# EVOLUTION:From Big Bang to Nanorobots

Leonid Grinin, Andrey Korotayev

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

VOLGOGRAD CENTER FOR SOCIAL RESEARCH

# EVOLUTION

## From Big Bang to Nanorobots

**Edited by**
**Leonid E. Grinin**
**and Andrey V. Korotayev**

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‘Evolution’ Yearbook



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The present volume is the fourth issue of the Yearbook series entitled ‘Evolution’. The title of the present volume is ‘From Big Bang to Nanorobots’. In this way we demonstrate that all phases of evolution and Big History are covered in the articles of the present Yearbook. Several articles also present the forecasts about future development.

The main objective of our Yearbook as well as of the previous issues is the creation of a unified interdisciplinary field of research in which the scientists specializing in different disciplines could work within the framework of unified or similar paradigms, using the common terminology and searching for common rules, tendencies and regularities. At the same time for the formation of such an integrated field one should use all available opportunities: theories, laws and methods. In the present volume, a number of such approaches are used.

The volume consists of four sections: *Universal Evolutionary Principles; Biosocial Evolution, Ecological Aspects, and Consciousness; Projects for the Future; In Memoriam.*

This Yearbook 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 Cosmology, Biology, History, Anthropology, Economics and other areas of study. More than that, this edition will challenge and excite your vision of your own life and the new discoveries going on around us!

'Uchitel' Publishing House
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400079 Volgograd,
Russia

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# Contents

# Introduction

# Once More about Aspects, Directions, General Patterns and Principles of Evolutionary Development

*Leonid E. Grinin and Andrey V. Korotayev*

The present volume is the fourth issue of the Almanac series entitled 'Evolution'. Thus, one can maintain that our Almanac, which has actually turned into a Yearbook, has succeeded (see below).

The title of the present volume is 'From Big Bang to Nanorobots'. In this way we demonstrate that all phases of megaevolution and Big History are covered in the articles of the present Yearbook. Several articles also present forecasts about possible future developments.

The main objective of our Yearbook as well as of the previous issues (see Grinin, Korotayev, Carneiro, and Spier 2011a, Grinin, Korotayev, and Rodrigue 2011a, Grinin and Korotayev 2013a) is the creation of a unified interdisciplinary field of research in which scientists specializing in different disciplines could work within a framework of unified or similar paradigms, using common terminology and searching for common rules, tendencies and regularities. At the same time for the formation of such an integrated field one should use all available opportunities: theories, laws and methods. In the present volume, a number of such approaches including those which will be described below are used.

One of the most popular approaches in this respect is universal evolutionism which is the description of the major evolutionary trend (Big History, cosmic evolution); several articles on this topic were published in our previous issues (Grinin *et al.* 2011b; Grinin, Korotayev, and Rodrigue 2011b; Grinin and Korotayev 2013b[1]). This aspect has always been of special (and understandable) interest for those evolutionists who, following Herbert Spencer, aimed at defining evolution as a transition from the simple to the complex, from less developed to more developed, *etc.* (Spencer 1972 [1862]: 216, 71). At present Big History and the theory of megaevolution face very complicated issues whose solutions have not been found yet: Is this the direction of intergalactic or only planetary (local) character? Is this a development cycle consisting of de-

[1] See also, *e.g.*, Grinin *et al.* 2015; Rodrigue, Grinin, and Korotayev 2015a, 2015b.

stroying and creating cosmic civilizations? Does one need to use an anthropic principle to explain it?[2] Undoubtedly, one can observe this trend within the interval of megaevolution about which the contemporary science is able to propose some reasonable hypotheses.

But universal evolutionism naturally has its own limits and vulnerabilities.

First, the universal evolutionism examines only one evolutionary trend (which is in certain respect the major one); meanwhile, it is necessary to pay attention to other trends and aspects as well.[3] Let us note that the similarities between objects and processes of different nature can become evident (and are often found) within the secondary trends (*e.g.*, the similarity between social insects and the society).[4]

Second, the universal evolutionism is supported by a rather narrow theoretical base of the unity of the world. In addition to distinguishing the historical and genetic unity it is necessary to find an ontological base for the unity which would be based on common principles, laws, and rules showing the internal similarity of the existence and functioning of the matter at all phases of its development.

Third, it is necessary to examine the common features disregarding the differences in nature and complexity of the objects; thus, one can formulate certain (but rather general) principles of 'behaviour' of the objects belonging to different evolutionary levels.

Fourth, one can postulate the unity of evolution proceeding from the assumption about the general principles (which originated genetically or typologically) of the world structure. To find out the general elements of this structure, one should compare the evolutionary levels (fields) applying different criteria.[5]

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[2] The anthropic principle, which does not have the general formulation, reveals the presence of relationship between large-scale properties of the expanding Universe and the origin of life, reason, cosmic civilizations. Sometimes this principle is interpreted as the principle which explains 'extremely fine-tuned Universe' (see Davies 1993). Of course, in terms of the anthropic principle such important phenomena as the emergence of carbon and atoms of heavy elements, the formation of galaxies, planets, etc. are crucial for the Universe. With respect to inanimate nature, we can also use the notion of *preadaptation* (which means possessing the characteristics which appear to be decisive during the transition to a different environment, *e.g.*, from water to land) (about such preadaptations see Grinin 2014a, 2014b).

[3] As Eric Chaisson points, '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 (Chaisson 2012: 38).

[4] In Fred Spier's article published in one of the previous issues of the Yearbook (see Spier 2011b: 32), special attention is paid to the idea that the transition to a new quality (new complexity, according to Spier) probably occurs on the outer edges of galaxies and other systems. And the article by Leonid Grinin, Andrey Korotayev, and Alexander Markov considers the rule of special conditions for the emergence of aromorphoses (which is in many respects applicable to the whole process of megaevolution) (Grinin, Korotayev, and Markov 2011).

[5] Alexander Krushanov writes, 'If by the present time within various scientific disciplines there has been already found a much greater (than it has been previously assumed) uniformity of objects

In the previous issues of our Yearbook we have tried to overcome the above mentioned restrictions. In particular, the unity of evolution on the theoretical and epistemological levels as well as the directions of the search for a general theoretical base for the evolutionary studies are analyzed in the Introduction to the first volume of the 'Evolution' Yearbook (Grinin, Korotayev, Carneiro, and Spier 2011b). The article by Grinin, Korotayev and Markov 'Biological and Social Phases of Big History: Similarities and Differences of Evolutionary Principles and Mechanisms' in the second volume of the Yearbook considers the general laws and rules for biological and social evolution (Grinin, Korotayev, and Markov 2011; Grinin, Markov, and Korotayev 2011). In the present volume, the article by Leonid Grinin 'Cosmic Evolution and Universal Evolutionary Principles' is devoted to the analysis of universal evolutionary principles which are revealed at different phases of Big History.

One can find many similarities between all types of macroevolution. However, unfortunately, there are few works on the opportunity to reveal them. In the present Introduction we will briefly consider a number of quite important similarities but unfortunately in a rather unsystematized manner as they are presented here only as an illustration of some important aspects which in our opinion clearly show the systemic-structural and evolutionary functional unity of the world starting from the microworld up to contemporary global humankind. In fact one can distinguish several similarities and group them into large blocks.

**The capacity for development, self-preservation and self-organization.** Evolution, that is the changes of objects, actually means the destruction of their stability and identification. From this point of view, at any stage and in any sphere of evolution the matter can be divided into two types: the first one is able to self-preservation and the second one is able to self-transformation (of course, these characteristics are present to a different degree). In other words, one can speak about evolving and non-evolving matter. There exist rather conservative elements even within human society and there still exist some societies which are not quite prone to changes, especially this phenomenon was strongly pronounced in the previous epochs. An average lifespan of a biological species is less than 10 million years. At the same time there are species which have endured for 200–300 million years, and the presumable age of blue-green algae is several billions years, that is they have not changed significantly since the Archean Eon. At any phase, the evolving matter makes up the minority (see Nazaretyan 2011); thus, the light (baryonic, stellar) matter according to some current views amounts for only 3–5 per cent. And such proportion is relevant even to the human society in which, according to some reports, the number of innovators is also 3–5 per cent. But at the same time, we suppose that just in the course of evolution of this comparatively small part of the matter the latter ac-

and processes which are related to different structural levels of the Universe, then who can at present categorically determine the limits of such uniformity?' (Krushanov 2007: 247).

quired the ability to self-organization. Many scientific disciplines, including Complexity Studies and Cybernetics, deal with the processes of self-organization of the matter. Self-organization is one of the most important and universal properties of the matter at any stage of evolution. One can say that the stronger the property of the matter to evolve, the stronger is its ability to self-organization and interaction with the environment. The issue of interaction with the environment, which is typical of evolution, can be illustrated by the problem of 'wastes' resulting from objects' functioning and of the best ways to get rid of the wastes. This is a cross-cutting evolutionary and more urgent problem of the present time. Fred Spier considers this aspect from a rather interesting point (Spier 2011b).

Let us note once again that the inability to evolve means the ability of the matter to self-preservation; thus, the dark matter (the composition of this matter is still unknown) has probably undergone no significant changes over the last 13–14 billion years after the Big Bang, and perhaps, it had existed before this event. Though the latest discoveries confirm the consistency of the dark matter and dark energy (cosmic vacuum), one can suppose that they are capable to transformations, but it takes much more time for the dark matter to transform than for the light matter. But some time ago the stars used to be considered unchangeable too.

**The law of the age stages/phases of object's life.** Oswald Spengler (1993) and Arnold Toynbee (1991) are known for their theories of civilization which stated that every civilization passes through certain stages of life (birth, youth, maturity, and decline) before the collapse. The similar idea was suggested more categorically by Lev Gumilev, who stated that the life period of any ethnic group from its birth till death lasts for 1500 years and during its life time an ethnos passes through the same stages (see Gumilev 1993). This idea still arouses discussions; but still the idea of certain phases of social organisms' life is rather reasonable. But while in social life a society can prolong its life and retrieve its dynamism at the expense of innovations and reformations, in the case of evolution we clearly observe that all material objects and systems have a certain lifespan and pass a certain phase. It is quite obvious among the biological organisms and even species. The stars also have certain life phases. After the phase of ordinary thermonuclear reactions, which is called the main sequence phase, is completed, a star transforms into a white dwarf (after passing the red giant stage) or (having a large mass) into a neutron star. One can find certain phases within the life span of many other objects as well.

**The rule of 'block assemblage' in evolution.** This rule was formulated by Grinin, Korotayev and Markov (see Grinin, Markov, and Korotayev 2009, 2011) for the analysis of the similarities between biological and social macroevolution.[6] However, it is quite relevant for the cosmic, chemical and geologi-

[6] For the analysis of some other similarities between biological and social evolution see also, *e.g.*, Grinin, Korotayev, and Markov 2011, 2013; Markov and Korotayev 2007a, 2007b, 2008; Markov, Anisimov, and Korotayev 2010; Korotayev and Markov 2014.

cal phases of evolution. The essence of this rule is that in the course of evolution there emerge some elementary and more complex units, systems and constructions which are used in different variations. The elementary particles are the units which form the atoms. With the emergence of atoms there also emerge the stellar systems, and in the stellar interior new types of atoms including heavy elements are formed from additional elementary particles. Due to the diversity of emerging atoms one can speak about a chemical evolution. Atoms are the universal units and components for the formation of various molecules and this marks the beginning of geological and then of a complex molecular organic evolution leading to life. The cell becomes an element for the formation of living organisms; there progressively emerge entire blocks of organs and systems which are surprisingly similar in different classes and even types of living organisms. One can recall genes and chromosomes as standard components and blocks of biological systems. One can insert a gene of a mouse into an elephant DNA, and the human gene – into the bacteria! Thus, there is a striking standardization of elements and 'components' at all evolutionary levels; and since entirely new objects within evolution are for 90–99 per cent created from the already existing components, the speed of evolution increases dramatically. Let us also add that in human society the borrowing occurs rather frequently: societies adopt (sometimes as complete wholes) religions, legal, political and technological systems. As a result we observe the phenomenon of globalization in the course of which the unification reaches an unprecedented level.

