thus, he recognized evidence for two periods of flooding in Tuscany, each of them marked by accumulations of sedimentary rock, and he attributed the first to the universal flood of creation and the second to Noah's flood. It was not until the late 18th and early 19th century that geologists recognized that the fossils found in sedimentary rocks provide a way of establishing the ages of those rocks, based on the changing shape of the fossils, a record of evolution that Darwin later interpreted as the result of natural selection.

Early geologists worked out the sequence of changing, evolving fossils, put that sequence into a chronological time scale, and gave names to the different periods, which were characterized by different fossils. It was at this time that names for periods, like Jurassic and Cretaceous, were established. The fossils used by the early geologists were large enough to be studied with the naked eye, but unfortunately there was no way to determine the ages in years of the fossils or of the rocks they were found in.

Jacopo Beccaria, Ambrogio Soldani and the Beginnings of Micropaleontology

The large fossils studied by the early geologists, which are sometimes called macrofossils, can be identified with the naked eye but they are relatively uncommon and can be difficult to find. But it turns out that there are also tiny microfossils, produced by single-celled marine organisms, and they are extremely abundant in some sedimentary rocks, including pelagic limestones of Cretaceous and younger age. Microfossils were first studied by Jacopo Bartolomeo Beccaria in Bologna and Ambrogio Soldani in Siena in the 18th century (Alvarez 2009: ch. 5). After a century of careful study with microscopes, paleontologists now know a very great deal about the evolution of these tiny fossils, and in rocks where they are present, they are the dating tool of choice.

Gubbio and the Scaglia Limestones

Gubbio is a wonderful little medieval city in the Apennines of the Region of Umbria (Alvarez 2009: ch. 6). In the Bottaccione Gorge and the Contessa Valley, cutting through the mountains behind Gubbio, there are continuous exposures of pelagic limestones (Fig. 3). Several different rock units, or formations, can be studied in these two canyons, and the most intensely investigated is the formation known as the *Scaglia Rossa*. These rocks were first seriously studied by the Italian geologist Guido Bonarelli, at the turn of the 19^{th} to the 20^{th} century. At the time, these limestones were very strange and puzzling. They did not contain macrofossils and thus were difficult to date, and their whole character was completely foreign and unfamiliar to the geologists like Bonarelli. We now understand the reason: most pelagic limestones still lie inaccessible beneath the floor of the ocean and it is only in rare situations like the Apennines that any pelagic limestones have been lifted up above sea level to where geologists can easily study them.

Fig. 3. The Vispi quarry in the Contessa Valley near Gubbio. The beds slant, or 'dip', gently to the left, whereas the horizontal lines are quarrying terraces. The thin black band in the upper left is the Bonarelli Level, representing an oceanic anoxic event 94 million years ago. The pelagic sediments in this photograph record about 40 million years of Earth history

However, since the 1930s, and especially since the 1960s, pelagic limestones have been better and better understood, through very careful studies by large numbers of geologists and paleontologists who have been drawn to the remarkable historical record preserved in these rocks. Although pelagic limestones are exposed all over the Apennines of Umbria and Marche, it is the splendid outcrops of Gubbio that have attracted the most attention and have yielded the most abundant historical information (Fig. 4).

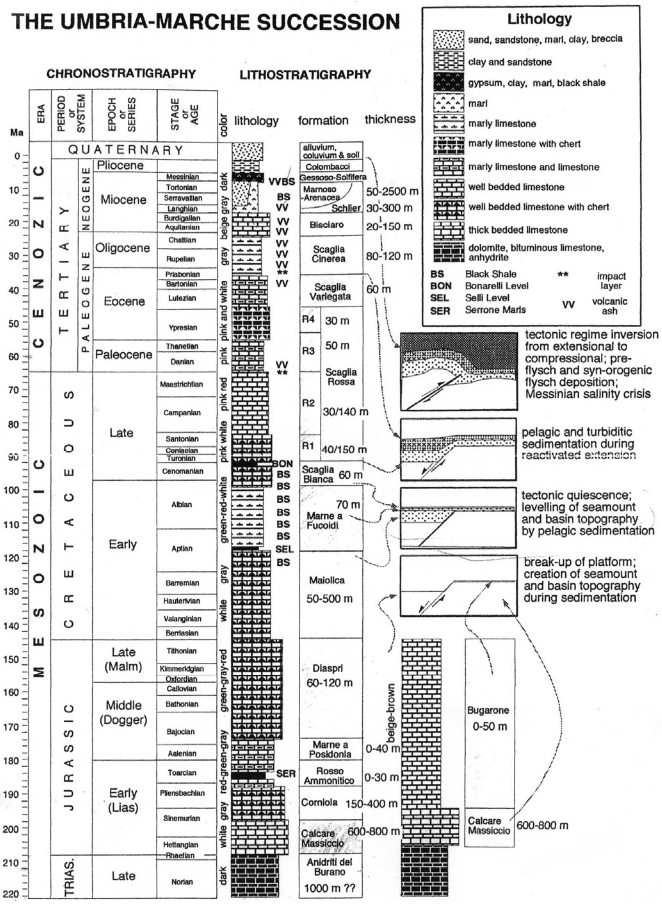

Fig. 4. A time-chart, or stratigraphic column, showing schematically the main features of the limestone sequence of the Umbria-Marche Apennines. Two important features to note are that (1) geologists and paleontologists draw their diagrams with younger rocks at the top, because that is the way they occur in nature, and (2) this diagram is scaled to time in millions of years ago (Ma); other widely-used diagrams are scaled to thickness in meters, which is what we observe in the field. From left to right the diagram shows 'Chronostratigraphy', the standard names and dates into which geologic time has been divided by international agreement, 'Lithostratigraphy', the kind of rocks present and their local names and thicknesses, and sketches indicating the environment in which they were deposited

Isabella Premoli Silva and the Evolution of Foraminifera

Although macrofossils are vanishingly rare in the Scaglia limestone, it turns out that microfossils are extremely common. But at first they were very hard to use. Paleontologists are accustomed to working with whole fossils, or whole microfossils, that they can study in three dimensions, either with the naked eye or with the microscope. Unfortunately, the Scaglia pelagic limestones are very hard, and you cannot get the microfossils out whole or intact. In the 1930s, Otto Renz found that if he made a thin section, gluing a slab of limestone onto a glass slide and polishing until it was very thin, he could study the microfossils in a two-dimensional slice (Fig. 5). It was not as satisfactory as studying loose microfossils in three dimensions, but Renz began to learn how to identify them, and in the 1960s, Isabella Premoli Silva and Hans-Peter Luterbacher perfected this way of identifying microfossils.

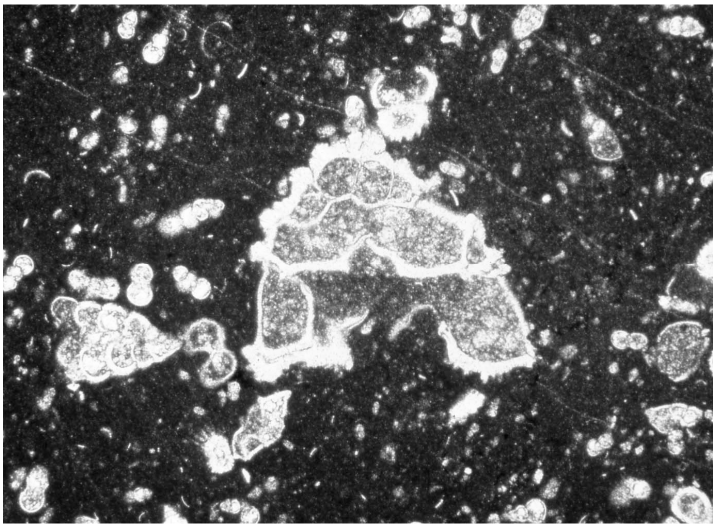

Fig. 5. Microfossil (the largest is the foraminifer *Globotruncana contusa*, 1 mm across) seen in a microscope view of a thin section from the Scaglia limestone at Gubbio

Meanwhile, other micropaleontologists had found that microfossils provide an extremely useful way of determining the ages of sedimentary rocks. So once Premoli Silva and Luterbacher had figured out how to identify the Scaglia microfossils, they were able to determine in detail the age of the pelagic limestones at Gubbio. Bonarelli's frustration at not being able to date these rocks was overcome at last, and it turned out that the Gubbio pelagic limestones were deposited over a time interval of almost 200 million years. This was a historical record of remarkable extent!

Gubbio and the Origin of Magnetostratigraphy

Geologists soon found out that the Gubbio limestones record more than just the evolution of microfossils. In the 1970s, paleomagnetists discovered that these pelagic limestones also record the direction of the Earth's magnetic field at the time they were deposited. It is as if the limestones contained fossil magnetic compasses that can be read by sophisticated instruments in the laboratory. One of us (WA) was involved in this work, studying the magnetic record of the Gubbio limestones (Alvarez 2009: ch. 6). A few years earlier, geologists had discovered that the Earth's magnetic field reverses every now and then – every few tens of thousands of years to few millions of years – and that these magnetic reversals are recorded in the Earth's ocean crust because of seafloor spreading. The pattern of magnetic reversals in the ocean crust could be read by magnetometers towed behind ships or airplanes crossing the oceans, but there was no way to date those reversals.

However, at Gubbio, we realized that the limestones that record the magnetic reversals are full of the tiny microfossils that provide our best tool for dating sedimentary rocks! Through the 1970s and into the 1980s, the work of numerous geologists and paleontologists at Gubbio and nearby parts of the Apennines made it possible to determine the reversal history of the Earth's magnetic field over 150 million years. That was one of the first steps in developing the field now called magnetostratigraphy, in which the record of magnetic reversals has been used all over the world as a second major dating tool, to supplement the use of microfossils.

Iridium and the Rock Record of Mass Extinction

While collecting samples for the paleomagnetic research, we became ever more familiar with the stratigraphy of the Scaglia limestones. A prominent feature that attracted our attention was the boundary between the Cretaceous and Tertiary periods of geological time. Geologists have long known that this boundary at least approximately marked the extinction of the dinosaurs and of many other groups of animals and plants, but they did not know whether that extinction had been sudden or gradual. In the Gubbio sequence, the boundary was very abrupt, marking the near extinction of the microfossils known as the foraminifera.

In an attempt to understand what had happened at that abrupt extinction in the Gubbio strata, we collected samples across the boundary and measured them for iridium, a marker for extraterrestrial material. To our surprise, the amount of iridium was remarkably high, and after considering many possible explanations, we concluded that the anomalous iridium was the result of impact of a very large extraterrestrial object – a comet or an asteroid – on the Earth, causing the mass extinction of dinosaurs and the near extinction of foraminifera (Alvarez 1997). In 1991, the very large crater that resulted from that impact was discovered beneath the surface of the Yucatán Peninsula of Mexico. Although a few paleontologists have continued to dispute this interpretation, it has now been confirmed to the satisfaction of almost all the scientists who have studied the matter in detail (Schulte *et al.* 2010). And so another major piece of historical information was extracted from the Scaglia limestones.

Radiometric Dating and the Ages of Rocks in Years

The sequence at Gubbio provided yet another piece of historical information when, during the collection of samples for paleomagnetic studies, we discovered that at a few levels there were concentrations of mica grains and other minerals that could only have come from explosive volcanic eruptions and have been carried by the winds to the site of deposition of the Scaglia limestones. One of us (A.M.) led the research effort in which the volcanic mineral grains from these levels were dated on the basis of radioactive decay (Montanari and Koeberl 2000).

This was a remarkable opportunity, because none of the minerals in the normal pelagic limestone can be dated radioactively. However, the volcanic mineral grains were indeed datable, and the dates obtained gave the age of the volcanic eruption, and thus also of the level in the limestone where the mica grains were found, because the grains must have been carried by the wind to their site of deposition in a geologically instantaneous interval of time. Thus we were able to obtain ages in years for a number of levels within the sequence of microfossil zones and paleomagnetic reversals. It was the first time that all three of these methods of dating rocks – fossils, magnetic reversals and radioactive dates – had been tied together. It was a critical contribution to the development of the modern geological time scale.

The Geological Time Scale

Through stratigraphic studies like those at Gubbio, carried out by geologists and paleontologists all over the world, the geological time scale has been worked out in detail and formalized at an international level of agreement. Every few years, a new and updated version of the timescale is published. The most recent was published in 2004 and edited by Gradstein *et al.* (2004). Additions and revisions since that time are available on the web at this address: https://engineering.purdue.edu/Stratigraphy/index.html

Although superficially the geological time scale units look like the kinds of periodizations that historians use to organize their narrative accounts of human history, the geological time scale is in fact quite different. In particular, the geological time scale units, like Jurassic and Cretaceous, have been agreed upon at an international level, and have been formally established at specific geological outcrops chosen after exhaustive consideration and debate. The difference between geological and human-history periodizations is considered by Alvarez *et al.* (2009).

Cyclostratigraphy and the Future of the Geological Time Scale

In the 2004 Geological Time Scale most numerical dates are given with a precision of 1 million years, 100,000 years, or 10,000 years, depending on the quality of information available for that particular time-unit boundary. As people working on the time scale move towards the next version, there is some hope that it may be possible to calibrate the history of the Earth with a precision of 1000 years, back to about 100 million years ago. This extraordinary development comes from the relatively new field of cyclostratigraphy, in which stratigraphic rhythms are being tied to the calculated cyclicities of the Earth's rotation and its orbit around the Sun – rhythms that are known as Milankovitch cycles (Kuiper *et al.* 2008). In the fall of 2010, a conference of mainly European scientists, held at the Geological Observatory of Coldigioco, laid the groundwork for this next geological time scale, with the unprecedented chronological precision that may be achievable.

Because of the richness of the historical record of the pelagic limestones of the Apennines, it has been possible to tie together in great detail many aspects of the history of the Earth throughout the time interval in which these rocks were deposited. With cyclostratigraphy offering the prospect of dating with a resolution on the order of a thousand years, an unprecedented clarity of understanding of Earth history is emerging, and this synthetic effort is being called 'integrative stratigraphy'.

Bringing the Earth History and Human History together on ChronoZoom

One of the central problems of Big History is how to integrate the historical record of humanity, in years, with the record of Earth and life, in millions of years. Geologists and paleontologists studying pelagic limestones and other rock records have produced thousands of graphical representations of different aspects of Earth and life history, and in those diagrams human history is invisibly small at the most recent end. A logarithmic scale can be used to show all of Big History on a single diagram, but this introduces such extreme distortion that log scales are rarely used.

A new approach proposed by Roland Saekow, holding much promise for Big History, is to use zoomable computer graphics, with a diagram showing all of history at true scale, and allowing a historian to zoom in and out to examine any portion of the diagram, from all of the cosmos to a single day. To do this, we are developing 'ChronoZoom' in collaboration with Microsoft Research (Saekow, this volume). We intend for it to be a useful tool for all Big Historians. The first version of ChronoZoom is available on the web: http://eps.berkeley.edu/~saekow/ chronozoom/

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10
Biological and Social Phases of Big History: Similarities and Differences of Evolutionary Principles and Mechanisms

Leonid E. Grinin, Andrey V. Korotayev,
Alexander V. Markov

Abstract

Comparison of biological and social macro-evolution is a very important issue, but it has been studied insufficiently. Yet, analysis suggests new promising possibilities to deepen our understanding of the course, trends, mechanisms and peculiarities of the biological and social phases of Big History. This article analyzes similarities and differences between two phases of Big History at various levels and in various aspects. It compares biological and social organisms, mechanisms of evolutionary selection, transitions to qualitatively new states, processes of key information transmission, and fixation of acquired characteristics. It also considers a number of pre-adaptations that contributed to the transformation of Big History's biological phase into its social phase and analyzes some lines of such a transformation.

Introductory Remarks

In this article, we continue our analysis of similarities and differences between social and biological evolution, which makes it the continuation of an article that we published in the previous issue of *Evolution* (Grinin, Markov, and Korotayev 2011). Since the comparison of biological and social evolution is an important but (unfortunately) understudied subject, we shall re-state a few of the salient points from our previous article.

We are still at the stage of a vigorous discussion about the applicability of Darwinian evolutionary theory to social/cultural evolution. Unfortunately, we all are mostly dealing with a polarization of views. On the one hand, we confront a total rejection of Darwin's theory of social evolution (see, *e.g.*, Hallpike 1986). On the other, we deal with those who stress that cultural evolution demonstrates all the key Darwinian evolutionary characteristics (Mesoudi, Whiten, and Laland 2006).

We believe that, instead of following the outdated objectivist principle of 'either – or', we should concentrate on the search for methods that could allow us to apply achievements of biological evolutionary science to social evolution and *vice versa*. In other words, we should concentrate on the search for productive generalizations and analogies for analysis of evolutionary mechanisms. The Big History approach aims for inclusion of all mega-evolution within a single paradigm (this paradigm is discussed in Grinin, Carneiro *et al.* 2011). Hence, this approach provides an effective means to address the above-mentioned task.

As is known, not only systems evolve, but mechanisms of evolution evolve too (see more on this in Section 3). This concept also appears rather fruitful as regards the development of Big History itself. Let us consider some of the parameters and examples that we might consider.

Each sequential phase of Big History is accompanied by the emergence of new evolutionary mechanisms; therefore, certain prerequisites and preadaptations can be detected within the previous phase. So, development of new mechanisms of evolution does not imply invalidation of evolutionary mechanisms that were active during previous phases. As a result, one can observe the emergence of a complex system of interaction of forces and mechanisms determining the evolution of new forms. Biological organisms operate in the framework of certain physical, chemical and geological laws (see Kutter's contribution on this topic and also on the comparison between physical and biological evolution).

Likewise, the behaviors of social systems and people have certain biological limitations. New forms of evolution that determine Big History transition into a new phase may result from activities going in different directions. Some evolutionary forms that are similar in principle may emerge not only at a breakthrough point, but may also result in a deadend – from the overall view of Big History. For example, the emergence of social forms of life took place in many phyla and classes – bacteria, insects, birds and mammals. Additionally, among insects, we can find rather high forms of socialization (see, *e.g.*, Reznikova 2011; Ryabko and Reznikova 2009; Robson and Traniello 2002). Despite the common trajectory and interrelation of social behaviors by these various life forms, there has been a large overall difference in the impact that each has had on the Earth.

What is more, as regards information transmission mechanisms, it appears possible to speak about certain 'evolutionary freaks'. Some of those mechanisms (in particular, the horizontal exchange of genetic information) were spread rather widely in the biological evolution of simple organisms but were later discarded (or transformed into highly specialized mechanisms, *e.g.,* sexual reproduction) among more complex organisms. Today, they are mostly confined to the simplest forms of life. We mean the horizontal exchange of genetic information (genes) among microorganisms, which makes many useful genetic 'inventions' literally a sort of 'commons' of microbe communities. Among the bacteria, the horizontal transmission of genes contributes to the fast development of antibiotic resistance (*e.g.*, Markov and Naymark 2009).

For the present article, the following turns out to be important: The horizontal exchange of genetic information (in its general function) is distantly similar to those forms of information exchange that became extremely important for social evolution – the direct borrowing of innovations and their introduction into social life. Hence, principles and mechanisms that appear of marginal relevance at a certain phase of Big History may turn out to be extremely important in a later phase.[1]

These parallels suggest that analysis of similarities and differences between the mechanisms of evolution may help us to understand the general principles of mega-evolution[2] and Big History in a much fuller way. They may also help us to better understand their driving forces and supra-phase mechanisms (mechanisms that operate in two or more phases of Big History). Our first article was devoted to the analysis of one such mechanism – *aromorphosis* (Grinin, Markov, and Korotayev 2011; also Grinin and Korotayev 2008, 2009a, 2009b; Grinin, Markov, and Korotayev 2009a, 2009b).

Let us return now to a comparison of biological and social evolution. It is important to describe similarities and differences between these two types of macro-evolution – at various levels and in various aspects. This is necessary because such comparisons tend to be deformed by conceptual extremes[3] and tend to be incomplete. These limitations are true even in respect of the above-mentioned paper by Mesoudi, Whiten and Laland (2006), as well as a rather thorough monograph by Christopher Hallpike (1986), *Principles of Social Evolution*. There, Hallpike offers a fairly complete analysis of similarities and differences between social and biological organisms, but does not provide a clear and systematic comparison between social and biological evolution.

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[1] Note that in the biological macroevolution the 'borrowing' is found mostly at lower levels of the biological evolution, whereas it is found much less frequently at higher levels. The opposite situation is observed in social macroevolution – in general, the older the society, the lower its borrowing rate (incidentally, this accounts to a considerable extent for a low rate of change in the majority of ancient societies).

[2] We denote as *mega*evolution all the process of evolution throughout the whole of Big History, whereas we denote as *macro*evolution the process of evolution during one of its particular phase.

[3] This is typical, for example, for a very interesting and controversial article by Mesoudi, Whiten, and Laland *Towards a Unified Science of Cultural Evolution* (2006), where we clearly deal with an attempt to impose the Darwinian methodology on the study of social evolution. The importance of the above-mentioned differences (including such fundamental differences as the absence in social evolution of a clear distinction between genotype and phenotype) is downplayed by a statement that those differences are either illusory or unimportant (*Ibid.:* 345). Such an approach also reduces the value of a rather interesting methodology that they propose.

Section 1. Biological and Social Organisms: A Comparison at Various Levels of Evolution

There are a few important and understandable differences between biological and social macro-evolution, nonetheless, it is possible to identify a number of fundamental similarities. One may single out at least three basic sets of shared factors.

- First of all, there are similarities that stem from very complex, non-equilibrium, but stable systems whose principles of function and evolution are described by General Systems Theory, as well as by a number of cybernetic principles and laws.
- Secondly, we are not dealing with isolated systems but with a complex interaction between organisms and their external environment. As a result, the reaction of systems to external challenges can be described in terms of general principles that express themselves within a biological reality and a social reality.
- Thirdly, it is necessary to mention a direct 'genetic' link between the two types of macro-evolution and their mutual influence.

It is important to emphasize that similarity between the two types of macro-evolution does not imply commonality. Rather significant similarities are frequently accompanied by enormous differences. For example, the genomes of chimpanzees and the humans are 98 per cent similar. However, there are enormous intellectual and social differences between chimpanzees and humans that arise from the apparently 'insignificant' variations between the two genomes.[4]

It appears reasonable to continue the comparison between the two types of macro-evolution on the basis of the analysis used by Hallpike, who singles out the following **similarities between social and biological organisms** (Hallpike 1986: 33):

1. 'The institutions of societies are interrelated in a manner analogous to the organs of the body, and preserve their continuity despite changes of individual membership, just as individual cells are renewed in organs.'
2. 'There is a specialization of organic functions analogous to the social division of labor.'

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[4] It appears appropriate to mention that the genomes of the humans and the chimpanzees differ by ten major genome reorganizations. A few years ago it turned out to be possible to sequence the genome of the rhesus macaque (a special issue of the *Science* was devoted to this subject; see in particular Rhesus Macaque... 2007). This is the third primate genome that was sequenced (after the human and chimpanzee genomes). Up to that moment, when detecting differences between the genomes of the humans and the chimpanzees, specialist could not determine which of those differences emerged in the human evolutionary line, and which appeared in the evolutionary line of the chimpanzees. The reading of the rhesus macaque genome substantially facilitated this task. The comparison with the macaque genome allowed detecting that three of those differences happened in the human evolutionary line, whereas the other seven occurred in the evolutionary line of the chimpanzees (see Markov and Naymark 2009 for more detail).

3. 'In both cases self-maintenance and feedback processes occur.'
4. 'There are adaptive responses to the physical environment.'
5. 'In organisms we find the transmission of matter, energy, and information analogous to trade, communication, *etc.,* in societies.'

According to Hallpike, **societies are unlike organisms in the following respects** (Hallpike 1986: 33–34):

1. 'They are not physical entities at all, since their individual members are linked by information bonds, not by those of a purely physical nature.'
2. 'Societies are not clearly bounded, *e.g.,* two societies may be distinct politically, but not culturally or religiously.'
3. 'Societies do not reproduce, so that cultural transmission from generation to generation is indistinguishable from general processes of self-maintenance.'[5]
4. 'Societies are capable of metamorphosis to a degree only found in organic phylogeny.'
5. 'The individual members of a society, unlike cells, are capable of acting with purpose and foresight, and of learning from experience.'
6. 'Structure and function are far less closely related in societies than in organisms.'

Hallpike also comes to the sound conclusion that similarities between social and biological organisms are in general determined by similarities in organization and structure (we would say similarities between different types of systems). As a result, Hallpike believes that one can use certain analogies when institutions can be represented as similar to some organs. In this way, cells may be regarded as similar to individuals; central government similar to the brain, and so on. Spencer (1898) and Durkheim (1991 [1893]) are important representatives of this tradition.[6] Hallpike also has sufficient grounds to add Alfred Radcliffe-Brown and Talcott Parsons.

When comparing biological species and societies, Hallpike (1986: 34) singles out the following similarities:

1. 'Species, like societies, do not reproduce.'
2. 'Both have phylogenies and metamorphosis.'
3. 'Both are composed of competing individuals.'

He also singles out the following difference: '*Unlike* species, however, societies are organized systems, whereas species are simply collections of individual organisms' (*Ibid.*).

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[5] However, there are cases when societies create new societies rather similar (with basically the same 'memotype') to the 'maternal' ones, for example, with the establishment of settler colonies. See the next section for more information on the differences in ways of information transmission.

[6] See also Heylighen's (2011) contribution to the first issue of the Almanac.

Further, Hallpike tries to demonstrate that, because of such differences between biological and social organisms,[7] the very idea of natural selection does not appear to be very productive with respect to social evolution. We believe that his proofs are not very convincing, although they make some sense in certain respects. In addition, his analysis is concentrated mostly at the level of an individual organism and an individual society. He hardly moves at the supra-organism level (though he, of course, discusses the evolution of species). We believe that with this, Hallpike (notwithstanding his desire to demonstrate the sterility of the application of Darwinian theory to social evolution) involuntarily amplifies the effect of similarity between biological and social evolution, because the analogy between the biological organism and society (as Hallpike admits himself) is rather salient indeed.

On the other hand, Hallpike does not take into account the point in social evolution where a few substantially new supra-socium levels of development emerge. We contend that it is very important to consider not only evolution at the level of a society but also at the level above individual societies, as well as the point at which both levels are interconnected. The supra-organism level is very important, as regards biological evolution (but, perhaps, less so in respect to social evolution). Thus, it might be more productive to compare societies with ecosystems rather than with organisms or species. However, this would demand the development of special methods, as in this case it would be necessary to consider the society not as a social organism, but as a part of a wider system, which includes the natural and social environment.[8]

We identify the following differences between the social and biological evolution.

A. At the Level of an Individual Society and an Individual Biological Organism

1. As Hallpike (1986: 33) notes, societies are capable of such rapid evolutionary metamorphoses that they were not observed in the pre-human organic world. However, social systems are not only capable to change and transform, they are also capable to borrow innovations and new elements.

2. They may be also transformed consciously and with a certain purpose. Such characteristics are absent in natural biological evolution in any form.

3. In the process of social evolution the same social organism may experience radical transformation more than once.

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[7] Because the systems of transmission of traits within biological and social systems are rather different; because of the higher degree of complexity of social systems, and so on.

[8] See Lekevičius 2009, 2011 for more detail on the problems of the evolution of ecosystems. Note that one of those articles, in addition, contains a discussion of analogies between the evolution of ecosystems and the evolution of capitalist society.

4. Key information transmission differs significantly in biological and social evolution (we shall consider this point in more detail in the next Section).

5. In biological evolution, the acquired characteristics are not inherited; thus, they do no not influence the biological evolution that proceeds very slowly. This point will be also considered in more detail in the next section.

6. It appears very important to note that, though biological and social organisms are significantly (actually 'systemically') similar, they are radically different in their capabilities to evolve. The biological organism does not evolve by itself; evolution may only take place at a higher level (population, species, *etc.*), whereas social evolution can often well be traced at the level of an individual social organism. What is more, it is frequently possible to trace the evolution of particular institutions and subsystems within a social organism.

B. As Regards the Results of Social/Natural Selection

1. Biological evolution is more additive (cumulative) than substitutive; put in another way: 'the new is added to the old'. In contrast, social evolution (especially during the two recent centuries) is more substitutive than additive: 'the new replaces the old' (Grinin, Markov, and Korotayev 2008, 2011).

2. Since social evolution is different from biological evolution, in respect of mechanisms of emergence, fixation and diffusion of evolutionary breakthroughs (aromorphoses), this leads to long-term restructuring in size and complexity of social organisms. It is important to note that, in contrast to biological evolution, where some growth of complexity is also observed, such social reorganization becomes continuous. In recent decades, societies that do not experience a constant and significant evolution look inadequate and risk extinction. In addition, size of societies (and systems of societies) tends to grow constantly through more and more tightly integrative links (this trend has become especially salient in recent millennia), whereas the trend towards increase in the size of biological organisms in nature is rather limited and far from general.

3. Within social evolution, we observe the formation of special suprasocietal systems that also tend to grow in size. This can be regarded as one of the results of social evolution and serves as a method of aromorphosis fixation and diffusion.

C. At Supra-organic (Suprasocietal) Level

As a result of the above-mentioned differences, within the process of social evolution, we observe the formation of two types of special suprasocietal systems: A) amalgamations of societies with varieties of complexity that have analogies to biological evolution; B) emergence of elements and systems that do not belong to any society, in particular that lack many analogies to biological evolution.

Naturally, type B needs a special comment. The first type of supra-organic amalgamation is rather typical not only for social but also for biological evolution.[9] However, within biological evolution, amalgamations of organisms with more than one level of organization[10] are usually very unstable and are especially unstable among highly organized animals.[11] Within social evolution, we observe the emergence of more and more levels: from groups of small sociums to humankind as a whole. Of course, it makes sense to recollect analogies with social animals: social insects, primates and so on. Neither should we forget to compare society with the individual biological organism but also with groups of organisms bound by cooperative relationships. Such groups are widely present among bacteria and even among viruses.

It should be noted that modern biologists have developed well respected theories that account for the emergence of intragroup cooperation and altruism, including competition, kin selection, group selection and so on (see, *e.g.*, Reeve and Hölldobler 2007). However, it is not clear if societies should be really compared with groups of organisms rather than individual organisms, whether we should not consider societies within the system of numerous intersocietal links?

In any case, it is clear that the level of analysis is very important for comparison of biological and social evolution. Which systems should be compared? Such analogies are more frequent when society (the social organism) is compared to a biological organism or species. However, in many cases, it may turn out to be more productive to compare societies with other levels of the biota's system organization: with populations, ecosystems and communities, with particular structural elements or blocks of communities (*e.g.,* with particular fragments of trophic networks or with particular symbiotic complexes), with colonies (with respect to colonial organisms), or finally – and this is the closest analogy – with groups of highly organized animals (cetaceans, primates, and other social mammals or termites, ants, bees and other social insects).

Thus, here we are confronting a rather complex and hardly studied methodological problem: which levels of biological and social processes are most congruent? What are the levels whose comparison could produce the most interesting results? In general, it seems clear that such an approach should not be a mechanical equation of 'social organism = biological organism' at all times and

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[9] There is, however, a major difference: any large enough society usually consists of a whole hierarchy of social systems (*e.g.,* with respect to a typical agrarian empire these would be: nuclear family – extended family – clan community – village community – primary district – secondary district – province), so that it can hardly be compared with a single biological organism (though both systems can still be compared functionally, as is correctly noted by Hallpike [1986]).

[10] We could mention various flocks and packs of animals as examples of such amalgamations with one level of organization.

[11] More complex superorganic amalgamations may be found in the biological evolution among less complex organisms. This trend seems to be opposite to what is observed in the social evolution, though, say, village communities in more complex societies tend to be less complex than in more simple ones (see, *e.g.*, Korotayev 1995; 2003: 75–90; Korotayev *et al.* 2000, 2011).

in every situation. The comparisons should be operational and instrumental. That means that we should choose the scale and level of social and biological phenomena, forms and processes that are adequate for their respective tasks.

We would say again that sometimes it is more appropriate to compare an individual biological organism with a society, whereas in other cases it could well be more appropriate to compare a society with a community (of, say, ants or bees), a colony, a population or a species. We believe that the issue of the 'presence' of the social ontogenesis (and its comparison with the biological ontogenesis) should be studied in this framework (Grinin, Markov, and Korotayev 2008: ch. 6 for more detail). However, there are some cases when it seems more appropriate to compare social ontogenesis with biological phylogenesis. Hence, different scales and types of scientific problems need special approaches. This subject will be discussed further in the subsequent section of the present article.

Section 2. Similarities and Differences at the Level of Evolutionary Mechanisms

1. Biological and Social Aromorphoses

In certain respects, it appears reasonable to consider biological and social macro-evolution as a single macro-evolutionary process. This implies the necessity to comprehend the general laws and regularities that describe this process, though their manifestations may display significant variations, depending on properties of a concrete, evolving entity (biological or social). We believe that many similarities and differences in laws and driving forces in the biological and social phases of Big History can be comprehended more effectively if we apply the concepts of biological and social aromorphosis. As our contribution to the first issue of the *Evolution* Almanac (Grinin, Markov, and Korotayev 2011) was devoted to aromorphoses and their regularities, in our present article we shall restrict ourselves to a summary of some principal concepts.

Aromorphosis is understood by Russian biologists along the lines suggested by Alexey Severtsov (Severtsov A. N. 1939, 1967). As any broad biological generalization, the notion of 'aromorphosis' remains a bit vague; it appears difficult to define it in a perfectly rigorous and unequivocal way. As a result, a few quite reasonable definitions of aromorphosis have been proposed, for example:

1. '*Aromorphosis is an expansion of living conditions connected with an increase in complexity of organization and vital functions*' *(Ibid.).*

2. '*Aromorphosis is an increase in the organization level that makes it possible for aromorphic organisms to exist in more diverse environments in comparison with their ancestors; this makes it possible for an aromorphic taxon to expand its adaptive zone*' (Severtsov A. S. 2007: 30–31).

Among the classical examples of major biological aromorphoses, one could mention the emergence of the eukaryotic cell (see, *e.g.*, Shopf 1981); the transition from unicellular organisms to multicellular ones that took place more than once in many lineages of unicellular eukaryotic organisms (see, *e.g.*, Valentine 1981: 149); the transition of plants, arthropods, and vertebrates to life on dry land (see, *e.g.*, Valentine 1981); origin of mammals from theriodonts (Tatarinov 1976); origin of *Homo sapiens; etc.*

The process of aromorphosis formation is called *arogenesis,* which is rather close to *anagenesis*, in the sense in which this term was originally proposed by Rensch (1959: 281–308; see also Dobzhansky *et al.* 1977; Futuyma 1986: 286 *etc.*).

The concept of aromorphosis (or its analogue) does not appear to have been worked out with respect to social macro-evolution. We believe that the adaptation of this notion for the theory of social macro-evolution could be an important step forward for the development of this theory itself, and for the general theory of macro-evolution.

The matter is, it appears difficult to understand the general course of macroevolution and the evolutionary potential of various structural reorganizations without certain analytical tools, including appropriate classifications. Unfortunately, the research on social and cultural evolution lacks such classifications almost completely. We believe that the introduction of the notion of social aromorphosis may contribute to the development of such typologies and classifications. Thus, we believe that it may contribute to the transformation of social evolutionism into a truly 'scientific activity of finding nomothetic explanations for the occurrence of… structural changes' to use Claessen's (2000: 2) phrase. Moreover, one may also compare this with Ervin László's idea that the application of 'evolution' as the basic notion opens the way toward the rapprochement of sciences (see, *e.g.*, László 1977).