**The unevenness and catastrophes (gradualism and catastrophism).** Within evolution, periods of slow changes (accumulations), that is of an evolution in its narrow sense, are alternated by rapid metamorphoses and qualitative transformations (which sometimes look like revolutions) and periods of explosive growth are followed by catastrophes. In geology and paleontology there were hot debates between proponents of catastrophism (the school of the famous paleontologist George Cuvier) and adherents of gradual changes (*e.g.*, Charles Lyell) whose approach is known as 'gradualism'. The victory of the latter was a progress; however, later it became clear that it was very difficult to explain many things by slow and insignificant changes only. Thus, the evolutionary theory was enriched by the ideas of leaps, revolutions, and catastrophes enabling us to understand how and why the world kept changing. It is important to note that catastrophism is an essential part of evolution at all its stages. The idea of 'Big Bang', the biggest 'catastrophe' in the history of the Universe, underlies its origin. Thus, catastrophes appear to inevitably accompany the development and evolution, to be a kind of compensation for the development and rapid growth (and at certain evolutionary stages – a compensation for progress). In cosmic life, catastrophes are an inevitable result of long life of stars which, after having depleted their energy reserves, turn into the white dwarfs or red giants and sometimes they produce extremely bright outbursts of light – the outbursts of supernova. In the field of biology, the catastrophes are the great extinctions which enabled new progressive species to appear. It should be noted that the catastrophes provide an abundant data for the scientific reconstruction of the past events. Thus, as a result of the study of supernova's outbursts, the spectrum shift analysis served a firm foundation for the discovery (one of the most important in astrophysics and the most important for the last 15 years) of antigravitation of cosmic vacuum (the so-called dark energy) which constitutes the vast majority of the total mass of the Universe.

**The typical and the unique objects.** On the one hand, one cannot help wondering at the Nature's 'production-line' ability to create millions and billions of exceptionally similar copies of the same objects. The issue of ideal eternal essences and real copies-existences of things has been the philosophers' main concern since ancient times. But, on the other hand, the variability of objects which are similar in type is undoubted. In fact, every star is very different from another even if it belongs to a narrow classification group (and there are a lot of such groups). And even if the stars are formed (like enzygotic twins) from one gas-dust cluster (as a result of a single outburst of supernova, *etc.*), still they differ in mass, chemical composition, the presence or absence of planetary system (and in the planetary system types), brightness, characteristics of reactions, and position. None of the biological species is identical with another. The same refers to human beings (various papillary patterns on the fingers, unique genetic code, *etc.*). Not so long ago we believed that animals act like mechanisms according only to their genetically determined instincts. But at present, ethology identified a large range of individuality among animals as well as among insects (see, *e.g.*, Reznikova and Panteleyeva 2012). Thus, *typical and unique (individual) characteristics* are peculiar to all macroobjects in nature. At the same time individuality increases as the evolution develops. Probably, the number of variability attributes increases along with the complication of systems (*e.g.*, in human society, language, social position, nationality, *etc.* are added). Such analysis allows identifying the roots of the features which seem typical of humans only, as though they were inherent to Nature's grand scheme.

The variability of typical objects (belonging to one class, species, group, *etc.*) is the most valuable tool of evolution which allows selecting variations of attributes (as well as their concentration, *etc.*) which are the most appropriate for a variety of tasks. A qualitative breakthrough can occur only as a result of the emergence of unique circumstances (whose possible occurrence is significantly increased through variability). Finally, only the endless variety of stars, planetary systems, planets and preceding events could be a trigger of emergence of life on planets of the Earth type. But it is quite likely that, in the field of microworld, elementary particles, atoms and molecules might also have some individual features which may be found out to affect (through certain mechanisms) some properties. It is impossible to identify the differences between the grains of sand with the naked eye, but it is easy to do it under the microscope.

**Recombination, or the circulation of matter of similar class in nature.** The Nature's workshop is based not only on the selection from the diversity but also on a constant remaking of objects. Every object has its own lifespan, therefore its decaying substance is involved into the circulation and new objects are formed from it. New stars are formed from exploded stars but they differ from their predecessors and this brings about an increasing diversity and enhances chances of the emergence of something brand new. Decayed biomass is a source of nutrients to support the reproduction and life of other living creatures. On debris of a destroyed empire a new one appears. On the one hand, in inanimate nature we observe a strong ability to direct and reverse transitions (contraction and expansion of the matter), transformation of energy into matter and vice versa; thus, the rebirth of a star from a gas-dust cloud is possible (*but it is impossible to make an exact reproduction of a unique object as it is the general characteristic of nature*). The irreversible character of processes is much more evident in animate nature. But in human society we observe an increasing irreversibility of typical processes at a certain level (not in the sense of revival of people but of the revival of social organisms which are very different from the animated organisms in a number of parameters). Thus, the *decay and revival (in different ways) of objects (organisms) is a general law of evolution/the Universe.* We say 'of the Universe' because these processes are ensured by the laws of perdurability of matter and energy. We say 'of Evolution' because these processes allow some constant testing of new variants (in biology they also include mutations and in human society – deliberate changes which accelerate the given process, but its general basis consists in individualization of objects and recombination of the matter/energy). On the other hand, as the evolution becomes more complicated, the effect of mutual influence emerges resulting from the recombination of matter. Thus, the living matter produces a huge impact both on geological changes (organic raw materials – coal, oil[7], soils, *etc.*, not to mention the oxygen which appeared in the atmosphere as a result of the greatest aromorphosis in animate nature – of the transition from anaerobic to aerobic dissimilation) and on the geographic ones (the emergence of islands, *etc.*) while the anthropic matter influences both animate and inanimate nature (channels, ploughing up, *etc.*).

Here we complete our survey of the universal similarities and patterns (note that there are also some interesting examples and conclusions in Leonid Grinin's article in the present Yearbook).

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The present Yearbook consists of four main sections.

***Section I. Universal Evolutionary Principles*** comprises four articles.

**Leonid E. Grinin.** 'Cosmic Evolution and Universal Evolutionary Principles'.

The given article attempts at combining Big History potential with the potential of Evolutionary Studies in order to achieve the following goals: 1) to apply the historical narrative principle to the description of the star-galaxy era

[7] However, there are some theories about their inorganic origin.

of the cosmic phase of Big History; 2) to analyze both the cosmic history and similarities and differences between evolutionary laws, principles, and mechanisms at various levels and phases of Big History. We think that nobody has approached this task in a systemic way yet. It appears especially important to demonstrate that many evolutionary principles, patterns, regularities, and rules, which we tend to find relevant only for higher levels and main lines of evolution, can be also applied to cosmic evolution. Moreover, almost everything that we know about evolution may be detected in the cosmic history, whereas many of the evolutionary characteristics are already manifested here in a rather clear and salient way. Of course, many of the characteristics are manifested in initial or nonsystematic forms but some features, on the contrary, appear to be more distinct just in the cosmic phase. And at the same time when many characteristics and features which are typical of biological and social evolution unexpectedly reveal their roots or protoforms at earlier phases, one becomes aware that the universal character of evolution is real and it can be detected in a number of manifestations. One should also bear in mind that the origin of galaxies, stars, and other celestial objects is the lengthiest evolutionary process among all evolutionary processes in the Universe. Such an approach opens new perspectives for our understanding of evolution and Big History, of their driving forces, vectors, and trends, it also creates a consolidated field for the multidisciplinary research.

**David LePoire.** 'Potential Nested Accelerating Returns Logistic Growth in Big History'.

The discussions about the trends in rates of change, especially in technology, have led to a range of interpretations including accelerating rates of change and logistic progress. These models are reviewed and a new model is constructed that can be used to interpret Big History. This interpretation includes the increasing rates of the evolutionary events and phases of life, humans, and civilization. These three phases, previously identified by others, have different information processing mechanisms (genes, brains, and writing). The accelerating returns aspect of the new model replicates the exponential part of the progress as the transitions in these three phases started roughly 5 billion, 5 million, and 5,000 years ago. Each of these three phases might be composed of a further level of about six nested transitions with each transition proceeding faster by a factor of about three with corresponding changes in free energy flow and organization to handle the increased generation rate of entropy from the system. Nested logistic transitions have been observed before, for example in the ongoing exploration of fundamental physics, where the progress so far suggests the complete transition will include about 7 nested transitions (sets of subfields). The reason for this number of nested transitions within a larger transition is not known, although it may be related to the initial step of understanding a fraction of the full problem. Too small of an initial fraction would lead to incomplete problem scope and definition. Too large of an initial step would lead to complications between the development of basic understanding and higher level derivations. An original step of one-seventh of the problem ends up within one standard deviation from the inflection point (mid-way through the transition).

**David Christian.** 'Universal Darwinism and Human History'.

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

**David Baker.** 'Collective Learning as a Key Concept in Big History'.

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

**Craig Benjamin.** 'Collective Learning and the Silk Roads'.

The Silk Roads are the quintessential example of the interconnectedness of civilizations during the Era of Agrarian Civilizations, and the exchanges that occurred along them resulted in the most significant collective learning so far experienced by the human species. The primary function of the Silk Roads was to facilitate trade, but the intellectual, social, and artistic exchanges that resulted had an even greater impact on collective learning. The Silk Roads also illustrate another key theme in Big History – evolving complexity at all scales. Just as the early universe was simple until contingent circumstances made it possible for more complex entities to appear, and that the relatively simple single-cell organisms of early life on the planet were able to evolve into an extraordinary, complex biodiversity, so human communities and the connections between them followed similar trajectories. The comingling of so many goods, ideas, and diseases around a geographical hub located deep in central Eurasia was the catalyst for an extraordinary increase in the complexity of human relationships and collective learning, a complexity that helped drive our species inexorably along a path towards the modern revolution.

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***Section II. Biosocial Evolution, Ecological Aspects, and Consciousness*** consists of five contributions.

**Andrey V. Korotayev, Alexander V. Markov, and Leonid E. Grinin.** 'Modeling of Biological and Social Phases of Big History'.

In the first part of this article we survey general similarities and differences between biological and social macroevolution. In the second (and main) part, we consider a concrete mathematical model capable of describing important features of both biological and social macroevolution. In mathematical models of historical macrodynamics, a hyperbolic pattern of world population growth arises from non-linear, second-order positive feedback between demographic growth and technological development. Based on diverse paleontological data and an analogy with macrosociological models, the authors suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by non-linear, second-order positive feedback between diversity growth and the complexity of community structure. They discuss how such positive feedback mechanisms can be modelled mathematically.

**Alexander D. Panov.** 'Prebiological Panspermia and the Hypothesis of the Self-Consistent Galaxy Origin of Life'.

The author argues that the panspermia can mean not only the other place of the origin of life but also another mechanism of the origin of life that increases the probability of the origin of life to many orders compared to a single-planet prebiological evolution. The prebiological evolution can be an all-Galaxy coherent process due to the fact that prebiological panspermia and the origin of life are similar to Galaxy-scale second-order phase transition. This mechanism predicts life to have the same chemical base and the same chirality everywhere in the Galaxy.

**Olga A. Sorokina and Rendt Gorter.** 'Social Evolution of Humankind as an Integral Part of the Evolution of the Biosphere'.

A theoretical reconceptualization of social evolution is proposed in order to construct the principles for socio-economic governance that can expand the resilience of global systems that in turn determine the world's carrying capacity for the human population. Big History approach shows how world societies are in a transition phase that can be explained using evolutionary laws with the understanding that the development of human civilization is considered as an integral part of the evolution of the Earth's biosphere.

**Michael Charles Tobias and Jane Gray Morrison.** 'The "Ahimsa Factor": Ecological Non-Violence Process Analysis in China and its Implications for Global Paradigmatic Shifts'.

The world is witnessing the sixth extinction spasm in the annals of 4.2 billion years of life on Earth. We lose some 40,000 discrete populations of organisms every day. Species and habitat loss exceeds anything comparable during the last 65 million years. The human population is poised to hit between 9.5 billion and – in the absolute worst case scenario, 15 billion – with all of its accompanying consumption. A new global paradigm that can set the gold standard for ecologically-humble human behavior is urgently required and the nation of China – the largest country in human history, by far – has the potential to set in motion the global processes that are a prerequisite to a new gold standard for rectification of ecological violence. This will be no easy challenge, to be sure. In this essay the authors examine some of the comprehensive biodiversity, global trade, ecological degradation, demographic and animal rights challenges facing the China of 2013 and suggest some solutions.

**Ilya V. Ponomariov.** 'Situational Binding and Inner Speech: Cross-Sectional Evidences'.

Different evidences of inner speech development are gathered and discussed from the perspective of situational binding – a conception developed within the framework of cultural-historical tradition of L. S. Vygotsky. This conception explains and systematizes many facts which have otherwise caused much perplexity to scientific knowledge. It predicts that the future neurobiological research of inner speech in non-school societies should discover that it has fragmentary and sympractical character.

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***Section III. Projects for the Future*** contains three articles.

**Valentina M. Bondarenko.** 'Governing the Time will Govern Development – or, "Territory of Faster Development: Everything for People" Megaproject Realization Proposals'.

The author substantiates the thesis that the contemporary scientific knowledge has exhausted its explanatory potentials and does not contribute to definition of the objective causes of the emerging systemic crisis in Russia and in the world. Hence, such knowledge does not help to conduct the search and to substantiate transition to the new economic growth model, although Russia in its current condition is doomed to stagnation, further slow-down of growth rates, increase in unemployment and poverty. As argued further on in the article, only by reaching the visionary level of understanding the roots of the emerging systemic crisis and all other problems it has become possible to form the methodology for cognition of regularities in the human system development, and then, basing on the given methodology, to substantiate the need and possibility to realize the megaproject of 'Territory of Faster Development: Everything for People'.

**Vasily N. Vasilenko.** 'The Noospheric Concept of Evolution, Globalization and Big History'.

The followers of Vladimir I. Vernadsky's ideas claim that the relevance of the biospheric concept is increasing, as well as the biosphere-noosphere transition, thereby providing public safety and reaching sustainable development. Philosophical, ontological and futurological nationwide recognition of Vernadsky's legacy is proved by including the 150$^{th}$ anniversary of Vladimir Vernadsky in the UNESCO calendar of anniversaries under the title 'Noospheric Thinking – the 21$^{st}$ Century Thinking'. The author considers the issues of Evolution, globalization and Big History from the perspective of noospheric paradigm. The issues deal with the future development of the civilization within the Earth's biosphere. In order to take into account ecological threats for citizens in different regions of the planet, the criterion of noospheric approach to globalization challenges was chosen.

**Anton L. Grinin and Leonid E. Grinin.** 'Cybernetic Revolution and Forthcoming Technological Transformations (the Development of the Leading Technologies in the Light of the Theory of Production Revolutions)'.

The article analyzes the technological shifts which took place in the second half of the 20$^{th}$ and early 21$^{st}$ centuries and forecasts the main shifts in the next half a century. On the basis of the analysis of the latest achievements in innovative technological directions and also on the basis of the opportunities provided by the theory of production revolutions the authors present a detailed analysis of the latest production revolution which is denoted as 'Cybernetic'. They offer some forecasts about its development in the nearest five decades and up to the end of the 21$^{st}$ century. It is shown that the development of various self-regulating systems will be the main trend of this revolution. The authors argue that at first the transition to the beginning of the final phase of the Cybernetic Revolution will start in the field of medicine (in its some innovative directions). In future we will deal with the start of convergence of innovative technologies which will form the system of MBNRIC-technologies (*i.e.* the technological paradigm based on medicine, bio- and nanotechnologies, robotics, IT and cognitive technologies). The article gives a detailed analysis of the future breakthroughs in medicine, and also in bio- and nanotechnologies in terms of the development of self-regulating systems with their growing ability to select optimum modes of functioning as well as of other characteristics of the Cybernetic Revolution (resources and energy saving, miniaturization, and individualization).

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***Section IV. In Memoriam*** is devoted to George Modelski.

***George Modelski*** was an outstanding American social scientist and world historian. He contributed to an impressive number of different research questions. Throughout a long and distinguished career, George Modelski emphasized the need to bring together theory, evidence, and history in the unraveling of the World System evolution. Although never widely cited or known in wide circles of social scientists, his contributions were always distinctively different and original.

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# I. UNIVERSAL EVOLUTIONARY PRINCIPLES

## 1
## Cosmic Evolution and Universal Evolutionary Principles

*Leonid E. Grinin*

**Abstract**

*The present article attempts at combining Big History potential with the potential of Evolutionary Studies in order to achieve the following goals: 1) to apply the historical narrative principle to the description of the star-galaxy era of the cosmic phase of Big History; 2) to analyze both the cosmic history and similarities and differences between evolutionary laws, principles, and mechanisms at various levels and phases of Big History. As far as I know, nobody has approached this task in a systemic way yet. It appears especially important to demonstrate that many evolutionary principles, patterns, regularities, and rules, which we tend to find relevant only for higher levels and main lines of evolution, can be also applied to cosmic evolution. Moreover, almost everything that we know about evolution may be detected in the cosmic history, whereas many of the evolutionary characteristics are already manifested here in a rather clear and salient way. Of course, many of the characteristics are manifested in initial or nonsystematic forms but some features, on the contrary, appear to be more distinct just in the cosmic phase. And at the same time when many characteristics and features which are typical of biological and social evolution unexpectedly reveal their roots or protoforms at earlier phases, one becomes aware that the universal character of evolution is real and it can be detected in a number of manifestations. One should also bear in mind that the origin of galaxies, stars, and other celestial objects is the lengthiest evolutionary process among all evolutionary processes in the Universe. Such an approach opens new perspectives for our understanding of evolution and Big History, of their driving forces, vectors, and trends, it also creates a consolidated field for the multidisciplinary research.*

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

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

The formation of modern structure of the Universe lasted for many billions of years when our Universe 'lived' for quite a long period of time without any stars, galaxies, Hubble's law, clusters and superclusters of galaxies (Khvan 2008: 302). Now it is recognized that the first stars and galaxies turn out to have emerged much earlier. According to the latest astronomical observations, the first galaxies emerged not later than several hundred million years after the Big Bang. In what follows we will consider this in detail. What was the matter from which they had emerged?

## Tiny Material for the Formation of Giants: About the Gas-Dust Clouds and Cosmic Dust

Approximately 270,000 years after the Big Bang, a large phase transition occurred resulting in the emergence of matter in the form of atoms of hydrogen and helium. Later, they started to consolidate in new structures. The main mass of this matter concentrated in gas-dust clouds that could be of tremendous sizes (dozens parsecs, or even more).[1] At present we usually speak of such cosmic fractions as interstellar gas and cosmic dust. They can be both in vacuum condition and in the form of clouds. But as is known the observed today clouds consist mainly of equal proportions of gas and dust. That is why they are usually called gas-dust clouds.

For the first time we observe Nature in the role of a constructor. Before that, it had formed just the basic elements. Now one could observe the emergence of enormous structures from tiny particles and 'specks of dust'. Later one could constantly observe similar processes in evolutionary developments: *large-scale structures are composed of myriads of minute particles and grains*.

**Minor factors are also necessary for structuring**. The formation of clouds (and later of stars and galaxies) involved concentrating of matter on enormous scale, which could have been caused only by gravity. However, this only force is insufficient for structuring, because in 'an absolutely homogenous universe the emergence of large-scale structures (galaxies and their clusters) is impossible' (Dolgov *et al.* 1998: 12–13). Thus, certain 'seed grains' are needed, similar to the process of formation of rain drops emerging around particles of dust or soot; or the formation of a pearl around grit.

Small fluctuations are often needed for the powerful forces to start working. Actually, minor fluctuations (minute deviations from homogeneity and isotropy) occurred in the Universe from the first nanoseconds after the Big Bang. Then the larger fluctuations happened. They could act as seed grains for the formation of galaxies. However, it is not clear what kind of fluctuations caused the formation of galaxies and what the mechanism of their formation is. In other fields of evolution initial fluctuations also often remain a mystery.

[1] 1 parsec ≈ 31 trillion km.

Thus, the non-uniformity (including the non-uniformity connected with different concentration) is one of the main foundations of development and evolution at all its stages and in all its forms. Any major evolutionary shift in biological and social matter at a certain stage of evolution is necessarily connected with some form of accumulation or concentration when matter becomes abundant and occupies certain niches (the periods which are similar to the first stages after the Big Bang). The higher the stage of evolution, the more important it is. Thus, in a large-scale system the common processes may proceed in their usual way, whereas in the concentration zone some peculiar processes start (as it takes place in the stellar formation zones).

## The Epoch of Formation of the Large-Scale Structure of the Universe. First Galaxies and Stars

**Dark and light matter.** Nowadays it is generally accepted that dark matter plays an important role in the formation of the first galaxies, as it appeared capable of much quicker consolidation into clusters than the light (baryonic) matter. The latter could not condense until the end of the hydrogen recombination (atom formation) due to radiation pressure (270,000 years after the Big Bang). Only when hydrogen nuclei and electrons were able to merge and form atoms, whereas photons separated from the matter and flew away, the radiation pressure dramatically decreased to zero. As a result, the light matter would fall in potential holes prepared by the dark matter. Perhaps, we observe here a very interesting evolutionary pattern. Nevertheless, the non-evolutionary dark matter initially appeared to be more capable to structuring than the light matter, but the progress of the former toward structuring turned out to be very short and almost leading to a dead-lock. However, as with any evolutionary dead end, this does not mean an absolute stagnation. At present, in galaxy halos the dark matter continues structuring in certain smaller structures, the so-called clumps and sub halos (see, *e.g.*, Diemand *et al.* 2008). Meanwhile, the evolutionary potential of the light matter was based on the 'achievements of the dark matter'. Such a model of development is rather typical for evolution. For example, long before the transition to agriculture some gatherers of cereal plants invented many things (including tools, granaries, and grinding stones) that later turned to be rather useful for agriculturalists, but the hunter-gathering mode still turned out to be an evolutionary dead end.

There are rather diverse opinions on the timing and characteristics of the process and sequence of formation of stars, galaxies, galaxy clusters and superclusters.

The galaxy protoclusters are supposed to have been the first to originate. As Ph. J. E. Peebles (1980: 389–390) notes, 'The same process could operate on a larger scale, the first generation of gas clouds being protoclusters that fragmented to form galaxies, some clusters dissolving to produce field galaxies. A sequence of this general sort has appealed to many authors'. Such phenomena take place at higher levels of evolution when something general is formed (which will turn into a larger taxon in future) that later differentiates into primary level taxa. The species and classes in biology form in this way. The same refers to a society: at first there emerge rather large formations such like families of languages and then the languages, ethnic super-groups and then ethnoses, and sometimes large early empires or states; and afterwards within their framework statehood goes one or two levels down. In other words, there emerges a non-differentiated large structure which is capable to produce a great number of peculiar structures.

However, a more commonly held hypothesis suggests that protogalaxies (in the form of giant condensed gas clouds) were the first to emerge within the structure of the Universe, and later they became the birthplace for individual stars and other structural elements (see, *e.g.*, Gorbunov and Rubakov 2012: 27). However, in recent years new evidence has come to hand to support the idea that those were the stars that appeared first. This discovery somehow modified the previous theories. As a result, at present it is widely accepted that the stars were first to emerge, but those were the giant stars, much more massive than most of the later-formed ones (May *et al.* 2008). Because of the absence of carbon, oxygen and other elements that absorb the energy from condensing clouds, the process proceeded more slowly in that epoch; thus, only giant clouds could condense producing massive stars hundreds times larger than the Sun (*Ibid*.). Nowadays there are also such giants of 100–200 solar masses but they are considered unstable (see Surdin and Lamzin 1992). We will see below that the larger is star, the shorter is its life. Thus, such giant stars lived only a few million years. In addition, the first stars contained a small amount of heavy elements. Thus, more than one generation of stars could change, until the quantity of heavy elements gradually increased. The emergence of 'heavy elements' from the 'dead star stellar remnants' resembles the formation of fertile soil from the remnants of dead plants. The circulation of matter in the Universe is always observed everywhere and at all levels.