The social aromorphosis can be defined as a universal / widely diffused social innovation that raises social systems' complexity, adaptability, integrity and interconnectedness (Grinin and Korotayev 2007a, 2009b; Grinin, Markov, and Korotayev 2008). Social aromorphoses lead to the following results:

a) significant increases in social complexity and societies' abilities to change their natural and social environments, to raise carrying capacity, as well as the degree of their stability against changes in their environments;

b) more rapid developmentary changes (including borrowings) that do not destroy social system;

c) increase in the degree of intersocietal integration, formation of special stable super-systems (civilizations, various alliances, *etc.*) and suprasocietal zones, special suprasocietal spheres that do not belong to any particular society;

d) more rapid evolution toward the formation of super-complex maximum super-systems (world-systems, the World System and, finally, humankind as a single system), in whose framework each particular social system (while remaining autonomous) becomes a component of such a super-system and develops within it, through specialization, inter-system functional differentiation.

As examples of social aromorphoses of the highest type one can mention:

- origins of early systems of social kinship that created a universally convenient system of social structuration;
- transition to food production that led to an immense artificial increase in the quantities of useful (for humans) biomass;
- state formation that led to a qualitative transformation of all social, ethnic and political processes;
- invention of writing that served as a basis for the revolution in information processing technologies involving the development of elaborate administrative systems, literature and science;
- transition to iron metallurgy;
- formation of developed market systems that laid the basis for the industrial revolution;
- invention of computer technologies.

Each of these aromorphoses had a number of important consequences that contributed to an increase in the potential of success for the adopting societies for increasing the carrying capacity of their territories and heightening the stability of their systems. Often these aromorphoses were of evolutionary importance too.

There are some important similarities between the evolutionary algorithms of biological and social aromorphoses. Thus, it has been noticed that the basis of aromorphosis

> is usually formed by some partial evolutionary change that... creates significant advantages for an organism, puts it in more favorable conditions for reproduction, multiplies its numbers and its changeability..., thus accelerating the speed of its further evolution. In those favorable conditions, the total restructurization of the whole organization takes place afterwards (Shmal'gauzen 1969: 410; see also Severtsov A. S. 1987: 64–76).

And then, in the course of adaptive radiation, those changes in organization diffuse more or less widely (frequently with significant variations).

A similar pattern is observed within social macro-evolution. An example is the invention of iron metallurgy. Iron production was practiced sporadically in the 3rd millennium BCE, but regular production of low-grade steel began in the mid-2nd millennium BCE in Asia Minor (see, *e.g.*, Chubarov 1991: 109) within the Hittite kingdom, which guarded its monopoly. Diffusion of iron technology led to revolutionary changes in different spheres of life: one can observe a significant progress in plough agriculture and consequently in the agrarian system as a whole (Grinin and Korotayev 2006); an intensive development of crafts; the transformation of barbarian societies into civilizations; the formation of new types of militaries that were made up of massed forces armed with relatively cheap but effective iron weapons; the emergence of significantly more developed systems of taxation as well as information collection and processing systems that were necessary to support those armies.

In this regard, the difference between social and biological aromorphoses is similar to the difference between the overall patterns of both types of macroevolution:[12] the development of biological aromorphoses tends to contribute to an increase in biodiversity, whereas the diffusion of social aromorphoses tends (but just tends!) to lead to the replacement of more simple social forms with more complex ones. Thus, with the diffusion of iron technologies, all the societies that confronted this diffusion had to borrow iron technology, otherwise they risked being absorbed or destroyed by those societies that possessed it.

The application of the notion of biological and social aromorphosis has helped us to detect a number of regularities and rules that are common for biological and social evolution – 'payment for the arogenic progress', 'special conditions for the aromorphosis emergence', and so on. Such rules and regularities are similar for both biological and social phases of Big History. However, as they have been already considered in detail in our contribution to the first issue of this Almanac, we shall not analyze them in the present article.

2. On the Peculiarities of Key Information Transmission at Various Phases of Big History

Replication on the basis of the matrix principle is a fundamental feature of all forms of life (see, *e.g.*, Timofeev-Ressovsky *et al.* 1969: 15–16). However, the process of such replication cannot be conducted with a 100 per cent accuracy; hence, the replication of a complete genome without any errors is virtually impossible. That is why the emergence of practically any new biological organism is accompanied by random change in genes (*i.e.*, mutations). However, a significant change of the genotype occurs extremely rarely. Yet, the role of mutations in biological evolution is extremely important and very well known, because the mutations are one of the main sources providing 'raw materials' for evolution (see *Ibid.*: 72).[13]

However, it is important to emphasize that the number of distortions by which transmission of information is accompanied from generation to generation within social evolution (especially in complex societies) is orders of magnitude higher than that observed within biological evolution. There are grounds

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[12] The biological evolution is predominantly additive/cumulative, whereas the social evolution is predominantly displacing (see above).

[13] However, there is also an opinion that the importance of mutations for evolution has been exaggerated, whereas the main source of new genetic material for major morphobiological reorganizations was provided by the gene duplication (see, *e.g.*, Shatalkin 2005: 30). The gene duplication may indeed be a source of new material; yet the studies that try to prove that the morphobiological reorganizations are, first of all, results of duplications have been conducted just for 15 years, and at the moment we are rather dealing with accumulation of data in this field, that is why we still prefer to keep to the classical point of view on the role of mutation in the process of biological evolution.

to maintain that the role of such 'distortions' in social macro-evolution tends to increase (in addition to conscious and purposeful alteration of cultural information). In the meantime, it appears that we observe just the opposite within biological macro-evolution. For example, among viruses and some bacteria, mutational variability is constantly necessary for their mere survival; on the other hand, in complex biological organisms, it is necessary only up to a very limited extent.

Within social evolution, some unconscious distortion of transmitted cultural information always takes place, which may be regarded to some extent as analogous to biological mutations.[14] This, by itself, may lead to certain socio-evolutionary shifts (Korotayev 1997, 2003; Grinin and Korotayev 2007b, 2009b). However, the conscious directed alteration of the information by its carriers is significantly more important. Though many are still sure that 'history never teaches anything to anybody', already the elites of many complex agrarian societies quite often tried to take into account errors made by their predecessors and to modify the 'socio-cultural genotype' accordingly in order to avoid them in future.

One may recollect, for example, the conscious alteration of the social position of the military elite by the founders of the Sung dynasty in China (960–1279 CE), in order to prevent the military coups that jeopardized the political stability of their predecessors (Wright 2001). Similarly, there was the conscious and purposeful replacement of traditional military systems with the modernized military systems of Western Europe by Peter the Great in Russia and Muhammad Ali in Egypt (see, *e.g.*, Grinin 2006a; Grinin and Korotayev 2009c, 2009d).

Thus, the major part of fixed socio-cultural alterations (supported by social selection) emerge not as a result of 'random errors of copying' (though, of course, such random errors do exist), but as a result of purposeful alteration of respective memes. Such 'mutations' are directional from the very beginning and do not seem to have any anologues in natural biological evolution.

3. On the Inheritance of Acquired Characteristics

The other (and perhaps even more important) difference is that, in the process of biological (but not social) evolution, the acquired characteristics are not inherited.[15] That is why socio-evolutionary changes are accumulated much faster than biologically useful changes of phenotype determined by mutation processes.

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[14] Close results are arrived at by Dawkins (1993) in his theory of the 'evolution of memes'.

[15] As one of the differences between social and biological evolution is connected with the absence in the former of clear equivalents of genotype and phenotype (see, *e.g.*, Mesoudi, Whiten, and Laland 2006: 344–345), it appears quite evident that the expressions 'sociocultural genotype' and 'sociocultural phenotype' should be regarded as metaphors rather than as exact scientific terms.

Thus, because the acquired characteristics do not influence biological evolution, biological evolutionary processes go extremely slowly (in comparison with social evolution). On the other hand, within social evolution, the acquired characteristics can be inherited, and, hence, social evolution goes 'according to Lamarck' rather than 'according to Darwin'. This point has been noted many times by a number of evolutionists (see, *e.g.*, Mesoudi, Whiten, and Laland 2006: 345–346). Consequently, social evolution proceeds much faster. In addition, as social evolution tended to go more and more 'according to Lamarck', it became more and more Lamarckian rather than Darwinian, which was one of the main factors for the acceleration of social evolution.

Still, it appears necessary to mention that in some rare cases one can observe the inheritance of acquired characteristics in complex biological organisms (Zhivotovsky 2002a). For example, somatic mutations may well be inherited in plants both with vegetative and sexual reproduction. In animals, viruses can insert themselves into the genome of gametes – subsequently the offspring inherit quite an 'acquired characteristic', the virus infection. The ability to inherit acquired characteristics is found in many plant-eating insects, in which specialized symbiotic bacteria live. Biochemical and ecological characteristics of such symbiotic complexes are determined up to a very large extent by bacteria (see, *e.g.*, Dunbar *et al.* 2007).

The possibility of inheritance of acquired characteristics through special particles (pangenes) was proposed by Darwin (1883) himself. Within the genomes of complex biological organisms one can find a very large number of retropseudogenes and even working copies of genes that emerged as a result of the 'copying' of genetic information from RNA molecules to the chromosome with special enzymes (such genes are characterized by the absence of introns). Thus, in biological evolution, one may observe the 'copying' into the genome of information on the structure of mature matrix RNA. Because the alternative splicing is quite a controlled process, regulated by the cell and subject of intermediate influence of external conditions (see, *e.g.,* Lareau *et al.* 2007), mature mRNA may actually carry some (albeit rather incomplete and fragmentary) information on 'acquired phenotypic characteristics', and this information may be transmitted to the genome of the germ line.

The impossibility of genetic inheritance 'according to Lamarck' postulated by the Synthetic Theory of Evolution is because the mechanism of reverse translation does not appear to have emerged. That is why there is no way for changes that occur in an organism during its lifetime, at the level of proteins, can be recorded back into the genome.[16] On the other hand, at present, we know

[16] On the other hand, there is a hypothesis that such a mechanism may have existed at the earliest phases of biological evolution. What is more, scientists have experimentally obtained RNA molecules that can perform certain stages of reverse translation (Nashimoto 2001).

that the phenotype at the cellular level is determined not only by proteins, but also by a great variety of functional RNAs, whereas intravital changes of those molecules may well be written into the genome because here the mechanism of reverse transcription exists and is rather widely spread in biological organisms (including complex organisms). Hence, the point is not that within the biological evolution the 'Lamarckian' inheritance is totally impossible; rather the point is that such an inheritance is rather disadvantageous in most cases (see also Steele *et al.* 2002; Zhivotovsky 2002b). Consequently, such an inheritance is not usually an important mechanism of evolution (and, especially, of arogenic evolution).

For example, it is evident that the hereditary fixation of adaptive modifications ('modification genocopying') is disadvantageous in many cases. Note that this includes those very consequences of the organ exercise whose inheritance played such an important role in Lamarck's theory. In order for an adaptive modification to appear, we should observe first a genetically determined capability for such a modification (*e.g.,* the muscles' ability to grow as a result of exercise or the lymphocytes' ability to develop immunity against new pathogens). However, if such a genetically determined ability has appeared, the firm fixation in the genotype (the *genocopying*) of only one of many possible versions of the final state of the trait (*e.g.,* a precise size of a muscle or an immunity toward a specific pathogene) will not be a progressive evolutionary change; it will be a degenerative evolutionary change, accompanied by a decrease of the organic complexity and a loss of one of the ontogenetic regulatory circuits. In biological evolution, such events take place rather frequently, but this is not the arogenic evolutionary pathway.

Within social evolution, there is no significant difference in the inheritance mechanisms between those traits that have been inherited from 'ancestral' societies and the ones that have been acquired throughout the history of existence of a given society. There could be some insignificant difference as regards the firmness of the fixation of the respective alterations, the easiness of their acceptance, and so on, but it is impossible to say that acquired social characteristics are transmitted to new generations with significantly more difficulties (especially in complex societies).

A serious obstacle for the operation of the 'Lamarckian' mechanism can be seen in traditionalism, which holds negative attitudes toward innovation and glorifies everything inherited from ancestors. This was very typical for simple traditional societies. However, such attitudes have weakened in a significant way in modern complex social systems.[17] This might be connected with the de-

[17] On the other hand, we observe another trend in connection with some sorts of regulation mechanisms. One should not think that the only evolutionary mechanism in social evolution is a conscious change of existing objects. There is also an opposite trend that may be denoted as institutionaliza-

velopment of the means, methods and technologies of forecasting, which is the conscious evaluation of innovation. Forecasting makes those characteristics that might be considered dangerous or disadvantageous by traditionalists to become acceptable in a society, in particular: (1) a very low precision of the 'memotype' replication (the memotype concept will be dicussed in more detail below) and (2) 'Lamarckian' inheritance.

4. On the Nature of Hereditary Variation

Hereditary variation is a key issue in the theory of evolution. This is the issue, around which the main discussions between representatives of various schools of evolutionary thought (classical Darwinism, Synthetic Theory of Evolution, Orthogenesis, Nomogenesis, Neolamarckism and so on) are concentrated. *Variation is the main material basis of evolution; its character, mechanisms, factor, and emergence rates determine to a very high extent the character of the evolutionary process*. These mechanisms of variation are one of the most fundamental areas of difference between biological and social evolution.[18]

Starting with Darwin, biologists have based their evolutionary theories on the idea that hereditary variation is basically 'indeterminate' or undirected, that is, random. However, as we have noted, within biological evolution, one can still detect a trend toward a decrease of andomness, both in mutational and recombinational variation. In some sense, this trend continues into social evolution, where variation is even less random and more directed.[19]

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tion. In many cases certain relationships are fixed by customs or laws in order to avoid excessive variation/equivocality that may often be harmful for a social system. For example, one could observe the development of rather rigid marriage institutions, various legal codes and constitutions that can be only altered with significant difficulties (that are usually consciously established by respective norms aimed at the provision of the stability of respective codes and constitutions). In this respect the trend toward the canalization of changes may be also traced in the social macroevolution.

[18] It appears that this is relevant not only for the biological and social phases of Big History, but also to all its preceding phases.

[19] When we make such comparisons, we compare genotype with that totality of sociocultural information (it may be denoted as 'memotype'), which is transmitted from generation to generation and determines main characteristics of social systems. In social systems, in addition to biological generations, parents and children, we find other types of continuity (that could be sometimes even more important) like institutional and legal continuity whose role increases constantly. That is, we observe the growth of the importance of information transmission in the framework of institutions, corporations, organizations, and so on, that is conducted not between biological generations (from parents to children), but, say, from an experienced worker to an inexperienced one, or from a teacher to a pupil. In addition the emergence of external information carriers (in form of books, electronic records, and so on) allows conducting a distance transmission of information without any direct contact between respective people, which, incidentally, contributes to the growth of the sociocultural evolution rate. Actually, as a result, in complex social systems the number of information transmission channels grows by orders of magnitude (especially with the emergence of external information carriers). In some sense, this growth already starts with the development of social life among the animals.

As mentioned above, there are significant differences between biological and social evolution in regard to the accuracy of copying (reproduction of replicators), because in general the precision of copying of genes (and, correspondingly, periods of their existence in a recognizable form) exceeds by orders of magnitude values of analogous indicators for memes. That is why 'memetics' (in contrast with genetics) has to deal with a much lower precision of replication and with a much higher speed of mutagenesis, though some replicators (memes) may have rather long periods of life.

For example, according to some recent estimates, roots of some most widely used words may be preserved in a recognizable form for about 10,000 (and even more) years of linguistic evolution (Pagel *et al.* 2007). Another example can be provided by 'long-lived' folklore-mythological motifs that can survive for dozens thousand years (see, e.g., Korotayev and Khaltourina 2011; Berezkin 2007; Korotayev 2006; Korotayev *et al.* 2006). The same can be said about a very long life of some technical methods, for example, the production of stone tools. However, it makes sense to distinguish between various types of information transmission, depending on the number of copies in which the information is stored and reproduced (as well as the forms of that reproduction).

There could be situations in which there is just a single carrier of important information. An ancient engineer could take his secrets of construction to the grave so that nobody could continue his techniques any more. There are lots of historical facts known to us from just one source; and if, in the process of transmission, there was distortion of the initial text, this could affect our current knowledge of the past. Those unique ancient books that disappeared in fire did not let us know the important information contained in them, and so on. These are examples of distortion or loss of information by functioning social systems.

It seems appropriate here to recollect the **information irreplaceability principle (Lyapunov principle)**. According to this principle, information that has entirely disappeared cannot be reconstructed in its entirety – what can be replaced are portions of information coming from a common source (see Rautian 1988a, 1988b). We confront a different case when we deal with information that is used by numerous carriers (as in the case of the use of a mass language). In such cases, changes in a living language should not be always regarded as information distortion; we should rather speak about some drift in the use of linguistic matrices and patterns (similar to gene drift in populations), because language carriers may well know older forms, but prefer new ones. One may even observe the coexistence of persons using differently linguistic forms and lexemes (similarly within one population there could be different phenotypes). However, with time, some forms win the competition and language changes.

When we speak about the accuracy of transmission of biological information, it is necessary to take into account that biological evolution has worked out rather effective molecular mechanisms that allow for sharply reduced precision of DNA replication when necessary (for example, *SOS-response* among bacteria).

For some primitive biological objects, such as viruses, too high a precision of replication can even be lethal; in order to successfully go through their life cycles they *need very low precision of replication* or, in other words, a very high rate of mutation (*mutagenesis*). For such organisms, evolutionary changes turn out to be necessary components of their everyday life! (Vignuzzi *et al.* 2005)

Generally, though, in biological evolution, replication accuracy increases rather than decreases with the growth of the organismal complexity. In this sense, the reduction of precision that is observed in the transition from biological to social evolution looks as if this were a 'step backward'. However, this observation is rather superficial, as it does not take into account the nature of those errors that emerge in the process of replication, notably the degree of their randomness/directionality.

Within biological systems, replication errors are basically random. Taking into consideration the decrease of randomness, this may be interpreted in the following way: Nature has not developed any biological mechanisms that allow us to forecast results of concrete genetic changes and to plan them. Though a cell (for example, a lymphocyte) may 'know' in advance that, in order to achieve a needed result, it should alter some particular part of the genome, it, however, lacks mechanisms that would allow it to forecast results of a concrete genetic alteration.[20] That is why, in the framework of biological evolution, the acceleration of adaptatio-genesis through a radical reduction of the precision of replication is a very expensive and risky strategy that can be afforded only by very primitive forms of life. The situation changes radically if the replication 'errors' become not random, but actually purposeful, based on forecast of the possible results of concrete changes introduced into the 'memotype' of a social system.

The presence of 'directed mutations' (in addition to undirected ones) **radically distinguishes the process of 'mutational variation' in the evolution of memes from what is observed within the evolution of genes, where ALL the mutations are basically undirected.**

That is why we believe that the difference between biological and social evolution in respect to randomness/directionality of hereditary variation is more fundamental than the differences in precision of replicator copying or mutation rate. In the process of 'sociocultural mutagenesis', the element of randomness is significantly smaller, because people possess the ability (albeit limited) to foresee results of certain concrete 'mutations'. That is why human creativity (say, in development of new judicial laws or new technologies) may differ qualitatively from the 'creativity' of biological evolution – especially, as regards the effectiveness and the speed with which the respective results are achieved.

On the other hand, one should not exaggerate the role of conscious planning in relation to social innovation. Random search, trial and error remains very im-

[20] Such a mechanism (in the form of scientific methods and genetic engineering) was finally developed in the course of sociocultural evolution; this mechanism, however, could still hardly be called perfect.

portant in social evolution (Grinin 1997, 2006b, 2007a, 2011a; Korotayev 2003), although there has been a clear decreasing trend in randomness in recent centuries (see, *e.g.*, Korotayev 1999, 2003, 2004; Korotayev, Malkov, and Khaltourina 2006; Grinin 1997, 2007a, 2009a). Thus, it is not sufficient just to have respective challenges in order that serious transformations could take place. Most societies 'respond' to new problems in old, habitual, tested and familiar ways, as they choose – not from a set of hypothetical alternatives – but from a set of accessible alternatives (Van Parijs 1981: 51). In other words, they use actually known measures instead of potential ones (Claessen 1989). In these situations, their behavior is often quite similar to that of social animals. Naturally, not all such 'responses' are effective. As a result, many societies perish, disappear or lose their independence (Grinin 2011a).

For example, after the Roman regiments were withdrawn from Britain in 410 CE, the Britons (Romanized British Celts) sought protection from the raids of their Irish and Scottish neighbors. They invited Saxons to defend them in return for plots of land in Britain. Actually, this was a variation of the very well-known Roman method 'to use barbarians to fight barbarians'. However, the Saxons, after they had seen the Britons military weakness, stopped obeying local authorities and became masters of the country (together with Angles and Jutes). In this way, the Britons, notwithstanding their fierce and long resistance, were partly evicted, partly destroyed and partly enslaved. As a result, barbarian Anglo-Saxon states were found in place of the state of the Britons (Blair 1966: 149–168; Chadwick 1987: 71; Philippov 1990: 77).

If we take into account general historical contexts, we see that an extremely small fraction of all responses to various challenges turned out to be capable of becoming sources for system aromorphoses. This implies that most societies turned out to be incapable to move to new qualitative levels: They did not have the necessary potential for change, their construction had certain 'defects', the system might have been too rigid to transform easily, or some necessary conditions were lacking, and so on (Grinin 2011a, 2011b; Grinin and Korotayev 2009e).

5. The Ability to Borrow and the Horizontal Exchange of Genetic Information

These facts illustrate a rather strange situation. There are similarities in biological and social evolution, such as the transmission of information, variability, community complexity, *etc.* However, these similarities occur at the lower stages of biological evolution (involving simple biological organisms), whereas they are absent in higher stages of biological evolution (involving complex biological organisms).[21]

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[21] We do not have a full explanation of this phenomenon, but one may think about the application to the macro- and even megaevolution of **the law of the negation of the negation**, which in this

One of the main differences between social and biological evolution is the ability of social systems to not just change and transform, but also to borrow new elements. However, in this respect, social evolution resembles the biological processes that prevailed during the epoch of the 'prokaryotic biosphere' (and those processes continue up to the present among prokaryotes and monocellular eukaryotes). Among the prokaryotes, we find the ability to 'transform naturally' – to absorb DNA from the environment and to insert it into their genome, which leads to an immediate transformation of the phenotype. There is also, of course, a significant difference between this biological and social analogue: in society the borrowings are usually made consciously.

Horizontal gene transfer produces many useful genetic 'inventions', a sort of commons for microbe communities. For example, communities of marine planktonic microbes use the genes of proteorhodopsins – proteins that allow them to partly utilize sunlight. In contrast to the proteins that participate in real photosynthesis, proteorhodopsins do not need the help of many other specialized proteins. Thus, in order to acquire a useful function, it is sufficient for a microorganism to borrow a single gene (Frigaard *et al.* 2006).

Complex borrowing of entire gene systems is observed much less frequently, but when they occur, they have more significant consequences. An original and wide-spread version of such 'borrowing' results in the emergence of symbiotic systems, which sometimes actually leads to the formation of a new organism out of several other organisms. The role of such systems is often underestimated, but all functioning of the modern biosphere is based on them.

There are many examples. *Terrestrial plants* would not have been able to achieve evolutionary success without symbiosis with mycorrhizal fungi and nitrogen-fixing bacteria. *Herbivorous animals,* both insects and vertebrates, are unable to digest plant food without symbiosis with specialized microorganisms. Indeed, the principle ecological, biospheric role of animals is precisely to process plant food!

In highly complex biological organisms, in contrast to social organisms and human societies, large-scale 'borrowings' in the form of symbiotic relations or alien genetic material **rarely take place, but many of the most important aromorphoses are connected just with them.**

6. Analogues of 'Suprasocietal Institutions' in Biological Evolution

Let us come back to the question: Are there analogues of such structures in the evolution of the biosphere? The answer will depend on the level of the bio-

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case may be interpreted in the following way: '*From a free borrowing of information to its rigid isolation and canalization, and then again to its free (but now conscious) borrowing'. 'From contraposition of biological (genetic) and social mechanisms of evolution (within the process of anthropogenesis and sociogenesis) to genetic evolution controlled by the humans.'*

sphere's system organization. Society is frequently compared with biological organisms, but – in this case – we are comparing supra-societal amalgamations with supra-organic systems: populations, species, ecosystems, groups of social animals, and so on. However, this is probably not quite an appropriate scale of analysis, so we need to compare suprasocietal institutions of a global scale (like the United Nations) with biological objects of immeasurably smaller scale, *e.g.,* with particular 'casts' of the ant family.[22]

At any scale, it is difficult to find good analogies to the formation of supra-societal institutions within biological evolution. This becomes even more evident if we compare societies, not with organisms, but with supra-organic biological systems (*e.g.,* populations or species). Although those biological systems (like societies) can amalgamate into systems of a higher order (ecosystems or the biosphere), these higher-order systems are not centralized but are weakly integrated – nothing like supra-societal institutions as the World Health Organization, UNESCO, or even a complex tribal confederation with its own supra-tribal regulation organs. For example, one can observe the formation of rather complex links between species in ecosystems; certain key species may produce a decisive influence on other species in the community, but this does not result in the formation of any 'supra-species institutions'.

On the one hand, it is possible to see in this comparison one of the fundamental differences between social and biological macro-evolution. On the other hand, some biological analogues of 'suprasocietal institutions' did emerge. In the Holocene (the last 10,000 years, starting with the Agrarian Revolution), human societies developed suprasocietal institutions. In the course of the socio-biological evolution of the resulting 'anthroposphere', we observe a parallel growth in the integration of humankind and integration and coordination of evolutionary changes of biological populations, species and ecosystems. In other words, the development of the global human community (the World System) may be regarded as a factor of integration of biological evolution at its upper level.

Thus, social and biological evolution are related processes that supplement and maintain each other. Indeed, there is a tendency toward their fusion into a single complex process, one leading to the development of an 'anthropo-biosphere'. In this respect, it appears to be possible to speak about the co-evolution of biological and social development.

7. On the Role of Selection in Biological and Social Evolution

The role of selection in social evolution differs significantly from the one in biological evolution. In the biological world, the main source of stable, herita-

[22] On the other hand, a large anthill or termitary may well be compared with a large village community.

ble innovations (mutational and recombinational variation) is characterized by a high degree of randomness and unpredictability. Although, of course, it is also necessary to take into consideration all the above-mentioned qualifications about the means of optimization. In this situation, 'post factum selection', the selection among the deviations that have already emerged and have found their realization in the phenotype, becomes the only way to give the process a certain directionality (in this case – to secure the additive character of changes).

In the social world, the main sources of heritable innovations are not random errors of copying and reproduction but conscious and purposeful correction and alteration of memes. However, such purposefulness is unable to foresee not only all the consequences of its actions but even the near consequences. That is why intentional actions may appear random. Throughout human history, failures of some societies have been a sort of payment for the success of others (what we denote as 'a rule of payment for the arogenic progress'), from which the role of selection in the search for successful aromorphic variants acquires an especially important meaning (Grinin, Markov, and Korotayev 2011; Grinin 1997, 2007a; Grinin and Korotayev 2009b). Societies frequently confront such situations when an old system does not work. Those who do not change or look for more effective means perish.

Selection at the gene/meme level plays a less important role in social evolution than it does in biological evolution. However, selection in social evolution takes place not so much at the level of memes but more **at the level of organizations, institutions and social systems**. At the level of inter-societal competition, until recently, social selection acted in an especially tough way: 'the victor gets more or everything; the defeated may lose himself' (Grinin 2003, 2004, 2009a, 2009b, 2010, 2011a, 2011b). So, this is a selection mechanism that is rather different from the one found in biological evolution.

One more important aspect of social selection that is absent in biological evolution is the struggle for the selection of a certain model (model of reforms, model of unification, ideological model) at the level of individual societies, as well as at the inter-societal level. Everywhere, we can observe the selection of leaders, models, courses, central positions and so on. The decisive advantage could be rather different in different cases. In some cases, this could be a very capable and talented leader; in others this could be an advantageous geographic position; in still other situations this could be just a lucky contingency.

Thus, although we are dealing with rather different mechanisms of selection in biological and social evolution, their roles are very important in both cases. Still, within biological evolution, selection process is more important, because there is no alternative, whereas such an alternative exists within social evolution.

Section 3. Some Preconditions of the Transition from Biological to Social Macro-evolution

1. Social Evolution as a Logical Result of the Development of Adaptiogenesis Mechanisms

In addition to what has been already said about the organic links between biological and social evolution, one should consider another aspect of adaptiogenesis. The process of adaptation that constitutes the principal contents of biological evolution may proceed at different levels: 1) the organism structure; 2) its behavior; 3) structure and behavior of a socium as a superorganic amalgamation.

At all those levels, one may observe the transition from primary, primitive and slow methods of adaptiogenesis based on random mutations, recombination and selection to more progressive, effective and rapid ways of evolutionary change. **Not only organisms, species and societies evolve; mechanisms of** evolution evolve too. The general direction of this evolutionary movement may be characterized as a trend to the reduction of the role of random processes and the growth of systematic controlled processes. The initial and primary evolutionary algorithm is the random search, the trial-and-error method. However, at all levels of adaptiogenesis, one may observe a gradual development of such mechanisms that decrease the role of randomness and, thus, optimize this algorithm; though it appears impossible to exclude entirely an element of randomness either from biological or from social evolution.

1) The organism structure level. Even at the basic level of biochemistry, physiology and morphology, many forms of life have developed ways of adaptiogenesis that are faster and more effective than the random search conducted according to the scheme of 'random mutations + selection'. One of these mechanisms is regulation of the mutagenesis rate, depending on available conditions: under favorable conditions, the mutagenesis rate is low; in unfavorable conditions it increases (Grinin, Markov, and Korotayev 2008: ch. 6, §6.8).

It is also appropriate to mention epigenetic changes of hereditary material that are transmitted to a number of generations, in particular parental genomic imprinting that became especially developed in the most complex organisms, such as mammals and flowering plants (Jablonka and Lamb 1999). Imprinting is actually a sort of purposeful manipulation of hereditary properties of offspring. With the maturation of male and female gametes, certain parts of the genome are marked in a special way, for example through methylation. The methylation of DNA is not a chaotic process but is regulated by complex molecular systems. What is especially important is that methylation of particular nucleotides increases the probability of their mutating. Thus, through the methylation (or non-methylation) of particular nucleotides, the cell can in principle regulate the probability of their mutation (Vanyushin 2004).

Another example of the purposeful change of hereditary information is provided by the development of adaptive (acquired) immunity through combining genetic blocks, subsequent somatic hypermutation, and clonal selection. Both the combining of DNA fragments (V-(D)-J recombination) and hyper-mutation are processes that are only partly random. In other words, the limits of randomness in this case are rather accurately demarcated (Grinin, Markov, and Korotayev 2008: ch. 4, §4.2.4). The combination of DNA fragments is conducted from a precisely defined set and the hyper-mutation takes place at a rather accurately demarcated part of a gene, while the selection of lymphocyte clones makes the whole process unequivocally directional. As a result, the final outcome of such a 'sequence of random events' turns out to be quite deterministic.

Such a mechanism may be designated as '**optimized** random search'.[23] Note that in the case of the acquired immunity, from a 'technical' point of view, the achieved result may well be transmitted to the offspring, for example, via the mechanism of reverse transcription and transmission of the genetic material from lymphocytes to gametes through endogenous retroviruses (Steele *et al.* 2002). However, this does not happen, because it is more advantageous to transmit not a concrete immunity to a particular pathogen to the offspring but a universal capability to develop immunity against any pathogen.

In general, such mechanisms of purposeful genome alteration do not have a universal presence in biological organisms, and the overwhelming majority of mutations take place in a quite random way.

Biologists rarely consider that assortative (selective) mating, mediated sometimes through extremely complex mechanisms of mate-choice, is nothing but an extremely effective mechanism for management of recombinational variation. However, in the real biological world, absolutely unselective, random mating is hardly ever observed. Indeed, random mating is a scientific abstraction, like an 'ideal gas', or an 'absolutely dark body'. With growth in the level of organization of biological organisms, the complexity and effectiveness of mate-choice also grew, whereas the recombinational variation became less random as a result.

2) Level of individual behavior. One can trace the transition from predominantly hereditary and genetically determined behavioral patterns to more flexible learning-based ones. As we saw above, in the case of immunity, it was more advantageous to transmit to the offspring a universal capability to 'learn'

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[23] In this way, a more flexible reaction to unknown situations develops; this may be compared with multifunctional institutions in human societies that while remaining apparently the same institutions may allow social systems to behave differently in different situations, whereas respective institutions would experience certain changes with the change of situations. Thus, army may be relatively small during the time of peace, and then it would grow sharply in size as a result of mobilization, whereas its functions also substantially change. The same can be said about the flexibility of the family, the village community and many other social groups and institutions.

instead of a rigidly determined means of resistance to a particular pathogen. In an analogous way, in the general course of evolution, it has turned out to be more advantageous to transmit the ability to learn rather than to transmit rigidly fixed behavioral stereotypes.[24] No doubt, the emergence of the capability to learn is a major aromorphosis, though it is very stretched over time. Even unicellular organisms have some inchoate abilities to learn (sensitization, habituation), let alone such highly organized animals as ants or bees.

3) Biological socium level (social adaptiogenesis). A wide variety of living organisms – from bacteria to mammals – lead a social way of life. The socium as a whole has certain system characteristics that can be more or less adaptive (Popov 2006). Here, we also observe the transition from rigidly genetically determined forms of social relationships to more flexible versions, within which a social system may adequately (adaptively) react to changes in its environment. For example, the size of subsidiary colonies of an anthill may change in a reasonable, that is, adaptive way, depending on resource availability (Zakharov 1978: 49). However, in general, for all the pre-human forms of life, such possibilities are limited. The human development of the ability to evolve socially, which implies the possibility of an almost limitless change in the structure of social systems, appears to be a natural (though qualitatively higher) continuation of this evolutionary trend.

2. One of the 'Preadaptations' that Facilitated the Transition from Biological to Social Evolution

The issue of how biological evolution transformed into social evolution is among the most important questions of Big History and Evolutionary Studies. What 'preadaptations' were needed for the transition from biological to social evolution? This is a very complex subject. And here we shall restrict ourselves to consideration of just one of those preconditions.

Social macro-evolution became possible due to the emergence of an uniquely human ability denoted as 'ultra-sociality' (Boyd and Richerson 1996). This is only found among humans and designates the ability to change their social organization radically and almost limitlessly in response to internal and external challenges. Only humans are capable of forming collectivities that could be entirely different as regards their structure, their traditions, their norms of behavior, their modes of subsistence, their systems of intragroup relationships, their family types, *etc.*

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[24] It appears necessary to note that in both cases the ability to learn does not replace entirely the genetically determined concrete adaptations; the former is added to the latter. In the immunity system of higher organisms, the system of innate immunity is preserved in addition to a new system of adaptive (acquired throughout the life) immunity; similarly, in the behavior of higher animals, behavioral patterns developed throughout the life through the learning are combined with innate genetically determined behavioral traits.