In recent years we have witnessed the discovery of a few galaxies that are claimed to be the oldest in the Universe. Meanwhile, the dates of formation of the first galaxies are shifted closer and closer to the Big Bang. The emergence of the first galaxies is dated to less than 400 million years after the Big Bang; and there are even claims that some more ancient galaxies have been discovered. They are claimed to have emerged only 200 million years after the Big Bang.[2]

The evidence on the first stars refers to *c.* 150–200 million years after the Big Bang; hence, stars and galaxies appear to have emerged almost simultaneously. Since that time depending on its density the matter in the Universe coexists in three main types: in dense state in celestial bodies, in rarefied state in the clouds of different size, and in low-density state (in tens of times compared to the clouds) in interstellar gas.

[2] The evidence refers to the team of the French astronomer Johan Richard who seemed to discover the galaxies that formed 200 billion years after the Big Bang (see European Commission 2011).

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

The formation of galaxies and their clusters, as well as of stars and other celestial bodies was the longest evolutionary process that had ever taken place in the Universe. At present we observe that this process is still going on alongside changes and disappearance of galaxies and stars. During the first eight billions years, the formation of huge diversity of stellar bodies and new heavy elements took place in the Universe until about 5–4.5 billion years ago there the conditions were formed for the formation of stellar (Solar) system. On one of its planets there started new geological, chemical and biochemical processes.

### The Structure of the Universe in the Past and Present

**Evolutionary principles of the structure of the Universe.** Thus, the formation of the large-scale structure of the Universe has not occurred at once. Formation of galaxies and their clusters, probably, was the process which had lasted for billions years.

There are several evolutionary principles in the characteristics of the structure of the Universe which are well traced at all levels of evolution. But we will consider only two of them.

1. *The combination of antagonistic features.* In the structure of the Universe one can find the combination of uniformity and non-uniformity. The uniformity is already manifested at the inflation phase, when the Universe started inflating evenly in all dimensions. The uniformity has preserved till present, but only at the largest scale (of an order of magnitude of 100 megaparsecs). For reference, the size of the largest galaxy clusters (such as our Local Group with the center in the Virgo constellation) is 40 megaparsecs at most (Gorbunov and Rubakov 2011). The non-uniformity of the Universe is manifested at scales smaller than 100 megaparsecs; and the smaller is the scale, the more salient is the non-uniformity. The combination of antagonistic features is a phenomenon that is rather characteristic for many other evolutionary levels. Thus, the antagonistic features of 'even surface' and 'uneven surface' are quite applicable to the Earth surface: at bird's eye it looks even.

2. *Density and sparsity can be traced everywhere,* starting from the atomic structure, where the mass is concentrated in a tiny nucleus, while most of the atom is an empty space. There is a huge non-uniformity between the scale of the Universe and the space that the main mass of (at least, baryonic) matter occupies within it. At the present stage of evolution of the Universe its matter is concentrated, first of all, in stars which actually occupy only a $10^{-25}$ part of the total volume of the Universe (not taking into account the galaxy nuclei [Pavlov 2011: 43]). Were there such proportions in ancient Universe? Maybe, not. Therefore, the concentration of the matter is strengthening. Not only the hard matter is distributed very unevenly throughout the Universe; the same is true of the gas. Much of this gas is concentrated in giant molecular clouds which are of many thousands of solar masses (Lipunov 2008: 37). At the same time the difference in density is fractal, which is especially evident in the zones of high

density. The factors contributing to such unevenness are not always clear; for example, it is not clear, what the uneven distribution of masses during the formation of galaxies (Weinberg 1975: 608) as well as many other processes of distribution, concentration and dissipation are connected with. But the principles of uneven distribution of the matter mass at different evolutionary levels are rather similar. For example, at present the main mass of the Earth's population is concentrated in a rather small territory in comparison with the total territory where life on the Earth is possible.

**The structure of the contemporary Universe.** The main structural elements of the Universe are galaxies, their clusters, and superclusters. Our Metagalaxy is mainly formed of superclusters.[3] All the structural elements are rather stable in terms of gravitation, though they can split, merge, and collide, *etc.*

Galaxies are integral structural entities with a rather complex structure which includes, in addition to regions arms, *etc*., a nucleus (core), semi-periphery (so called 'disc'), and periphery (so called 'halo') (Baade 2002: 255). The halo consists of both single stars and various stellar clusters. The halo's radius (a few hundred thousand light years) is much larger than the radius of the galaxy's disc.[4]

A galaxy generally contains from 100 to 200 billion stars. There are small (dwarf) galaxies with a few million stars, as well as giant galaxies consisting of up to a trillion stars.

Our Galaxy with the mass of about $10^{11}$ solar masses is one of the giants. However, the mass of our neighbor – the Great Andromeda Nebula (M31, is found in our cluster of galaxies (the Local Group) – is about three times larger. Probably, the most famous M87, which is situated in the central part of the cluster of galaxies in Virgo constellation, has the largest mass. Apparently, the mass of this Galaxy exceeds by hundreds times the mass of our Galaxy. At the other pole there are dwarf galaxies whose masses are ~ $10^7$ of solar mass, that is several dozens of times more than the mass of globular cluster (Shklovsky 1987: Part 1, Chapter 6).

Stars are distributed rather unevenly throughout galaxies, stars are parts of various groups and clusters; some of them consist of just a few stars, but some clusters can contain up to several million stars. For example, they identify more than 1,500 star clusters in our Galaxy (Surdin and Lamzin 1992). There are many globular clusters, which are the spherical clusters tightly bound by gravity and consisting of hundreds of thousands, which occupy the spherical volume in the space. These are rather old stars (there are about 150–200 such clusters in our Galaxy). According to Hubble, the galaxies are classified into spiral, elliptical, and irregular with various subtypes (Baade 2002: 18–32); yet, by now one

[3] If, according to some researchers, Metagalaxy is not the only one in the Universe, then for some time it will be considered as the largest structural unit of the Universe (see Pavlov 2011: 52). If the Universe is not a Universum but a so-called Multiverse, then the Universes or their groups will be the maximum unit of the structure.

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

more galaxy type has been identified – the lenticular galaxies. The latter make about 22 per cent among our nearest galaxies. In these galaxies a bright main flattened body, 'a lens', is surrounded by a weak halo. Sometimes the lens is surrounded by a ring (see Novikov 1979: Chapter 1, § 8). More than a half of the members of the Local Group are the older elliptical galaxies with intermediate or minor luminosity (*Ibid*.: 31). Galaxies are complex and to a considerable extent self-regulating systems, within which there is a constant circulation of matter: some stars disintegrate, whereas new stars emerge from cosmic gas and dust. Thus, the circulation (which results in the processes of renovation of matter and its mixing) takes place at all its spatial levels and at different levels of evolutional complexity.

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

**Generations of galaxies and stars.** There are rather diverse opinions not only on the time of formation of stars and galaxies but also on the number of generations throughout the evolution of the Universe. In addition, there is no consensus on which galaxies should be regarded as old, and which galaxies should be considered young. The point is that within a single galaxy one can find stars and their aggregates which considerably differ in their type, age, and other parameters. Yet, it appears possible to single out a few widely accepted basic ideas.

1) In the evolution of the Universe, there have been three (or at least two) generations of galaxies and stars. In general, old galaxies are smaller and dimmer. Their stars contain dozens of times smaller quantities of heavy elements than the Sun. The astronomers can hardly observe any star formation processes within such galaxies. There is also a hypothesis that more dark mass is concentrated in old galaxies in comparison with younger ones. The same way, older and younger stars differ from each other in their size, luminosity, and chemical composition.[5]

2) One can hardly define an exact periodization of generations of galaxies, because the process of formation of galaxies and stars is constantly going on. Galaxies need to constantly renew their composition in order to retain their identity. As Joseph Shklovsky maintains, in this respect galaxies are very similar to primary forests with its mix of tree ages (whereas the age of trees is much less than the age of the forest in general [Shklovsky 1984: 45]).[6] The mobility

[5] The later the star was formed, the more heavy elements (the remnants of interstellar nuclear reactions) it includes. This has become one of the arguments in favor of multistage star formation in the galaxy (Surdin and Lamzin 1992).

[6] Though, according to Shklovsky, the age of small stars can exceed the age of the galaxy (it is the large stars that die quickly); therefore, he supposes that in the course of time the number of small stars will increase (Shklovsky 1984: 45).

and variability of the celestial landscape resembles very much the mobility of geological landscapes.

One should also consider the fact that the formation of galaxies can proceed in different ways, for example, through the absorption of smaller galaxies by the massive ones when the collision between the galaxies takes place. 'If a small galaxy comes into collision with a massive one, it is absorbed by it and loses its identity; and every time when passing near a massive galaxy the stars estrange from it' (May *et al.* 2007: 140). In this case both young and old clusters and groupings of stars are combined (see about it below). Another pattern is through merging. Galaxies of younger generations can sometimes form through the accretion of a few small, weak and compact galaxies into a single galaxy. In this case they became 'building blocks' for the present galaxies. Finally, it may happen that two massive galaxies collide. Such a collision may take billions of years and be accompanied with active star formation and emergence of massive and very bright stars. The latter means that these are short-living stars, that is there will be many bursts of nova and supernova. Finally, galaxies may diverge again, but in this case they turn out to be very different from what they used to be before the collision, whereas one more galaxy may emerge out of the matter estranged from the both galaxies (see May *et al.* 2008: 142).

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

4) Galaxies are collections of different types of stars. However, there are certain peculiarities as regards the position of old and young stars within galaxies which is probably connected with the self-regulation within the galactic systems or the peculiarities of star formation which occurs in large groups, or with other factors. Thus, within our galaxy the younger stars (such as the Sun which is a few billion years old) are generally larger, hotter and brighter. They are located closer to the disc plane, and, especially, within the galaxy arms; whereas in the galaxy periphery (in its halo) one can find older stars more than 12 billion years old (which suggests the overall age of our galaxy). Yet, of course, older and younger stars may be also located rather close to each other. Thus, one may find many old stars near the galaxy center (bulge), but there are also young stars that emerged from the matter produced by the disintegration of older stars. The highest stellar density is found in the galaxy center where it reaches a few stars per cubic parsec.

As we mentioned, the very old, not bright, not hot and not massive stars contain many times less amounts of heavy elements than the Sun. It is not surprising that these stars and young, hot, and bright stars of the surface of disc, arms and halo were named 'Population I' and 'Population II'.[7] It is generally accepted that the majority of globular clusters are very old (12 billion years old or even more). But the dispersed or open galactic clusters are dozens or even hundred times younger than globular clusters (*i.e.* they are just hundreds of millions of years). But there are younger stellar associations (see, *e.g.*, Surdin and Lamzin 1992; Surdin 2001).

On the one hand, the preservation of generations of stars and galaxies demonstrates an additive character of the evolution of abiotic systems; however, the capture of stars and galaxies with their subsequent integration and prolonged processes of collision of galaxies demonstrates that in abiotic natural systems one may also find some other models of evolution – connected with 'wars' and 'submission of outsiders'.

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

## Change of the Chemical Composition of the Universe

Though, hydrogen has always been the most abundant element in the Universe chemical composition; its share constantly decreased. This occurred (and occurs) because hydrogen is the main fuel for the nuclear fusion reactions that support life and luminosity of stars. Despite tremendous amounts of released energy during these reactions, the energy release rate is very low. For example, the intensity of the solar radiation is 2 erg/g·s, which is almost equal with the piles of burning leaves. Stars shine brightly because they are massive and large (Surkova 2005: 9).

Increasing temperatures inside the core of some stars were needed for the formation of new elements that were absent in the era of recombination. How-

[7] This is an outdated division of stars. That is why when there appeared an evidence of the existence of the stars of the first generation which emerged at the age of the Universe of 150 million years from the moment of the Big Bang (see about it above), they were named 'Population III' in order to follow the conventional designation.

ever, all the fusion reactions that occur to produce elements larger than iron no longer release energy. Reactions of another type are needed for the formation of elements heavier than iron – those reactions consume more energy than release. That is why there are such relatively small amounts of heavy elements in the Universe. Yet, such peculiar reactions do take place – for example, in neutron stars and during explosions of supernovas. In supernovas, during their bursts, for about just 100 seconds heavy elements form, which expand Mendeleev's periodic table including uranium and thorium (*Ibid.*).