Whatever the complexity of the collectivities of non-human primates, they do not have such flexibility. Each species usually has only one type of social organization; some cultural differences are observed, but they are incomparable with the ones observed in *Homo sapiens sapiens*. Yet, some animals possess a limited ability to adaptively change the structure of their socium. For example, in disadvantageous circumstances, one may observe growth in the rigidity of social hierarchy (the 'power vertical'), whereas the relationships become more egalitarian under more favorable conditions. Sometimes the transition to a social way of life occurs during unfavorable conditions, whereas the same animals may return to solitary life with improvement of conditions (Popov 2006). Those adaptive modifications of social structure in animal communities are still significantly inferior in their scale to what is observed in human societies; in addition, among other animals, they are characterized by a much higher degree of predictability.

The emergence of ultra-sociality was a natural result of the preceding *co-development of intellect and social relations* among our ancestors. The progressive development of the brain and intellectual capacities in primates is inseparably linked with a social way of life – with the necessity to predict actions of other members of their group, to manipulate them, to learn from them, to achieve an optimum combination of altruism and egoism in their behavior. At present, this is the point of view of the majority of primatologists (*e.g.*, Byrne and Whiten 1988; Byrne and Bates 2007).

The idea that the primates intellect developed first of all for, say, effective search for fruit (the 'ecological intellect hypothesis') does not now have many supporters. It cannot explain why primates need such a large brain, if many other animals, such as squirrels, perfectly manage similar tasks, though their brain remains small. In contrast, the 'social intellect hypothesis' is supported by facts. Scientists have detected a significant positive correlation between brain size in primates and the size of their social groups (Dunbar 2003). It is necessary to note that primates (in contrast to the majority of other social animals) know all the members of their group 'by sight' and have particular relationships with each of them. There are grounds to maintain that individualized pair relationships are the most intellectually 'resource-intensive' (Dunbar and Shultz 2007).

A positive feedback appears to have existed between the development of a social intellect and the growth of complexity in social relationships of hominids.[25] Those individuals that managed to achieve a higher status within a social hierarchy, due to a higher intellect or a better ability to foresee actions of others, left more numerous offspring, which in turn led to the general intellectual growth of the socium. As a result, in subsequent generations, in order to move

[25] This social intellect is also called the 'Machiavellian intellect', *e.g.*, Byrne and Whiten 1988.

up the social ladder, it was necessary for individuals to possess an even more developed social intellect, and so on.

Interesting experimental facts have been recently obtained. They indicate that intellectual abilities of a 'social' character, which allow for resolution of social tasks, developed in our ancestors earlier in comparison with the intellectual capabilities of the other types (*e.g.,* the ones that allow to solve 'physical' and instrumental tasks) (Herrmann *et al.* 2007).

In order to function effectively in a complex, constantly changing sociocultural environment, our pre-human ancestors had to develop intellectual abilities of a rather concrete type: abilities of effective communication, learning and – most importantly – of understanding not only actions, but also thoughts and desires of members of their groups (Vygotsky 1978). It is quite evident that abilities of this kind should become apparent in early childhood, in the period of active learning and social adaptation. There are two alternative hypotheses about possible mechanisms in the evolutionary development of these social abilities.

The first hypothesis suggests that they emerged as a result of the uniform development of the intellect as a whole (*general intelligence hypothesis*). The second suggests that this was the directed development of specific socially-oriented abilities, whereas all the other abilities (such as abilities to think logically, to detect cause-and-effect links in the physical world, and so on) developed later, as something additional and secondary. This is called the *cultural intelligence hypothesis* (Barkow *et al.* 1992; Shettleworth 1998; Herrmann *et al.* 2007).

At first glance, the *general intelligence hypothesis* looks more plausible, but, it is also possible to provide evidence in support of the *cultural intelligence hypothesis*. For example, it is known that specific intellectual abilities develop locally in many animals, but their overall intellectual level does not grow (or grows insignificantly). One can mention, for example, the birds' unique orientation abilities (Shettleworth 1998). Special experiments have been conducted in order to test these hypotheses.

The experiments were based on the following reasoning: If the *cultural intelligence hypothesis* is true, then there should be an age in the individual development of humans when we are not different in our 'physical' intellect from the apes, even though we are already far above them in our 'cultural-social' intellect. Experiments have confirmed the *cultural intellect hypothesis*: it turns out that 2.5 year old children have the same level of development as adult chimpanzees and orangutans in respect to solving physical tasks (spatial, quantitative, detection of cause-and-effect relationships, and so on), but they are significantly superior as regards the effectiveness with which they solve tasks of a social nature, such as those connected with the prediction of others' actions, communication, learning, and so on (Herrmann *et al.* 2007).

In general, present-day anthropological data suggests the following:

1) The development of social relationships and intellectual abilities in the higher primates (in general) and the hominids (in particular) proceeded within a single evolutionary process that was accelerated by the above-mentioned positive feedback;

2) This process tended to lead to the growth of complexity and flexibility of social relationships. Thus, the development of ultra-sociality and the ability to evolve socially within one of the groups of primates was a natural and logical result of the development of a trend that started among the primates long before the emergence of *Homo sapiens sapiens*.

Afterword. The Formation of Social Evolution's Own Mechanisms

The transition from the biological to social phase of Big History was a very complex process that we do not quite understand even now. *Within this transition it appears possible to speak about a phase change of a few subtypes of macro-evolution: the biological type of macro-evolution was first transformed into the biological-social type, then the biological-social type was transformed into the social-biological type; and, finally, the latter was transformed into the social type of macro-evolution already in the framework of the unequivocally human society* (see Grinin and Korotayev 2009b: ch. 1 for more details).

In the course of anthropogenesis, biological macro-evolution was transformed into bio-social evolution. The discoveries of recent decades have moved the dating of the emergence of our species deep in the past to about 200,000 BP.[26] However, the borderline around 50,000 – 40,000 BP still retains an immense importance. This is the point from which we can speak with a complete confidence about humans of a contemporary cultural type, in particular about the presence of full-fledged languages, as well as 'really human' culture (*e.g.*, Bar-Yosef and Vandermeersch 1993: 94). There is, of course, some hypothesis that human language appeared long before 50,000 – 40,000 BP. Although this is contested by other scientists, everybody agrees that by 40,000 BP language existed wherever humans lived (*e.g.*, Holden 1998: 1455).

Richard Klein, an anthropologist from Stanford University proposes the following hypothesis to explain the gap between the emergence of anatomically modern *Homo sapiens sapiens* and the emergence of language and cultural artifacts that took place much later. According to Klein, the modern brain is a result of rapid genetic changes. He hypothesizes that such changes took place around 50,000 BP, pointing out that the affluence of cultural artifacts starts just after

[26] See, *e.g.*, Stringer 1990; Bar-Yosef and Vandermeersch 1993; Pääbo 1995; Gibbons 1997; Holden 1998; Culotta 1999; Kaufman 1999; White *et al.* 2003; Lambert 1991; Zhdanko 1999; Klima 2003: 206.

that date, as well as the migration of anatomically modern humans out of Africa (see Zimmer 2003: 41ff.). Thus, the emergence of *Homo sapiens sapiens* did not automatically result in social macro-evolution proper.

We believe that the evolutionary driving forces were still mostly biological when modern humans first emerged, but that the social forces gradually increased their importance and prevailed over the biological ones at a certain point. Naturally, this was a rather prolonged process, within which the breakthrough point could hardly be identified. We contend that the social component became dominant after 50,000 – 40,000 BP. However, it did not become absolutely dominant, as biological adaptation and physical anthropological transformation continued in many important ways. The point is that they did not disappear, but their role significantly decreased.[27]

This transition to modern human society is sometimes denoted as the *Upper Paleolithic Revolution*. If we use the title of the book by Mellars and Stringer (1989), we may call this radical transformation: *The Human Revolution*. Thus, starting with the Upper Paleolithic Revolution, we may speak about *the transition from socio-biological evolution to social evolution*, a process that was finalized by the Agrarian Revolution.

There were not many major aromorphoses in the hunter-gatherer epoch (Grinin 2006b, 2009a), which is why the overall rates of socio-evolutionary processes were slow and their directionality rather vague. *Such a type of social macro-evolution may be denoted as socio-natural*. As a result of a system of inter-related aromorphoses connected with the agrarian revolution, one could observe the transition to the socio-historical type of macro-evolution. As a result of this, social macro-evolution changed its algorithm in a rather significant way, resulting in modification of certain evolutionary laws. We shall consider below how the significance of laws of evolution and the process of social macro-evolution changed as a result of the Agrarian Revolution.

Main factors of social change in foraging societies were the result of adaptation to new and various environments – from the deserts of Australia to the pack ice of the Arctic. This was only possible through the modification of socio-cultural systems. This made it possible for humans to people most of the world's landmass, to create an enormous variety of tools and crafts, as well as social and other institutions. Effective adaptations let people not only survive, but also live 'comfortable' lives that Sahlins (1972) called the *original affluent society*. The character of human relations with their environment varied significantly,

[27] There are sufficient grounds to maintain that the biological evolution of the humans did not stop 200–150,000 BP; it did not stop either after the Upper Paleolithic Revolution (see, *e.g.*, Alexeev 1984: 345–346; 1986: 137–145; Yaryghin *et al.* 1999, vol. 2: 165; Borinskaya 2005; Borinskaya and Korotayev 2007). Thus, the above-mentioned factor must have played some role in the biosociocultural evolution of *Homo sapiens sapiens*.

but generally these were ones of human adaptation to the natural world (see, *e.g.*, Leonova and Nesmeyanov 1993; see also Grinin 2006b: 82–83).

In the agrarian epoch, the character of those inter-relations changed significantly through the transition to much more conscious and effective change of the environments at a rather wide scale (irrigation, clearing of forests, plowing of steppes, soil fertilization, construction of cities, roads and so on). Natural forces (animal, wind and water energy) started to be used on a much wider scale (earlier humans actively used only fire). Natural raw materials started to be transformed into entirely new products (metals, fabrics, ceramics, glass).

Thus, within social evolution process a more and more significant role started to be played by peculiarly social factors that (in contrast with natural factors) are connected to conscious goal-setting and goal-achieving. Gradually, with economic-technological progress, the growth of surplus accumulation capacities, as well as general cultural complexity of social systems, their evolution became almost purely social. As a result, the 'vector' of evolutionary selection turned out to be directed toward societal capabilities to adapt to social (rather than natural) environments, which implies the capacity to compete with neighboring social systems in economic, military, commercial, cultural, ideological and other spheres.

Finally, we would like to mention the following important changes in the 'algorithm' of social evolution:

- *The start of the mechanism for resource accumulation.*

In the tens of thousands of years of the human foraging epoch, long-term material resource accumulation was relatively insignificant when compared to subsequent epochs. There was, of course, a certain amount of accumulation, of knowledge, traditions and technologies, albeit at a limited scale. This accumulation took place not in every society, but was observed on the global stage and was due to the overall demographic growth, increase in numbers of social systems, emergence of new tools, products, *etc.* There was practically no special accumulation sector prior to the Agrarian Revolution[28] (see in particular Artzrouni and Komlos 1985; Grinin 2007b).

In many cases, people could produce more than they actually needed, and sometimes even so-called 'original affluent societies' could emerge (Sahlins 1972). For example, with respect to the gatherers of sago in New Guinea, people would spend a minor part of their time securing food for themselves, whereas they would spend the rest of the time at other activities and leisure (Shnirel'man 1983, 1989). The impossibility to accumulate and/or the absence of the desire to accumulate slowed down development, which contrib-

[28] With a possible exception of some highly specialized hunters (usually of large aquatic animals), gatherers, and fishers – for example, some social systems described ethnographically for the North-Western Coast of America (see, *e.g.*, Averkieva 1978; Shnirelman 1986).

uted to the slow speed of social evolution (Grinin 2006b, 2009a). *In simple social systems of agriculturalists and pastoralists, the emergence of the possibility (and, later, the desire) to accumulate led to numerous transformations in the spheres of functional differentiation, distribution, social stratification, exchange, trade, development of property relationships, increasing political complexity and so on.*

- *Strengthening of the ability of social systems to change.*

Agrarian societies turned out to be more capable of serious social transformations than hunter-gatherers, while complex agrarian societies turned out to be much more capable of such transformations than simple agriculturalist and pastoralist systems. The growth of social systems' ability to change provides a vivid demonstration of the main difference between social and biological evolution – that humans were capable of consciously transforming their social systems, with preconceived goals.

- *Intersocietal contacts become the leading factor of social evolution.*

The importance of various contacts increased sharply, and this contributed to a more active adaptation of social systems to their environments. The growth of the role of contacts dramatically raised the importance of external social driving forces (Grinin 1997–2001 [1997/2: 23]; 2007a: 177). Note that this had an enormous importance for the development of the World System and for humankind as a whole. Military and other interactions stimulated improvements in administration, defense, culture, technology and so on. All this contributed to development of a single global process involving numerous societies and peoples.

It is also appropriate to note that the growth of societal size is not only due to natural demographic growth, but is more importantly due to the integration and unification of social systems. Thus, external contact factors become most important with respect to societal evolution.

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11
The Evolution of Information Systems: From the Big Bang to the Era of Globalisation

David Hookes

Abstract

The aim of this paper is to show the importance of the evolution of information systems to the emergence of life and the trajectory of human history. It locates this development in the widest possible context, that is, the history of the Universe as a whole. One can view the development of the Universe from the Big Bang to the present social existence of our species as a series of revolutionary/evolutionary stages, with each stage associated with the development of a new information system. The present form of globalization is made possible, in part, by the development of modern Information and Communications Technology (ICT). In this context, the change in character of the working class will be examined. It will be argued that information workers are the dominant category in advanced economies, and that one of their sub-groups, the knowledge workers, can play an especially important role in the resolving the crises of both the socio-economic system and the environment.

The Big Bang and the Quantum Physics Information System

After the Big Bang, as the Universe cooled, stable matter particles (such as electrons, protons and neutrons) were formed from the high energy fields, as determined by the special relativity law of equivalence for matter and energy. The baryonic matter particles (protons and neutrons) condensed out of a precursor plasma about 10 micro-seconds after the Big Bang. This plasma consisted of quarks, leptons and force carrier particles like photons (Electromagnetic force), W and Z bosons (Weak force), and gluons (Strong force). This is sometimes referred to simply as the 'quark soup'. Neutrons and protons, for instance, are each composed of a combination of three different quarks that are held together by gluons (Turner 2009).

During the interval 0.01 to 300 seconds after the Big Bang, further cooling allowed the formation of the light nuclei of Helium, Heavy Hydrogen (Deuterium), and Lithium. About 380,000 years later, the Universe was sufficiently cool to allow the formation of electrically neutral atoms from electrons and the nuclei. This released the electromagnetic radiation previously trapped in the plasma, which then increased its wavelength with the expansion of the universe to become the cosmic microwave background radiation that was first detected in 1965 by Arno Penzias and Robert Wilson (Penzias and Wilson 1965: 419–421). This background radiation has been extensively studied with increasing accuracy ever since. After 13.7 billion years, it now has a temperature of about 2.7 Kelvin and wavelengths of several millimetres. It provides important evidence for the Big Bang model of cosmology (Turner 2009).

About 300 million years after the Big Bang, the first stars and galaxies formed, as a result of the action of gravitational forces. Because of the mass of the stars, these forces were sufficiently strong to initiate nuclear fusion of hydrogen and its isotopes, which resulted in the emission of electromagnetic radiation in the visible spectrum – in other words, the first stars lit-up. It is this radiation that carried and still carries important information about the structure of the stars, galaxies and the Universe itself, and thus made possible the science of Astronomy. This radiation also created the energy source for the evolution and continuation of life on Earth, as well as stimulating the evolution of visual sensors in higher animals. These sensors contributed to the evolution of the ultimate information processor, the human brain.

The laws of quantum physics decide on how particles of matter interact with various types of fields, most importantly, the electromagnetic field. In fact, quantum physics can be thought of as the first and fundamental information system in that it allows matter particles to be aware of or ‘know’ about each other's presence even when there is no physical interaction between them. The ‘wave-function’ of quantum physics carries statistical information about the possible states of the particle, that is, the probability for its being in each of its different possible states of energy, motion and location. *It also makes possible the many subtle processes that allow particles of matter to act collectively to form higher levels of organisation in atoms and molecules, including, eventually, the possibility of life itself.*

For example, the laws of quantum physics allow different elements to be synthesised in dying stars through nuclear fusion processes. These elements then combine together into molecules and crystalline material also due to the laws of quantum physics. This resulting type of matter, under the influence of gravity, eventually aggregated to form planets, such as our own.

It should be noted that work by physicists Stephen Hawking and Jacob Bekenstein, using an ad-hoc combination of quantum physics and General Relativity, has shown that the information content of a black hole (matter so concentrated that light cannot escape from it) is encoded on its surface (Hawking 1988). This result has recently been applied to the Universe as a whole by Gerard t'Hooft, Leonard Susskind and other physicists, using the holographic principle. From this point of view, all physical processes in the bulk of the Universe are seen as a holographic projection of information stored in quantum fields on a distant boundary. Each unit of information (bit) is contained in an area of $10^{-70}m^2$, that is, the Planck length (10^{-35}m) squared.[1] This means that $1m^2$ of this boundary surface contains 10^{70} bits of information! Thus, these recent theories, in effect, describe the universe itself as a giant quantum information processor (Greene 2011: ch. 9).

The Molecular-Genetic Information System of Life

It is still by no means clear in detail how life emerged, but obviously an important step was the evolution of molecules that could trap and store energy through quantum processes. Initially, perhaps this energy was derived from thermal sources, but later from sunlight, and was then utilised to promote the chemical synthesis of more complex molecules such as proteins and the poly-ribonucleic acids, such as RNA and especially DNA. Both these types of molecules are linear polymers made of a number of different structural units (or monomers). For proteins, these are the twenty possible different amino acids that form the monomers in chains containing several hundred or more monomer units. For DNA, there are four organic bases – A, T, G, C – adenine, thymine, guanine, and cytosine. These are the possible monomer 'letters' linked together on a sugar-phosphate backbone in groups of three, called triplets. There are thus 64 ($= 4^3$) possible triplets. Each of the 20 amino acids is coded by one or several of these triplets. Whereas the proteins have both a structural and a functional role (such as enzymes), the DNA molecules form a molecular-genetic system that codes the information to make the proteins. This led to the possibility of organisms reproducing themselves by reproducing copies of their DNA information molecules, which act as a 'blueprint' to create a new generation.

The emergence of this molecular information system was obviously a crucial step that enabled evolution itself to take place. It allowed living forms to adapt to changing environments. It is even possible to show, using information theory, that the protein-DNA system itself would have been that selected as optimal by evolutionary processes (Davies G., Lt-Commander, Royal Navy, retired, private communication, 1996).[2] Organisms can differ slightly in their structure and properties due to random changes (mutations) in the information 'letters' of their DNA. Those variations that allow the organism to survive in changing environments would pass on these survival properties to the next gen-

[1] The Planck length is the smallest length that can be consistent with physical laws. It can be thought of as the size of an 'atom' of space so that space is no longer continuous at this scale.

[2] This is referred to by Gareth Davies as a G (20, 4, 3) structure coding system – 20 structural units, coded by 4 letters, with code word length of 3 letters.

eration. Mono-cellular organisms combined to form multi-cellular organisms to survive in certain environments and so on up the evolutionary ladder. The development of information-gathering organs such as touch, smell and sight, together with an associated information processing organ – like a brain – were also crucial for survival and the eventual emergence of different levels of consciousness, including that of our own species.

So, in short, the emergence of living systems depended on the complex interplay of matter, energy and information. But the development of a molecular genetic information system was the crucial and revolutionary step that made possible the long evolutionary process that led to human kind.

Information Systems and Homo Sapiens

Speech

Similarly, a crucial step in the emergence of the genus *Homo* from our near primate relatives was the evolution of the capacity for language. This was, first, perhaps, a system of non-verbal signs that later developed into a full verbal system. This information system meant that it was possible to form cohesive social groups that had vastly improved survival chances. It also meant collective defence against predators and more effective communal hunting and gathering.

The development of the brain as an external and internal information and communication organ, through the stimulus of language, also meant the capacity for more abstract thought. This was most probably also closely linked to the development of a tool culture. In this way, the functionality of a tool could be abstracted from its material embodiment. Knowledge about suitable materials and the effectiveness of tool design could be shared more effectively and more rapidly through the use of language. And, of course, the use of tools also improved chances of survival.

Writing

The movement from hunter-gatherer societies to settled, agrarian societies in some regions occurred between 12,000 and 7,000 years BP, and distinct towns and cities were created, circa 7000–6000 BP. Some time later the early urban settlements turned out to be connected to the next stage in the evolution of information systems, namely, the invention of writing. Living in much larger settled groups required a more complex system of group rules of behaviour that could be unambiguously understood by every member of the group. Within such a context the writing must have been helpful since the existence of a multiplicity of purely verbal interpretations of the rules would have been somewhat disruptive. Writing also allowed for the accurate transmission of all sorts of useful knowledge between generations, thus improving group chances for survival.

The surpluses produced by more productive agrarian settlements could then support a literate priestly caste that was in charge of knowledge production and transmission, as well as the encoding of superstitious beliefs about, and explanations for, natural phenomena – namely religious beliefs. The latter gave the priesthood social and political power, as it does even today in some advanced capitalist countries, such as in the United States and in less advanced societies such as Iran.

The invention of writing must have also helped to promote the exchange of goods and services within settled groups and between such groups. This is because it was then possible to communicate information reliably about the amount and conditions of labour, raw materials and techniques of production, so as to establish an agreed equivalence between different amounts of various goods and services.

Money

Monetary systems arose to facilitate the exchange of goods and services between communities. It was also closely associated with the emergence of writing information system, even preceding it somewhat in some areas. The monetary system is essentially an information system that allows the representation of value of goods and services. This monetary form contains information about the amount and quality of labour needed to create goods or services, the cost to transport them to locations of exchange, and the scarcity of materials used in the creation of goods or services. The development of different forms of money information systems greatly facilitated the trade in goods and services between the early human settlements. It solved the 'coincidence of needs' problem associated with other forms of exchange, such as barter systems. Early writing systems were used to codify the laws governing the use of money, for example, the Code of Hammurabi in ancient Babylon circa 1760 BCE.

There are many forms of money, such as commodity money (crops, animals, precious metals, cowry shells, or beads); fiat money (created by and guaranteed by the power of a state body); and fiduciary money (a promise pay the bearer of the fiduciary money in commodities or fiat money). In effect, most currencies today are a form of fiat money, since they are no longer linked to the dollar, which itself was taken off the gold standard in 1971. Fiduciary money is by far the most common form of money used by banks in relationship to their customers. This form of money is now stored as digital information on credit cards and computer systems, thus clarifying its role as an information carrier system.

As Adam Smith pointed out, money itself can also be a commodity, one that is bought and sold in the market place (Smith 1776: Book 1, ch. 4). This is most characteristic of late capitalism, when finance capital dominates over production capital. For instance, on any given day in the City of London, 90 % of the transactions deal with financial instruments rather than with capital for production. Production investment forms only the remaining 10 % of transactions. This makes money an object of speculation, which can lead to destabilization of whole economies. It also leads to massive debt/credit bubbles as a result of the detachment of money from the value-creating system of labour producing useful goods and services. This is certainly the root cause of the present instabilities in the global financial system.

Printing

As I discussed in a previous paper, the invention of printing with moveable type was a critical development necessary for the emergence of the capitalist system in its first phase, which was called 'mercantilism' (Hookes 2003). Printing allowed for the mass production and dissemination of information about markets, the means of production, and improvements thereof, and most importantly, the spread of scientific knowledge and its method. Thus, the Age of Reason and Enlightenment in the 18th century, as well as the Industrial Revolution and the modern bourgeois state, were long-term consequences of this information revolution.

The emergent social classes, capitalist and worker, become distinct classes as a result of the ability of the members of each class to act together, cooperatively, in defence of their collective interests. This process required a communication system, that is, exchange of information. The existence of printing greatly enhanced this emergence of class behaviour and, eventually, of class consciousness.

Thus, we can view printing as the first Information and Communication Technology of the modern age initiated by the birth of capitalism. The industrial phase of capitalism was associated with the controlled release of energy, firstly from hydraulic systems and then, most importantly, from steam power, and later electromagnetic forms of energy derived from steam power. The control technology for energy release made it possible to vastly increase the productivity of labour within a factory system. In this system, each worker had his/her labour enhanced by availability of energy in a parallel network of supply from a centralized energy plant.

Electromagnetic Communication

The development of other powerful electromagnetic information technologies that proliferated in the 20th century, such as the telephone, radio, and television helped to strengthen the bourgeois state through increased political and social control, as demonstrated by Edward Herman and Noam Chomsky in *Manufacturing Consent* (Herman and Chomsky 1994). These developments also led to intensifying of commodity production, and the consequent temporary stabilisation of the capital system, through the creation of artificial needs by mass-media advertising that was in turn based on information technologies.

Digital ICT

Most importantly, this process includes not only the Internet but all other digital technologies used by information processing and for control of productive processes. In the present epoch, the modern computer-based ICT is also a control technology, which syntheses the two stages of capitalist technological development. To some extent, this was anticipated by the development of electromagnetic power and the early electromagnetic communications systems, but it achieves it full synthesis in the computer-control of information production, processing and communication, as well as control of the instruments of production themselves, such as machine tools and power plants.

It should also be noted that the solid state-based technology, on which modern ICT component devices are largely-based, depends on quantum processes. This illustrates the important role of quantum physics in many information systems. There is also much research being carried out to develop purely quantum information processors based on quantum bits (q-bits). These are based on the property of quantum superposition and entanglement, such that a q-bit can contain a mixture of '0' and '1' binary states. Although the arrival of quantum information processors is still some distance in the future, they are expected to make present processors appear pedestrian in comparison. Thus, quantum physics is again centre stage, as it was at the time of the Big Bang.

Information Systems, the ICT Revolution, Globalisation and the Labour Process

The character of work has changed considerably during the 20th century. The classical proletariat, namely, manual factory workers, have gone from a decisive majority of 60–70 % of the workforce a century ago to 10–20 % in advanced capitalist countries today. Those members of the workforce who provide services, especially information processing and delivery, now form the majority.[3] Members of a sub-group of this 'information proletariat' are sometimes called 'knowledge workers', those whose jobs require high levels of education obtained from advanced schooling.

Overall, these knowledge-workers now constitute about 40 % of the workforce in the United States, more than twice as numerous as the manual factory proletariat (Drucker 2001). Information workers form the core of the proletariat in an information-based society, but the membership is a mixed group: it in-

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[3] In advanced capitalist economies, roughly 70 % of the active working population are engaged in providing services, 27–28 % in industry, and 2–3 % in agriculture. In Russia, in 1996, the service sector predominates at about 48 %, industry at 36 % and agriculture at 16 %.

cludes many highly exploited workers, such as those in call-centres and data-input offices, alongside highly privileged workers, such as university teachers and researchers, whose level of alienation is, let us say, tolerable, as well as some privileged technical workers.

The modern manual factory workers are themselves also affected by this new information society, producing considerably more goods per worker than when they were the majority of the workforce. This is due to the increased use of automation, especially intensified by the recent and on-going ICT revolution, based on micro- and nano-engineering. This technology also involves the parallel work of the information proletariat in the production process: writing computer programs, in-putting data, operating computers, answering telephones, operating reprographic machines, *etc.*

The numerical dominance of the information proletariat over the manual factory workers should give Marxists, for instance, cause to rethink their political agenda and strategy, but, sadly, in most cases it has not. There is a persistent and unthinking attempt to continue to celebrate manual work over 'brain' work, even when most manual workers today mainly use their brains rather than their muscles. Why should this be so? – especially since Marxists claim to be scientific materialists?

Perhaps the answer is related to the character of the information proletariat itself. For instance, they are less likely to behave as willing followers of a Marxist vanguard party and its 'correct program' than even the manual factory proletariat ever was. In fact, such workers tend to reject hierarchies (political or otherwise) and often embrace the concept of a non-hierarchical network society, the nature of which has been exhaustively discussed by Manuel Castells and others (Castells 1996, 2004).

The Nature of Work or Labour

The dominance of the information proletariat means that it also necessary to re-evaluate the nature of labour as such. Traditionally, labour has been considered to be closely associated with the physics definition of work: *Work is said to be done when a force displaces itself in its own direction.*

So, it is easy to identify manual labour with this definition of work. During manual labour, forces are applied to a material body. These forces are displaced while changing the shape, position and/or composition of the body.

But such work also involves considerable activity of the brain: Processing sensory information about the location of objects and the effectors whether the latter are bare hands or most usually a tool operated by the hands; making judgments about when to change the position of material objects with the effectors; consulting past experience about the appropriate degree and pattern of force to apply; the correct orientation and position of the effector relative to the material object; deciding when sufficient force(s) has been applied by judgments about the effects on the material object. The chemical energy expended by the brain during even simple unskilled manual labour is comparable with that consumed by the muscles. In the case of skilled manual labour using machine tools, the amount of mechanical work done by a worker is a small fraction of the energy consumed by the brain. Only in the case of heavy, unskilled manual labour the energy is expended by the muscles significantly greater than that expended in the brain.

So, in any human labour process, energy is expended both to do mechanical labour (work in the physics sense) and also in a mental labour that we can loosely refer to as internal 'information processing and control'. The proportions of each type of energy consumption during a labour process will vary depending on the nature of the labour process itself. For many types of labour, very little mechanical work is necessary, such as in operating a machine tool or a powered mechanical excavator, computer operating and programming, or teaching.

A Definition of the Working Class

From the above discussion the working class can be defined as follows: *The working class is that group in society that lives, principally, by earning wages in exchange for the expenditure of their own energy. The latter process is called 'labour'.*

This energy is stored in the form of chemical energy derived from food and drink, which, in turn, is derived from solar energy captured through the quantum processes involved in photosynthesis. The molecule that actually stores the energy in its final form before use is identical for muscles and for the neurons that compose a brain, namely, adenosine triphosphate (ATP). Most of this aggregate chemical energy is expended in peoples' brains or keeping them at the correct temperature, rather than in their muscles.

This means one must reject 19th century mechanistic interpretations of 'labour', as the purely manual application of forces, that is, as physical work. Even in most forms of manual labour, the majority of energy expended is in mental labour processes. The excess value, or the surplus value, created by the labour of the working class is appropriated by capital, either as a reward to capital-owners for lending the capital, or else to strengthen and extend the capitalist system by maintenance or increased investment.

The Working Class, Globalisation and the Environmental Crisis

Most workers, especially the new information proletariat, tend to work in small groups, making large-scale collective action more difficult through increased isolation. In the extreme case, ICT allows an individual to carry out information creation and processing labour in the confines of the home. There is the example of the computer programmer who is woken up in the night in his remote Scottish Highland cottage in order to allow him to fix the computers controlling the harbour traffic in Hong Kong, without leaving his cottage.

The vastly improved standard of living of the working class in advanced societies is heavily dependent on the availability of *cheap* fossil fuel energy in the form of oil, gas and coal (Kunstler 2005). This era, especially for oil and gas, is coming to an end, with acute shortages expected in 2–3 decades... if not sooner (McKillop 2005). Although there is much discussion amongst environmentalists, it would appear that capitalist economies largely ignore this reality. It is similar to being in a container under conditions of free fall, under gravity, in which one would appear to be weightless, that is, until one hits the ground. It is unclear, and probably unlikely, that the capitalist system can make a smooth transition to a distributed, sustainable renewable energy system before this contact with reality occurs.

The emerging climate crisis and the end of cheap fossil fuel means that there will have to be a reduction of consumption by those sections of the working class in advanced economies and thus a convergence of living standards with those of the newly formed proletariat in the developing world. This may be difficult to sell politically, but it also presents an opportunity to establish, in practice, the universal character of labour as a concrete historical reality.

Since the Industrial Revolution, manual labour has been amplified by applying new sources of energy so as to enormously increase the productivity of labour. Recently, the ICT revolution has produced a similar amplification of information processing, and of thinking processes in general, and has lead to automation in almost all spheres of work. One should also note that ICT has also had a major impact on the productivity of manual labour by considerably reducing the cost of automation. For instance, computer-controlled machine tools are commonplace even in small workshops, and can produce a complex machined object in a few minutes, which would take hours with a manual machine tool. Thus, there is a gain in productivity by a factor of the order of a hundred.

These developments underlie the phenomenon of 'globalisation'. One important contribution of this process is that money, which contain information about value, can be transmitted electronically and therefore almost instantaneously, to any part of the globe. The production and exchange processes themselves can also be globally integrated through these information systems. It is now possible to design a product in one country, transmit the design via the internet to machines operated by low-wage workers in a second country, and then market the product in a third country. It is even cheaper (more 'efficient' to use a current euphemism) to process data in developing countries, data that has been generated in advanced capitalist countries.

One important series of events that has contributed to the intensification of globalisation is the collapse of the pseudo-socialist regimes in Russia, Eastern Europe and China, along with their transition into a market economy. In the case of China, it has occurred without a political regime change. This has made vast reserves of skilled and unskilled labour accessible to capital, as well as new sources of raw materials. Russia, for instance, has the largest reserves of natural gas and now seeks to dominate this global market. One can even say that the long term consequence of the Bolshevik revolution was to create a very large army of new proletarians disciplined, either by circumstance (Russia) or state power (China), to submit themselves to exploitation by private and state capital.

Conclusion: Modern Information Systems and the Survival of our Species

We are now entering a critical era for the survival of our species. The next few decades will decide whether we have a future on this tiny speck of matter, rotating around an average star – the Sun – towards the edge of the moderately sized galaxy of the Milky Way, containing about 200 billion stars. Our galaxy is one of perhaps 150 billion or so galaxies in the known Universe. At first glance, matters do not seem very promising.

The capitalist system now has no competitors to its hyper-expansionist ‘growth for growth's sake’ economic philosophy, with little or no consideration of the finite limit of resources and the finite capacity of the Earth to absorb the detritus of this process. Most critically, the age of cheap fossil fuel is coming to a close and the consequences of its profligate (mis)use are upon us, in the form of climate instability that threatens to ‘cook’ the planet and eliminate many species, including, possibly, our own. Urgent action is required – most climate scientists believe that the move from fossil fuel to carbon-neutral renewable energy technologies must begin within the next ten years.

The seeds of change are paradoxically contained in the ICT revolution. While capital has developed a qualitatively more powerful information system, one aspect of which is loosely referred to as the ‘internet’, capital has not yet been able to bring it under control, and possibly never will, due to its distributed, networked character. ICT represents a synthesis of the main technology elements of capitalist development and it has arrived at a time when a large-scale restructuring of the production system of capital – globalisation – is taking place. Indeed, it has made this restructuring possible. But it also makes possible the transcending of production relations of capital through an alternative form of globalization (alter-globalization), which is based on cooperation, mutuality and sustainability. This alter-globalization is required to solve the multiaspect social and environmental crises confronting the world socio-economic system, due to the anarchic character of the market system of capital.

There is the need to switch to renewable energy technologies: largely solar. These will generally have the character of distributed, small-scale energy production units, whose output can be networked to overcome problems of supply intermittency. ICT can enable this networking of energy production to take place. It can also be used to replace blind market forces by the conscious production of necessary use-values, but without the need for a dominant role of centralized state planning bureaucracy with its attendant self-interested inertia, corruption and privileges.