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

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

The similarities and differences of stars in their structure (the presence of heavy elements) are similar to the similarities and differences in genome. All living organisms mainly have the similar structure and all huge differences are caused by small divergences (by several percent) in genes.

## The Evolution of Galaxies and Stars

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

On the whole, this process may be described in the following way. Within giant hydrogen and helium clouds, some heterogeneities emerge (which is quite natural for atmosphere) which launch (under certain conditions) the gravitation processes that start to collect that mass into spherical forms. Sometimes a direct formation of a giant mass of gas clouds takes place, from which a galaxy or a star cluster later emerges. In this case the cloud fragmentation may occur and thus, more and more gas-cloud spheres (there could be hundreds of millions, or even hundreds of billions of them) emerge, which can gradually transform into protostars. This process continues up to the point when the gas density becomes so high that each new fragment already has a mass of a star (Surkova 2005: 49).

Then the gravity starts impeding further fragmentation. This process is denoted as 'a cascade fragmentation'. It is remarkable that it resembles certain processes in social evolution – for example, the fragmentation of large early states into separate parts that decentralize up to the point when further division becomes unreasonable (*e.g.*, in certain periods there were dozens and hundreds of independent states in the territories of Germany or France).

As enormous gas/dust clouds appear unstable, they disintegrate into large bundles, so the formation of stars proceeds in groups. This phenomenon is of interest not only with respect to stellar evolution. The group formation is rather typical for evolution in general (in this way populations and sometimes new species emerge; chiefdoms, city-states, and sometimes political parties emerge in groups, and so on).

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

**Diversity of stars and galaxies.** Diversity is an absolutely essential prerequisite of evolutionary development. And this condition is fully realized within cosmic evolution. Stars greatly differ in their mass, temperature, luminosity, age and the lifetime. They also differ in many other characteristics including the chemical composition and the immediate system to which they belong, for example whether they are binary or isolated stars, whether the stars have the planet system or not, *etc.* Those differences may vary greatly.

The differences in influence of gravitation and the peculiarities in behavior under its influence of gas-cloud masses could become the reason of formation of different types of galaxies. That means that the galaxies are born either as spiral or elliptic ones and in the course of evolution the type of galaxy is preserved. A galactic structure is to a large degree determined by the initial conditions of its formation (*e.g.*, by the character of rotation of the original gas clump from which a galaxy is formed).

The sizes and mass of stars vary greatly. For example, with respect to masses, stars range in mass from about 0.1 to 100 or more solar masses. There are some considerations that the thermonuclear fusions cannot go in a star with the mass of less than 8 % of the Solar mass that is why such objects do not belong to the stars. The stars of small masses prevail. Thus, for every ten million of red dwarfs there are only about a thousand of giants and only one supergiant. It is rather natural that the number of smaller entities is orders of magnitude larger; actually, the same phenomenon may be observed, for example, in Zoology or Political Geography where the number of small animals or countries is much larger than that of large ones.

**Individual fates within evolution.** Individualism of stars is exceptionally diverse, despite the fact that the parameters in which they differ are limited. Thus, one can maintain that with the formation of stars we observe the emergence of individual objects in nature, 'individuals' that, on the one hand, are rather similar, but, on the other hand, have rather different individual fates much depending on circumstances of their birth and various contingencies. For example, stars with small masses (in which nuclear fusion occurs at a slow rate) can use all of their fuel (*i.e.*, remain in the main sequence) for many billions of years, the potential lifetime of some stars can exceed the modern age of the Universe. On the other hand, blue giants (which quickly consume fuel and lose most part of their mass due to their instability) burn out hundreds of times faster.

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

## Stellar Birth, Stages of Life and Death

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

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

One may also note that the emergence of stars and galaxies must have a certain trigger that creates turbulence and heterogeneity. Those triggers (catalyzers) are the inherent components of evolutionary mechanisms that may be found in many processes: in chemical and geological processes, within biological evolution with respect to fast formation of species, or within social evolution with respect to state formation (see Grinin 2011, 2012 for more details). The supernova shock wave, the collision of a molecular cloud with spiral arms of a galaxy and other events can become such a trigger to the star formation (Surkova 2005: 50).

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

**Red giants.** The new phase of stellar evolution is connected with the exhaustion of hydrogen supplies. The gas pressure (that maintained the star balance when necessary fuel was available) decreases and the stellar core compresses. This leads to a new increase in temperature. A star starts to burn heavier elements and thus, the stellar composition significantly changes. Simultaneously with the compression of the core, the star's outer layers expand. In general, the star inflates and expands a few hundred times, and it transforms into a red giant and then with the larger expansion – into a red supergiant (large stars with the mass of more than ten solar masses transform into supergiants at once). This phase lasts for about one tenth of the 'active lifetime' of a star, when the processes of nuclear fusion go on in its depths.

**Star death: three cases.** The next phase is the transformation of a red giant or supergiant. Actually, the new form depends on stellar mass and a number of other characteristics such as the stellar rotation and velocity, the degree of its magnetization, and so on. The following three outcomes are considered most typical. They depend on stellar mass (but the limit value estimates vary significantly, and so below I will mention the main alternative values after the slash).[8] Stars with the masses smaller than 1.2–1.4/3 solar masses transform from red giants into the so-called 'white dwarfs', when the star sheds its outer envelope to form a planetary nebula with an extremely contracted core (down to the size of the Earth). The further compression does not occur because of the so-called degenerate electron gas pressure that does not depend on temperature. As a result, the white dwarf is rather stable. However, due to the lack of hydrogen

[8] According to one of classifications (that might be more correct than the one reproduced below), one can subdivide all the stars just into two classes: massive stars (with a mass equal or exceeding c. 10 solar masses), producing neutron stars and black holes, and non-massive ones producing white dwarfs (Lipunov 2008: 99). But the latter ones, depending on the mass, differ in the elements which form their core.

and helium, thermonuclear fusions can no longer proceed within such a star. A white dwarf is very hot when it is formed; yet, afterwards the star cools and transforms into a 'black dwarf', that is, it becomes a cold dead cosmic body.

For stars with initial mass of more than 1.2–1.4/3$M_{\odot}$, but less than 2.4–3/7–103$M_{\odot}$, their slow and gradual aging results in an 'infarct', that is a collapse. After the depletion of hydrogen and the decrease of the internal gas pressure (that used to balance the gravity), under the influence of gravity the core gets extremely compressed (by dozens thousand times – up to the radius of ten kilometers) just in a few seconds. Almost simultaneously the outer layers of the star are blown away with a huge speed as a result of shock wave. This supernova shines brighter than millions of ordinary stars, but for a very short period of time. This explosion expels the stellar material into interstellar medium and thus, there occurs the formation of considerable quantities of heavy (heavier than iron) elements that afterwards concentrate in various celestial bodies. The remaining core contracts to become a neutron star (which is supposed to contain super dense neutron fluid). With respect to its size, such a star is five billion times smaller than the Sun, but it is hundreds of thousands of times brighter because the temperature on its surface is 1000–1500 times higher than on the Sun (Lipunov 2008: 133).

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

## III. UNIVERSAL EVOLUTIONARY PRINCIPLES THAT APPEARED DURING THE STAR-GALAXY ERA

### Life, Death, and Catastrophes in the Evolutionary Aspect

The irreversible character of evolution is its most important characteristic. It can be observed as a steady movement to more complex structures and forms of organization, to the changes in the chemical composition of the Universe, *etc.* As regards the individual objects, the irreversible character of evolution is obvious and undoubted. A star which passed through a certain phase of life cannot reenter this phase.

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

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

**Stellar life in terms of self-organization and maintaining of the dynamic equilibrium.** In the initial phase under the compression a cloud of gas 'burns' itself like packed straw or rags mow burn. The next phase of self-organization is connected with the formation of complex stellar structure on the main sequence phase during which burning out of hydrogen occurs. After burning out of the most part of hydrogen a star enters a new phase, it expands and transforms into a red giant. At the same time the processes of self-organization occur again and the stellar structure radically changes (highly compressed core coexists with the expanded envelopes). After the fuel is burnt out in a red giant, the next phase is compression under the influence of the gravitational force and formation of a brand-new structure: small but very massive core with extremely high density of the matter within it.

Let us consider the stellar life in terms of maintaining and breaking the equilibrium. First of all, there is a thermal equilibrium, when the rate of energy produced in the core (through thermonuclear fusions) balances the loss of energy through the emission of radiation into space. This equilibrium is broken when hydrogen fuel is gone. The reserves are apparently compensated when a star starts using another type of energy. This may occur through the contraction of the star which begins fusing helium into carbon, thus producing many times more energy for every atom; afterwards heavier elements may be used as fuel, and each heavier element will produce more and more energy per atom. Meanwhile, the core of the star begins to increase in temperature. There is equilibrium in terms of pressure of different forces and preservation of a certain form and size of the star. Within the main sequence phase, the balance is maintained as the gravity pulls all the stellar matter inward, toward the core, while gas pressure pushes heat and light away from the center. This pressure exists until the reserves of nuclear fuel are exhausted (Efremov 2003: 97). With respect to red giants one may speak about equilibrium of another kind in two dimensions. In the core the temperature grows due to contraction and thermonuclear reactions of higher levels start (*i.e.*, involving not hydrogen but helium or heavier elements). As a result of those reactions the temperature may grow up to 100 million Kelvin. That is why a stronger gravity is balanced by a stronger (due to temperature) gas pressure. In the meantime, within the shell the equilibrium is achieved through the multifold expansion of the outer layers. In neutron stars and white dwarfs, the subsequent phases of the stellar lifetime, there is their peculiar equilibrium.

**Structuring, self-organization and 'Russian nesting doll' structure.** The whole history of star-galaxy phase of cosmic evolution is the history of formation of different structures of different size and grouping of these structures into larger ones. At the same time, as we already mentioned, we deal here with the ability of objects to self-organization at all phases of general and individual evolution. It is very important that structuring occurs not only among stars and galaxies but also among molecular clouds. The latter can be regarded as a parallel branch of evolution. Parallelism plays a great role in evolution dramatically increasing the opportunities of transition to something new and creating a field of contacts between various directions of evolution (see about it below).

Giant molecular clouds as a rule have a rather complex 'Russian nesting doll' structure when small and large condensations are nested into larger and more vacuum ones (see Surkova 2005: 48). 'Russian nesting doll' structure (strongly resembling a fractal one) is also typical of higher levels of evolution. Thus, smaller groups of herding and social animals, which are the part of larger groups, are similar in a general way to the structure of a large society. This also refers to social evolution, in particular, the organizations which are not centralized, for example, tribal alliances. The components of the latter (lineages, clans, subtribes) are less similar to the structure (and the principle of structuring) of a tribe. That is why the tribes can easily be separated and if necessary be gathered. This is typical of the amalgamations of the representatives of the fauna (flocks, herds).

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

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

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

- **Evolution proceeds via constant creation and destruction of objects.** Nature, when creating, destroying, and renewing various objects, 'tests' many versions, some of which turn out to be more effective and have more chances to succeed in terms of evolution. For such a situation of selection within constant destruction and creation process, it appears possible to apply a rather appropriate notion of 'creative destruction' introduced by Josef Schumpeter (2007).
- **'Evolution is stronger than individual objects'.** Cosmic processes are accompanied with constant emergence, development, change, and death of various objects (stars, galaxies, and so on). Thus, here one can point as relevant the principle that was expressed by Pierre Teilhard de Chardin (1987) with respect to life in the following way: 'life is stronger than organisms', that is, life goes on exactly because organisms are mortal. The same is relevant to stellar evolution. We may say here that the cosmos is stronger than stars and galaxies; and in general, evolution is stronger than individual objects.
- **Rotation and keeping balance** take place due to constant destruction (or transition to new phases in the lifecycle) of some objects and the emergence

of the others. This keeps balance and creates conditions for development, because development is a result of change of generations and species.

- **In every end there is a beginning. Star-evolutionary 'relay race'.** The material of dead objects becomes building blocks for the formation of new objects. This represents the circulation of matter and energy in nature; on the other hand, this represents a sort of 'relay race'. The latter allows using the results of long-lasting processes, in particular, the accumulation of heavy elements (for example, the Solar System was formed from the remnants after the explosion of a supernova; that is believed to be one of the reasons of the presence of great number of heavy and super-heavy elements on the Earth and other planets).[9] Thus, we deal here with the above mentioned 'creative destruction' – the creation of new objects due to the destruction of the old ones. Furthermore, the new objects are different from the old ones, and sometimes these differences are quite apparent. It ensures continuity and provides new forms with space for advancement (*e.g.*, the change of generations of biological organisms always results in certain transformations). The change of rulers may not necessarily lead to radical social changes; however, each new ruler is somehow different from his predecessor, as a result the accumulation of historical experience occurs.

- **New generations of organisms and taxa are the ways of qualitative development.** One may also detect generations of taxa, which already have significant evolutionary and systemic differences. Thus, generations of stars differ in terms of their size, chemical composition, and other characteristics. Only through the change of several generations of objects this class of objects acquires some features that, nevertheless, are considered to be typical for the whole class of objects. (Thus, species in biology are determined by the impossibility to sire with the representatives of other species. However, many species reproduce asexually).

### 1. Individuality as a way to increase evolutionary diversity

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

- **The phases of individual development (ontogenesis) – myriads of different paths.** Every type of objects has their own regular phases of life

[9] About the rule of evolutionary relay race see Grinin *et al.* 2008.

which depend on both internal characteristics of the object and the environment (proximity of other objects, *etc.*). As we have already seen, stars depending on their mass, composition and other characteristics have very different duration of the phase which is called the main sequence (from several tens of millions of years to 10–15 billion of years and even more). As was mentioned above, the fate of stars at the last stage of their life also depends on their mass and other circumstances. Depending on this they can turn into the White Dwarf, become a neutron star or a Black Hole.

• **Required and excessive variation as conditions of a search for new evolutionary trajectories.** Within the processes described above one can observe the formation of the taxonomic diversity of the objects; we may even speak about occupying the evolutionary 'niches'. There emerge the types of stars which have different mass, luminosity (accordingly, different spectrum/color of the light), temperature, system (single stars, planet systems and systems of stars from two to seven), period of rotation, magnetic field, *etc.* The same refers to the galaxies among which one can distinguish a number of types (elliptical, spiral, and lenticular) and subtypes. Such diversity is extremely important. Only the achievement of a necessary level of taxonomic and other diversity allows a search for ways to new evolutionary levels. This is sometimes denoted as the rule of necessary and excessive diversity (see Grinin *et al.* 2008: 68–72; for more details see also Panov 2008).

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

• **Continuity**, which actually means the emergence of a continuum of forms, sizes, life spans, and lifecycles, is rather characteristic for space objects. Thus, the stars can be presented as a continuum from heavier to lighter ones, whereas the latter become hardly distinguishable from planets, their temperature does not contribute to the thermonuclear reactions, *etc.* The types of planetary systems uniformly cover a wide range of parameters. There is also a sequence of phases in the transformation of cosmic clouds into stars: condensation of clouds – formation of protostars – formation of young stars, and up to the death of stars. A wide range (a continuum) of forms and sizes of objects may be observed at geological, biological, and social phases of the evolution.

## 2. Object, environment, competition, development systems, and self-preservation

• **The relations between structure and environment.** Multilevel systems (galaxy – galaxy cluster – galaxy supercluster) act as a system of a higher order for stars, and, simultaneously, they create an environment that produces an enormous influence on those stars. A star directly interacts with its immediate environment (*e.g.*, with neighboring stars because of the strong gravity which affects the movement of both stars), whereas with the distant environment the interaction proceeds at its higher levels. Within star-galaxy evolution the environment generally produces less impact than at other evolutionary levels but nevertheless, it is highly important. For example, the role of the immediate environment is very important in systems of double, triple, or multiple stars. On the whole, single stars are separated by great distances and that is why they collide rather infrequently except for the center of the galaxies where star density is much higher. There occurs one collision once a million years (Shklovsky 1987: Ch. 1). For a small galaxy the influence of neighboring larger galaxy may turn out to be fatal, if it leads to its absorption. A star explosion close to clouds may (as we have seen) trigger the process of formation of stars and galaxies. The role of the environment is important for planets; the most important thing of this environment will be characteristics of a star and nearest planets as well as the influence of satellites and the danger of collisions.

With the development of a certain type of evolution, its own laws and environment gain a growing influence on the development of its subjects and actors. For example, both abiotic nature and the biotic environment influence biological organisms. However, within a complex ecological environment, it is the intraspecies and interspecies competition that may have larger influence than any other natural factors, whereas within a complex social environment it is just the social surrounding that affects individuals and social systems more than the natural forces do (though in consuming societies the role of influence of natural environment on people is much more important). Thus, with the formation of star-galaxy structure of the Universe there emerged macro-objects which start to interact with environments which are larger by many orders of magnitude.

- **The formation of evolutionary driving forces of development.** The study of cosmic evolution shows that evolutionary driving forces emerge just at this phase of evolution (although they turn to have small-scale impact on ‘progress’). Of course, evolutionary changes are determined by the influence of physical or chemical forces, but we observe them sometimes in the form of preadaptations. For example, the emergence of organic chemical compounds in the clouds of molecular gas exemplifies such a preadaptation. In principle such kinds of complex compounds do not play a significant role in cosmic evolution, but they are in the ‘reserves’ of development. It is of interest that a peculiar type of structure of such clouds which protect the molecules from cosmic radiation, makes their existence possible. In other words, special conditions are required for preadaptations. Preadaptations in biology often emerge in special environment. Thus, it is supposed that the transformation of crossopterygian fin, which gave rise to amphibians, into a limb occurred in terms of shrinking shallow water.

- **‘Struggle’ for preservation of forms.** It is important to note that stars, galaxies and planets (as well as other celestial bodies) have their definite, quite structured, and preserved form. The ‘struggle’ for the preservation of those forms, the capacity to live and shine, the use of different layers to minimize energy losses lead to a slow but evident evolutionary development. This way the atomic composition of the Universe changes, whereas the diversity of variations of the existence of matter increases. The bilateral transition of matter to atomic (in hot bodies) or molecular state (in cold structures, in particular in the clouds of gas and on outer layers of stars) and vice-versa when forming from the giant clouds of stars is an outstanding manifestation of this type of evolution, a preparation for the formation of its biochemical and biological forms.

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

- **External factors as the triggers of transformations** play a great role, for example passing by giant molecular clouds of a large celestial object, stellar explosion, *etc.* can start the process of stars and galaxies formation (*i.e.* become the trigger of gas concentration). Collisions between celestial bodies can cause the creation of new objects. Thus, it is supposed that the Moon was formed as a result of a collision of a large object with the Earth.

### 3. Multilinearity

Multilinearity is one of the most important characteristics of evolution.

Unfortunately, it does not get sufficient attention, and there is a tendency to reduce evolution to a single line – the one that has produced the highest complexity level, which is often interpreted as the main line of evolution. *However,* *at every stage of evolutionary development one can find an interaction of a few lines that can have rather different futures.* In other words, in addition to the main evolutionary line one can always identify a number of lateral ones. Firstly, they contribute to the increasing diversity; secondly, they allow expanding the range of search opportunities to move to new levels of development; thirdly, the lateral lines may partly enter the main evolutionary stream, enriching it. We quite often deal with two or more coexisting and comparable lines of development whose convergence may lead to a quantitative breakthrough and synergetic effect. Various lines of development may transform into each other. Elsewhere we have written a lot on the issue of social evolution in this context (see, *e.g.*, Korotayev *et al.* 2012; Grinin 2011).

- **Classical forms and their analogues.** The main and lateral lines of evolution may be considered in two dimensions: 1) horizontal (as regards complexity and functions), 2) vertical (concerning the version that would be realized later at higher evolutionary phases). It appears also possible to speak about classical versions and their analogues. Thus, various forms of aggregation and specialization of unicellulars can be regarded as analogues of multicellulars (see Eskov 2006), whereas various complex stateless polities can be regarded as state analogues (see Grinin and Korotayev 2009; Grinin 2011, 2012 for more details). Classical forms and their analogues can transform into each other; however, these are just the analogues that tend to transform into classical forms, rather than the other way round (the latter may be regarded both as a direct degeneration and as a forced adaptation to sharply changing conditions).[10]

- **Stars and molecular clouds: two parallel forms of existence of cosmic matter.** In this respect we may consider stars and galaxies as the main line of evolution and the giant clouds as its lateral lines; also the former may be designated as 'classical forms', and the latter may be defined as 'analogues'. In fact, on the one hand, galaxies and stars emerge from giant molecular clouds. On the other hand, as we have seen, these clouds have the same gravitational force and even structural complexity as stars and galaxies[11] have. And they are also able to concentrate, to take part in the energy exchange, *etc.* They also exceed the stars in the level of organization of elementary particles as the molecules are concentrated in the clouds, and there is the concentration of elementary particles and atom's nuclei in the stars.[12] Besides, stars when losing the matter, shedding its envelopes and through the explosion transform into gas-dust clouds, *i.e.* into interstellar gas which forms the molecular clouds.

[10] Thus, in difficult environmental conditions, (*e.g.*, of semi-deserts and deserts), centralized forms of polities – large chiefdoms and early states – can dissolve into a system of interacting societies and polities but without centralization (see Grinin and Korotayev 2009, 2011; Korotayev 2000).

[11] Accordingly, on different levels of generalization the clouds of one size are the analogues of the stars and the clouds of larger size – of galaxies.

[12] The molecules can also be found in periphery layers of some stars, in the places with low temperatures.

## INSTEAD OF CONCLUSION. The Formation of Various Evolutionary Lines at the Microworld Level

**Astrophysical and astrochemical evolution.** Almost from the very beginning of the development of the Universe (when the temperature reached thousands of Kelvin) chemical evolution emerges as accompanying physical and astrophysical evolution. Of course, chemical evolution also occurs within stars with the emergence of heavier elements. However, that was rather laying the foundations for chemical evolution, because chemical processes involve reactions which lead to the emergence of new substances. Such processes proceed, first of all, within gas-dust clouds where molecules emerge. Hydrogen molecules are absolutely prevalent in number; however, molecules of water and some other substances also emerged. Chemical evolution goes on also on planets (where it combines with geological, or rather planetary evolution) as well as on small celestial bodies (asteroids and meteorites, *etc.*). At the same time on the planets where due to volcanism, pressure upper layers to lower ones and other geological processes the temperatures could be high enough, chemism significantly differed from that in cold clouds.

**The position of chemical evolution in cosmic evolution.** The representatives of dialectical materialism following Friedrich Engels (in his 'Dialectics of Nature' [Engels 1940]) stated (and we can agree with this statement) that the chemical form of organization of matter is evolutionarily higher than physical. In contrast with biological and social forms which from their very start displayed substantially higher levels of organization of the matter, the chemical form (that emerged a rather short time after the physical form) did not represent a higher form of evolution for a rather long period of time. The same refers to the geological form which emerged on the planets long time ago but it became higher only after the formation as a result appropriate conditions. That is not to say that chemical evolution is not important in the framework of general stellar and galactic evolution; however, before the emergence of the Earth-like planet, the physical and chemical forms of organization of matter should be regarded as equally important, constantly transforming into each other (see also Dobrotin 1983: 89).[13] The chemical form of development in many respects was regarded as the 'preadaptation' for new levels of evolution. Let us note that in biology the term 'preadaptation' denotes the situation in which such achievements do not play the important role as a whole (without taking account of the certain organism) in the environment where they emerged. But without them it appears impossible to make a breakthrough at a certain moment. As a result, at some evolutionary turning point the forms which have these 'preadaptations' benefit from this and become evolutionarily higher or leading. They can give an impulse to the formation of new taxa and occupying new ecological niches. Within the Big His-

[13] In any case, it is important to note that due to thermonuclear reactions the chemical evolution of the Galaxy proceeds in a single direction, namely, from simple to complex elements (Surdin and Lamzin 1992). This also refers to evolution in general.

tory framework, the principle of 'preadaptation' means that at the level where a preadaptation emerges, it generally plays insignificant role; however, at a new evolutionary level such innovations generally give evolutionary impulses.[14]

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[14] About the preadaptations in the megaevolution framework, see Grinin, Korotayev, and Markov 2011.