Most significantly, the majority of proletarians in advanced economies is now information workers who expend most energy using their own information organ, the brain, rather than their muscles. The dominant sub-group of this information proletariat, the knowledge workers, deal in a universal quantity – knowledge – especially scientific knowledge. Because of their unique position, they form the group most aware of the impending climate and environmental crises. In addition, they also possess the skills and knowledge to create the technologies for alter-globalisation. In order to implement such a program, they must form alliances with all other sections of the working class (Hookes 2003, 2009).

Although the new information technologies were created to increase exploitation and social control they also can lead to the exact opposite. They can be the basis of a new system of production on the planet based on the principle of cooperation to meet human needs. Digital ITC can now make possible true social control of production and, at the same time, lead to the global enlightenment of the vast majority of humanity as part of this process.[4]

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12
Post-singular Evolution and Post-singular Civilizations

Alexander D. Panov

Abstract

It is shown that the ability of the world civilization to overcome a singularity border (a system crisis) determines some important civilization's feature in an intensive post-singular phase of development. A number of features of the post-singular civilization can stimulate its 'strong communicativeness', which is a prerequisite for the formation of 'the galactic cultural field'. Post-singular civilizations – carriers of the cultural field – are considered as potential partners in interstellar communication and as our own potential future.

1. Introduction. Scale-Invariance and the Singularity of Evolution

Initially, this work was motivated by a question related to the SETI program (Search for Extra-Terrestrial Intelligence): If intelligent life is a normal phenomenon in the Galaxy and if the rate of technological evolution is as high as on Earth, then the Galaxy must be full of highly-developed technological civilizations and we should see them in all directions.[1] So why do not actually we see them? This question is well known and is frequently referred to as the 'Fermi paradox'.

I prefer, however, the following form of the question, which is of much more significance: Assuming intelligent life to be a normal phenomenon in the Galaxy, what would such a highly-developed, technological civilizations look like and why would it be 'invisible' to us? This question has great practical importance. If we would like to find extraterrestrial civilizations, we need to understand what we are trying to find. Our methods should depend on the object of our search. If you go hunting for a duck, you should know that the duck likes water!

In order to find such an answer, one needs to first develop an understanding of what civilization might look like in the future. This is a challenge, of course,

[1] The Kepler mission (Borucki *et al.* 2011) has already discovered 68 planetary candidates of approximately Earth-size during its first three months of operation; 54 of these are found in the temperature range appropriate for a habitable zone. Undoubtedly, this is only the first small portion of what will be much larger results, because long-period planets (about one year and more) have not yet been considered, *etc.*

but not impossible. The idea is to look at technological development in the light of the general laws of evolution.

I outlined one such model of evolution on Earth, from the origin of life up to the present, as a sequence of phases with phase transitions between them. It was a model of *global biospheric revolutions.* Each biospheric revolution is the result of some *evolution crisis*, and the revolution (the phase transition) overcomes the crisis. The list of these phase transitions includes 19 events, including the Cambrian explosion, mammalian revolution and the Neolithic revolution; The last analyzed event was the information revolution (computers, post-industrialisms – 1950) (Panov 2005).

Each of the phases becomes shorter in duration with the passage of time. Moreover, the sequence of the phase transitions is scale-invariant, which means that the corresponding sequence of time-points is a simple geometrical progression and that various parts of this sequence may be derived from other parts by scale transformation. We call this *the scaling law of evolution*. But such a sequence of points may not be prolonged to infinity in the time. Yet, the duration of phases tends to zero and the frequency of the phase transitions tends to infinity near a point of time t^*. Indeed, the sequence does not exist after the point t^*. This point is called the *singularity of evolution*. By its physical meaning the singularity of evolution is a concentration of evolutionary crises – it is something like 'a crisis of crises'. Of course, the singularity of evolution is only a mathematical artifact, because any real quantity may not become infinite. But the prediction of the Singularity inevitably means that the scaling law of evolution that has held for about 4 billion years must be changed to some other law near the point t^*.

The position of the Singularity point t^* may be estimated by extrapolation of the sequence of the biospheric revolutions. The result is: $t^* = 2004 \pm 15$ (*Ibid.*). Therefore we are now in the time of the Singularity!

My analysis of the sequence of biospheric revolutions is not the only method that leads to a derivation of the Singularity. It has been long known that the hyperbolic growth law of human population also possesses the property of scale-invariance and that extrapolation of it predicted the Singularity for 2026 (Foerster *et al.* 1960). Additional details of this scenario were elaborated by Kapitza (1996). There is also the notion of a 'technological singularity' that was proposed by Vernor Vinge (1993); it is based on arguments like scale-invariance and was predicted to occur in the first half of the 21^{st} century. Thus, a variety of arguments, each of which points to almost the same date for t^*, force us to seriously consider the singularity of evolution. But, we must keep in mind that the Singularity is not a single point in time – it is a period of time, approximately the first half of 21^{st} century, a time when the laws of evolution and historical trajectories will change dramatically.

Now, suppose that scale-invariance and the existence of the Singularity is a universal property of evolution on all planets where life can produce intelligent civilization. Based on our experience here on Earth, the technological period of our civilization has only been a few decades long and our efforts at cosmic transmission have been low. So the probability of us detecting a similar *pre-singular* civilization in the SETI process would be almost negligible. Therefore, a potential contact partner could only be a *post-singular* civilization. Thus, the problem that we should address is: What would such a post-singular civilization look like? The other side of the question is: What is our own post-singular future? We will argue that these two sides of the question are very closely connected with each other.

2. The 'Exo-humanism' of a Post-singular Civilization

Let us consider the use of the concepts of 'humanism' and 'ethics'. A human being is a creature devoid of natural powerful tools of aggression – claws, fangs, *etc.* When a hominid took a stone tool and became the owner of the first technology, nothing prevented them from crippling or even killing a near relative with it. Perhaps, in many cases this was indeed done, but it might also be a reason why populations of especially aggressive hominids did not leave descendants. Less aggressive populations survived, and the prohibition on murder was fixed – first genetically (by survival), then culturally (by regulation).

As technology developed, the killing power of weapons increased. Correspondingly, cultural restrictions on aggression against both people and nature needed to improve. These restrictions were imprinted in ethics, morals and humanism. They were by no means given to human beings *a priori*, but were developed to limit the destructive action of human technology (Nazaretyan 2004, 2009; Eco 2002). There are also other such mechanisms in human culture, such as criminal legislation and its punitive system of fines, prison, *etc.* Hereafter the term 'humanism' will be considered in this kind of a wide sense: any form of cultural restriction on destructive technology.

It is clear that the survival of a civilization after its Singularity means that that civilization has managed to overcome its deepest technogenic crises. In order to overcome them successfully, a post-singular civilization must have elaborated the corresponding adaptation mechanisms and used them for its homeostasis. *If a civilization does not elaborate such mechanisms, it will not enter the post-singular stage of development* – it degrades and/or perishes. It is not difficult to imagine at least some of the necessary preservation mechanisms.

• First, sufficiently effective mechanisms to deter aggression must be elaborated. Otherwise, a civilization will destroy itself by internal conflicts related to the increasing use of irreplaceable natural resources and the simultaneous increase in the killing power of weapons.

- Second, powerful mechanisms restricting material consumption and effective use of resources must be implemented.
- Third, a civilization must overcome the centrifugal influence of corporate and state self-interest and elaborate planetary concepts, because crises near the Singularity occur on a global scale and can be overcome only by common efforts and continuous compromise.
- Fourth, the preservation of civilization must include an increase of ecological consciousness that matures to the point of becoming a social instinct.

A singularity crisis cannot be overcome without a huge jump in the power and in the depth of the mechanisms developed to constrain the destructive effects of technology. We call this jump, *the post-singularity humanization of civilization*. I emphasize once more that such 'humanization' should not be understood simplistically or too literally. It certainly can include ethical principles accepted by the majority of people, *i.e.* humanism in its classical sense. However, 'humanization' can also be implemented as a system of legal and punitive measures. Its focus must be on a holistic system of cultural constraints that curb destructive technogenic effects and which will keep civilization alive as a cosmic-technological entity.

The assumption that elaboration of such constraining mechanisms is possible is not arbitrary. Based on many facts, Akop Nazaretyan has shown (2004, 2009) that cultural constraints of aggression have been increasing throughout the history and pre-history of humankind as technological power was increasing. Moreover, they were increasing at a growing rate, so that in spite of the increase in the killing power of weapons, the level of bloodshed (per capita) decreased. Nazaretyan summarized this conclusion which is *paradoxical* for ordinary consciousness as the 'Law of Techno-Humanitarian Balance' (*Ibid.*).

Recent examples of the Law of Techno-Humanitarian Balance in action are the sweeping-out of the bloodiest political regimes of the 20th century (Stalin, Hitler, Mao Zedong, Pol Pot) and their replacement by gentler methods of administration. A sign of the awakening of planetary consciousness and the development of ways of overcoming corporate and state self-interest is the Kyoto Protocol. A lot of other examples of the formation of ecological consciousness can be adduced, from Earth Day to international NGOs. Certainly, the idea that a developed form of humanism should be typical for highly-developed cosmic civilizations is not new. It was expressed by K. E. Tsiolkovsky and I. A. Efremov early in the 20th century, and recently, *e.g.,* in the papers by Gindilis (2001, 2003) and the book by Nazaretyan (2004).

It is curious that this humanization of terrestrial civilization finds its most direct expression in attitudes to the Cosmos. For example, it is clear that if there were life on Mars, it would be of a most primitive kind. We would expect that humans would think only about their own safety and ignore such potential life. But actually, all vehicles sent to Mars have been carefully sterilized so as to not harm potential Mars life! Another example is the destruction of the space explorer *Galileo* in the atmosphere of Jupiter in 2003, so as not to allow terrestrial microorganisms to infect the Jupiter satellite Europa, where the existence of life is also possible.

The dispute about the permissibility of the experiment ‘Deep Impact’, whose aim was to bomb the comet Tempel-1 in order to study the chemical composition of the comet, is also indicative of such concerns. Opinions varied. Many professional astronomers and astrophysicists thought that such ‘barbaric’ methods should not be allowed. The apotheosis of this dispute was a lawsuit brought by Marina Bai in the Presnensky court of Moscow against NASA for an award of moral damages caused by this experiment. The formulation of the lawsuit was as follows: ‘The NASA activity encroaches on the vital cultural wealth and the natural life of the Cosmos, which upsets the balance of natural forces in the Universe’. The case was considered by the court, but the claim was denied. A transfer of ethical norms and ecological thought to the Cosmos lies at the heart of this case.

All this could be considered an amusing incident if not for the sympathetic attitude of many professionals. Any large-scale astro-engineering activity, including transformation of comets and other bodies in the solar system, would cause fierce opposition from the public. Large-scale astro-engineering activity may turn out to be impossible, not due to technical reasons but from a post-singular cosmo-ethics point of view.

These examples show that post-singular humanism could hardly exist in a civilization ‘for internal use only’. These properties must also appear in relation to the Cosmos as a whole, whatever these relations might be: cosmic engineering, contact with non-sentient and intelligent forms of life on other planets, *etc.* An intrinsically perfect, highly-humanistic system cannot be primitively aggressive in its external manifestations. *Exo-humanism is a system of cultural constraints that limit destructive potential at the technogenic planetary level.*

It should also be emphasized that it is unknown if the process of humanization of *terrestrial* civilization is fast enough and deep enough to overcome the crisis of the Singularity. Our statement is rather conditional: *If* post-singular, cosmo-technological civilizations exist, *then* the process of their humanization in the period of overcoming the Singularity must be fast and deep, and that is why they must be exo-humanistic.

3. Cosmic Expansion and Intensive Development

There is a widespread belief that the negative consequences of the need for extensive technological development and the related exhaustion of irreplaceable resources on Earth can be overcome by expansion into outer space. In this fantasy scenario, billions of people will live in cosmic towns, we will use resources of other planets, all unsafe industries will be located in outer space, far from Earth. But such visions are quite groundless.

In particular, the time needed for preparation of such large-scale opening-up and settlement of space is insufficient (Gindilis 2001). It is impossible to physically accumulate enough resources for organization of an ecologically safe and inexpensive but intensive traffic to even a near-earth orbit during the few decades of the technological period. Another obstacle to large-scale astro-engineering could be cosmo-ethical or cosmo-ecological reasons related to exo-humanism. As we saw, these factors are already appearing, in spite of the modest nature of the present-day challenges.

Predictions from the 1970s about what would happen with space technology and space exploration by the end of the 20th century turned out to be highly unrealistic. For example, K. Erike, a participant in the U.S. space program, predicted a space station for 25–100 persons that would be put into orbit after 1985 (Levantovsky 1976: 37). Similarly, a solar power station with the capacity to produce 5 million kilowatts was also predicted, one that weighed 9570 tons and had 45 km^2 of batteries in stationary orbit.

These predictions had been based on a linear extrapolation of the rate of space development that had occurred in the middle of the 20th century, which is why they failed to materialize. The tempo of such advances was too much to maintain and many of the proposed plans are still unimplemented. Indeed, a sharp decline in space activities has already occurred. There are other things that need to take place on Earth before such extraterrestrial activity can get back on track.

After overcoming a singularity, a civilization must establish a stable existence for itself without any hope of engaging in rapid cosmic expansion. This period of stabilization must focus on the intensive development of Earth's own resources. Even if large-scale cosmic expansion is possible in principle, it cannot be allowed to occur at the expense of the technological explosion. A considerable period in the post-singular phase must pass before enough necessary resources are accumulated. Since it is difficult to make forecasts about the possibility of cosmic expansion in a distant post-singular phase, and since transition into the intensive phase of development must come first, then let us concentrate on features of behavior of a cosmic civilization in the intensive phase of development.

Proposed models of SETI research during the intensive phase of development would be determined by the overall existing conditions. Since energy resources of a cosmic civilization would be rather restricted, transmitters of signals would be only of pencil-beam diameter, whatever carrier might be used. The most probable receivers also would be of pencil-beam size and would be oriented to monitor separate stars. Powerful omni-directional stationary radiators would be excluded because of their large energy requirements. And it would also be quite probable that they would be rejected because of ethical or ecological imperatives of exo-humanism, because of their destructive effects on outer space.

4. Information Crisis

The issue of 'the end of science' deserves a large paper or even a book of its own, but for our purposes here, this range of study will only be considered in brief.[2] First, let us define what we mean by 'science'. There are several methods of cognition: philosophic, religious, *etc.* Science is one of these forms of cognition. A scientific truth is not a synonym for truth in general, but its results can be reproduced. In science, there are two basic classical methods to verify results: 1) a reproducible experiment in natural sciences, or 2) a deduction or calculation in mathematics (deduction is also a method of reproducible reasoning in natural sciences). We call the methodology based on the combined use of reproducible experiment and deduction: *the classical scientific method.* By definition, science is a method of cognition assisted by classical scientific method.

In the period of technological explosion, science – along with consumption of resources and energy – is in a state of a heavy (exponential) growth. The time of doubling (of different characteristics – the number of scientists, the number of publications, and the number of discoveries) is only 10–15 years (Lem 2002; Idlis 1981). The current rate of the development of science cannot last infinitely or simply for a long time; this follows from elementary arithmetic.

In his famous book, *Summa Technologiae*, Stanisław Lem asserts that we will reach the near 'saturation' of the scientific method (Lem 2002). Apparently, he was among the first to seriously discuss the limitations of science and thought that it would cause a future crisis of civilization, which would demand special measures to overcome it. Lem called it the 'information crisis', and we will use this term here.

In 1963, when this book was written, Lem thought that the exponential growth of science would last 30–70 years and that it would end in the period between 1990 and 2030. Lem wrote: 'Thus, if the current rate of scientific growth will remain, then in some 50 years every inhabitant of Earth will be

[2] Much more detailed analysis is presented in our paper (Panov 2009).

a scientist'. Apparently, his forecast refers to about 2010 and, as can be easily seen, strongly overestimates the real number of scientists. Indeed, as with the space program discussed above, the growth rate in numbers of scientists has already fallen. It seems that Lem's general forecasts are coming true.

The problem of 'the end of science' still keeps exciting peoples' minds. Currently, there is a lot of literature dedicated to it, such as Krylov (1999) and Horgan (2001). From my point of view, the issue is especially important in the context of the evolution of civilization. Such an approach allows us not only to better understand the essence of the crisis but to also think of possible ways of overcoming it.

The scientific method arose in the evolution of civilization, at a specific stage of development, for the solution of important problems. The first elements of the scientific method appeared in the ancient world; however, they were not a leading factor of development at that stage, *i.e.* they were merely one of the forms of *superfluous diversity* (superfluous diversity is a pool of ideas from which society selects and which then lead to new systems after a phase transition). In the ancient world, the leading methods of cognition were philosophy, religion and art. However, the scientific method played a more important role in overcoming agrarian crisis in the late Middle Ages, and then became one the leading factors of the first industrial revolution and the subsequent development of civilization. It was a special case of very general mechanisms of evolution. Superfluous diversity was involved each time in overcoming evolutionary crises (Nazaretyan 2004).

However, sooner or later, effective solutions become exhausted, and the classical scientific method is not an exception. This does not mean that science will disappear. Old forms do not totally disappear when new forms appear; they just remain in a reduced form, yielding leadership to more progressive systems. It should be expected that the classical scientific method will lose its leading role in the development of civilization and will be replaced by other forms of cultural activity. 'The end of science' is not necessarily the end of cognition, and, moreover, it is not the end of evolution. New forms of cognition or other types of cultural activity will arise, ones that might not even be considered cognition in our contemporary meaning. This has happened before: The world of mythology was extracted from a whole primeval worldview, which was then replaced by philosophy on nature, religion, *etc.*

Although we employ inductive logic to consider the future of science, it should be understood that, while induction can be a method of constructing such hypotheses, it cannot be used as proof of anything. As far as questions about the very distant future go, a special caution should be made, since some ideas are extrapolated from the scale-invariant pre-singular stage of evolution to the post-singular stage, where the evolutionary result can turn out to be very different than expected.

It is also important to have a notion of the concrete causes that can lead to 'saturation' of the scientific method. It will allow us to understand the dynamics of the process and to estimate, at least roughly, the time scale involved. At least three basic groups of causes can be identified.

First, sooner or later, science will run into limitations caused by the lack of availability of natural resources. Such tendencies already exist. In the United States, we saw the cancellation of construction on the Superconducting Supercollider in 1993 and the recently pared-down space programs. In prospect, *at best,* science expenses could be stabilized at a constant level, taking into account the intensive character of development of post-singular civilization.[3] This must mean stabilization and a gradual decrease of the flow of *new* scientific results, because the cost of every newly solved scientific problem increases due to the increase of its complexity, in spite of development of new scientific methods (computer simulation, processing of data, *etc.*).

At present, only rare cost-effective studies are carried out by lone scientists, as was done a century ago. For the most part, scientific teams work together today, exploiting giant and very expensive experimental facilities. Many modern scientific problems can be solved only by international collaboration. Decline in the flow of scientific information (more precisely, discoveries) causes a decrease of interest of the society in science, which leads to a decrease of fiscal appropriations for studies and a further decrease in the flow of new results. A positive feedback loop is thereby closed. As a result, scientific investigations are cut back. This is especially dangerous because, due to the high rate of collapse, many participants in these events can have no time to understand what is going on. I have presented a mathematical model of this development (Panov 2009).

Secondly, it is clear that science will also encounter ethical limitations related to post-singular humanization. From examples of recent history, we can remember the strong opposition to experiments on the cloning of human beings. Other kinds of concern also fall into this category, such as opposition to genetically modified products that impede genetic investigation or concerns about radioactive contamination that hinder the development of nuclear-power research. Even a general distrust of science is quite widespread among uneducated people.

In addition, a third group of limitations exist – a field of research can simply be 'exhausted' for further scientific study (Horgan 1996). L. V. Leskov and V. M. Lipunov wrote about that problem in relation to SETI research (Leskov

[3] Please, note that it would not be so under the conditions of the extensive growth of a civilization at the expense of the cosmic expansion.

1985; Lipunov 1997). Certainly, the potential completeness of studies in fundamental physics would not cancel out a possibility of studying phenomena at higher system levels, but it strongly reduces a probability of scientific discovery which, in fact, coincides with the interests of society.

Please, note that, in my opinion, there are no serious grounds to consider the problem of 'the exhaustion' of science to be real. But the public opinion related to it is quite real. Expectations of the end of fundamental physics (even if based on false premises) can cause public pessimism which, via feedbacks, affects the stability of science on the whole.

We have not yet mentioned the expansion of pseudoscience with its distinctly negative attitude towards real science, as well as other factors that seem to us to be less important. Thus, there is not one, but a number of interacting causes that can impede the development of science. That is why the information crisis is actually, to a great extent a *system crisis of science*. Apparently, sooner or later, post-singular civilization must deal with this phenomenon.

Overall, resource limitations would seem to be the most important issue in the crisis of science, but ethical concerns can grow stronger with time. We do not at all mean that the current state of scientific research soon forebodes the end of science; it just indicates an inevitable falling off of efficiency by the classical scientific method. Apparently, terrestrial civilization is near the first phase of this scientific crisis. Nonetheless, developing processes are so dynamic that it is unlikely that the classical scientific method will be a leader of cognition in the coming centuries. This is an issue that will unroll over the next few decades. This knowledge presents us with an opportunity to seek a solution.

Is the information crisis dangerous for civilization? A positive answer is most obvious, but some qualification is necessary. If the cognitive function of mind can be exhausted, then the end of civilization is inevitable (Lipunov 1997). Though this thesis has not been proven, it seems quite plausible and I accept it as a hypothesis. Although science is now the leading method of cognition, it is not the only one, as mentioned above. The information crisis means the closing of only one channel of cognition.

Can a civilization avoid the crisis by making one of the other existing methods of cognition the leading one? Every method mentioned above is older than science and was once a leader, but evolution does not enter the same river twice. It seems that the information crisis will inevitably lead to a general crisis of civilization. This crisis could first manifest itself in science and technology, but it is easy to imagine that such a crisis of science will lead to a larger crisis in general culture: An all-planet 'longing for something new' and a feeling of being in a blind alley may arise.

The crisis can be overcome, if a new strategy is found that can replace the classical scientific method as the leading function of cognition. Such a new strategy could be related to a considerable modification of ideas about reproducibility or truth. Brand new channels of obtaining information could also appear. The search of possible new directions for future development should be related to analysis of the pool of superfluous diversity, since all known cases of new strategies were taken from these pools. Therefore, a number of different scenarios can be conceived. That is to say, it is quite possible that the information crisis is a point of polyfurcation with different possible exits.

Here, we will not analyze all the possibilities of overcoming the information crisis (there are many of them). But it is important that one of the ways of replacement of the classical scientific method is related to solution of the SETI problem. This variant will be discussed in detail in the next section together with other particularities of post-singular civilizations. It is not difficult to see that we are dealing with the search for possibilities to overcome the information crisis among the factors of superfluous diversity. Keep in mind, though, that while work on the SETI problem is one of the forms of cultural activity of humankind, it does not yet play an essential system-forming role.

Let me make one important concluding remark about this information crisis. Although we see the inevitability of a system crisis in science in the more or less distant future, it does not follow that the support of science should be discarded. On the contrary, science should be supported as much as possible, because scientific knowledge will serve as a basis for overcoming many other crises of the singularity.

5. Communicativeness of Post-singularity Civilizations

It was shown above that, in the post-singular phase of development, a civilization will have to meet two problems: A restriction on space exploration and an information crisis. Besides taking out a civilization to the way of intensive development, the first problem can cause serious internal discomfort, because it will make people feel closed-in, restricted to their stellar system or a planet, as in a shell. The second problem can cause a dangerous destabilization of the overall system. Let us try to imagine the behavior of a civilization in this situation, relying on the above analysis.

A civilization like ours, which has approached the information crisis, must understand that it is necessary to access new ways of obtaining knowledge in order to preserve homeostasis. These new pathways to knowledge must be alternative to the saturated and degraded classical scientific method. If the problem cannot be solved in some other manner, then obtaining of information from other non-terrestrial civilizations could provide such a method, if it is sufficiently rich and connected to as many correspondents as possible.

Moreover, in such a crisis situation, the discovery of at least one extraterrestrial civilization could give powerful moral support for it to overcome its crisis, because it would demonstrate that civilization has prospects for progress. Simultaneously, this would also solve the problem of 'the shell complex': Real cosmic expansion would be replaced by a virtual informational one. Such cosmic transmissions probably contain information about the historical path of millions of other civilizations, which could be used to optimize pathways for our own civilization's development. That is why SETI contact could radically increase the stability of our civilization.

Such information could be obtained only if other civilizations made cosmic transmissions, which is most likely. Being exo-humanistic, a post-singular civilization would have to engage in this form of communication, which would be so important for other civilizations in the Cosmos. Highly-developed civilizations would not spare themselves with transmissions into space but would try to maximize these efforts. It should be expected that transmissions into space would actually be a stabilizing component for a post-singularity civilization that had experienced the information crisis. Perhaps, this is a possible answer to the question raised by Viktor Shvartsman (1986) about the purpose of interstellar transmissions: Since obtaining new knowledge cannot be the purpose of transmissions, consequently, this activity does not belong to science. But what could be their purpose then?

Civilizations should seek to not only send transmissions into space, but to make them as informative as possible. The simplest way to do that is the transmission of not only its own information but also that received from other cosmic civilizations. An exo-humanistic civilization also must think how to share information about vanished civilizations, which is similar to our present attitude about ancient monuments. Thus, one of the actions of a post-singular civilization at the stage of a system crisis and afterwards is active transmission of messages into space and the relaying of everything that has been received.

On the basis of such a model, any civilization that may have not yet found a contact partner and *which is at the stage of the information crisis* must apply all of its efforts to solve the SETI problem. Obtaining a new source of knowledge becomes a vital necessity of the civilization, if only to provide hope for its people. Only in this state of awareness will a civilization becomes *communicative in a strong sense.* The readiness of a civilization to spend significant resources to address the SETI problem should not be expected to take place earlier than when the information crisis becomes evident to the majority of its people. Historical experience shows that the important problems of civilization are solved only on the principle that: 'Without thunder, there is no religion'. It is evident that terrestrial civilization is still far from this communicative phase.

Does it mean that it makes no sense to engage in solving the SETI problem now? – By no means. At the time when such contact will be seriously needed, the theoretical base and methods of search for cosmic civilizations and communication with them must be ready. The on-going research and growing database of exo-planets of the terrestrial type is extremely important. And all that should be done now. As was noted, the work on the SETI problem could be a key factor in overcoming the future information crisis.

6. Galactic Cultural Field and the Character of Information in Cosmic Transmissions

In an earlier paper, I discussed the positive influence that such cosmic contacts might have on stabilizing civilizations. I also showed how a phase transition might be possible in our Galaxy, from the time when the probability of finding a contact partner during the lifetime of a civilization is much less than 1 (*the epoch of silence*) to when it is close to 1 (*the epoch of contact saturation*). Moreover, during the latter state of the Galaxy, it would be very stable (self-sustained). It has been shown that the dynamics of such a transition would be similar to a second order phase transition (Panov 2007).

It was further argued in the previous section that the possibility to overcome the information crisis by engaging in cosmic transmissions would actually have a significant positive influence on the linked civilizations. The expected properties of post-singular civilizations create the possibility for the transition of the Galaxy from the 'epoch of silence' to the 'epoch of contact saturation'. In such a state, the cosmic civilization population of the Galaxy would have rather remarkable properties.

In the epoch of contact saturation, messages sent by a civilization to space during the communication phase will be received and relayed by at least one other civilization with a probability of about 1. That is why information about civilizations that completed the communication phase can be kept in the Galaxy during an indefinitely long time, being transmitted from one civilization to another. Upon establishing the state of contact saturation, the amount of information available to all in the Galaxy increases steadily and turns into a single cultural field. We emphasize that the existence of the cultural field does not mean two-way communications between civilizations.

As information in the cultural field is accumulated, every civilization, proceeding from the imperative of exo-humanism, will process and relay greater and greater amounts of it. When that information begins to flow, the post-singular communication system will become so saturated with data that it will be impossible to relay all of it. Cosmic civilizations will start selecting the most valuable. In its turn, changes of the information content will have a feedback influence on the constitution and properties of civilizations in the Galaxy. The cultural field will turn into a single umbrella-civilization, evolving according to its own laws. Actually, we deal with a qualitatively higher level of organization of matter following the social one. As such, the galactic cultural field has many interesting properties, which I have discussed in detail in a previous paper (Panov 2003).

Establishment of the cultural field is very similar in its essence to the 'big correction' of V. A. Lefebvre (1997). The case in point is the coordinated activity of many intelligent 'cosmic subjects' for improved development of life and intelligence in the Universe. Lefebvre considered the situation in which cosmic subjects do not have the possibility to agree directly with one another upon fulfillment of this work and have to act on the basis of the moral imperative in the hope that the others act in the same manner. Such a scenario of behavior of post-singular civilizations corresponds closely to his idea.

A model of the cultural field suggests that the typical cosmic transmission of one cosmic civilization must contain information of many, maybe millions of other civilizations. It would be a complicated and branched information system. The term 'transmission' is inadequate; one needs to talk about *an exo-bank of data.* Transmission of such a huge amount of information with the help of a modulated laser beam or a wide-band but narrow-beam radio signal would not be an unsolvable problem for a civilization whose energy resources do not exceed those at the planetary stage of development, as expected for an exo-humanistic, post-singular civilization.

It is easy to imagine the possible character of information in exo-banks of knowledge. Obviously, it is mainly meant for post-singular civilizations that have already faced the information crisis (since only such cosmic civilizations could find a contact partner). That is why, such fundamental sciences as physics, mathematics and astronomy would not be the most interested parties in exo-banks, because post-singular civilizations that are close to exhaustion of the scientific method must have a similar level of knowledge in this field. Certainly, some specific information of the fundamental character can be of interest, for instance, parallaxes of quasars and distant galaxies, which was pointed out by V. S. Lebedev (2007).

However, a more fundamental kind of knowledge will become important to facilitate the decoding such exo-bank data. It should be expected that most information will be 'humanitarian' in character, such as biology, history, sociology, literature, art and religion. It would feed the function of cognition instead of cognition in the form of natural sciences. We call a cosmo-technological civilization that has stabilized its existence by processing external information of a humanitarian character as an *exo-humanitarian civilization*.

The conclusions by which we arrive here are close to the idea expressed by Philip Morrison at the Byurakan SETI conference in 1971:

> In my opinion, the most part of this rather complicated signal will mainly refer to what we would call art and history, but not natural sciences and mathematics. For me this is clear from combinatoric considerations, because our society or any other long-living society will solve many natural-scientific and mathematical problems by easier ways than by studying records of interstellar messages (Morrison 1975).

Victor Shvartsman stated similar ideas in 1986: 'An opinion generally accepted among physicists that the extra-terrestrial intelligence must pass fragments of its scientific knowledge to "younger brothers" seems to be very disputable'. He noted that information related to art and games can turn out to be much more important. This opinion is mainly grounded in two considerations. First, scientific information forms a single logical construction. If a part is lost, the whole is lost too. In other words, the scientific information is difficult for decoding and understanding.[4] Whereas information contained in art is much more resistant to the loss of fragments – the kept parts have a definite integrity and value as before. Rules of logical games are very simple and compact. They can be transmitted easily. At the same time, they contain huge amounts of information about an unimaginable number of potentially possible logic sets. Second, art and games say much more about the intellect that created them than impersonal scientific information or even data of neurophysiology.

It should be noted that, in the present paper, the way to similar conclusions differs from arguments of both Morrison and Shvartsman. They consider that the main motive of 'humanization' of a message is that it is difficult to understand interstellar messages of a scientific character. Our idea is that interstellar messages will be accessible for study (or, perhaps, the necessity to study them) only after most of the problems are solved within the framework of the classical scientific paradigm. However, our second motive about the predominant importance of 'humanitarian' information in comparison with scientific has much in common with Shvartsman's ideas though it does not repeat them literally.

But the considerations of Morrison and Shvartsman that it is difficult to extract information from an interstellar message are also very important. How do we decode the exo-banks of knowledge? Certainly, it is difficult to pose such a problem. Only some general considerations about that can be expressed.

It should be expected that an exo-bank of information will contain one or several root messages with a signal attracting attention and instruction for further search for information. This part of the exo-bank must be decoded easily (for instance, on the basis of reduction to natural-scientific or mathematical concepts). But difficulties are certain to be faced in advancement to the 'humanitarian' parts of the exo-bank.

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[4] I do not agree with this reasoning. *Vice versa,* the knowledge in mathematics, physics, chemistry and astronomy (cosmology) are common to all and should be easy to decrypt.

Here the papers of B. N. Panovkin (1981) about the difficulty of mutual understanding of different cosmic civilizations should be remembered. Panovkin considered the process of setting up correspondence between systems of ideas (thesauri) of these civilizations and showed that, generally speaking, this problem is not solvable algorithmically even for a two-way contact. However, in our opinion, such a conclusion does not mean that understanding is impossible. It only means that the process of understanding must be of a substantially non-algorithmic character. But it is the man that is able to an illogical guess or irradiation inaccessible to a finite automaton.

At the initial stage of studying materials of the exo-bank there can be no correspondence between thesauri of different cosmic civilizations at all (except a very narrow field of simple mathematic or natural-scientific concepts). It can be built gradually as the exo-bank is studied in the cycle of a conceptual model or a test. Models of the understanding of some fragments of the exo-bank are suggested, and then these models are tested on other materials of the exo-bank. If the model stands the test, it is accepted and used for construction of newer and finer models, otherwise it is rejected. A non-algorithmic element of this process is the suggestion of new models. Here it is impossible to do without guesses and irradiations. The understanding achieved in this way will never be final, but it will always be of a model-building character.

It is easily noticed that this cyclic process is very similar to the standard cycle of the classical scientific method of a hypothesis – an experiment. That is why the process of understanding the exo-bank can be called 'exo-science'. Thus, after the information crisis the leadership in methods of cognition can pass from science to exo-science.

Exo-science is not simply another version of science. The key-components of exo-science are truth and reproducibility. In exo-science the notion of truth turns out to be of two-levels: 1) How adequate are models of interpretation of information, and 2) How truthful is the interpreted information itself? If it is still possible to achieve something resembling repeatability of results at the first level, then at the second level, in many cases, it will be unachievable in principle. The element of belief becomes inevitable in the obtained knowledge. Besides, the obtained knowledge itself refers not to nature directly, but either to artificially generated information, or to nature, but indirectly through artificial information.

Let us emphasize that the possibility itself of a long process of obtaining knowledge by the method of exo-science is not less important than the content of obtained knowledge. The process of exo-scientific cognition can drag on many thousand years, but this is just what is necessary to support the homeostasis of civilization at the intensive post-singularity phase of development. It is hard to tell how and when this process of exo-scientific cognition will be exhausted (since this must happen eventually).

7. Final Remarks

We proposed the scenario of post-singular evolution in which the leadership system is a post-singular civilization in intensive phase of development. A post-singular civilization is exo-humanistic and exo-humanitarian, one that is part of the galactic cultural field (Section 6). The typical features of an exo-humanitarian civilization must be moral imperatives of exo-humanism (Section 2) and, apparently, a declining state of investigations with the classical scientific method, at least in the field of fundamental sciences (Section 4). Such a civilization is communicative in the strong sense (Section 5). It would not be overstating the case to say that, when establishing contact with such a civilization, we contact the wider cultural field and become an element of it.