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# 2
# Potential Nested Accelerating Returns Logistic Growth in Big History

*David J. LePoire*

## Abstract

*The discussions about the trends in rates of change, especially in technology, have led to a range of interpretative models including accelerating rates of change and logistic progress. These models are reviewed and a new model is constructed that can be used to interpret Big History. This interpretation includes the increasing rates of the evolutionary events and phases of life, humans, and civilization. These three phases, previously identified by others, have different information processing mechanisms (genes, brains, and writing). The accelerating returns aspect of the new model replicates the exponential part of the progress as the transitions in these three phases started roughly 5 billion, 5 million, and 5,000 years ago. Each of these three phases might be composed of a further level of about six nested transitions with each transition proceeding faster by a factor of about three with corresponding changes in free energy flow and organization to handle the increased generation rate of entropy from the system. Nested logistic transitions have been observed before, for example in the ongoing exploration of fundamental physics, where the progress so far suggests that the complete transition will include about 7 nested transitions (sets of subfields). The reason for this number of nested transitions within a larger transition is not known, although it may be related to the initial step of understanding a fraction of the full problem. Too small of an initial fraction would lead to incomplete problem scope and definition. Too large of an initial step would lead to complications between the development of basic understanding and higher level derivations. An original step of one-seventh of the problem ends up within one standard deviation from the inflection point (mid-way through the transition).*

***Keywords:*** *Big History, logistical growth, complex adaptive systems.*

## Current Technological Trends

The forecasts of the near future vary widely in scope and outlook, predicting from near utopia to near dystopia. The issues of great concern during this period include: (1) the energy transition problem of moving from an unsustainable fossil fuel-based economy to something else; (2) the widespread nature of the problems currently being discussed in terms of global warming, global trade, global terrorism, and global knowledge transfer; and (3) the possible opportunities and risks of new technologies such as genetics, nanotechnology, and artificially intelligent computers and robots (Bainbridge and Roco 2005). To gain a wider perspective on this transition, this paper further explores the transitions involving energy, environment, leadership and new technologies (Tainter 1988; Diamond 1997; Ponting 2007; LePoire 2010a) in time scales from the current era, modern history, extended past, and potential future.

Recently, various interpretations of trends in technological progress have led to widely differing predictions. Specifically, Ray Kurzweil (2005) hypothesized an ever-increasing rate of technological change, based on his analysis of over a century of progress in computation technologies. Theodore Modis (2002) hypothesized a very different future, one having a decreasing rate of technological change, based on the analyses of events from the 'Big Bang' to the present. Kurzweil investigated the more recent technological acceleration of computing performance. The inclusion of early electronic technologies, such as relays and vacuum tubes, led Kurzweil to propose that the rate of technological change is increasing with time, that is, Moore's Law of the doubling of electronic device densities every 18 months will be surmounted by new technologies that double in performance in less time. An ever increasing rate of technological change could soon lead to a technological 'singularity'. One attempt at a definition of the technological singularity is a 'future time when societal, scientific, and economic change is so fast we cannot even imagine what will happen from our present perspective, and when humanity will become posthumanity' (Vinge 1993).

Another model of technology progression and diffusion that has been studied is based on the logistic equation. This progression assumes that the rate of progress is proportional to both the current level of complexity and the fraction of complexity yet to be discovered. Logistic analysis has been found not only in market adoption and substitution of new products, but also in technology development and ideas (Marchetti 1986, 1980) such as democracy and energy. Theodore Modis (2002) suggests that the history of the Universe might also be considered as a logistic development of complexity. He arranged important events in the history of the Universe from a variety of sources, assumed that each event was equally important, and then made the assumption that the complexity of an event is its importance divided by the transition time to the next event. The dependence of the cumulative fraction of complexity on milestone number (not the event's time) could be interpreted either as (1) the first half of a logistic curve or (2) a sequence of events that will culminate in a singularity. Modis favored the logistic development interpretation.

These two scenarios can be related to different simple models: Kurzweil's singularity scenario, with continual increasing exponential progress, might derive from a simple complex model, whereas Modis's long-term logistic growth with a tipping point determined by limitations in the learning rate and energy extraction rate, might be related to the more complex but realistic model. If this latter transition is accurate, the rate of technological progress might peak and eventually slow with impacts for economics and leadership (LePoire 2008, 2014).

History may well form a large complex adaptive system (Jantsch 1980; Marchetti 1980; Perry 1995; Spier 1996, 2010). As systems progress, new options that arise for the systems may spontaneously bifurcate into two potential discrete states (see Fig. 1). While the simplest model of complex systems can be driven into chaos, more realistic models with limitations suggest a possible reversal of increasing complexity (Stone 1993). The emergent properties of an evolving complex system might display simple patterns despite the complicated underlying processes (Cohen and Stewart 1994). Another approach is to take a longer view of historical trends and phases. Carl Sagan (1977) presented the stages of information processing, progressing exponentially from the early Universe to the present day. These stages were the development of life, brains, and technology, starting with life origins about 5 billion years ago. A geometrical progression rate would suggest transitions from life evolution to brain evolution around 5 million years ago and further transition to civilization and technological development about 5,000 years ago. The characteristic properties of complex adaptive systems include: (1) a resource which drives the level of complexity, such as energy use (Chaisson 2004); (2) new options at critical stages along development paths (Jantsch 1980); and (3) competition and learning as the options are explored (Dyke 1987).

Complex adaptive systems are found in a variety of fields and display a range of common emergent phenomena, such as bifurcations or transitions (Kauffman 1995). These transitions occur when an input to the system, such as energy flow, increases beyond critical levels. Studies of physical systems far from thermal equilibrium suggest that the energy flow is important in the development of more complex organization. Chaos and adaptation have been investigated in many natural developing systems such as biological evolution, ecosystems, and social systems. In such dissipative systems order can spontaneously form only when the system is maintained far from equilibrium, as measured by the usable energy that flows through a system.

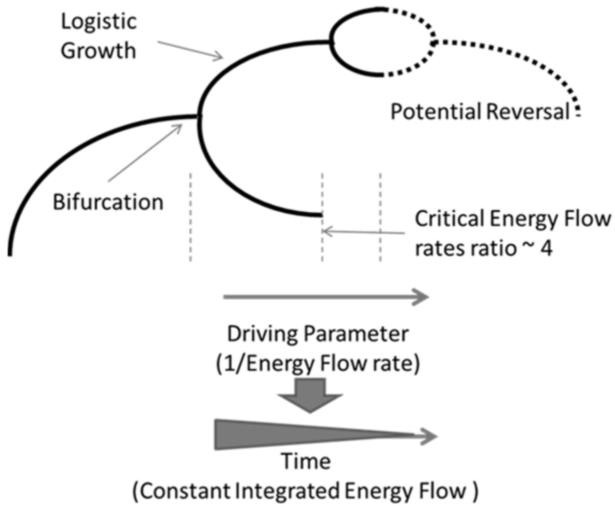


**Fig. 1.** Characteristics of an evolving Complex System. As the driving parameter (related to energy) increases over time, the organization of the system reaches a point where it is unstable but instead can grow in one of two ways. The growth between bifurcations is logistic

An approach to explore whether these processes are occurring (LePoire 2010b) include: (1) investigating the intensity and timing of energy flow organization; (2) investigating simple systems dynamics models; (3) rate of critical events in human historical transitions; (4) exploring the nested geometrical transition periods and energy uses in biological, mind and technology evolution; (5) exploring possible indications of a reversal in rate of change in fundamental physics and environmental issues; (6) examining the length scales of interacting systems and fundamental agents from the Big Bang to present.

A time contraction factor of about 3 is similar to time and energy contraction factors found by Snooks (2005) and Bejan and Zane (2012). This time contraction factor was used in describing the changes in energy intensity (Fox 1988; Morowitz 2002; Niele 2005; Chaisson 2004; Smil 1994; Bernstein 2004), as summarized in Table 1. Note that just one time contraction factor was realized from the Big Bang to the beginning of life on Earth. The remaining three large phases of life, human, and civilization evolution are separated by bold lines with different shadings. Each of these major phases has five or six subphases. Note that six subphases with a contraction factor of the square root of 10 (about 3) gives an overall contraction factor of 1,000 within each major phase.

**Table 1.** Possible way to organize changes in energy flows through extended evolution covering life, human, and civilization development

| Transition Start (Years ago) | Description | Energy Change |
|---|---|---|
| 1 | 2 | 3 |
| 15 Billion | Gravitational | Gravitational energy causes clumping and nuclear energy causes energy to be release and element formation |
| 5 Billion | Planet/Life | Life first gathers energy through chemicals or thermal gradients. Later the light from the sun is captured and turned into chemical energy |
| 1.5 Billion | Complex Cells | Simple prokaryotes form symbiotic relationships to form a larger and more organized eukaryote cell |
| 500 Million | Cambrian | Oxygen levels reach a concentration so that multicellular organisms can be supported. The many body types and survival strategies lead to rapid evolution |
| 150 Million | Mammals | Animals move to land after plants. The larger temperature variations lead to a way to regulate temperature to ensure ability to be active throughout the day and seasons |
| 50 Million | Primates | A generalist strategy using various food sources including fruits leads to greater energy to the brain |
| 15 Million | Hominids | Further generalist strategies and social organization again leads to greater energy use by the brain |
| 5 Million | Humans | Humans adapt to a changing climate by leaving the forest for the savannah along with the capability for walking to expand the range of natural resources |
| 1.5 Million | Speech | Further social organization leads to an expanded food sources including scavenging |
| 500,000 | Fire | Fire improves the energy availability from food |
| 150,000 | Ecoadaptation | Humans move out into other ecosystems expanding the range of energy resources |
| 50,000 | Modern humans | The benefits of specialization and social organization are realized during the ice age |

| 1 | 2 | 3 |
|---|---|---|
| 15,000 | Agriculture | Domestication of plants and animals leads to a more intense and reliable use of the land |
| 5,000 | Civilization | Organization at a city level allows risk reduction and order with increasing population |
| 1,500 | Commercial Revolution | Financial and mechanical technological techniques are applied and improved in a sustaining growth organization |
| 500 | Scientific/Exploration | Exploration of lands and ideas leads to expanded energy resources |
| 150 | Industrial | Fossil fuel allows large amounts of resources to be used along with increasing specialization |
| 50 | Information | Control through systems and computers allows greater efficiency in the use of energy and handling of pollution |

There are similarities and differences between this interpretation and previous papers in this series. Specific issues include: 1) the nature of the current inflection point (Panov 2011); 2) the emphasis on non-equilibrium dynamics including bifurcation or energy, technology and also social organization (Nazaretyan 2011); and 3) the organization of evolutionary trends into two or three phases (Grinin, Korotayev, and Markov 2011).

Alexander Panov (2011) also organized evolutionary history with 19 evolutionary crisis transitions with decreasing duration (by about a factor of 3). This is called the scaling law of evolution. If the trend continues, evolution would come to a very rapid rate of evolution at some point in time, the Singularity, which was predicted to occur somewhere within the past two decades. However, as he notes, the rate of evolution cannot approach this infinite rate but instead would be constrained by resources and the ability for evolutionary processes to work by testing various environmental fitness of technologies and cultures. This is similar to the law of Accelerating Returns by Ray Kurzweil. However, just as normal logistic transitions first start with exponential growth and later slow due to limitations to form the S-curve transition, the hyperbolic growth of evolution might also begin to slow. The combined law of accelerating returns and the logistic developed here is one way to model this important inflection point in evolution, the 'crisis of crises' as stated by Panov. Such an inflection would indicate the conflict between conventional economic and resource growth and constraints of global resources, pollution, population, and conflicts.