We would like to emphasize that the quantitative estimates show (Panov 2007) that even at the epoch of contact saturation of the Galaxy (Section 6) it is a very difficult problem to find the first partner for interstellar communication if pencil-beam channels dominated in the galactic cultural field. Therefore, the Fermi paradox (silence of the Cosmos) may easily coexist with the galactic cultural field: Great efforts from each civilization are needed to establish contact with the cultural field. We cannot see a lot of civilizations in all the directions because the civilizations are in intensive post-singular exo-humanistic stage when the energy resources of the civilizations are not large and they can use only pencil-beam channels for interstellar communication. This is a possible answer to the main question stated at the beginning of this paper.

Though we were trying to avoid arbitrary hypotheses, the approach used in the analysis is the scenario approach. The scenario suggested in this paper can turn out to be more or less plausible or be wrong. The crisis phenomena in science can be softer than it was assumed, but they can occur against the background of other crises, which was not taken into account. The strategy of overcoming crisis phenomena based on the solution of the SETI problem can be combined with the strategy of creation of an artificial intelligence or other global conceptions. Maybe, different strategies are incompatible, so, civilizations can be divided into several types according to their way of overcoming the information crisis: cybernetic, communicative, *etc.* Even if a suggested scenario is correct in general, nevertheless, rare strong deviations from it are possible. So, for instance, at a small distance between two civilizations the contact can be established not at the post-singular phase when the strong communicability is achieved, but much earlier. It easily may take place in a star cluster. Such civilizations can go by the way of creation of super-civilizations with a large-scale astro-engineering activity, as is assumed, for example, in some papers (Kardashev 1981; Kaplan and Karadashev 1981). Maybe, the galactic cultural field created by exo-humanitarian civilizations is only a kind of 'incubator' for super-civilizations and only a phase in development of intelligence. All that means that both the search for beam signals typical for the cultural field and the search for 'cosmic miracles' typical for super-civilizations must be implemented simultaneously.

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III. ESSAYS ON BIG HISTORY

13
The Change We Can Believe in: Ten Facts about the Evolution of the Earth-Life System and their Relevance to Current Global Environmental Change

Nigel C. Hughes

Abstract

For the first time in human history, what we believe about the past of the Earth has direct implications for our future. If we are to make responsible choices about global environmental change, we must understand what the Earth's prior history of physical and organic evolution says about how the planet and its inhabitants have co-evolved in the past, and be able to relate these insights to current condition. The Big History movement is an important bridge between scientific understanding of this past, varied views of humanity's place in Earth history, and practical environmental issues that affect our daily lives. If Big History is to gain serious traction, the movement must emphasize linking lessons from the past to the choices we must make as a global society. This paper presents ten facets of Earth history that contextualize some current issues concerning global change and species extinction within a Big History perspective. I argue that, although extinction has played an important role in shaping the evolutionary history of life and we are here partly because of it, the fact that almost all species that have ever lived are extinct cautions against a passive response to global climate and environmental change.

The origin and destination of a journey are critical components of any travel, but they are not the journey itself. Likewise, although we are naturally drawn to events associated with the origin of the Universe, and to understand our unique place within it, neither of these issues are, in my opinion, the meat of the Big History movement. We are drawn to such terminal events because they appear seminal, and also because they are temporally and spatially comprehendible to us. Even though we may find the behaviours of subatomic particles bizarre and unfamiliar, they are at least distinctly odd. Black holes fascinate because reassuringly they reconnect the realms of the universal and the subatomic: they link the start and the finish. Likewise, we are intrigued by the first few millennia of this Universe's history because the temporal scale and rate of change are more familiar to us than the huge interstellar distances or the eons of geological time that constitute the real journey of Big History. That journey concerns concepts we experience routinely in our own lives, time and distance, but which are expressed at scales we find disturbingly incomprehensible.

An irony of these terminal events is that they are among the least important when it comes to accessing the societal significance of Big History as a discipline. From that perspective, what is vital is the attempt to contextualize our actions in the place and at the physical scale over which our personal choices have consequence. In this regard, the central issue of Big History is whether or not the Earth has an extensive past that can be read and interpreted from the record it has left behind, and from its current state. This issue is central, because it reflects a fundamental choice. If we accept that the Earth has a history that we can interpret using a science-based approach, then we can hope to learn from the past and use it to predict what may happen in the future. If we reject this history, as does a substantial proportion of the world's population, then that history has no relevance to us. We are thus living during a unique time: for the first time in the history of our species, what we believe about the age and history of the planet and life upon it has critical significance for our future as a species.

Accordingly, the realms in which Big History is most relevantly characterized are those of geology and biology, two disciplines that are becoming increasingly intermeshed as we learn how closely the Earth's physical and biotic environments are, and have been, interwoven. These issues relate intimately to the journey of history, rather than to its origin or current destination. They take place over time scales that are impossible for humans to conceptualize or relate to in any realistic sense. Nevertheless, it is these events that set the scene and hold the promise for understanding our own future on this planet. Below I will present ten of the most striking features of Earth's history that are, in my view, critical knowledge for those making responsible political choices concerning our collective future.

1. Many Earth-like planets.

Almost every week the world's leading scientific journals, *Nature* and *Science*, discuss new successes of the search for planets beyond our solar system. Given the numbers of such planets already detected, and the numbers of stars in the Universe, it is probable that other Earth-like planets exist in appreciable numbers, and that some of these planets support, or have supported, life.

2. The Earth's surface has been continuously dynamic.

Our planet stands out from others in our solar system in many ways, the most obvious of which is the peculiar chemistry of its fluids in the oceans and the atmosphere. More subtle, but even more telling, is that fact that the surface of the planet is littered with the record of the planet's active history – testified by the layers of rock strata (Zalasiewicz 2008). Each of these layers is a record of the dynamic interaction between the consequences of heat energy released by radioisotopic decay within the interior of the Earth and those of heat energy from the Sun that is absorbed at the Earth's surface. It is this interplay that has fostered the extended proliferation of life on the planet. Without it, life might have been initiated, but it would have been hard or impossible to maintain over the long term.

3. Life began early in Earth's history.

The dynamic nature of the Earth's surface means that much of the record of its history has been eroded and recycled. Hence, the longer ago an event took place, the lower the probability that a record of that event has been preserved today. This notwithstanding, some of the oldest rocks on Earth contain evidence for the presence of living organisms, perhaps as old as 3.5 billion years or even older (Schopf 1993). One implication of this early origin of life, though based on the sole example of our own planet, is that the evolution of life on a planet of this kind may not be highly improbable.

4. Planetary and organic history is intimately linked.

The chemistry of the atmosphere and oceans of our planet has changed slowly, intermittently, but persistently over the 4.6 billion years of Earth history. Life has played a defining role in achieving these changes, and most particularly in altering the amount of free oxygen available in Earth's surficial fluids (Scott *et al.* 2008). The interplay between life and the physical environment is highly complex – major changes in the system have coincided with dramatic changes in the physical environment, such as major reorganizations of the continents, or the times at which large portions of the Earth's surface were covered in ice. As these events are highly complex, it is commonly hard to constrain their precise causal sequences, and thus to know how likely similar events are to have occurred on other Earth-like planets.

5. Microorganisms only for a vast majority of Earth's history.

Despite points 3 and 4, we do know that complex multicellular life only became established on Earth after an extremely extended period of time, during which both microorganisms and planetary conditions evolved in tandem. It took the Earth a vast amount of time before complex organisms made from multiple cells with differentiated functions could operate viably, and before evolutionary novelties such as sexual reproduction enabled more rapid spread of complex biological innovations. We do not yet know, in detail, the sequence of events that lead to multicellularity, but we do know that it took a vast amount of time to appear and that it was associated with a significant rise in the volume of atmospheric oxygen. It is possible that other worlds harboring ancient life have yet to evolve multicellularity and may never do so because they have not experienced the unique combination of physical and biotic changes that the Earth has.

6. Geologically rapid establishment of complex life.

Once multicellular life became established on Earth, complex forms and ecologies evolved relatively quickly over a period of about 100 million years or less (Hughes 2001). At the end of this period, ecosystems obtained animals structured in ways broadly similar to those we see around us today. Both the array of forms and the diversity of types rose rapidly, reaching in the shallow oceans (the site of the most complete fossil record) a rough plateau of diversity relatively quickly, by about 450 million years ago. This plateau has been since maintained at an approximately similar level of diversity, although there has been a series of geologically rapid major diversity drops superimposed upon it, followed by more temporally prolonged intervals of the recovery of diversity. The diversity drops are called 'mass extinctions' (Raup 1991).

7. Mass extinctions, their causes and consequences.

Five major drops in marine diversity have been recognized since the advent of abundant complex life in the oceans some 550 million years ago. These are times when the numbers of species going extinct were orders of magnitude higher than at normal 'background' extinction rates. The driving mechanisms for these extinctions have varied, but they all appear to be related to significant changes in physical conditions on a planetary scale (*e.g.,* Finnegan *et al.* 2011). These include the meteor impact that terminated the dinosaurs and many other organisms about 65 million years ago, but also more indigenous causes, such as geologically rapid changes in ambient temperature conditions, as well as associated variations in the mixture of gases in the atmosphere and oceans. Such mass extinctions are characterized by sharp and permanent changes in the species compositions before and after the events. The larger the mass extinction, the more drastically different is the new biota that succeeded it. Accordingly, mass extinctions have had a major effect on the architecture of complex life. The removal of incumbent forms that dominated ecological systems prior to the extinction also provided opportunities for new evolutionary innovations to become widespread – the rise of the mammals following the demise of the dinosaurs is a classic example of this.

8. Drastic environmental change was sometimes rapid in ancient times.

From the point of view of our own choices, the most prescient fact we are learning about this record of past change is that, in certain circumstances, ancient and drastic environmental change apparently took place on the timescale of a human life. An example is the series of apparently extremely rapid changes in the values of the various isotopes of carbon that took place in a series of pulses that are recorded in the Jurassic rocks of Yorkshire, and which were accompanied by a series of extinctions that each apparently eliminated over 50 % of the local marine animal life (Kemp *et al.* 2005, but see also Wignall *et al.* 2006). These changes appear to have been related to the rapid population of the ocean and atmosphere by isotopically 'light' carbon atoms that had previously been locked away from the oceans and atmosphere in the form of hydrocarbon resources stored in the Earth's shallow crust. A likely candidate source for this light carbon may have been the rapid release of methane gas from resources of ‘methane ice’ (also know as ‘clathrate’). Similar resources occur today in huge volumes on the shallow ocean shelves and in the tundra, and – if similar resources occurred in the Jurassic – then their rapid destabilization could have yielded sufficient ‘light’ carbon rapidly enough to explain the isotope signal and its warming-related extinction. These Jurassic pulsed changes in isotope values, each of which probably took 100 years or less to achieve, were apparently related to cyclical, astronomically induced episodes of climatic warming. They were not caused by humans, who did not evolve until more than 150 million years later. Nevertheless, they suggest that the Earth has been vulnerable to drastic environmental change, which occurred on timescales that we can relate to in our own lives. Extremely rapid warming at the end of glacial cycles is another example (Alley 2000). The key point about these ancient changes is that they demonstrate that scientific understanding of the past is critical for predicting our immediate future. As huge and unstable accumulations of methane ice exist on the ocean shelves today, the global warming we are causing via our increasing carbon dioxide concentrations could trigger the release of large volumes of the far worse greenhouse gas methane. The effect of rapid methane release on the present global environment would be immediate and drastic, just as it appears to have been during the Jurassic.

9. The knife-edge balance of biological diversity.

According to some estimates, 99.9 % of species that have ever lived on Earth have gone extinct (Raup 1991). Hence, we live on a knife-edge balance in which the excess of events of species origination just fractionally exceeds the number of species that have gone extinct. This is a salient fact amidst talk of ‘adaptation’ as a survival strategy in a time of global change. While adaptation during evolution has allowed us the privilege of being here, far more species leave no descendants at all than the few that have gone extinct through evolving into something else. It is both true and ironic that we owe our own evolution to mass extinction, but it is equally important to realize that, as a living species interested in our own survival, it is in our best interest not to cause rapid environmental changes, the full impacts of which we cannot yet predict with confidence.

10. Change we can believe in.

Everyone reading this will be aware of the issue of global change, but some may feel challenged by it. Few can evaluate or articulate the arguments cogently, because to do so requires in-depth understanding of the way the Earth works, and this draws on a vast array of scientific knowledge. I for one, despite 30 years of training, feel well versed only in a few related topics. But the bottom line of global change is straightforward. Firstly, the scientific debate about whether human-induced global warming is happening was over about ten years ago, despite what some politicians would prefer. Global warming is happening, and it is happening fast. Secondly, this should not be a surprise to anyone reading this article, because the fundamental basis of global warming is very simple. We are taking vast numbers of carbon atoms that the Earth, over hundreds of millions of years, has locked away as hydrocarbons (coal, oil, natural gas, clathrates, *etc.*) in its crust, and are releasing them back into the oceans and atmosphere in a mere 150 years. When in the atmosphere, these atoms in their various molecular combinations cause warming through the greenhouse effect. This current rate of carbon transfer to the atmosphere is extraordinary in Earth history and can only be expected to lead to dramatic and rapid consequences, some of which can be predicted, but others cannot. As extinction rates now match those of previous mass extinctions, we are in the midst of a sixth mass extinction (Barnosky *et al.* 2011), but this one is ultimately induced by a biological change – our own actions – not primarily by a physical cause. The largest threat is that the warming we are causing at present initiates a feedback chain of events that rapidly accelerate with far worse consequences. Such rapid changes have occurred in the past, and we know that the same potential triggers occur on Earth today.

Although some colleagues might quibble with the tone of some of what I have presented above, the factual basis of the record is very strong. This has not prevented misstatements about the consequence of deep history. For example, it has been suggested that global warming is less worrying than it might seem, because the Earth teemed with life during the Cretaceous period some 100 million years ago, during which temperatures were warmer than anything we know today or expect to achieve soon, in spite of our best efforts. However, this rosy outlook overlooks the simple fact that despite the warm conditions of the Cretaceous, we were not there to experience them. Worryingly, only a tiny fraction of the species that were living during the Cretaceous are still represented in today's biota, for it is extinction, not survival, that is the motif of life's history. The challenge of human-induced global warming and other self-induced changes is not that all life on Earth will go extinct, or even that complex life will vanish. It is merely that, if unchecked, we will not be able to sustain the sort of societal structures and comforts we have become accustomed to, and that collapse of our society could precipitate our ultimate demise via vulnerability to additional calamities.

Hence, the choice before us, and the challenge for the Big History movement, is quite stark. In my own classes, I find significant numbers of students who do not accept the overwhelming evidence that the Earth is ancient and that it has a history that can be interpreted scientifically with significant implication for our own times. Their motivation is adherence to some version of Abrahamic tradition (Jewish, Muslim or Christian) that they feel requires a short Earth history. When I have engaged such students in discussion, some have appealed to democracy as justifying equal assertion of multiple views. Alternative views are certainly legitimate within their own frames of reference, but science itself is not democratic. Ideas offering strong explanatory insights into natural phenomena are retained, while those that do not are rejected. Many more students simply do not make the connection between what they learn in any science class with other part of their lives. This is where, in my opinion, Big History has a potentially important role, particularly when the scientific perspective on our place in nature is respectfully contrasted with other expressions of our origins and history. This is a path by which we may link what science tells us about our place in history with the reality of the choices we make in our daily lives.

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14
Once upon a Time…
There was a Story to be Told…

Jos Werkhoven

Abstract

The author was a teacher for more than thirty years. The article starts with the story of a teacher: the story of everything! For a while, we follow the story in the classroom. But it is a long, very long story. So we leave the classroom and he writes us about his approach to telling this story of Big History to children of the age of six. He calls his story 'questioning' – questioning of space and time. He helps the children with three frameworks, which is the core of the article. For the framework of space he uses the concept of the Powers of Ten developed by Kees Boeke. For time, he uses a framework that he himself developed: The Lines of Life, a set of four timelines for use in primary school. For questioning, he uses the material for sentence analysis developed by Dr. Maria Montessori.

The children are aged approximately six years and their teacher tells them the story because s/he thinks it is the best story of all time. And strangely enough, despite being a truly wonderful story, it is almost never told to the children! Most adults do not even know it! The teacher thinks that is very sad, because s/he believes that every child and every person living anywhere on Earth, rich or poor, white, yellow or black, has the right to hear and to know this story. It is a long, exciting story and it will be unfinished when the children leave school at the age of twelve, but most of them will be able to continue writing and telling the story. Shall we just listen for a while?

> 'Good morning, dear children. Today, it is a very special day. I think and hope it will be a day you will never forget in your life. Because today, I'm going to start to tell you a story. I am sure that if you leave this school when you are twelve years old, I will still not be ready with the story. Yet you will not get mad at me if I have not told the outcome. I think that you will be so curious that you, without my help, will seek further how the story goes. I expect, and frankly I hope also, that you will do that together, each of you with his or her own task. Anyway... since we have a few years, I better get started now.
>
> It is a story so special, so wondering, so exciting... the best storyteller could never have imagined it. The most remarkable is

the fact that the story is about ourselves. And the story is not just about us or our school or our country... no... it is about all people on Earth. And not just the people living today... no... it is about all the people that ever lived. I am still not finished with my list, because it is not just about all people, but also about all animals. All animals of today and all animals that ever lived. And it is about our Earth, about everything we can see on our planet... and it is even about the time when the Earth was not there...'

Bewildered Jacqueline jumps up and says indignantly: 'But the Earth has always existed!'

Our teacher is a gentle type and takes her waving hand lovingly and asks: 'Tell us, Jacqueline, how do you know?' The answer rolls immediately from her mouth: 'My mother says.'

'And tell me, Jacqueline,' continues the teacher, 'have you asked your mother how she knows?'

'Of course,' says Jacqueline. 'But Mom says the Earth was already there when people came.'

'That is interesting,' says the teacher. 'And do you know when the first people came?'

Jacqueline hesitates, she does not know so well. The teacher responds with understanding and begins to say that we have a presumption when the first people came and also a presumption when the Earth was created, but we are not sure.

Then I have a question for you all: 'Do you know the difference between a presumption and a sure thing?' This question keeps everyone awake, and there are many answers quickly:

'What you know, you can prove it!'

'When you presume something, you think it is true.'

'Yes, sometimes you think you know, or you know something of it, but you can not prove it.'

After hearing many answers, and sometimes a real debate, the teacher picks up the thread. 'I probably can help best by continuing my story, because that has to do with knowing something for sure or presumption. The most I am going to tell, you probably have not heard before. And although we know a lot of things for sure, we have only a strong presumption how the story in reality has been told. Therefore, it is good if you remember two things. Try to remember well! There are only two, so it will certainly succeed.

Here comes number one, which we call 'perception'.

A perception is something we can see, hear, smell, feel, measure. Perception is nearly a sure thing: on any given day you can observe the same thing again, you can also talk or read about something that others have observed. In that case you say: 'I know, I saw it too.'

Number two is called 'theory'.

We think something happened a certain way, or could happen and we have seen a lot of things like that, but we do not know for sure. We have not seen it in every situation, and we do not know that we will observe it always that same way. Thinking that something happened a certain way, or could happen, comes close to presumption. You may say: 'I have much (or little) faith in this theory'.

'So we know we have perceptions and theories. The story that I continue to tell has a lot of perceptions, but it also has many theories. I will tell you every time when a part of the story is a perception or a theory.'

'Jacqueline, what do you think? I just spoke about the time that the Earth was not there. Is that a perception or a theory?' The teacher asked Jacqueline the question, but there is a lot of noise in the classroom. All the children speak together. It seems that almost everyone has an opinion about it.

'The people could not write!'

'There was not life at all on Earth!'

'You can never prove it!'

'How can we know?'

'First there was a great super-something!'

Smiling the teacher follows the heated debate a while, then he continues: 'Let us be honest; I asked the question to Jacqueline and you all gave answers. We do not behave in that way, do we? We do not speak together; everyone gets to speak separately. If I hear all your arguments, then I can tell you that you all are a little bit right.'

'Then it is a theory!' said Jacqueline aloud. She found that she still had the right to answer.

If you allow me, we leave the teacher alone with his or her class. In this limited space, we are obviously unable to follow six years of the story that s/he is going to tell the children. We have recently witnessed an enthusiastic teacher who, in any case, made it clear to us that he wants to tell the children a grand and universal story; he wants to tell them that they themselves are a part of it. Often it is not much more than a presumption, but they can continue and discover the story by themselves!

Hopefully you now are curious about how the teacher will develop it.

Our teacher likes simplicity. When telling a universal and great story, it is always useful to keep an overview, and s/he succeeds wonderfully. S/he describes his approach: *to query space and time.* The teacher uses a number of easily understandable and communicable frameworks, which makes the total space and time accessible to the children, so they learn to question space and time and to apply their knowledge. In order to support these applications, the teacher prepares an environment, a rich environment, through which the children can find their own way and can discover relationships. Also, s/he invites each child to create a private portfolio, which reveals how they are forming their relationships with the world. In summary the teacher gives shape to his or her mission 'to make school' and accompany the child in his or her relationship with the world by:

- telling a grand and universal story;
- quering space and time;
- preparing (rich) environment to draw upon;
- inviting the child to create an own portfolio.

At the end of this article, I will tell more about 'making school', the prepared environment and the portfolio. I continue the article now with the discovery of space and time.

Space

The young child of six years old is not a toddler anymore. As a toddler, they are mostly oriented to their own little world. At about the age of six, a child discovers that the world is much larger, that there is even a very large universe. The child wants to know what is beyond the stars! The child discovers not only that the world is larger, but that there also exists large worlds in very small parts!!! Give a child a microscope and s/he will investigate everything; it will open new worlds for them.

Kees Boeke, the Dutch educator and educational reformer, felt very good about what to offer children in primary education from the age of six years.

> We all, children and adults tend to live in our own world... as we do, we can easy forget how vast the area of the existing reality is and our attitude may be slightly narrow and chauvinistic. It is necessary that we obtain a broader view, so we can learn to see ourselves in our relative position in the great and mysterious universe in which we are born and live. The school brought us into contact with different aspects of life but often they are not linked together, so the danger is that we collect a large number of separate images, without our realizing that they all form a great whole. Therefore it is important for our education as men, that we have resources available that can give us a broader and more continuous image of our world and thus a truly cosmic view of the universe and our place in it, so a cosmic orientation (Boeke 1959).

Although Boeke wrote these words in 1959, they are still highly topical today. His brilliant idea appears as follows (see Fig. 1 for a few of Boeke's original drawings).[1]

Kees Boeke and his children made a macro-trip from 1 meter height, where a student was seated in a chair on the playground, in 26 steps of the powers of ten to the frontiers of human knowledge. From the same starting position, a micro-journey was also undertaken. With the powers of ten, children travelled in 13 steps deep into the atoms of the human body.

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[1] See also Fig. 'Just 42 steps to explore the whole cosmos' from coloured edition *Power of Ten* by P. and P. Morrison (1985: 21–103) in the electronic version of this Almanac at http://www.socionauki.ru/almanac/issues/evolution_2_en/#werkhoven

1 cm	10 cm	1 m	10 m	100 m

Fig. 1. From *We in the Universe, the Universe in Us,* Kees Boeke (1959: 5–6, 32–34)

Travelling and telling, the curiosity of the children grew bigger and bigger. They wanted to know! They wanted to investigate!

Was that what was told to the teacher in training: make the children curious by tickling them, then they want to learn naturally? I can tell, after thirty years of working with children, that I never saw any so curious and inquisitive as during the intellectual trip organized by Kees Boeke. They were, despite all their questions, satisfied, at rest; they better understood the complex world than ever before.

You understand that during this cosmic journey various teaching materials naturally arise. Not only in separate disciplines such as Geography, Biology and Mathematics, but also through integrated and interrelated studies. What a great value! The school, the teacher and the child make choices about the topics they want to offer and to investigate. In line with the powers of ten, the learning potential is not only in the subjects, but more in the way that the child learns to organize the access to knowledge through these topics. About this interesting information I will tell you more in the later sections. After the discovering of space, we now discover time.

Time

As a teacher, I was long looking for a way to organize knowledge that would have more value for children and could give more coherancy to the standard curriculum. On a cold November evening in the 1980s, I thought about a workable overview of 'total time'. I was drawing some timelines and suddenly found an overview.

Wow! It seemed I had addressed time! In one simple overview I understood:

- total time, a line of everything = 13.7 meters long;
- time of humanity = 10 meters, enlarged from 1 cm on the line of everything);
- time of human culture = 10 m long, enlarged from 1 cm on the line of humans);
- time of a school child = 10 meters, enlarged from 1 cm on the line of culture).

The mathematical beauty appealed to me, especially in relation to the history of everything: humanity, culture and the child. Later, when I came into contact with the work of Kees Boeke, with its own mathematical beauty, it felt as an additional reward. I was very pleased to have 'frameworks' that can give us an overview of space and time.

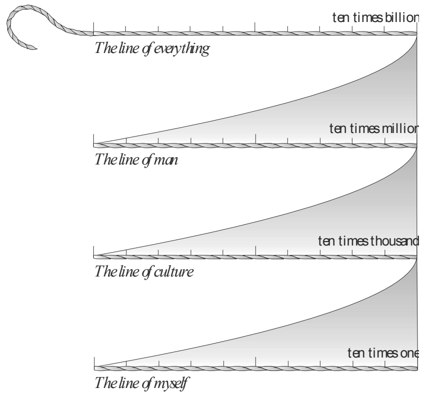


Fig. 2. *The Lines of Life*, Jos Werkhoven (1997)

For me it was clear that I not only should use this idea in my own classroom, but I had to share it with anyone else who wanted to use it. In 1997 I published the four timelines as *The Lines of Life* for schools (Werkhoven 1997) For this edition every timeline had name cards and illustrations of moments of development to support the telling of the story.

- The line of everything has name cards and pictures of the Big Bang; formation of matter; evolution of galaxies, Earth and life on Earth; continental drift; development of mountain ranges; *etc.*
- In the line of humans, there are many illustrations and name cards of the ancestors of humans, their tools, moments for the rise of many animal species, ice ages, cave paintings, the first use of calendars, *etc.*
- In the line of culture, the emphasis is on universal human history as well as particular history (though present) of individual cultures. There are illustrations and name cards of the first appearances of agriculture and livestock, weaving, irrigation, shelters, writing, use of copper and iron, *etc.* Important people such as Newton or Mandela are also present.
- In the line of 'myself', there are illustrations and name cards of birth, birthdays, the first time walking, *etc.* The child fills the line with their own pictures of various events.

The finest work in this series is always done by the children. Their own research and work are linked to the timeline. Books, artwork, fossils, handmade art objects, galaxies, Earth and planets, and the other examples create what is essentially a school museum and research centre for the timelines of life, which is revisited frequently by students. Indeed, there is a lot exchange of information between groups.

The Question

The teacher brings children into the wonderful story of space and time, making them curious, and, as a result, they ask a lot of questions. One of our resources comes from educator Maria Montessori,[2] who developed an ingenious process to analyze sentence structure (Fig. 3). It is however, also possible to use her technique in reverse: to make language. Every child has his or her own questions, so the teacher helps them develop at their own level towards graduation. This process helps the child organize questions and construct a format for their work, similar to a university dissertation, but at a more basic level (Fig. 4).

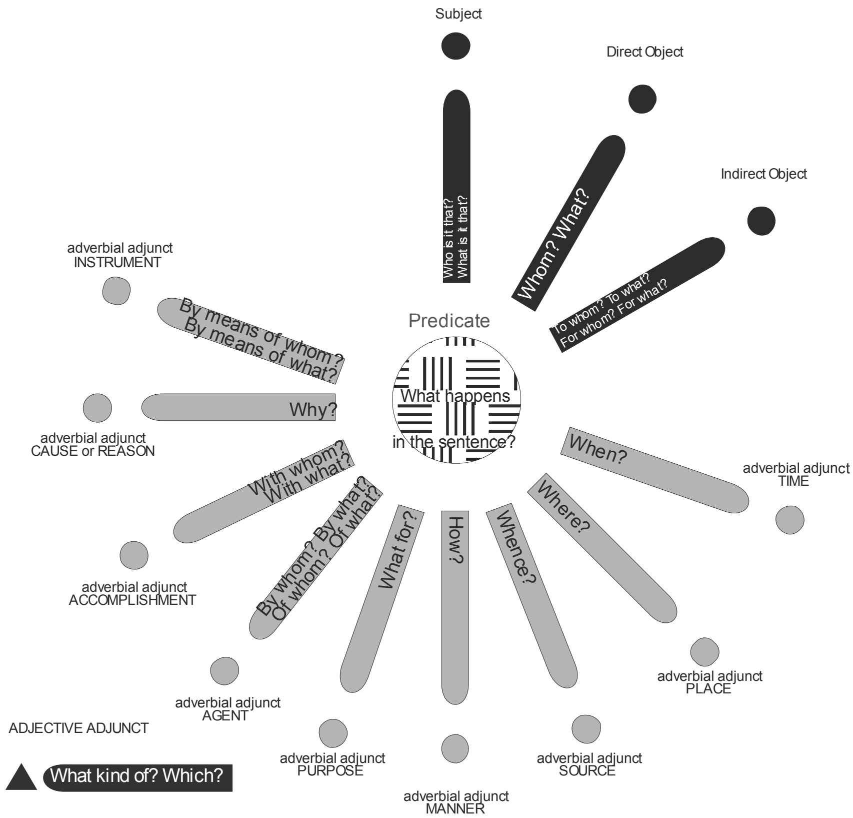


Fig. 3. Material for sentence analysis from Maria Montessori (1953)

[2] Montessori M. (1870–1952). Italian physician and educator who propagated learning by free choice of work within a well-prepared environment.

Ultimately, the work of the child in our program takes on the structure shown in the bottom right image, where the lines show the relationship between various sub-topics. The material from sentence analysis is extremely stimulating for the child's research. It introduces a very important value, in contrast to the traditional rote style of only answering questions about standard material from a book.

Building a book

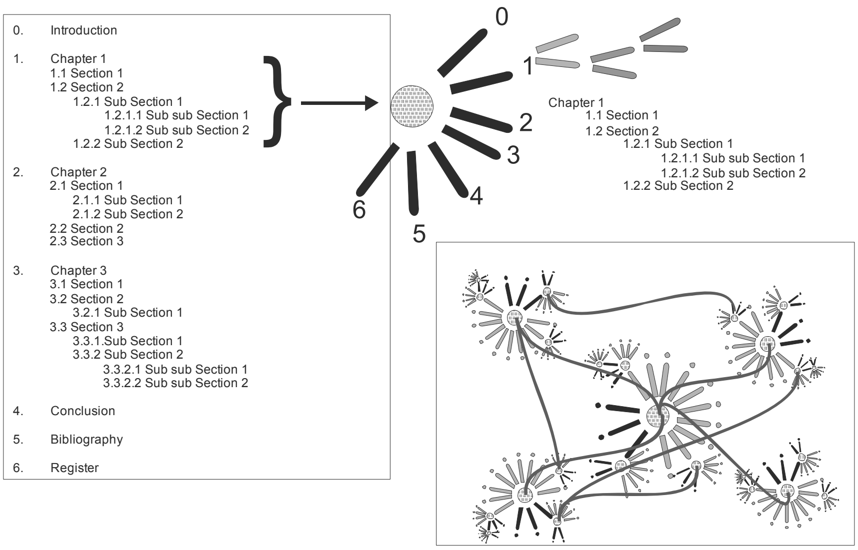


Fig. 4. Structure of a textbook compared with the structure of sentence analysis

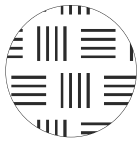
Repeating Patterns

As a result of combining the ‘Powers of Ten’ and the ‘Lines of Life’ and the ‘Material for Sentence Analysis’, a teacher can use easily understandable and transferable frameworks to study our complex Cosmos as a whole. No matter how complex elements of our universe are or how deeply we zoom-in on the smallest details, we are never lost and never lose sight of the whole.

But there is even more that we gratefully use in education!

When we are questioning space and time, the repetition of patterns supports a child in establishing their relationship with the world. It is not a coincidence that we find repeating patterns in human language that are similar to patterns in the Cosmos. If we study space and time with children, we see one thing all the time: there is always ‘development’. ‘To develop’ is – in linguistic terms – a verb and, in reality, it is an activity or energy. How about the origin of everything, the Big Bang? What an activity! What an energy! With the material for sentence analysis of Maria Montessori we can make a linguistic representation.

The linguistic representation of a predicate is:



As time progresses, a subject is created from matter. The linguistic representation of the subject is:

And then there is meaning!

There is a linguistic sentence formed by a subject and a verb. There is meaning, what we, humans, see as the connection of energy and matter. (In Dutch we have the same word for 'meaning' and 'sentence' – *zin*, which makes this comparison more beautiful!)

Wherever we look in the Cosmos, there is always the beginning of something. In the physical universe, this often occurs under the influence of gravity, while it takes place through attraction forces in the living universe. The interaction of these things and forces lead to 'something new' being created all the time.

As humans, we can duplicate this process of creation in space and time, and then express it in language. Fig. 5 can be seen as a highly simplified picture of this evolution in space and time, where the greatest circle represents the Cosmos that repeats itself.

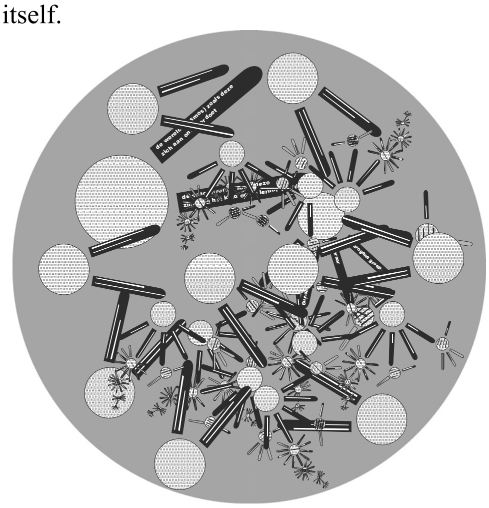


Fig. 5. Simple representation of the recurrence of development in space and time

The Prepared Environment

The teacher takes the child into a grand and universal story, helping to guide them through their developing relationship with the world by encouraging them to look at and to understand space and time. They provide a rich environment for the children, including books, maps, charts, illustrations, selections from the Internet, movies, art and other source materials. This 'prepared environment' for teaching, research and study encourages children to do their own investigations and find answers on their own (Fig. 6). The teacher utilizes four key planning principles, which constantly interact with each other.

1. The cosmic order, which fits with overall time and space.
2. The social order, consistent with conditions and covenants in our society.
3. The biological order, consistent with the biological development of children.
4. The personal order which suits the individual child.

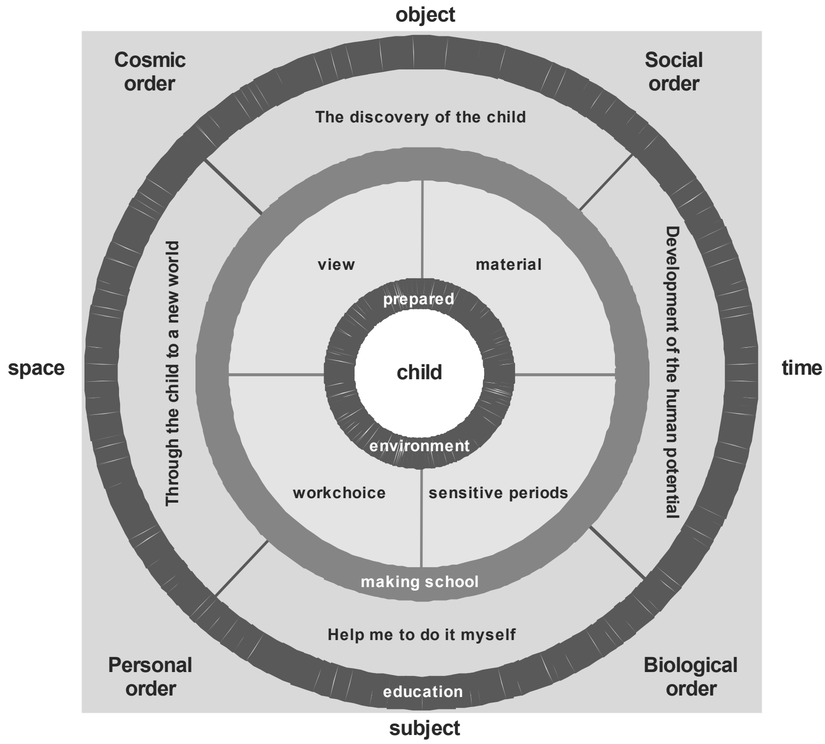


Fig. 6. The prepared environment with the starting points of Maria Montessori

The Portfolio

The teacher follows the child's development and helps them to create a 'masterpiece' for each subject. This masterpiece is an embodiment of the child's thinking about a given topic. It illustrates what the child has learned in a beautiful way, and justifies the work to the teacher and their fellow students. During their time in school, each masterpiece is saved in a portfolio. The portfolio embodies the child's pride in achievement; it is a collection in which their development is visible through images, language and in every way that the child wants to express himself, both physical and digital. This could include a 'dance of the Big Bang', for which a movie is made. It is not about comparing, but serves to represent what the child has made on their own, showing what they have come up against and how it has been resolved. It therefore represents the child's own strengths. The kids present their portfolios to each other, and so get a chance to see that everyone has made something different, something characteristic of their own selves.

Making School

I described earlier how, when we make the journey through space and time, all learning appears to be 'natural'. Using the 'making language' tool, as shown in Fig. 5, it is not difficult to make choices among essences (the smaller striped circles). If we look in this way at the *Line of Everything* (Fig. 2), without even pretending to be exhaustive, we see things that are normally not integrated into or even offered in traditional primary education:

- the Big Bang;
- gravity, the binding force of the cosmos;
- matter;
- aggregation states of matter;
- formation of galaxies;
- life cycle of stars;
- our solar system as a product of a second generation star;
- geological processes on Earth.

In the same way, we meet such essential development if we inventory the other timelines or when we investigate the journey through space with Kees Boeke. With the help of the structure of our language, which follows repetitive patterns of the Cosmos, it is pretty simple to identify and to select basic curriculum for basic education, as well as to offer it in an integrated and narrative format. For the child such an integrated presentation in story form is a very logical approach.

A teacher can have confidence that the repeating patterns, which they had previously encountered in the *Lines of Everything* will appear in the other Lines. For example, in the *Line of Life*, this appears as:

– the *Line of Humans* shows human self-awareness;
– the *Line of Culture* shows the results of human self-awareness;

– the *Line of Myself* shows the individual child as a repeating pattern of the Cosmos, with strength, self-awareness and a capacity for planning, research and building.

The child gets the opportunity to develop their own individual potential through a free choice of work within a well-prepared environment, in which the teacher is the guide for them to 'do it by yourself'. And 'appearance' is always surprising!

Now, from the point of view of a teacher, we get a number of important points to consider.

• The holistic structure of the topical frameworks, along with repeating patterns, gives the teacher and children a chance to comfortably contemplate things within the complexity of everything.

• The teacher and child learn how to deal with new situations in later stages by having learned from previous situations.

• Studied choices reinforce the teacher and the child in making new choices.

• The teacher and the child will never lose their way.

• For the teacher and the child it is pleasant to find out that they cannot know everything, but – at the same time – they have an overview of what they do not know yet, and this consciousness can be very stimulating for their later studies.

I see the investigation of relationships and connections that occur in our Universe to be the main task of good teaching. They can give us answers to all questions. It is important that school is therefore open to the Cosmos as a whole, as one great whole that we are part of. It is not for others to place any fence that can separate us from other knowledge. Everyday we consider the knowledge of today, the things that really matter: everything is there and everything should be there too so we can make our choices. No one should put on the brakes! Without limiting in advance, humans have a greater chance to find answers for tomorrow. Thus we can arrive 'through the child to a new world'!! (Montessori 1953)

Finally

The remarkable thing is that the teacher tells a universal story and that story will be different with every teacher, but uniform and universal. It requires the teacher to be very careful. The teacher does not have to know all the answers – s/he knows the ways to find an answer! And the child is not questioning the teacher, but questions time and space. There is room for the teacher to tell about 'not knowing' things. The point is obvious that a teacher does not know everything and that s/he is searching too. Answers are examples. The teacher has set an example for the child. S/he is also an example of working together. If you work together, everyone can gain new knowledge and together know even more!

In this context, I like to share some quotes from two of my sources of inspiration.

> Let us give the child a vision of the entire universe. The universe is a reality and an impressive answer to all questions. We will investigate the path of life together, but all things are part of the universe, all are linked together into a comprehensive unit. This image helps the mind of the child to focus, to stop wandering around in an aimless quest for knowledge. It is satisfied, it has the universal center of himself and all things found. It is essential to address the interest of the child at a center point. The methods commonly used today, are not effective. How is it possible that the spirit of a young person stays active and interested as all of us remain engaged in teaching a particular subject with a limited scope and limited to the transfer of knowledge with those little details that he is able to learn by heart? How can we force the child to be interested as interest can come only from within? Only obligation and fatigue may be induced from the outside, never interest! Let this be very clear (Maria Montessori 1947).

In fact, we can imagine the best the pattern that connects as a dance of interacting parts.

And a powerful thought that he formulated in a letter complaining about the shortcomings of Western education:

> Break the pattern that connects the curriculum and inevitably you destroy all quality (Gregory Bateson 1979).

Thinking about the last words of Gregory Bateson, I dare to say from experience that, especially since the time of writing forty years ago, still not much has changed in education. Bateson calls this stagnation a 'contagion of teachers'. Great thinkers of the past have stimulated me, often in opposition to the uncomprehending or indifferent attitude of my own colleagues. Their statements read like poetry (Weate and Lawman 1998):

• Socrates (469–399 BCE): 'Ignorance is the only evil'.

• Aristotle (384–322 BCE): 'There is something wonderful in all natural things'.

• Descartes (1596–1650 CE): 'I think, therefore I am'.

• Spinoza (1632–1677 CE): 'Joy can never be too much'.

• Kant (1724–1804 CE): 'Two things fill my mind with ever increasing admiration and awe, the starry heavens above me and the moral law within me'.

• Wittgenstein (1889–1951 CE): 'The limits of my language are the limits of my world'.

• Sartre (1905–1980 CE): 'A man makes himself'.

• Maria Montessori (1870–1952 CE): 'Help me to do it by myself'.

The (still very conservative) acceptance of Big History in the scientific world and the establishment of the International Association Big History is encouraging. It gives me extra motivation to promote Big History and Cosmic education as a liberating and potentially very strong alternative in education.

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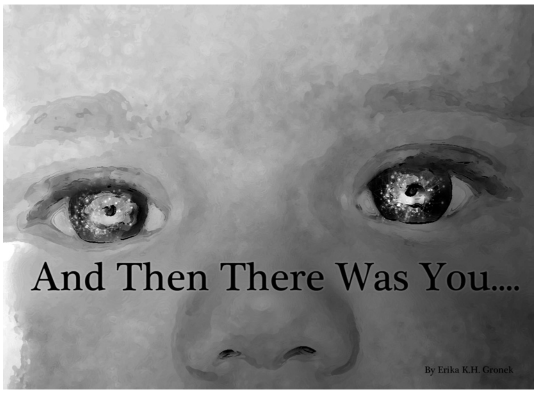
15
And Then There Was You…: A Children's Story of Science and Emotion

Erika K. H. Gronek

Abstract

This essay describes the background to the writing of the children's book 'And Then There Was You...' In addition, the multiple layers of the story that go beyond a child's initial comprehension are deconstructed. The book in question hits upon many of the themes of the Big History movement in academia.



And Then There Was You... (2010a, 2010b) is a story about everything. It was a story written and illustrated for my son about 6 months after he was born. One sleep-deprived night I nursed him in a rocking chair while pondering the design of his room. I had decorated the top half of the room with Maxfield Parrish-styled clouds and a layout of the summer constellations set in glow-in-the dark paint on the ceiling. I wanted this design to say: 'the future is wide open' and 'there is nowhere else to go but up'. The border of the room had wall paper that was a replica of a Victorian time-chart of all of human history. It started with Adam and Eve and was up-dated with the on-goings of the present day. Staring into my son's eyes, I pondered all of the events that had to take place for all of his atoms to be aligned into his tiny form. That is when I decided to write and illustrate a children's book that accidentally hit upon all of the major themes contained in 'Big History'.

I wanted my son to have a firm grounding in understanding where he came from. My quandary was where to start. There was always something that came before. I had no choice but to start at the utmost beginning – the Big Bang. Out of blackness, came something. It was binary. On or off. Either something existed or it did not. I was about to shove the deepest arguments that some of the world's best philosophers, thinkers and theologians could come up with into a children's book.

The first page I illustrated was black with a white hot explosion in the middle, captioned by the solitary word: 'Spark!' It does not answer any questions, it only creates them. The reader will have the rest of their life to ponder that one page. Is it simply the mechanical spark that created the Big Bang? Where did it come from? What, if anything, came before it? Or is the spark divine? It works either way depending on the reader.

After illustrating the formation of our solar system and our planet, the spark returns again. This time the spark is in the form of lightning and it is setting off the chain of events involved in starting life with the raw materials of carbon, water and various molecules and amino acids. One-celled organisms are illustrated, followed by a jump in the timeline to the time of the dinosaurs. This is my son's favorite part, and it causes him to roar.

Life occasionally has die-outs though, so the Cretaceous-Tertiary event is depicted with a giant meteor heading for the Gulf of Mexico. A small, fuzzy mammal survives, looking a bit traumatized. Life recovers and is represented as a phylogeny that is constructed out of photo-montages. This family tree starts with one-celled organisms and leads up to one of the highest branches, showing a man and a woman looking much like the ones etched on the side of the Voyager 2 satellite.

The rise of humanity is ignited with another spark. I photo-manipulated an image of my own hands to look like the dirty and weathered hands of presumably a *Homo habilis* smashing flint together and making a spark for fire. Language, writing and farming images segway into a map that explains the human diaspora out of Africa and the rise of human civilization.

A new phylogeny image morphs into a large family tree by the next page, displaying a variety of primates and the generations leading up to one family and one union. The final page combines science and emotion in the form of a sleeping baby. One is left to ponder all of the steps that had to go right in order for that one little life to exist. Life is complex. I want my son to understand that. There are books out there, such as *Of Pandas and People: The Central Question of Biological Origins* (Davis and Kenyon 1993), and then there were the school board hearings in Topeka, Kansas, which espoused the idea that evolution is too complex to be true. Evolution is complex, beautiful and profound, as well as mostly accidental and logical. Once one understands that, then the natural world makes sense.

Needless to say, this children's book has many layers that adults will enjoy. Children, however, will be dazzled by the images and – with the help of their parents – it can help explain where they came from. ‘Where did I come from?’ It is not an easy question to answer if you want to be accurate and thorough. I remember playing the question-game, ‘What came before that?’ with my mother. The poor woman was exhausted by the endless questions, but she made her best effort to answer them!

I hope that my son will cherish the keepsake I created for him. I used my talents of graphic design, photography and photo manipulation to create the story that I self-published for him. I even photoshopped snippets of images from the zoo, pictures of him, pictures from our back yard and images of his ancestors into the piece. I hope he tells his grandchildren about these ‘Easter eggs’ that I left behind for him to search for. The book lays the ground work for understanding the world, along with a fascination for science and, potentially, philosophy. There is truth in both art and science, and I hope I included some of it.

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16
Brain Stretching: Art and Big History

Paula Metallo

Abstract

'The particular combination of art and geology is nothing new. It was customary for geological surveying teams to include at least one artist. One great example is the artist, geologist and writer, Clarence Edward Dutton. His accomplishments remind us that we have fallen into an age of specialization. In order to deal with a universe expanding at an incredible rate we have a tendency to rely more and more on specialists with narrow shafts of knowledge and skills. And while specialists are necessary, the tendency to depend on them to the exclusion of all is dangerous. Somebody must integrate and synthesize what we know about ourselves and the world in order to prevent social, cultural, and even personal fragmentation'. Richard Shelton wrote this as the introduction to the book Art and Geology *(1986). It clearly describes, already twenty-five years ago, the objectives of this article to express in what ways Art can be a means of describing pattern and encourage openness to stretching the brain to comprehend inter-connectivity, and how Big History has the tools in hand to help implement a whole picture, interdisciplinary approach to learning.*

Art, as well as ideas about art, can be shaped by new places – just as people can be shaped by such experiences. Relating to and exploring other ways of seeing things ultimately lead to the addition of a new weft in the fabric of our human existence. Educator Micheal Schneider describes the progression in *A Beginner's Guide to Constructing the Universe*:

> Today we are emerging from the grip of literalism, mere quantitative measurement, and analysis. Where we saw 'things', nouns and objects instead of 'processes'. The Hopi language retains this vision, having no nouns. (I am not wearing a shirt, I am 'shirting'). Likewise our word 'cosmos' refers to 'outer space'. But the word derives from the Greek Kosmos (signifying 'embroidery'), which implies not a universe like a huge room filled with disconnected noun-things but the harmony of woven patterns with which the universe is embroidered and moves (Schneider 1995: xxiv–xxv).

To me, the most fascinating aspect of modern culture and Big History is the awareness of interconnectedness, the weaving of everything together on our planet and beyond, providing a new place to contemplate.

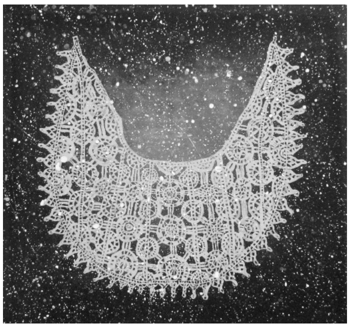

Fig. 1. Paula Metallo, Italy, *Kosmos*, acrylic on silk, 60x60 cm

Our Universe demonstrates this perspective, which today's communication systems imitates, allowing us the vantage point from which to appreciate the fullness. Anything anyone can point to in nature is composed of small patterns, which are part of large ones. The new age of communications can provide us, no matter where we find ourselves, with a means of transcending our own patterns, of standing back from a mosiac. Over 1500 years ago, St. Augustine of Hippo wrote in his dialogue *De ordine* I(2):

> If someone had a vision so restricted that, on a floor covered with vermicular mosiac, his gaze could take in no more than the width of a single tessera, he would accuse the artisan of not knowing how either to order or arrange his materials, and would believe the variety of stones utilized to be nothing but a confused jumble – all because of an incapacity to see and grasp how the whole picture in it's fullness and harmony constitutes a single and beautiful image.[1]

This brain-stretching distance allows us to pick out patterns, and then sample and compare supposedly disparate things, elaborating upon them, sometimes combining them gradually and imperceptibly into each other, and at other times just setting them side by side. Above all, this 'standing back' pushes us to feel the scale and the way in which we consider ourselves in relation to the world.

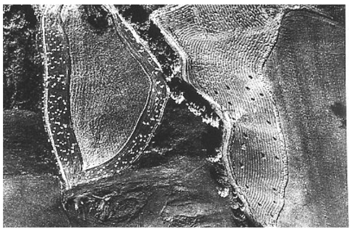

Fig. 2. Mario Giacomelli, Italy, *La Terra*, 1954

[1] See Fig. 'Particular, mosaic, Pompeiano, year 79 CE' in the electronic version of the Almanac at http://www.socionauki.ru/almanac/issues/evolution_2_en/#metallo

I experienced this personally as an American living in Europe. The interconnectivity and ease of worldwide communications has changed the experience of the immigrant or expatriate, as well as that of their host communities. The result is the widespread seeding of individuals, with cross-cultural backgrounds in many countries, who are trying to find ways to join the new without giving up the old, trying to unify geographical and historical extremes, trying to place and display past atrocities, and trying to reveal as visible the things that were once invisible. It is a critical correspondence between global and local with enormous creative potential.

Fig. 3. Paula Metallo, USA, *Place*, acrylic, 1995

We, artists, today believe that we are at the cross-roads and the time of dynamic change in how we privilege the optical. Art continues to evolve modes of expression and integration of perception beyond the visual. As video artist Bill Viola remarks:

> Fifty years from now I do not think optical reality is going to be an issue in visual communications anymore. Experience is so much richer than light falling on your retina. You embody a microcosm of reality when you walk down the street – your memories, your varying degrees of awareness of what's going on around you, everything we call the contextualizing information. Representing that information is going to be the main issue in the years ahead. We are beginning to shift into a category of information itself as the main conveyor of reality. And the transition periods, when the truth becomes embodied in multiple conflicting forms, are always the most interesting.[2]

[2] A version of this appears in Photoquotations.com: http://www.photoquotations.com/a/707/Bill+Viola.

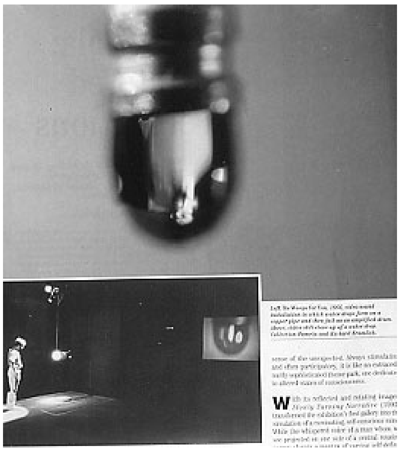

Fig. 4. Bill Viola, USA, *He Weeps for You*, Video, 2003

Our perspective is linked to understanding through gateways not limited to the eye. How the world meets our mind, how fast we feel time, and how we digest the pressing, continuous stream of suggestion and information coming at us are also issues for artists today. Mark Kingwell, in 'Fast Forward', an article from *Harper's Magazine*, compares the ecstatic speed of the human in a machine with that of the euphoria of a running human:

> The man behind the wheel feels nothing but a mindless; futureless impatience, a desire to go faster that exists only in the present... The running man feels the many past, present, and future costs of speed, the burning of his lungs, the fatigue in his legs. He must play mind games with himself, set intermediate goals, and then set new ones, knowing that eventually he will reach a point where the pain slips away (Kingwell 1998).

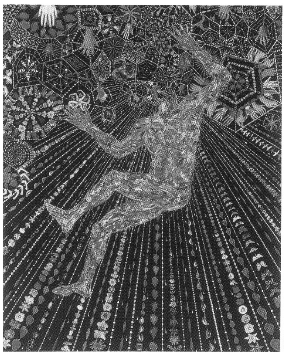

Fig. 5. Fred Tomaselli, USA, *Ecstacy and Altered States*, leaves and collage, 2005

These interactions that condition us as spectators of art raise questions of process for the artist and for others teaching and sharing knowledge and viewpoint, especially from a Big History perspective.

While considering these challenges to the human spirit and the meaning and purpose of art, I remembered a parenting book I used to consult periodially, *Raising Good Children: How to help your child develop a lifelong sense of honesty, decency, and respect for others* by Dr. Thomas Lickona, a developmental psychologist:

> There are two basic ways to relate to a child's stage of moral reasoning. 1) You can go with the flow, or 2) You can challenge it. When you go with the flow of a child's present stage of reasoning, you meet them where they are. You try to get their cooperation by talking the language of their stage, by fitting into the way they think about the world. When you challenge a child's present stage of reasoning, you try to get them to look at the world in a new way. You make them work at the cutting edge of their minds. You make them reach and stretch. If we were always challenging our kids to develop, we would wear them and ourselves out. If we were always accommodating, they would have no reason to develop. Both approaches are essential (Lickona 1994: 99).

Environments for learning that incorporate the tension of accommodation and challenge to facilitate the expansion of human perception are needed.

Fig. 6. Paula Metallo, USA, *Education Begins in the Home*, 1992

The Osservatorio Geologico di Coldigioco (Geological Observatory of Coldigioco) in the Marche region of eastern Italy serves as such a place. It is an interdisciplinary laboratory where science and the arts connect and cross-pollinate. The processes and perspectives of both are honored in our class content and experiences. For example, when I taught drawing to our geology students from Carleton University, I considered how to approach scientific thinkers in a way that would allow them to learn how to draw more accurately. Beginning with anatomical drawing exercises, I built on their already existing skill-sets of recording data – counting and measuring lines and angles – that they had honed in stratigraphy classes, as well as their sharply developed skills of scientific observation. Geology's perspective includes an awareness of deep time. Comprehending millions of years, instead of mere hundreds or thousands of years, means that there is much data to incorporate. Reconciling the 'slow motion' of mountain growth with the idea that everything is in constant change opens an exploration of the expression of what is impermanent and enduring.

Fig. 7. Aernout Mik, Holland, Insite 05, *Osmosis and Excess*, 2005

Challenging students at Coldigioco to utilize their scientific perspective to create art has been a rewarding and productive experience. You can see a sample of our efforts on the website and blog, *Geology in Art*, at http://www.geologyinart.blogspot.com/.

I would advocate that an art museum is a forum for exhibiting new things, while accommodating and challenging the human spirit to grow. A viewer's subjectivity can be honored, with all its idiosyncrasies, while it is expanded beyond current cultural and existential presumptions. The museum can be a setting in which our skills as 'art storytellers' can be nurtured through interaction with the exhibits, guiding us through historical and personal processes, showing us where we may be headed.

Studying only our history as living things on this planet is like observing no more than the width of a single tessera in a mosiac. Adding the history of our planet in the universe challenges us to expand, reach out and position ourselves more appropriately in the whole beautiful picture. The role of art is to accommodate and challenge us to trust our personal responses, feed our curiosity, and encourage openness to stretching the brain to comprehend this interconnectivity. Through art we can become active describers and comparers of our stories, illuminating our small, patterned part of the Universe.[3]

Fig. 8. Doris Salceda, Brazil, *Our Place in the Universes*, 2003

[3] Appreciation is expressed to Penelope Markle for editorial assistance.

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17
Big History and Bioregions

Gary Lawless

Abstract

Bioregionalism and Big History are part of the new way of looking at our homes and at the Cosmos that is unfolding around our planet Earth today. Bioregionalism is Big History in action. This writing shares some views of a bioregionalist poet about Big History from his home.

I grew up in the north-east corner of the United States, in the State of Maine, in a coastal town called Belfast. The ocean touches the land there, and that particular body of saltwater is called the Gulf of Maine. The Gulf of Maine touches three states (Maine, New Hampshire and Massachusetts), as well as two Canadian provinces (New Brunswick and Nova Scotia).

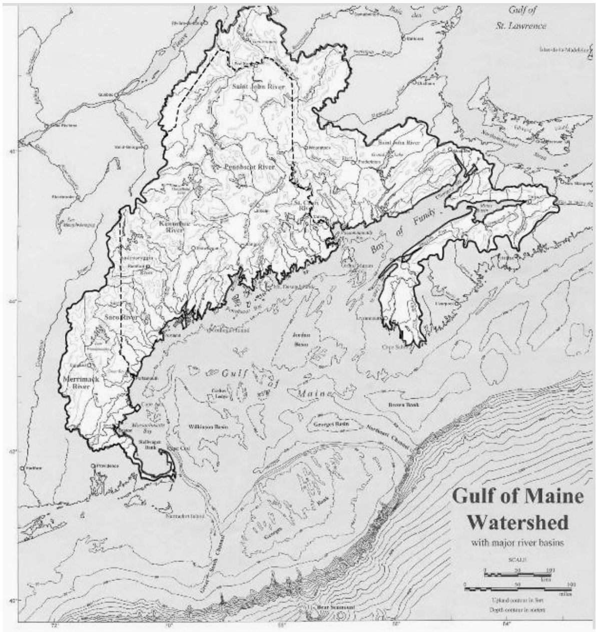

Fig. 1. The Gulf of Maine Bioregion

When I was growing up, the newspapers, radio and television reported about Maine news, and – on weekends – Maine and New England news. We had no idea what was happening in New Brunswick and Nova Scotia, even though we were connected with them by land, air and water. We did not know what was happening in rivers, forests, lakes and ocean in the other states and the provinces. We rarely knew what was happening among animal and plant populations, especially among those for whom we were a stop along a much larger migratory route.

During my high school years, I became interested in the earlier human inhabitants of the region, the pre-European populations who lived here. Their place names were so much different from ours. The names seemed functional – if you learned their names of the places along the river, you would know where you would need to carry around the rapids, where the sturgeon came, where people gathered to harvest clams or to smoke fish. A map with indigenous place names became your guide to what was happening on that part of the river, in the forest or along the shore. If you had the place names in your memory, you could survive in those places. You were informed by the place names, and learned much about the region from them. The region seemed to be defined more by rivers, portages and seasonal food sources than by lines on a map. There were no international borders requiring passports, no arbitrarily drawn lines on the map.

As I also became interested in forest ecology activism, I learned that the forest stopped at none of the human borders. The woods of northern New England and eastern Canada were being assaulted by the same multinational corporations using clear-cutting, along with herbicide and pesticide applications to destroy the natural forests of the region and replant them with a monoculture suited for the pulp and paper industry.

We heard about the nuclear power plant in Maine, and of the one in New Hampshire, but much less often about the nuclear plants in Massachusetts, and pretty much never heard about the Point Lepreau nuclear plant in New Brunswick.

We did not think that much about who was upwind of us, until it became clear that acid rain was poisoning Eastern lakes and forests, and that the pollution was coming to us in the wind from coal-burning power plants in the Midwestern United States. We did not think about who was upriver, until the dioxin in the fish helped us learn about the chlorine-bleaching process being used by paper plants upriver in Maine and New Hampshire.

I wanted to somehow have a wider sense of place, a larger sense of Home.

In 1973 I traveled west to live in northern California at the home of poet Gary Snyder as his ‘poet's apprentice’. The Big Idea that summer was bioregionalism, and there were many conversations trying to really nail down what that meant. People were looking for ways to define their home, their place, their community, in ways other than the arbitrary lines put onto the map by humans to create states, countries and political units or ways to collect taxes and enforce laws.

We were looking at the maps and trying to find other ways of defining who we were, and where we were, in the world. We were looking at rivers and mountains, oceans and deserts, plant and animal ranges, watersheds and plate tectonics. The first education in bioregionalism came in trying to define your own region. In order to come up with an informed answer, you really had to learn a lot about where you were. Where did your water come from, and where did it go? Where did the wind usually come from? Who are the local plants and animals, where does the forest mix change, what is over the next ridge?

We started seeing ourselves as citizens of biological communities and, as good citizens, we had to learn to live well within those communities. How do you live within the bioregion as a good citizen? – this involves learning as much as you can about the natural cycles of the place where you live, and learning how to live as a part of those cycles, as a part of that community. This is an ongoing, lifelong education.

Several decades into bioregional education, I started thinking about all of the species who pass through my bioregion, the great migratory tribes whose lives pass through my region on their way to some other place, at one time of the year or another. Their home regions cover a much wider range than my own. Here on the lake, we welcome the loons, the eagles and osprey, herons, bobolinks and so many more. We watch for turtles in the road. We welcome the alewives as they swim from the ocean into our lake, through a series of newly-built structures, human-made to assist them in their journey.

Fig. 2. Fish ladder and resting pools for alewives along the Damariscotta River (Maine). Photo by Barry Rodrigue, 2009

We look to the milkweed in late summer for monarchs, rising up to make their journey to Mexico. As a bioregionalist, I want my own bioregion to continue to provide the shelter and sustenance these travelers have found here, but now I feel that I must also be concerned with the rest of their journeys, the flyways, the migratory paths and ocean routes, all of the places where they stop to feed or rest – the places that are fast disappearing due to human use. Through these travels, as well as the movement of wind and water, my bioregion extends to the boreal forests, the songbird destinations in South America, the Sargasso Sea, all of the many parts of the world to which my home place is connected by movement.

The bioregion is fluid. Water, air and life flow through it every day. Plant populations change, animal populations change, human populations change. The climate changes, everything evolves, plates shift and light passes through.

My poet friend Nanao said that his bioregion was the Milky Way. He hoped to plant trees on Mars while hiking the length of the Milky Way. Our Universe is expanding. As we look out from our own bodies, we find that our connections reach farther and farther.

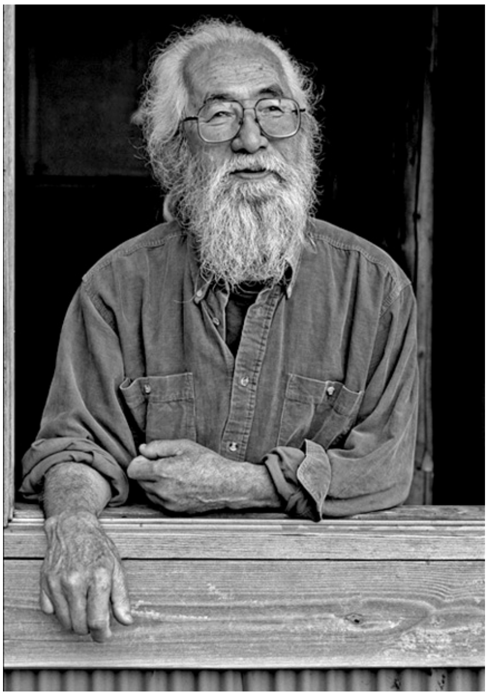

Fig. 3. Nanao Sakaki

The Big Idea here is Big History, and I am wondering what we do with it as individuals. How do we live our lives as citizens of Big History? It seems to me that living with a bioregional ethic gives us such a way. We can embrace Big History, but learn to live locally. I can think about my region back when the granite was liquid, when the glaciers covered the land where we live now, when caribou were here, when no European had set foot on the land, when there was no acid rain, when the waters were full of fish, or I can try to think back (or ahead) to a time when this planet did not exist… but there was matter, moving in ways that I do not understand.

I want most to learn how best to live as a citizen of a biotic community, how to be a partner in the natural workings of that place, and to lead a life informed by a growing understanding of the multitude of cycles and forces within which I am living. Bioregionalism brings me to that hope, to that way of seeing myself on this planet. Big History extends that hope to the ends of the Universe and beyond.

I came from the sky
green amber inside
the meteorite
then I was lichen
what the ice remembers
the taste of granite
what do the stars know

18
A Little Big History of Tiananmen*

Esther Quaedackers

Abstract

This contribution aims at demonstrating the usefulness of studying small-scale subjects such as Tiananmen, or the Gate of Heavenly Peace, in Beijing – from a Big History perspective. By studying such a 'little big history' of Tiananmen, previously overlooked yet fundamental explanations for why people built the gate the way they did can be found. These explanations are useful in their own right and may also be used to deepen our understanding of more traditional explanations of why Tiananmen was built the way it was.

Introduction

Big History, as its name implies, aims to study all of history, from the Big Bang until today. A Big History perspective therefore enables us to integrate knowledge from disciplines, ranging from Astronomy to the Social Sciences and the Humanities into a unified large-scale overview. Big History, however, does not only allow us to create a large-scale overview; it also enables us to study small-scale subjects in new ways. When studying small-scale subjects, applying a Big History lens can help us to focus on the most fundamental patterns that underlie certain processes. These patterns can sometimes be easily overlooked, exactly because they are fundamental; they can seem ubiquitous and as a result not very special and not worth exploring. This may be particularly the case in certain Social Sciences and the Humanities. In such fields of study, many remarkable details abound that can attract attention much more easily than ubiquitous patterns can. Therefore, studying small scale subjects from a Big History point of view, or in other words, studying 'little big histories', may be especially useful in these disciplines.[1] I would like to try to demonstrate this usefulness by analyzing a single building with the aid of Big History.

For this purpose, I could have selected any building. For practical and personal reasons, I chose Tiananmen, or the Gate of Heavenly Peace, in Beijing.[2] This choice is a practical one, because, due to the gate's iconic status, many

* I would like to thank Marcel Koonen, Fred Spier and Barry Rodrigue for commenting on this article.

[1] The term 'little big history' was coined by Fred Spier.

[2] Throughout this article, I will use the Pinyin system to transcribe Chinese characters.

readers will be familiar with it. Tiananmen is also a personal choice; ever since I first visited China, I have been wondering about the reasons for the differences between traditional Chinese and European architecture.

Fundamental Patterns

A little big history of Tiananmen has to start with the observation that the building is extremely special. Tiananmen is not only a remarkable building; the fact that it exists as a building is extraordinary. Buildings are a very rare product of nature. They are only constructed by living things, since only living things actively create environments that are beneficial for their own survival. Life is very scarce in our Solar System and probably even scarcer in our Universe. Furthermore, not all of these scarce life forms actually build things.[3] Most famously, insects, spiders, birds and a few mammals build, but many other organisms do not. Why would these animals build whereas so many other species do not?

The answer to this question may be quite simple. The reason why few life forms build may be that building can be expensive.[4] The act of building itself can require a lot of energy. Moreover, there are hidden costs to building that can add up quickly. Using buildings can be costly, particularly for animals that roam wide areas to find enough food. If these animals build stationary structures, they may need to spend a lot of energy either travelling large distances in order to reach and use their buildings, or rebuilding their structures frequently. If they build mobile structures, they may need to spend large amounts of energy moving them around. The ability to build can be costly as well. For instance, learning how to build may require energy in the form of time, effort and larger energy consuming brains.

Because building can be expensive, in many situations there may be cheaper ways to deal with certain problems. Organisms can, for example, grow fur or produce antifreeze proteins (Ebbinghouse *et al.* 2010: 12210–12211) in order to protect themselves from the weather, instead of building a shelter. They can grow spikes, produce venom or simply flee to protect themselves from enemies, instead of building a protective structure. They can grow claws to catch prey, instead of building a trap. Or they can grow colorful feathers or behave aggressively to impress members of their own species, instead of building an impressive structure. Only in some situations, can building be the best option. It seems to me that there are three types of situations in which it can be worthwhile for animals to build.

First of all, building can be a good idea for animals that frequently stay in a specific place. Such animals do not need to spend lots of energy travelling to

[3] By building, I mean creating structures that are relatively large compared to the builder's body and are not permanently attached to the builder's body.

[4] This answer was inspired by the energy approach to Big History, developed by Eric Chaisson and Fred Spier.

and from their buildings, rebuilding, or moving buildings. This may be the reason why birds or mammals that need to protect immobile offspring often build nests or other structures. In contrast, animal species that have mobile offspring seem to spend much less energy building elaborate structures. Rabbits that give birth to altricial young, for example, dig extensive burrows, while hares that produce precocial young do not build much. For more or less sedentary animals, such as certain eusocial insects and beavers, building may be worthwhile as well. For these animals, building is not only cheaper than for most other creatures, it is also more necessary. Organisms that stay at a fixed point can become an easy prey for predators once predators have found them. Moreover, being sedentary often requires food production or storage in the vicinity of the living location. Some bees for example store honey in combs, certain termites maintain fungi garden, and beavers build dams to create ponds full of fish. Such food supplies can attract thieves and can therefore create an even greater need for the sedentary animals to protect both themselves and their food. Because of the lower costs of and greater need for building, sedentary animals build pretty complex structures such as beehives, termite mounds, and beaver dams and lodges.

Secondly, building can be a good idea for animals that standardize their building routines. As pointed out by the British zoologist Mike Hansell, animals that do so do not need large energy-consuming brains (Hansell 2007: 71). The building behavior of certain caddisfly larvae can serve as an example. According to Hansell, the larvae start building by picking up any sand grain they can handle. Subsequently, the larvae perform two fixed tests to determine if the sand grain has the right shape and size. Only sand grains that pass these tests are used as building blocks for the larvae's houses. As a result, the larvae do not need to think about which sand grains they should select for their houses. They also do not need to think about how they should assemble their houses. Because they always use the same building blocks, they can assemble their houses the same way every time. Because the standardized building behavior of the caddisfly larvae is subject to evolutionary pressures, over the course of time the animals will start choosing the most suitable building blocks and applying the best assembly method. There is no need for the larvae to think about the best ways to build. Evolution thinks for them.

Animals that build with their own excretions have taken building standardization a step further. Just like the caddisfly larvae, they do not need to evaluate potential building blocks or think about assembly strategies, and therefore they do not need expensive, large brains. Additionally, the animals do not need to spend energy searching for and collecting building materials (Hansell 2007: 71). And, most importantly, over the course of time, the most energy efficient building excretions will evolve. Silk is perhaps the best example of such a remarkably energy-efficient building secretion. Silk enables all kinds of insects and spiders to build very strong cases and webs with relatively little material. Because such little material needs to be produced, building with silk is not too costly. Some spider species have reduced their building costs even further by recycling silk proteins; they eat their own webs after they have used them (Opell 1998: 621).

Lastly, building can be a good option for animals that use their structures as signals of fitness. Animals that do so, do not build in spite of the costs of building but because of these costs. By spending energy on buildings, and particularly on buildings that do not directly enhance their survival chances, they show other animals that they are fit. Or, in the words of the Israeli evolutionary biologist Amotz Zahavi: 'The behavior suggests that if an individual is of high quality and its quality is not known, it may benefit from investing a part of its advantage in advertising that quality, by taking on a handicap, in a way that inferior individuals would not be able to do, because for them the investment would be too high' (Zahavi 2003: 860).

Birds that build bowers may be the best example of animals that use building as a signal of fitness. Certain male bowerbirds build a maypole on a moss platform and often cover it with a large hut, which may weigh tens of kilos (Gould and Gould 2007: 234–244). Next, they collect up to hundreds of flowers, berries, fungi, sticks, stones or other conspicuous objects. They arrange these objects by type and color, and display them in and around their construction (Vogelkop bowerbird, see BBC – Wildlife Finder). The birds maintain their display with great care. They replace old objects with fresh ones and vigorously defend their bowers against other male birds' raids (Diamond 1988: 648). Obviously, construction of the bower, as well as its display and maintenance, requires tremendous amounts of energy. Developing the skills to do so requires energy as well. According to Hansell, juvenile male bowerbirds spend a lot of time studying how to build a proper bower and display. They work together on constructing the basic bower elements, construct partial bowers and dismantle them again, and they observe older males building-behavior and their bowers (Hansell 2007: 241). Birds that build bowers also have larger brains than birds that do not build bowers; they thus spend more energy on maintaining those brains (Madden 2001: 833). Male bowerbirds spend all this energy to attract a mate. Female birds seem to base their mate choice to a large extent on the male's ability to build and maintain a proper bower and display (Hansell 2007: 240). Apparently, this ability is deemed a reliable indication of the fitness of the male.

In sum, I think that building is rare because life generally only builds when it can reduce the costs of building, by becoming sedentary or by standardizing, or use these costs as a means of communication. Interestingly these three conditions seem to apply to almost all forms of human building. They apply to my own home, which I have invested in because I am there a lot. They apply to the houses across my street, which are decorated with cast iron ornaments that tell people something about the artistic taste and wealth of its builders. They apply to the apartment tower at the end of my street, which is clad with white standardized elements because such elements can be produced and handled efficiently. And they also apply to Tiananmen.

Fig. 1. Tiananmen (photo: Peter Morgan)

Application to Tiananmen

Before trying to explain how the patterns discovered in animal building apply to Tiananmen, I would like to provide some basic background information on the history of the gate (Aldrich 2006; Wu 2005: 56–68; and Zhu 2004). The history of Tiananmen can be traced back to the beginning of the Ming dynasty. In the early 14th century CE, the Yongle emperor ordered the construction of a capital that would later become Beijing.[5] Inside of Beijing, a wall was then constructed around an Imperial City. The southern gate in this wall was called Chengtianmen. This gate was rebuilt by the Qing Shunzhi emperor in the mid-17th century, after

[5] Chinese emperors were given a reign name that differed from the name they were born with. The Yongle emperor, for instance, was born as Zhudi. To prevent confusion, I use emperor's reign names.

it had been burned down following the fall of the last Ming emperor. The gate's design was altered and it received a new name: Tiananmen. Tiananmen was slightly remodeled once more in 1969 and 1970.

In my opinion, the fact that Chengtianmen and Tiananmen were built in the first place can be interpreted as an attempt at reducing building costs in Beijing. Let me explain. Because both the Yongle and the Shunzhi emperors lived in Beijing more or less permanently, the city attracted a lot of people and resources.[6] The city therefore tended to attract enemies and thieves, as do termite mounds, beehives and beaver lodges. For the Yongle emperor, such enemies included the Mongols, whom he was trying to keep out of northern China (Mote and Twitchett 1998: 224–229), whereas for the Shunzhi emperor they included rebel forces whom he had ousted from Beijing as well as some remaining Ming armies (Peterson 2002: 83–89). But the emperors did not only face threats coming from outside their capital. There were threats from the inside as well. The Yongle emperor had made enemies by contesting the mandate of the previous emperor (Mote and Twitchett 1998: 184–205). The Shunzhi emperor had also been at the center of imperial power struggles and had made enemies by starting an anti-corruption campaign and a major fiscal reform (Peterson 2002: 101–116). All these external and internal threats created incentives to build defensive structures. But although the construction of such structures was cheaper for the two more or less sedentary emperors than it was for their nomadic neighbors or other animals roaming wide areas, it was not cheap.

In response to a greater need for costly defensive structures, the emperors may have tried to build a minimum number of structures to the greatest possible effect. They did so by ordering the construction of an elaborate assembly of walls. Because strategically placed walls protect a group of buildings, there is less need to fortify individual structures. This strategy is less expensive, since it requires less fortified surface area. It also provides better security than fortification of individual buildings. Because this arrangement allows for less spaces that are open to the general public, most common people were not able to come close to areas in which important people worked and lived or in which important resources were stored.

I think that it was for these reasons, as well as others, that walls dominated old Beijing. The wall of the Imperial City, with its Chengtianmen (later rebuilt as Tiananmen) was one of these many walls (Figs 2 and 3). It was enclosed by larger city walls, such as those of the Capital City and, to some extent, the Outer City. And it enclosed a number of smaller walled compounds, such as the Palace City (or Purple Forbidden City), imperial parks, important warehouses, and compounds in which princes, officials and important eunuchs lived and worked (Wu 2005: 58; and Zhu 2004).

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[6] During the first years of his reign, the Yongle emperor lived in Nanjing as well.

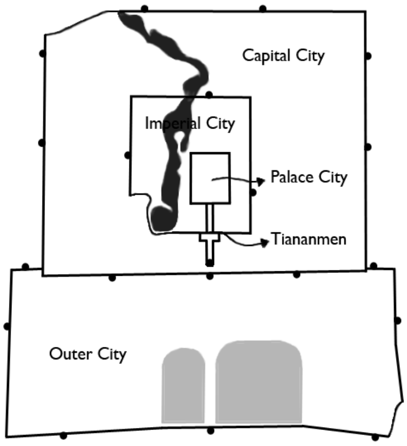

Fig. 2. The walls of old Beijing

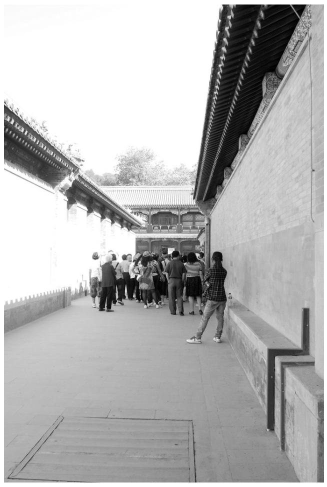

Fig. 3. Inside a walled compound inside the Imperial City (photo: CeciliaC/Flickr)

The emperors' choice to build walls around groups of buildings instead of fortifying individual buildings may have had some important consequences. It may have allowed the Yongle and Shunzhi emperors to use wood as the primary construction material for many buildings within Beijing's walls. In addition, it may have lessened the need to reduce the surface area of buildings within the city's walls. For instance, it may have been less necessary to merge several rooms into one larger or higher building; buildings consisting of only one or a few rooms could remain small and low, thus exposing their users to a maximum amount of light and fresh air. As a result, attempts at reducing building costs may not only have led to the construction of walls and gates like Chengtianmen and Tiananmen, but may also have sparked a building tradition based on relatively small wooden one or two-story buildings. The watchtower that is part of Tiananmen can be seen as a product of such a tradition (Fig. 1).

The idea that the Yongle and Shunzhi emperors combined walls with relatively small wooden buildings in an attempt to reduce building costs in Beijing raises two important questions. Firstly, if the combination was so efficient, why have not builders in many other places and periods used it like the Chinese emperors did? In this respect it is important to note that the ability to build lots of walls requires the authority to plan the construction or reconstruction of a whole city. It seems likely that for this reason, builders in many other times and places have not been able to build as many walls as the emperors in China did. Sometimes these builders could build a wall around a city, but they were rarely in a position to close off larger areas within a city and restrict access to these areas.

Secondly, how can the idea that the two emperors combined walls with relatively small wooden buildings in an attempt to reduce building costs be reconciled with more frequently given explanations for the presence of walls, the use of wood and the shape of buildings in Beijing? The city's walls, for example, are usually regarded as a means to hide power. There are good reasons for thinking that concealing power was important to China's emperors; there are numerous influential texts referring to the need to do so. Laozi, a Taoist philosopher of the 6th century BCE, wrote: 'The instruments of power in a state must not be revealed to anyone' (Laozi, *Daodejing*, from Dovey 1999: 71). And Hanfeizi, a legalist philosopher of the 3rd century BCE, wrote: 'The way of the ruler lies in what cannot be seen, its function in what cannot be known' (Hanfeizi, *The Way of the Ruler*, from Wu 2005: 58). The use of wood is often linked to the value the Chinese attached to the natural orders of materials, in which wood occupied a middle place between Earth and Heaven, which made it the only suitable materials for building vertical constructions (Ronan 1995: 63). Sometimes it is also linked to a lack of value attached to permanence within Chinese society (Boyd 1963: ch. 2). And the practice of constructing relatively small and low buildings is often connected to the Chinese notion that even within buildings, people should be surrounded by nature, in the form of open yards and gardens, as much as possible (Ronan 1995: 46). All these ideological considerations were probably very important to Chinese builders. This does not rule out, however, that cost considerations played an important role as well. The two types of considerations could have easily evolved together. For instance, certain ideological considerations may have been developed to justify certain cost considerations. It would be interesting to investigate such possible links between ideological and cost considerations in more detail.

Combining walls with relatively small wooden buildings was not the only way in which the Yongle and Shunzhi emperors were able to reduce their building costs. Just like spiders and caddisfly larvae, they were able to reduce these costs by standardizing as well. The Shunzhi emperor for instance used bricks to construct the base of Tiananmen (Fig. 1).[7] Bricks could be mass-produced in a process that had become highly efficient over time, just like the production of silk has become highly efficient in the course of evolution. And working with standardized bricks did not require as much skills as for instance working with natural rocks, just like working with standardized sand grains does not require a caddisfly larvae to develop extensive building skills. Working with bricks

[7] I have not been able to find any images of Chengtianmen yet. Therefore this paragraph will only deal with Tiananmen.

therefore did not require highly skilled and thus expensive workers. More interestingly, the construction of Tiananmen's wooden watchtower was standardized as well. Chinese builders relied on a fixed repertoire of columns, beams and construction details (Boyd 1963: ch. 2). For certain types of buildings, only certain combination of columns, beams and details could be used (Guo 1998: 7). Neither drawings nor architects in the European sense of the word were required (Boyd 1963: ch. 2); building was perceived as a rather mechanical task and builders were seen as master craftsmen and not as artists (Ronan 1995: 59). By standardizing wooden constructions, the building process was made more efficient as well. Once they had become part of a fixed repertoire, the proportions of columns and beams, as well as construction details became easier to perfect. And, because building with standardized elements required fewer original solutions, it was not necessary to pay for a highly creative and expensive artist.

The high levels of standardization that are characteristic of traditional Chinese wooden buildings are sometimes contrasted to the freedom architects had in Europe. It is often assumed that Chinese builders had less freedom than their western counterparts as a result of the extensive bureaucracy that governed building in China. But while the existence of this bureaucratic system certainly contributed to the standardization of wooden construction, there may have been another, simpler reason as well. Because wood is light, it is easy to standardize large wooden building elements. It is much more difficult to standardize large elements made of heavier materials, such as stone; such elements quickly become too heavy to handle. European architects often had to use heavier materials, because their cities lacked many of the walls that characterized Chinese cities. Therefore they simply may not have been able to standardize their building practices the way the Chinese did.

Although I think that the Yongle and Shunzhi emperors tried to reduce building costs, they also may have tried to use these costs as a means of communication. They may have done so by emphasizing building costs they could not or did not want to reduce. For this reason, the Yongle and Shunzhi emperors may not have put as much emphasis on the costs of individual buildings, which they had reduced in a number of ways, as they did on the spaces and relationship between buildings. Although designers of these spaces and relationships were restricted by a number of traditions as well, they had much more freedom than the master craftsmen that built individual structures. For this reason, designing spaces and relationships between buildings was seen as a much more intellectual activity than designing individual buildings. Consequently, activities such as gardening and city planning were seen as suitable pursuits for high-ranking officials, whereas the design of individual building was not. (Boyd 1963: ch. 2; Ronan 1995: 59; Moffett *et al.* 2003: 99).

This means that, in order to analyze the way in which the Yongle and Shunzhi emperors used building costs as a means of communication, it is necessary to study more than the gate itself. It is necessary to study the Chengtianmen and Tiananmen in their building context. The gate formed part of a ceremonial axis that started at the southern tip of the city of Beijing. From there, the axis led past the most important temples and through numerous gates like Chengtianmen and Tiananmen to the Hall of Supreme Harmony, where the most important imperial ceremonies took place. The spaces between the temples, gates and halls on this axis were large and decorated with streams, bridges, columns, statues and balustrades. This was all very costly. The relations between buildings on the axis were carefully planned by important and therefore expensive intellectuals.

The emphasis that was put on spaces and relations between buildings by the two emperors is usually attributed to the holistic worldview of the Chinese. According to this view, no objects should be considered in isolation from its context (Ronan 1995: 46); thus no single building should be considered in isolation. Although I think this worldview has greatly contributed to the development of gardening and urban planning in China, I would like to point out that there also may have been a simpler reason for the Chinese attention to spaces and relationships between buildings. The use of walls and relatively small standardized wooden buildings may have limited the opportunities to use individual buildings as honest signals of fitness, while it may have increased the opportunities to use the whole space within a wall.

Conclusion

Big History patterns that apply to building in general, apply to Tiananmen as well. Just like other sedentary creatures, the Chinese emperors who built the gate tried to find the most efficient ways to protect themselves and their court. Just like certain invertebrate builders, Chinese builders tried to reduce costs by working with standardized materials and building blocks. And just like intelligent bowerbirds, the emperors tried to use the costs of building as a signal of their position in their group. Focusing on these patterns in the history of Tiananmen brings to light a number of fundamental reasons for why the gate was built the way it was. I think these fundamental reasons may have been previously overlooked. This may have been the case because traditionally many scholars that have studied buildings like Tiananmen have focused on specific details. As a result, such scholars have come up with different and often more complex explanations of certain aspects of building. I am not arguing that the fundamental explanations that emerge when studying Tiananmen from a Big History perspective should replace these more traditional explanations. Instead, I think it is necessary to consider how we can relate simple Big History explanations to more traditional ones. Doing so might help us deepen our understanding of these more traditional explanations. For instance, connecting attempts to reduce the costs of building to the development of ideas about hiding power and the position of both building elements and man in the order of nature, could deepen our understanding of such ideas.

All in all, I hope I have demonstrated the usefulness of studying small-scale subjects such as Tiananmen from a Big History perspective. I hope to demonstrate this usefulness further by writing a PhD thesis on the 'little big history' of Tiananmen Square. And I hope that this contribution will encourage others to start writing 'little big histories' of different subjects as well.

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19
From Concept to Reality: Developing a Zoomable Timeline for Big History

Roland Saekow

Abstract

Big History is proving to be an excellent framework for designing undergraduate synthesis courses. A serious problem in teaching such courses is how to convey the vast stretches of time from the Big Bang, 13.7 billion years ago, to the present, and how to clarify the wildly different time scales of cosmic history, Earth and life history, human prehistory and human history. Inspired by a series of printable timelines created by Professor Walter Alvarez at the University of California, Berkeley, a time visualization tool called 'ChronoZoom' was developed through a collaborative effort of the Department of Earth and Planetary Science at UC Berkeley and Microsoft Research. With the help of the Office of Intellectual Property and Industry Research Alliances at UC Berkeley, a relationship was established that resulted in the creation of a prototype of ChronoZoom, leveraging Microsoft Seadragon zoom technology. Work on a second version of ChronoZoom is presently underway with the hope that it will be among the first in a new generation of tools to enhance the study of Big History.

In Spring of 2009, I had the good fortune of taking Walter Alvarez' Big History course at the University of California Berkeley. As a senior about to complete an interdisciplinary degree in Design, I was always attracted to big picture courses rather than those that focused on specifics. So when a housemate told me about Walter's Big History course, I immediately enrolled.

The course started with a bang, literally, as we toured the Cosmos, leaving our planet, our solar system, our galaxy and onward into the void. Walter used a combination of videos, along with images from the Hubble Ultra Deep Field to give us a sense of the scale of these things. The Cosmos was clearly vast and breathtaking.

But I had no way of understanding the concept of a billion years. Walter had told us that the Big Bang occurred 13.7 billion years ago. In my mind, practically everything prior to a few thousand years ago was 'a long time ago'. I truly had no way of comprehending the length of a billion years.

As we moved into Earth history, the scale changed from billions of years to millions of years. The Earth timescale was more manageable because of the various divisions into eons, eras, epochs and more, but I still did not have an intuitive sense of what a century looked like compared to a million years.

Earth history was also easier to understand because of the various stories that could be told as one moved from older times to younger times. For example, the dinosaur impact-extinction event 65 million years ago, which Walter and his father discovered in the 1980s, helped to give a sense of how long the Earth truly had been around. I, like many other students, had once considered the age of the dinosaurs to be long ago distant time. But it quickly became apparent in the context of Big History that the age of the dinosaurs was relatively recent.

In order to tackle the Big History timescale problem, Walter had created a series of timeline handouts, some on logarithmic scales, some with diagrams of a linear-log hybrid and others that used a series of 'zooming' boxes. The figures were drawn by Walter in Macromedia Freehand and later in Adobe Illustrator. Walter's handouts reminded me of magazine infographics – they were densely packed with all sorts of information, yet thoughtfully laid out to allow one to explore slowly all of the information.

Since the course was interdisciplinary in nature and open to all majors of various grade levels, the log-scale representations of time were understood naturally by some students, while foreign to others. One of the graduate student instructors created a custom version of the 'Powers of Ten' video using the UC Berkeley campus. The animation started with a given length shown on the campus map for which everyone had an intuitive understanding. The slide show then started to zoom out in factors of 10. Soon we went from campus to seeing the entire United States. Soon after, we left Earth all together and even our own galaxy too. Showing time on log scales was clearly impressive and convenient, but it did not show any details between the factors of ten.

Walter's other method used a series of boxes in which each successive box was understood to be a magnification of the last 10 % from the previous box. Another way to imagine this is as follows: if a single timeline ran from left to right, a second timeline drawn above it would be understood to be a magnification of the last 10 % of the first timeline.

This method solved the detail problem. Each additional timeline stacked above the original one showed more and more details, but as soon as the number of timelines exceeded more than three or so, it became increasingly difficult to remember that each successive box was only the last 10 % of each box that preceded it.

What lay in front of me was a perplexing but exciting challenge. As a design major, we had always been taught to seek out needs and meet them, rather than develop new ideas for which no real demand may exist. I was not an expert in graphical tools, video editing or web design, but I knew a little of each. I had often liked the aphorism: 'Jack of all trades, Master of none'. But I liked the updated version of it by Discovery Channel's Adam Savage even better: 'Jack of all trades, master of none, but often better than a master of one!'

So having some basic skills in graphic design, video and web design, I knew that modern computer technology could provide a solution to the timescale problem, lifting the timeline out from paper and into the digital world.

In Walter's Big History course, a semester-long project was assigned. Since I had identified the timescale problem, I elected to do my semester project on the history of timelines. Researching the history of timelines showed me the various attempts that had been made through time. My goal of creating an interactive timeline would merely be the latest attempt. In *Cartographies of Time* by Anthony Grafton and Daniel Rosenberg (Rosenberg and Grafton 2010), I read about everything from scrolls that ran hundreds of feet long to giant wall-sized posters that were intended to track the history of different civilizations and important people.

I eventually came across a TED (Technology Entertainment Design) presentation by Blaise Aguera y Arcas (2007) where he demonstrated a new kind of zoom technology called 'Seadragon'. In Blaise's presentation, he explained that the purpose of Seadragon was to provide a very smooth zoom into images of extraordinary high resolution (images exceeding one gigapixel, or one thousand megapixels each). Seadragon made possible the kind of zoom previously reserved for specialized high-performance computers. In his TED talk, Blaise showed a series of vertical lines, explaining that each line was actually a chapter from Bleak House by Charles Dickens. With a flick of a scroll wheel on his mouse, Blaise zoomed from seeing every single chapter of Bleak House to a single letter.

During my initial presentation on the history of timelines for the Big History class, I included the Dickens clip from Blaize's presentation, asking if this technology could be applied to a next generation timeline. As part of my final presentation, I created a rough prototype using Microsoft PowerPoint to paint a picture of how Seadragon technology could be used to zoom into intricately nested timelines.

With support and encouragement from Walter, it was becoming clear that the Big History timescale problem could be solved.

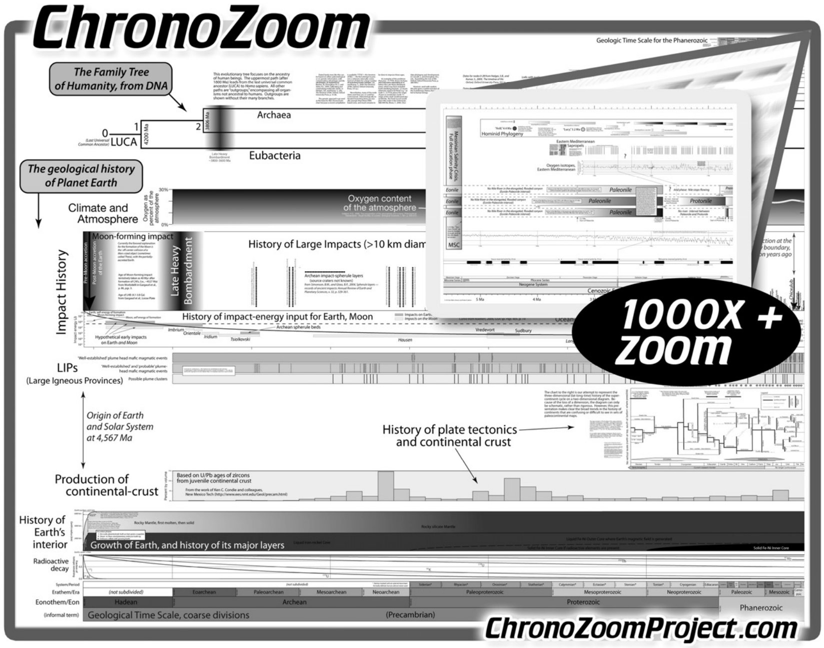

Fig. ChronoZoom Project

Soon after my presentation, I began meeting with Walter to discuss ideas for our interactive timeline. We often exchanged drawings on the blackboard after class, or quick sketches during office hours. The project was clearly exciting, and Walter soon began using Adobe Illustrator to create mockups with limited zoom capability. As we quickly found out, even professional-level tools such as Adobe Illustrator and Adobe Photoshop have a zoom limit of 6400 %. While that number would seem large, for the purposes of creating a timescale that would zoom from a single day to a Big Bang, this zoom factor represented only a tiny fraction of what was needed.

When a free program that enabled anyone to create Seadragon projects became available, Walter and I were able to begin realizing our concept in actuality. The program was called 'Deep Zoom Composer' and allowed the nesting of photos within photos, creating a high resolution image that can take advantage of Seadragon's smooth zooming capability. It is for this reason that our early concepts of ChronoZoom was called 'Deep Zoom Interactive Timeline' but eventually – after writing out various words related to time and space – we connected the Greek god Chronos with zoom.

Deep Zoom Composer allowed Walter and I to create the first early versions of ChronoZoom. Cobbling together various drawings created using Adobe Illustrator, we were able to achieve a zoom from all of the Cosmos down to about the last 2 million years. Armed with a demonstration model, we sought to contact the company behind Deep Zoom Composer and Seadragon technology: Microsoft.

Walter and me had no idea how to go about contacting such a large company, so we turned to an office on the Berkeley campus called the 'Office of Intellectual Property and Industry Research Alliances' (IPIRA). We put together a description of the project and rehearsed a demonstration of the prototype that we had built. After showing it to the IPIRA group, Walter and I distinctively remembered one of the first reactions. It went something like this: 'We are used to getting technical people such as chemists and biologists who come in and present their latest synthesized compound or chemical. Usually we just try to nod and pretend to share their excitement, but this is *really* cool!'

Spurred by this, the people at IPIRA helped us to arrange a conference call with Microsoft Research. Walter and I provided IPIRA with a tool to convey our idea. We produced a 7 minute video that explained both the Big History timescale problem as well as our initial prototype. Walter and I called our video the 'ChronoZoom Movie'. We scripted, rehearsed, and recorded take after take, which would eventually form a short but complete video explaining the field of Big History, the timescale problem, and how the Seadragon technology could be applied to creating a next-generation timeline. This video was distributed throughout Microsoft Research, eventually putting us in contact with a smaller group called Microsoft Live Labs, who were actively developing Seadragon technology.

A small but highly dedicated team at Microsoft Live Labs would go on to produce the first version of ChronoZoom, capable of zooming from a single day to the Big Bang. This impressive accomplishment was achieved in time for Walter's Faculty Research Lecture, where ChronoZoom made its worldwide debut. Walter had been selected as one of two faculty members to give the annual talk to the UC Berkeley community in 2010. The complete one-hour video is also available on the ChronoZoom website.

Development of ChronoZoom continues now with a completely new version underway as of Spring 2011. The project has graduated from the smaller Microsoft Live Labs team to Microsoft Research which is presently developing ChronoZoom 2. We hope that ChronoZoom can be among the first of a new generation of tools to enhance the study of Big History.

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Resources and Links

ChronoZoom Project Homepage.
URL: http://www.ChronoZoomProject.com

Original ChronoZoom Proof of Concept Video.
URL: http://www.youtube.com/watch?v = 3ztX8PmLNKU

Microsoft Seadragon and Deep Zoom.
URL: http://www.microsoft.com/silverlight/deep-zoom/

Microsoft Research.
URL: http://research.microsoft.com

Technology Entertainment Design (TED).
URL: http://www.ted.com/

University of California, Berkeley Office of Intellectual Property and Industry Research Alliances (IPIRA).
URL: http://ipira.berkeley.edu/

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Two Themes Inherent in Big History

James Tierney

Abstract

The following work ties together the Big History components of collective learning and complexity-building within the long term perspective of the evolution of the Universe and the shorter term perspective of human culture. Since human culture is at the leading edge of complexity-building, it is appropriate to wonder about where that process is taking us and whether there are ways through which it might be influenced. I suggest that the pace of cultural evolution is significant in terms of the heavy investment in war technology over the past 10,000 years, while the more leisurely pace from 25 to 45 thousand years ago may be a product of the peaceful coexistence inherent in sustainability.

Big Historian David Christian makes a gigantic leap forward in his book, *Maps of Time,* by connecting the 'collective learning' that humans do with the complexity-building that has been in progress for at least the past 13.7 billion years (Christian 2004). We humans are at the forefront of the process that has now been clearly demonstrated by Christian, and our culture is the vehicle through which this process is maximizing the energy-flow density metric that astronomer Eric Chaisson has so brilliantly identified for us (Chaisson 2010: 2). Is there some grand purpose to this complexity-building, as well as some significance to this moment in time, when our collective learning is amassing information at what feels like an overwhelming pace? Should or can we be taking clearer control of the process? If so, to what ends?

Collective learning is unique to humans, but it may not be exclusive to humans. Other species may pass information from generation to generation culturally and genetically, but no other species on Earth does so in the organized way that we do. Should we be paying more attention to the mechanisms that we build to filter and apply the data, which is the foundation of our learning? What we seem to be lacking are mechanisms that filter and apply the data in ways that benefit our species as a whole. To be sure, we have the market place and other components like the family, which sort and apply data as it emerges, but those mechanisms seem to be at best only a very poor actualization of the potential inherent in this process.

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Two themes march together as we look at history through this new and more comprehensive lens. The first asks: are we the only beings in the Universe contributing to complexity-building as we are doing it? So far, we have no way of answering this question with any certainty. Physicist Enrico Fermi's question from the 1950s has never been taken seriously, other than by Carl Sagan and a handful of others, but it holds humans in a place so special in the Universe that I, for one, cannot imagine that we alone maintain this place. 'If we are not alone', Fermi asks, 'where then are the others?' (Davidson 1999: 346).

This is a perfectly reasonable question, since Big History and all the fragmented histories that have preceded it make clear that our galaxy and solar system is 'new', compared to other galaxies in the Universe. And now we are finding other solar systems that have existed for billions of years before ours was even born. This is ample time for other intelligent beings to evolve and contribute to complexity-building… and ample time to evolve to whatever level intelligent beings can evolve, which would include, one would think, the technical capacity to make their presence known to other species with whom they might communicate. But we do not find this. What we find, so far, is an eerie silence.

Some have taken the position that our species, and those like us, should they exist, are so inept that they destroy themselves before they connect with other such species in the Universe (Davidson 1999: 353). This was a theory bandied about during the last half of the 20th century, when the great powers stood with nuclear weapons as a mechanism for resolving conflicts, which seemed irresolvable at the time. A major point in our favour, regarding our competence to survive as a species, is that we did not take our species and our world down that road of nuclear holocaust. To be sure, we still have the option to do so, but mutually assured destruction is not very appealing to even the most determined 'war hawks', and nuclear weapons, should they be used again as weapons, will probably be used either by accident or on a small enough scale for much of the planet to absorb the impact.

An interesting variation on this theme of self-destruction has been suggested by Big Historian Akop Nazaretyan, who has proposed the 'Law of Techno-Humanitarian Balance'. This proposition states that the higher the power of war production and technology, the more refined the behavior-regulation needs to be for self-preservation of society (Nazaretyan 2004: 160). Nazaretyan builds on the work of physicist/biologist Erwin Shrödinger, which shows:

> …anti-entropy work can be done only by means of 'order consumption' from outside – that is, at the cost of the increasing entropy of other systems. In instances of abundant environments, open non-equilibrium systems increase the volume of their anti-entropy work, and expand as much as they can. Sooner or later, this exhausts the available resources, and as a result, a specific crisis in system-environment relations fol-

> lows… Crises of this type are called *endo-exogenous* in ecology. The system – an individual, a population, or a human society – runs against the unfavorable environmental transformations provoked by its own activity. Endo-exogenous crises, including all anthropogenic (technogenic) ones, play a special role in evolution. As previous anti-entropy mechanisms turn counterproductive – being fraught with catastrophic entropy growth – a bifurcation phase develops. If migration is impossible, there are only two further possibilities. Either the system turns back to equilibrium – that is degrades (which is named *simple attractor* in synergetics) – or diverges from that owing to the development of advanced anti-entropy mechanisms. The last possibility is usually caused by inner diversity and structural complexity, and a more dynamic world model with higher resolving power and sensible feedback (Nazaretyan 2005: 75–76).

From this perspective, all social systems face the potential of devastating crises in their 'system-environment relations', from which no previous culture may have survived intact. It is precisely those societies that are most highly invested in the production of war technologies that are most vulnerable to demise. Nazaretyan does, however, offer the possibility that more refined behavior regulation might allow for even their self-preservation. It would seem that such refined behavior for self-preservation would require an understanding of the stakes involved by the participants, as well as a capacity for the system to reorient itself more sustainably.

There may be some evidence that this is actually happening within human culture, and it may indeed be the role of Big History to encourage this self-awareness to take place. In this sense, our culture would then perhaps be at the leading edge of many such cultures that have evolved over the eons. We might then engage in the effort to enable complexity-building to proceed beyond the barriers that entropy places before it. This is a startling perspective, but not nearly as arrogant as the position that humans are the be-all and end-all of the Universe, or as pessimistic as the view that all human-like cultures inevitably destroy themselves.

More importantly, the second theme relates to human culture itself. Eric Chaisson and others point out that cosmic evolution is a collection of evolutionary phases – from rudimentary alteration of physical systems to Darwinian modification of life forms to Lamarckian reshaping of society – all consistently and fundamentally characterized, at least in part, by mass normalized energy flow (Chaisson 2010: 3). Chaisson has applied his metric of energy-flow density to cultural evolution from 300,000 years ago through the agro-industrial revolution 10,000 years ago, tracking progression in terms of energy rate density. In addition to the vast increase in mass normalized energy flow, we find an increasingly accelerated pace.

I would like to suggest that this increase in pace, as well as the slower tempo prior to 20,000 years ago, has much to tell us about who we are and the role our culture is playing, if only we are able to pause and appreciate that significance. Prior to 300,000 years ago, the use of stone and bone tools – along with the domestication of fire – are events most might agree on as to when they occur. Once advances of such proportion are made, they tend to spread rapidly, with the use becoming common wherever we look in the archeological record.

The tendency is to lump all our ancient ancestors into the category 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'. There is not a lot we can do to validate that observation prior to 300,000 years ago, since what we know is very speculative. It is just as easy to draw erroneous conclusions as valid ones. And, in fact, it is probably only for half that time that we can, with some confidence, begin to see the symbols that we take for granted as a measure of sophisticated culture: art, music and language.

My point is that we have made lots of assumptions about how we have gotten to where we are today, and that by reviewing those assumptions we might get a better appreciation of a pace that allowed Modern Humans and Neanderthals to live together peaceably for tens of thousands of years. For example, it was not possible for people to be on the move in winter in Europe 45,000 to 25,000 years ago. They had to have a sustainable village setting from which to prepare for and endure winter. So, year-around hunter-gathering was not an option if it is viewed as a small group being on the move as plants matured. Clearly they stored firewood and food to survive winter and therefore were more sedentary than traditional views of hunter-gathering implies. How did they control population density for those thousands of years, or did the environment do it for them? This is one of the many questions that arise as we look more closely at the evolution of culture and the pace at which culture has been evolving.

If Nazaretyan's law of techno-humanitarian balance is correct, then the need for behavior regulation to enable self-preservation was less at that time than what later became necessary to protect oneself from one's neighbor, even though a sedentary life, that most of us attribute to the era of agriculture, must have existed. Clearly, conflict between neighbors is a result of the surplus inherent in the subsistence mechanism, not in the sedentary nature of village life. If firewood and food were sufficient to accommodate everyone prior to 20,000 years ago, as it must have been, since they survived, there was no need to be in competition and no need for war technologies. Previous advances in stone technology were not for killing each other, but rather for hunting or scavenging and for enhanced security against predators. People like Nicholas Wade, *New York Times* science reporter, would have us believe that our ancestors have been at war as far back as one can look (Wade 2006). If this is not the case, and if the only commodity that might have been scarce from time to time was fire, which lends itself to sharing rather than hoarding, since there is no advantage to having lots of fire, we may have a long period of peaceful co-existence in our history, prior to the period of violence we have had for the last 15,000 years.

What are the implications of that kind of history for dealing with the current pace of cultural evolution and the heavy investment in war technology? Is the pace of modern cultural evolution a product of our use of war technology to survive? Is the rather leisurely pace prior to 20,000 years ago a product of sustainability? Perhaps, the answer lies in a couple of major events that we can date with accuracy during the past 60,000 years – the expansion of our ancestors out of Africa and the development of sophisticated European cave art (Guthrie 2005).

In regard to the migrations out of Africa, there is a rather significant timeframe when our ancestors stayed in one place for tens of thousands of years in what is now France and Spain. Were they in conflict with each other? Probably not; at least there is little or no evidence in the archeological record to support that view. The European cave art is clearly dated at 32,000 to 12,000 years ago, an unparalleled recorded history, although we act as if recorded history only began with the printed word (Curtis 2006). In all that time, with the exception of the remarkable faces in the cave at La Marche in France, there are only four humans depicted in these caves; the rest of the artwork is of other animals, not humans. What does this mean? Were they trying to tell us something about a transition through which they were going?

I have written that confidence is the variable that allowed our ancestors to expand, as we have in the past 20,000 years, and that we were probably instrumental in the extinction of large mammals in the path of that expansion (Tierney 2002). Nazaretyan has written: 'Archeological, anthropological and neuropsychological data confrontation bring us to the conclusion that their survival was due to specific neurotic faculties' (Nazaretyan 2005: 76). Anthropologist Bernard Chapais believes that weapons allowed for greater equality between males and that general monogamy followed general polygamy, while psychologist Michael Tomasello suggests that cooperation gave humans our advanced culture (Chapis 2008; Tomasello 2009).

We are probably all correct and probably all wrong. The fact is, we do not know much about ancient social behaviors, especially what these people were thinking. The assumptions that we make are based more on the eyes we are looking through now rather than the eyes through which our ancestors viewed the world. Even our good friend David Christian only gives 30 pages to this period of our history, when the culture we now understand as critical in the complexity-building process was being established and beginning to show a leap in the pace that now feels a bit frightening (Christian 2004: 171–203).

It is only very recently that we have come to understand that our cultural evolution is driving complexity-building… and we have no idea whether that is being done just by chance. The pace of this cultural evolution seems to be increasing rapidly, if we use 300,000 years as our base for a fairly sophisticated culture. The pace of change today is a challenge to keep up with. My grandfather, for example, was expected to take his son, if he was disrespectful to his mother, 'to the wood shed' (a New England expression for physical punishment that was traditionally carried out in the shack used to store firewood). Nowadays, my son would go to prison for doing the same thing. This is a big change in individual and social behavior over the course of a mere century, but one that is all but taken for granted.

Do we have the option to modify the pace? Are the prospective outcomes inevitable? We do not know. What we do know is that we have the option to acknowledge that human culture is driving an extraordinary process. We have the option to wonder together about what kind of outcomes might be best for humans, and consider what kind of things might most likely lead to those outcomes.

Big History is the vehicle through which we are becoming aware of the connection between complexity-building as the function of the Universe and the gathering of data that fuels our collective learning. So, it is appropriate that Big History facilitate our wondering together about all the questions inherent in our collective learning. Chief among those, in my opinion, is how we sort and apply data to best insure a sustainable future. Maybe students can help sort through information that emerges as fact, but may not be accurate, which is all too often the case once one is committed to or opposed to an idea.

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Contributors

Walter Alvarez received his PhD in Geology from Princeton University. His thesis fieldwork (and honeymoon) took place in a roadless desert in Colombia, living with the indigenous Guajiro and smugglers. Much of his research has been in Italy, where he worked on archeological geology in Rome, on the tectonics of the geologically complex Mediterranean, and on the Earth's magnetic reversals recorded in deep-water limestones in the Apennines. In 1977, he joined the faculty at the University of California, Berkeley, and began a study of the mass extinction at the end of the Cretaceous Period. Evidence from iridium measurements suggested that the extinction was due to impact on the Earth of a giant asteroid or comet, and many years later that hypothesis was confirmed by the discovery of a huge impact crater, buried beneath the subsurface of the Yucatán Peninsula, dating from precisely the time of the Cretaceous-Tertiary extinction. He is currently engaged in work with Big History. Dr. Alvarez has received honorary doctorates from the University of Siena in Italy and the University of Oviedo, in the Principality of Asturias, in Spain, where his family originated.

Eric J. Chaisson has recently returned to the Harvard-Smithsonian Center for Astrophysics in Cambridge Massachusetts, where he holds multiple positions. He is also an Associate of the Harvard College Observatory and serves with the Faculty of Arts and Sciences at Harvard University. Trained initially in atomic physics, Dr. Chaisson obtained his doctorate in astrophysics from Harvard University. During his tenure as associate professor at the Harvard-Smithsonian Center for Astrophysics, his research focused largely on the radio astronomical study of interstellar gas clouds. This work won him fellowships from the National Academy of Sciences and the Sloan Foundation, as well as Harvard's B. J. Bok Prize for original contributions to astrophysics and Harvard's Smith-Weld Prize for literary merit. Previous to his current positions, he spent several years at the (Hubble) Space Telescope Science Institute at Johns Hopkins University. He has written nearly 200 publications, most in professional journals, and has authored or coauthored 12 books. Dr. Chaisson's major research interests are twofold: his scientific research addresses an interdisciplinary, thermodynamic study of physical and biological phenomena, thereby seeking the origin, evolution and unification of galaxies, stars, planets and life in the Universe. His educational research engages experienced teachers and computer animators to create better methods, technological aids and novel curricula to excite teachers and instruct students in all aspects of natural science. He teaches an annual undergraduate course at Harvard University on the subject of cosmic evolution, which combines both of these research and educational goals. Dr. Chaisson holds membership in many American and international scientific organizations and several honor societies, and serves on dozens of academic, public and federal advisory committees. For additional information, please, consult http://www.cfa.harvard.edu/~chaisson.

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.

Tom Gehrels is Professor of Planetary Sciences and an astronomer at the University of Arizona in Tucson (USA). During World War II, he was active in the Dutch Resistance and an organizer for the Special Operations Executive (SOE). He pioneered the first photometric system for asteroids in the 1950s, as well as a system of analyzing wavelength dependence for polarization of stars and planets in the 1960s. He was also Principal Investigator for the Imaging Photopolarimeter experiment on the Pioneer 10 and Pioneer 11 first flybys of Jupiter and Saturn in the 1970s. Dr. Gehrels initiated the Space Science Series of textbooks, for which he was general editor. He also initiated the Spacewatch Program and, until 1997, was its Principal Investigator (PI) for electronic surveying; their goal was to obtain statistics about asteroids and comets, including near-Earth asteroids. He has participated in the discovery of over 4000 asteroids, as well as a number of comets. Besides teaching at the University of Arizona, Dr. Gehrels also lectures at the Physical Research Laboratory in Ahmedabad (India), where he is a Lifetime Fellow. This is a United Nations program for graduate students from a variety of countries, from Uzbekistan to North Korea. Presently, his research focuses on universal evolution. He was winner of the 2007 Harold Masursky Award for his outstanding service to planetary science.

Leonid E. Grinin is Research Professor and Director of the Volgograd Center for Social Research, as well as Deputy Director of the Eurasian Center for Big History & System Forecasting. He is Editor-in-Chief of the journal *Age of Globalization* (in Russian), as well as a co-editor of the international journals *Social Evolution & History* and the *Journal of Globalization Studies*. His current research interests include Big History and macroevolution, long-term trends and sociocultural evolution (especially of technology), periodization of history, world-systems studies, long-term development of political systems, globalization studies, and economic cycles. Dr. Grinin is the author of more than 300 scholarly publications in Russian and English, including 22 monographs. These monographs include *Philosophy, Sociology, and the Theory of History* (4th ed. Volgograd: Uchitel, 2007, in Russian); *Productive Forces and Historical Process* (3rd ed. Moscow: KomKniga, 2006, in Russian); *State and Historical Process* (3 vols. 2nd ed. Moscow: KomKniga, 2009–2010, in Russian); *Social Macroevolution: World System Transformations* (Moscow: LIBROKOM, 2009, in Russian; with Andrey Korotayev); *Macroevolution in Biological and Social Systems* (Moscow: LKI/URSS, 2008, in Russian; with Alexander V. Markov and Andrey V. Korotayev); *Global Crisis in Retrospective: A Brief History of Upswings and Crises* (Moscow: LIBROKOM, 2010, in Russian; with Andrey Korotayev); *The Evolution of Statehood: From Early State to Global Society* (Saarbrücken: Lambert Academic Publishing, 2011). E-mail: lgrinin@mail.ru

Erika K. H. Gronek is a web-designer, filmmaker, educational technologist, children's book writer and illustrator, and – most importantly – a mother. She holds a BA degree from Arizona State University in Political Science and Anthropology, as well as a Master's degree in Educational Technology Leadership from The George Washington University (Washington, D.C.). Her creative work started in web-design in 1997, then merged into photography, filmmaking and education. She won best commercial and best documentary film awards at the SCC MP/TV Film Festival in Scottsdale, Arizona, in 2007 and 2010. She also worked as an educational technologist for the Institute for Supply Management in Tempe, Arizona, for 6 years and taught at the Art Institute of Phoenix. Her volunteer work has included video-editing for The WILD Foundation, as well as photography and web-design for The Harvard Club of Phoenix. Ms. Gronek lives in Phoenix, Arizona, with her husband and young son. Her hobbies are her occupations, because she believes that they should be one and the same.

David Hookes was born into a working class family close to the Liverpool dock road. Educated at Trinity College, Cambridge University, he received a BA in Natural Sciences with a major in Physics. Being dissatisfied with the fact that there were so many conceptual problems in Physics, such as the interpretation of quantum mechanics and the unexplained constancy of the velocity of light in Special Relativity, Dr. Hookes decided to switch his studies. He obtained a PhD in Molecular Biology at Kings College, London University, with a thesis on the molecular structure of bio-membranes. He then spent a year in Germany as a post-doctoral fellow of the Von Humboldt Foundation and carried out, *inter alia*, theoretical work on the transport properties of bio-membranes. Back in England, Dr. Hookes was appointed Head of Physics at Kilburn Polytechnic. Some years later, he decided to take an MSc in Digital Electronic Engineering at the University of Westminster. As a result, he was appointed Senior Lecturer in Electronic Engineering at Coventry University, where he researched biosensors, robot tactile-sensing, and computer-interactive educational technology. This led to his developing a 'Physics-is-Fun' workstation. After his retirement, he became an Honorary Senior Research Fellow at Liverpool University's Computer Science Department. Politically, he is a member of the Labour Party and a life-long trade unionist and socialist. His present research interests are: how to save the planet from the threat of global warming; renewable energy technologies; application of ideas from physics to political economy and computer networks; computer-interactive educational technology; and foundational problems of physics.

Nigel C. Hughes was born on a hill in northern England in 1964. He studied Natural History and Geology in the United Kingdom and the Bengali language in India. Dr. Hughes is presently a professor of Geology at the University of California, Riverside (USA) and has published widely on Himalayan fossils and geology, and on the biology of trilobites and other invertebrate fossils. He teaches two Big History classes, and much enjoys hiking up mountains with his family and friends, and playing the ukulele. He is just now in the process of completing a book, *Monisha ar Pathorer Bon* (Monisha and the Stone Forest), a story aimed at introducing scientific thinking about environmental change to children in rural Bengal.

Andrey V. Korotayev is Head and Professor of the Department of Modern Asian and African Studies, Russian State University for the Humanities, Moscow, as well as a Senior Research Professor at the Institute for African Studies and the Institute of Oriental Studies of Russian Academy of Sciences. He is the author of over 400 scholarly publications, including such monographs as *Ancient Yemen* (Oxford: Oxford University Press, 1995), *World Religions and Social Evolution of the Old World Oikumene Civilizations: A Cross-Cultural Perspective* (Lewiston, NY: The Edwin Mellen Press, 2004), *Introduction to Social Macrodynamics: Compact Macromodels of World System Growth* (Moscow: URSS Publishers, 2006; with Artemy Malkov and Daria Khaltourina), and *Introduction to Social Macrodynamics: Secular Cycles and Millennial*

Trends in Africa (Moscow: URSS, 2006; with Daria Khaltourina). At present, together with Askar Akayev and Georgy Malinetsky, Dr. Korotayev coordinates the Russian Academy of Sciences Presidium Project 'Complex System Analysis and Mathematical Modeling of Global Dynamics'. He is a laureate of the Russian Science Support Foundation Award in 'The Best Economists of the Russian Academy of Sciences' Nomination (2006). E-mail: akorotayev@gmail.com.

G. Siegfried (Sig) Kutter is an astrophysicist (PhD 1968, University of Rochester), who has been affiliated with the University of Virginia, NASA's Goddard Space Flight Center, The Evergreen State College, the Colorado Mountain College, and Colorado Online Learning. His research has focused on hydrodynamic events in stellar evolution. Additionally, he managed grants programs in the Astrophysics Division of NASA Headquarters and the Division of Astronomical Sciences of the National Science Foundation; and he was employed as Senior Scientist by BDM International, Inc., and TRW, Inc., managing the support of NASA's Advanced Programs Branch, writing science articles for NASA's website, *The Observatorium*, and representing two German subsidiary companies of BDM and TRW in the US. Dr. Kutter has published peer-reviewed research articles on stellar evolution, two science texts, and a popular book on fitness and nutrition; and he has written book reviews for *Nature*. In addition to his professional career, Dr. Kutter has had a life-long love for the outdoors and physical activity – hiking, climbing, bicycling, downhill skiing, and long-distance running. This love is still with him, despite being now past 75 years in age; but his ways of enjoying nature have become gentler. Of his many professional activities, Dr. Kutter enjoyed teaching the best. He still teaches a popular astronomy course at the Summit Campus of the Colorado Mountain College in Breckenridge (USA), and says: 'It is the interactions with my students that keep me going'.

Gary Lawless is a poet, small press publisher and co-owner of Gulf of Maine Bookstore in Brunswick, Maine (USA). He has published 17 collections of poems in the United States and four in Italy. Dr. Lawless has traveled widely to read his poetry in the world, and lives as caretaker at Chimney Farm, on Damariscotta Lake in Maine.

Alexander V. Markov is Senior Research Fellow of the Institute for Paleontology of the Russian Academy of Sciences. He is the author of more than 140 scientific publications in zoology, paleontology, evolution theory, historical dynamics of biodiversity, and in other fields of evolutionary biology, including monographs: *Morphology, Systematics and Phylogeny of Sea Urchins of the Schizasteridae Family* (1994); *Quantitative Laws of Macroevolution: Experience of Systematic Approach Use for the Analysis of Supraspecific Taxons* (1998; with E. B. Naymark); *Macroevolution in Biological and Social Systems* (2008; with Leonid Grinin, Andrey Korotayev), *Hyperbolic Growth in Biological and Social Systems* (2009; with Andrey Korotayev). Dr. Markov is a member of the Editorial Board of *Journal of General Biology,* an author of numerous popular science publications, the founder and author of the research and education portal 'Problems of Evolution' (http://www.evolbiol.ru).

Paula Metallo was born in Syracuse, New York (USA) in 1954. She received a BFA in Painting at the State University of New York at New Paltz in 1975. She continued her studies in 1978 at the Accademia delle Belle Arti in Urbino (Italy) and began a love-at-first-site experience with the country. After 13 years in the San Francisco Bay Area (USA), where she won the New Langton Arts/Swig Watkins Award, she moved back to live in Italy in 1993. At that time, Ms. Metallo and her husband, Alessandro Montanari, founded the Geological Observatory of Coldigioco. There is a kind of dualism in her research that has followed through to today. Living in another country pushed her towards an inevitable mindset of comparison. And Geology came to fit into the research process. It was inevitable, while living with and around scientists, that the 'twos' of research would eventually tackle the science/art relationship. Among exhibitions in the United States and Europe, her most recent ones include: *Rimanere Colpiti* (Awestruck) in collaboration with a Penrose Conference on climate and impacts in Ancona (Italy) in 2007; *(UN)Measuring The World*, a collaboration with the Humboldt Museum of Natural History of Berlin (Germany) in 2009; *Impact Art*, Reiskrater-Museum, Nördlingen (Germany) in 2010; and *Devoted Attention*, a show designed for a meeting on Big History at the Gallery Il Gioco, Macerata (Italy) in 2010. She will present a show in October 2011 titled, *Aspettando Il Prossimo* (Waiting for the Next One), which addresses Italians and Italian earthquakes, which is in collaboration with the Museo di Gibellina in Sicily. Her website can be found at http://www.paulametallo.com.

Alexander Mirkovic teaches courses in European and World History at Arkansas Tech University (USA). His current research project, entitled *Nationalism: Religion of Modernity* is a theoretical introduction to nationalism from a historical and cultural perspective. His research interests include urban history and the history of science. Dr. Mirkovic was an assistant editor of the ABC-CLIO *World History Encyclopedia, Crisis and Achievement: 1900–1945*, and assistant editor of the *World History Bulletin*, an official publication of the World History Association. In addition, he is the author of *From Courtly Curiosity to Revolutionary Refreshment: Turkish Coffee and English Politics in the Seventeenth Century* and *Prelude to Constantine: The Abgar Tradition in Early Christianity*. Dr. Mirkovic has been at Arkansas Tech University since 2006. Before that he worked at McNeese State University in Lake Charles, Louisiana, and University of South Florida in St. Petersburg, Florida (USA). Education: PhD (Vanderbilt University); MA (University of South Florida); BA (Diploma, National University of Athens, Greece).

Alessandro Montanari was born in Ancona on 25 July 1954 and lives at the Osservatorio Geologico di Coldigioco, in central Italy. His degrees include: Laureat in Geology, Urbino University, 1979; PhD in Geology, University of California, Berkeley, 1986; Postdoctoral Researcher and Research Associate, UC, Berkeley, until 1993; Founder and Director of the Geological Observatory of Coldigioco, since 1992. Teacher in *ad hoc* courses for American and European universities and active researcher in regional geology (Apennines, Dolomites, Croatia), sedimentary geology, integrated stratigraphy, paleoclimate and cyclostratigraphy, neotectonics, speleology, extremophile stygobitic biology. Awards: Louderback Award, UC, Berkeley, 1983; Rotary Award, Gubbio, 1992; Knighted by the President of the Italian Republic, 1993; Portonovo Award, Marche Region, 2001; Geology Renaissance Sabbatical Award, UC, Berkeley, 2005; EGU Jan Baptiste Lamark Medal, 2007; Corresponding Member of the Austrian Academy of Science, 2010; Fellow of the Geological Society of America, 2010. Dr. Montanari is author and co-author of about 100 technical papers (*Science, Geology, Bulletin, Special Papers, Earth and Planetary Science Letters, Paleo3, Journal of Geology, Terra Nova, Geological Society of Italy, Comptes Rendus de l'Académie de Sciences, Elsevier Developments in Paleontology and Stratigraphy, Bulletin de la So-*

cieté Géologique de France, Lecture Notes in Physics, Planetary and Space Science, Journal of Seismology, Italian Bulletin of Archeology, Geochimica and Cosmochimica Acta, Geophysical Research Letters, Meteoritics and Planetary Sciences, Episodes, Paleoceanography, ISMA Journal, International Journal of Climatology). He is also author and co-author of scientific and popular science books: *Tales from the Cònero Rocks, Geologic Guide for the Cònero Park* (1995); *Impact Stratigraphy: The Italian Record, Springer* (2000); *Drops of Time: Strolling among Rocks, Geologic Guide for the Frasassi Park*, with CD audio of Quaternary geophonic music (2001); *Dances with the Earth: Geophonic Music from the Stratigraphic Record of Central Italy*, with CD audio of geophonic music, Presses de l'Ecole des Mines de Paris (2003); *Stigobionti: vita acquatica nelle grotte di Frasassi, Speleologic Federation of the Marche* (2010). He is co-editor of *IUGS Eocene-Oligocene Boundary Ad Hoc Memoir* (1987); *Giornale di Geologia,* Special Issue, *Miocene Stratigraphy of Italy and Adjacent Regions* (1995); *Elsevier Miocene Stratigraphy: An Integrated Approach* (1997), *GSA,* Special Paper 452, *Hothouse, Icehouse, and Impacts: The Late Eocene Earth* (2009). His e-mail is: sandro.ogc@fastnet.it.

Akop P. Nazaretyan is Director of the Eurasian Center for Big History & System Forecasting, Senior Research Professor of the Institute of Oriental Studies of Russian Academy of Sciences, Full Professor in Moscow State University and Editor of the academic journal *Historical Psychology & Sociology* (in Russian). He is the author of over 300 scholarly publications, including books: *Intelligence in the Universe: Sources, Formation and Perspectives* (1991, in Russian); *Aggression, Morals and the Crises in World Cultural Development* (1995, 1996, in Russian); *Aggressive Crowds, Mass Panic, and Rumors: Lectures in Social and Political Psychology* (2001, 2003, 2005, in Russian); *Civilization Crises within the Context of Big History: Self-Organization, Psychology, and Forecasts* (2001, 2004, in Russian); *Anthropology of Violence and Culture of Self-Organization. Essays on Evolutionary Historical Psychology* (2007, 2008, in Russian); *Evolution of Non-violence: Studies in Big History, Self-Organization and Historical Psychology* (2010, in English). His e-mail is: anazaret@yandex.ru.

Alexander D. Panov graduated from Moscow State University, Department of Physics. At present, he is a senior researcher at the Moscow State University Skobeltsyn Institute of Nuclear Physics (MSU SINP), and is CSc (Physics and Mathematics). His major works are devoted to nuclear physics, surface physics, quantum theory of measurment, cosmic rays physics, and problems of universal evolution / Big History. He is the author of about 130 articles in the Russian and international academic press, as well as the author of the monograph *Universal Evolution and Problems of the Search for Extraterrestrial Intelligence* (SETI).

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). Barry lives on the Coast of Maine with his wife Penelope, son Kenai, and grandson Dimitri. He spends his free time hiking in the forest, and enjoys music, reading, and writing fiction.

Roland Saekow received his bachelor's degree in Science, Technology and Society through the Interdisciplinary Field Studies program at the University of California, Berkeley. His thesis, *The Transforming Role of Timelines in the Study of History*, investigated the educational utility of online timelines against their traditional paper-based counterparts. At Berkeley, Mr. Saekow led the student-run product design team called 'Berkeley Innovation'. Proudly wearing the team's bright orange shirts (a color chosen to represent new ideas), he and his teammates sought out ways of improving student life through creativity techniques, brainstorming sessions and rapid prototyping. During his senior year, Mr. Saekow developed ChronoZoom, an interactive timeline that shows all of Big History in collaboration with Professor Walter Alvarez and Microsoft Research. Mr. Saekow continues to develop ChronoZoom as part of the Earth and Planetary Science research staff at Berkeley.

David Shimabukuro recently completed his PhD at the University of California, Berkeley, on the tectonic evolution of Calabria, the toe of the Italian Peninsula. This study also included fieldwork in nearby areas critical for understanding Calabria, especially Sardinia and the northern Apennine Mountains. Calabria is a key piece of the tectonic puzzle in the complicated tectonic pattern of small mountain ranges and ocean basins within the Mediterranean, and his thesis supplies critical evidence for choosing between a number of hypothetical reconstructions of the geological history of Calabria. While doing research on this specialized topic in Earth history, Dr. Shimabukuro has developed a complementary interest in Big History, the broadest possible view of the past. As the founding Graduate Student Instructor, he worked with Professor Walter Alvarez to develop the Big History course that has been given at UC, Berkeley, for the last five years. Acquiring an ever-broader knowledge of the geological and human history of places throughout the world, Dr. Shimabukuro has traveled extensively throughout Europe, Asia, North and South America, Africa and Oceania.

Fred Spier is Senior Lecturer in Big History. He has organized and taught the annual 'Big History Course' at the University of Amsterdam since 1994, the annual 'Big History University Lecture Series' at the Eindhoven University of Technology since 2003, and the 'Big Questions in History Course' at Amsterdam University College since 2009. First trained as a biochemist with research experience in plant genetic engineering and the synthesis of oligonucleotides, Dr. Spier subsequently became a cultural anthropologist and social historian. He performed a ten-year study on religion, politics and ecology in Peru, which led to the publication of two books. He is currently Vice President of the International Big History Association (IBHA). His current research is devoted to developing a paradigm that helps to explain big history. In his article, 'How Big History Works: Energy Flows and the Rse and Demise of Complexity', which was published in *Social Evolution & History* (2005), the outline of this theory was proposed. An improved version of this argument is presented in his book, *Big History and the Future of Humanity* (Wiley-Blackwell, 2010). The paperback version was released in January 2011. The translation in Spanish *El lugar del hombre en el cosmos: La 'Gran Historia' y el futuro de la humanidad* was published in 2011 by Editorial Crítica, Spain, while a translation into Chinese by Truth & Wisdom Press is forthcoming.

James Tierney is a social worker, retired from the Maine Department of Health and Human Services (USA). His personal interest, since retirement, has been in trying to understand the role of violence, as it is used against children by parents who most often love them. By extension, he has engaged studying its corollary – of a culture that professes the wish to survive, yet teeters on the edge of self-destruction. Mr. Tierney is particularly interested in the functionality of public organizations, through which we, humans, contract to govern ourselves. He embraced the notion of Big History many years ago, using a cosmological context for an introductory course in social work that he taught in the late 1970s. He has four sons and nine grand children; he enjoys writing, gardening, biking, skiing and paddling a canoe.

Jos Werkhoven was born in Amsterdam in 1950. For thirty years (1972 to 2002), he was a Montessori teacher, director, trainer, supervisor and developer of educational materials. Since 1995, he has run his own publishing house, from which he publishes educational material in the spirit of Dr. Maria Montessori. Besides publishing, Mr. Werkhoven is still very busy with the development of new educational material. At this moment, he works together with a lot of Montessori professionals to renew material for mathematics for primary education. And, with other professionals, he is renewing material for language for primary education. The next step will be to publish a book of his ideas about modern education, inspired by Dr. Montessori. At the same time, there will be work on a new part of the *Lines of Life* – the *Line of Evolution*. He still teaches and supervises Montessori teachers or is present with lectures at congresses or parent evenings at primary Montessori schools. His aim is the enhancement of 'cosmic education' (the name of Big History in Montessori education).

Call for Papers

Kondratieff Waves

Editors: ***Leonid Grinin (Russia), Tessaleno Devezas (Portugal), Andrey Korotayev (Russia)***

Kondratieff Waves is a new international almanac that will be published, starting in 2012, in co-operation with the International N. Kondratieff Foundation and the Faculty of Global Processes at Lomonosov Moscow State University. The year when we publish the first issue of this almanac is not at all coincidental, as it is the 120th anniversary of economist Nikolai Kondratieff's birth, as well as the 90th anniversary of the publication of his *Mirovoye khozyaistvo i ego conyunktury vo vremya i posle voiny* [The World Economy and its Conjunctures during and after the War] (Vologda, 1922), in which he first spelled out the idea of long cycles, which later became known as Kondratieff cycles or Kondratieff waves (or just K-waves). The leading subjects of this publication will be as follows:

- K-waves at all levels of the economy, society, politics and culture;
- Economic crises and K-wave dynamics;
- Mechanisms of K-wave dynamics;
- Technological background of K-waves;
- Human problems in light of K-wave dynamics; *etc.*

The *Kondratieff Waves* almanac calls for papers for its first issue: Our deadline is 1 October 2011.

Statement of Purpose

Since the time of Nikolai Kondratieff, the economic cycles that he defined have generated much interest among scholars on topics as varied as the mechanisms initiating the long waves, the causes of regularity between upswings and downswings, and the relative stability of the K-cycle period. Essentialy, K-wave dynamics have become a special field of interdisciplinary studies, extending far beyond just economics. Of course, this suggests an immense importance for further research, especially regarding the application of K-cycles to the study of past centuries (if not millennia).

Notwithstanding the advances in the study of these dynamic waves, there is no consensus among K-wave scholars with respect to a number of the most essential points. They include such questions as:

- How many K-waves have been observed up until the present time?
- Did Kondratieff waves exist prior to the Industrial Revolution?
- What is the periodicity of the K-wave cycle?
- What variables should be used for the detection of K-waves?

- What social systems experience K-wave dynamics?
- Is economics the only system in which K-waves occur?
- Could K-wave patterns be traced in political, cultural and other systems?
- Are there spheres of social life that do not experience K-wave dynamics?
- What are the factors of the K-wave dynamics?
- Which of those factors are the most important?
- In what K-cycle phase is the World System at the moment?

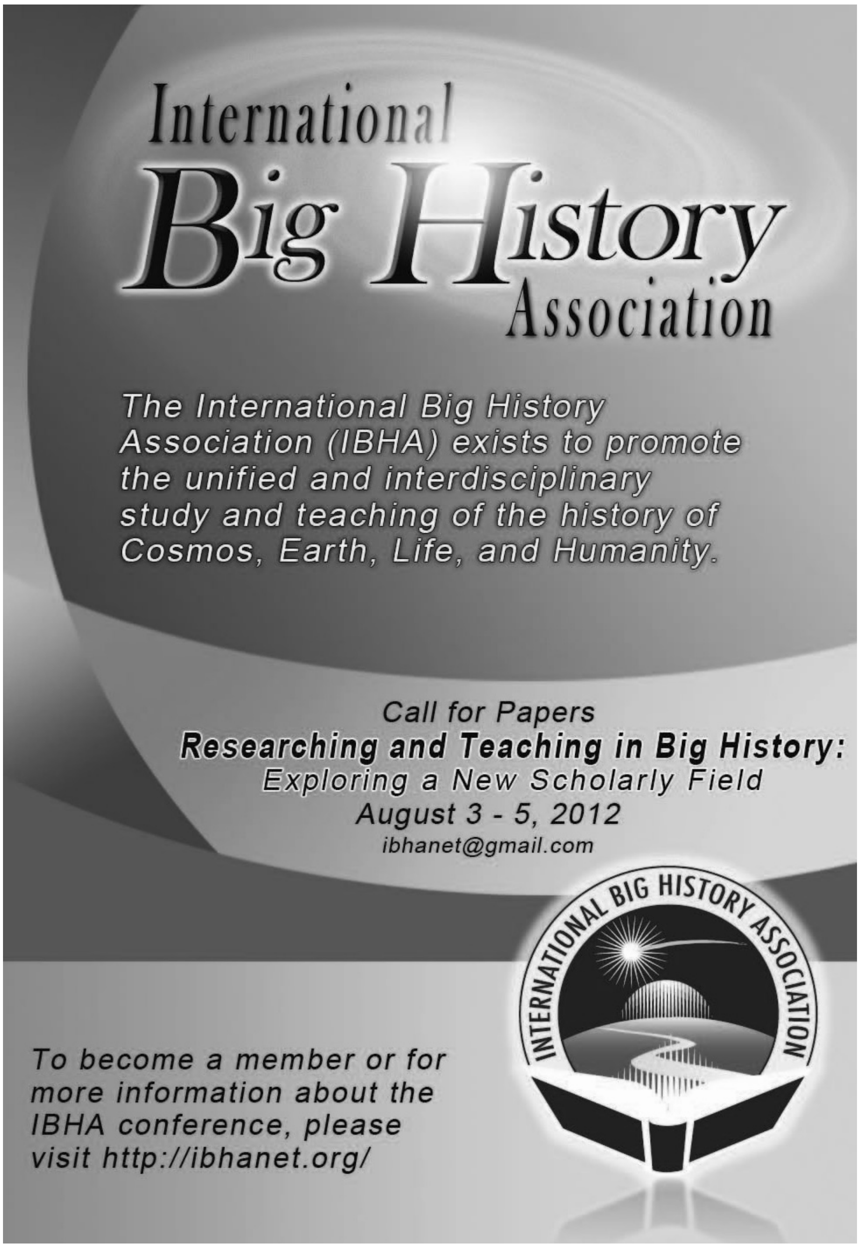
In the meantime, it is quite clear that a deeper penetration into the nature of the long waves can provide us with an important tool for forecasting social and economic macrodynamics.

We believe that we need to develop cooperation and interconnection between scholars of the long cycles, in order to advance the study of causes, mechanisms and patterns of K-wave manifestations. One of the steps in this direction may be advanced by this new almanac; with *Kondratieff Waves* as its permanent title, whereas each issue will have its own subtitle and special topic.

This new almanac is not the publication of an established group of scholars. It invites all students of Kondratieff waves to join in a free discussion of relevant problems, from all possible points of view. We expect that the almanac will publish theoretical articles dedicated to the study of K-waves, their various manifestations, and their interconnections with economic, political, cultural and social cycles and phenomena. We will also publish book reviews, as well as information on conferences and other academic events on long cycle themes. However, we plan to dedicate the first edition to the 120th anniversary of the birth of Nikolai Kondratieff. Thus, in addition to general theoretical articles, it will contain papers concerned with Kondratieff's biography and analysis of his works.

On 24–26 May 2012, we also plan to organize the 8th International Kondratieff Conference (‘Cyclical Dynamics in Global Processes’) in collaboration with the International N. D. Kondratieff Foundation and the Faculty of Global Processes at Lomonosov Moscow State University. This conference will be dedicated to the anniversary of Nikolai Kondratieff's birth, Kondratieff waves (and other cyclical processes in global dynamics), and Kondratieff's works. We plan to present the first issue of the almanac at this conference.

For detailed **guidelines**, please, contact the almanac editors: Professor Leonid E. Grinin, Eurasian Center of Big History and System Forecasting, Russia (lgrinin@mail.ru); Professor Tessaleno Devezas, University of Beira Interior, Portugal (tessalen@ubi.pt); Professor Andrey V. Korotayev, Russian State University for the Humanities (akorotayev@gmail.com). Also, see the almanac home page: http://www.socionauki.ru/ almanac/k_waves_en/.


International
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The International Big History Association (IBHA) exists to promote the unified and interdisciplinary study and teaching of the history of Cosmos, Earth, Life, and Humanity.
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