Panov (2011) continues to discuss the possible 'end' of science. The complexity of the increasingly intertwined processes of science, development, and production might be reflected in the limits of scientific growth within the constraints of society. An outgrowth of this entanglement might be seen in the recent organization of technological hubs which combine research into the scientific basis, product development, and production of new technologies. For example, the U.S. Department of Energy has formed many exploratory technological innovation hubs to pursue new energy technologies such as energy storage (batteries) for both transportation and electrical grid buffering.

This nested logistical pattern, interpreted as alternating evolution of smooth exploration followed by intense reorganizing transitions is compatible with the view of Akop Nazaretyan (2011). He emphasized the non-equilibrium aspects of the evolution and the role of mental capacities to form new organizations that would lead through the crises to a new sustainable growth. It is not just the energy flow that increases complexity, but the ability to control the environmental impacts of that flow. Control was important in many transitions including the use of fire, the use of engineered water projects, and the current issues with potential climate change. He identified the $21^{st}$ 'bifurcation' century as a test where a major inflection in the complexity, suggested by Big History, might raise many issues concerning conflict, energy, and the environment.

There is also the question of whether the evolutionary process occurred in three major phases discussed here – biological, human, and civilization, or two – biological and social phases as discussed by Grinin, Korotayev, and Markov (2011). The reason the phases were split into three in this paper is because of the three information storage and passing mechanisms identified (Sagan 1977), that is, DNA, the human mind, and writing/artifacts. It is true that genetic changes were key in the development of humans but much of the learning was passed through social signals leading to the new tool of spoken language, while also beginning to control aspects of nature such as fire, dogs, and plants. Grinin *et. al.* (2011) mention this aspect in the afterward of their paper by discussing intermediate subphases such as the biological-social type which would be similar to the human mind phase discussed here. Then the civilization, or pure social phase, is distinct because of the hierarchy of the social groups in combination with written records supporting the new organization.

## Growth Pattern Characteristics

The first topic concerns the combination of accelerating returns model and the logistic model. The accelerating rate of return can be written $y' = ky^2$. This tends to grow faster than an exponential with a singularity at some point in time. The logistic equation can be written $y'=ky(1-y)$, which has an inflection point but more linear progression of time scales. The super-exponential early growth can be combined with the logistic equation by combining the features of each $y'=k[y(1-y)]^2$. This is shown in Fig. 2 in linear and log form. This is appropriate for a long-term development discovery system, whereas the simple logistic equation is more appropriate for diffusion of information. More insight can be gained by noting the exponential growth rate, $y'/y$, which is proportional to $1-y$ for a traditional logistic growth, $y$ for an accelerating returns growth, and $y(1-y)^2$ for the combination.

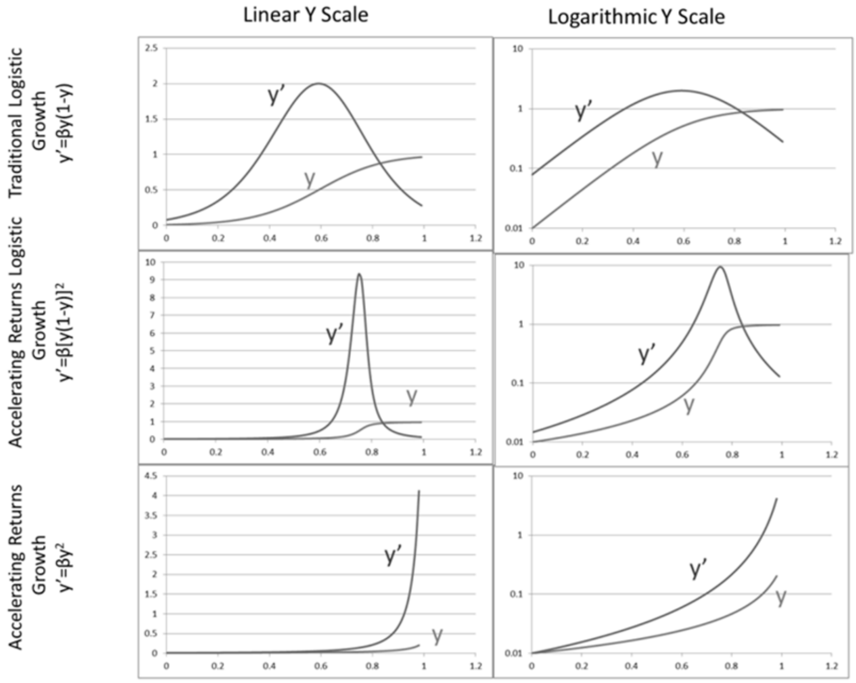


**Fig. 2.** Patterns of growth- Logistic (top), accelerating returns logistic growth (middle), and accelerating returns (bottom)

The second characteristic is the nested logistic growth pattern in the both overall information mechanism transition, and in energy flow. The historical complexity and energy use growth seems to have about 3 development phases with different information systems until the inflection point leading to a rate of 6 per full transition. Each of the three phases seem to be formed by 6 or 7 subphases where the information mechanism is the same (*i.e.*, DNA, brain, writing) but the energy flow is continually increasing.

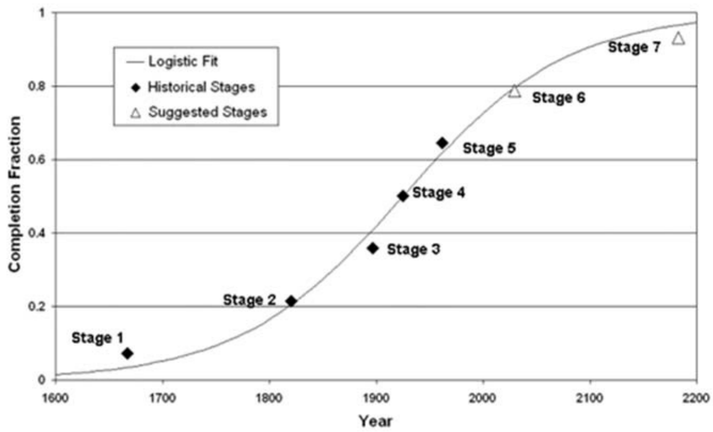


**Fig. 3.** Nested logistic growth in the area of fundamental physics. Each stage represents a logistic growth in at least one field of fundamental physics starting with gravitation and classical mechanics. Stage 4 occurred with the fastest pace as general relativity, quantum mechanics, and nuclear physics were being developed

This nested pattern of logistic growth with about 7 subphases was observed in the development of fundamental physics (see Fig. 3) (LePoire 2005). This analysis considered the rate of discoveries in various physics subfields. The subfields showed logistic growth patterns with initial slow progress followed by a period of steady progress, ending with another slow rate of progress as the subfield was fully integrated in a consistent manner. Within this one field of science, the nature of logistic development is seen in both the subfields and the complete field. If the logistic interpretation is correct and is followed, the data suggest that string physics is likely to be 50 per cent complete in 2030 and 80 per cent complete in 2090. However, if the development curve is logistic, then the development curve would be symmetric around the midpoint, identified as the 'Golden Age' of physics in 1920s with the simultaneous developments in general relativity, quantum mechanics, and nuclear physics. This would imply that there should be symmetric stages that correspond to each other, that is, if three stages are identified before the midpoint, then there should be three after the midpoint. String physics is only the second identified stage, leading to the suggestion that another stage in the development of fundamental physics might come after string physics. If symmetry holds, the last stage's 20 per cent, 50 per cent, and 80 per cent completion times would be 2100, 2180, and 2260.

Why would a logistic transition be broken into 7 substeps? In the process of exploring a new field, one of the more difficult steps is the first in defining the subject, the scope, and process. While there were many discoveries in physics before Galileo, the sustained nature of scientific progress afterwards points to this difficulty. Some difficult concepts to frame were inertia – bodies tend to keep on moving, the relationship between force and acceleration (versus the force in the static mechanics). This led Galileo to the experiment with simple toy-like apparatus' like rolling balls down inclined planes and measuring objects at the end of strings. If the first step was in the wrong direction, too small or too large, the progress could be halted. Some of the Greek philosophers tried to solve everything in one hypothesis but were not able to defend it with measurements. If Galileo had observed the moons of Jupiter and then asserted the laws of the heavens had inertia but that did not apply on Earth, the rolling balls down incline planes would not have generalized the concept, that is, it would have been too small. Instead the first phase of fundamental physics was the idea of laws of motion that applied on Earth and in the sky was set out by Galileo and took about 150 years through the great mathematics of the 18$^{th}$ century to develop the tools such as calculus, variational calculus, wave theory, and generalized laws of motion such as the Lagrangian. These tools that were developed in the first phase would become instrumental in further developments, for example, the Lagrangian formulation was instrumental in quantum mechanics whereas Newton's laws were found only applicable in classical mechanics.

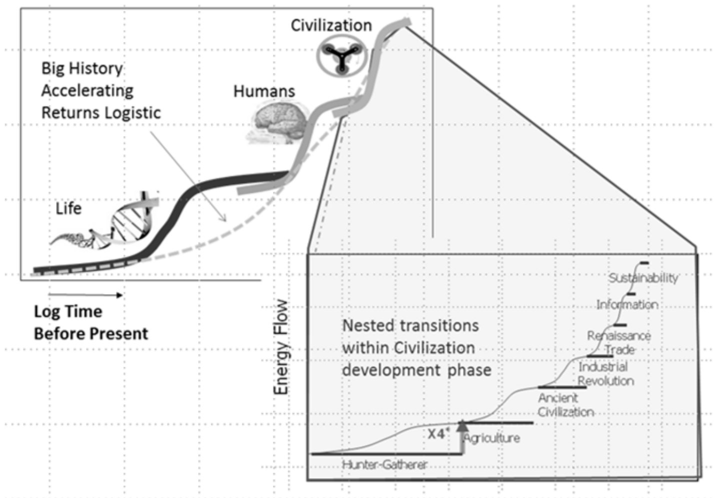


**Fig. 4.** Example how the major three phases of extended evolution might be considered to be each formed by a nested set of sub-phases (civilization sub-phases shown here)

An appropriate first step in a nested transition might be big enough to tackle fundamental issues. For example, in the physics case above, the fundamental laws of physics were developed and the common force of gravity was explained. However, the first step cannot be too big, due to the dependency of the steps. For example, again in the physics case above, the theory and experimental techniques developed in the first phase were a necessary prerequisite for the second step (electromagnetism) to be explored. An appropriate step size might be less than half of the transition. A simple measure of the width of the transition is its standard deviation, *i.e.*, a characteristic duration of the full transition. So the first step size of 16 per cent of the full transition means that the second step would start one standard deviation from the inflection (mid-point) of the transition (Fig. 5). If equal fractions of the problem (*e.g.*, 16 per cent as in the first step) are later tackled, it would take about 6 steps to complete the logistic transition.

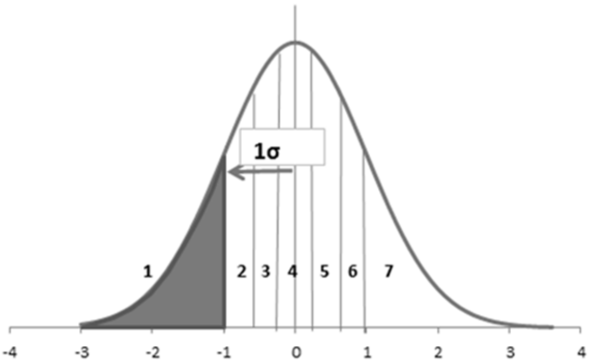


**Fig. 5.** Nested steps in approaching a normal distribution. If the full exploration of a phase is the whole normal distribution, one possible strategy to initiate the process is to break the problem into subphases, starting with a fraction that is neither too small nor too large. Here it shows that if the whole is divided into seven (or six) equal area sections, then the first section would represent exploring up to one standard deviation from the inflection point (middle of the normal distribution)

## Possible Pattern Extensions

One way to project what a logistic world would look like after the inflection point would be to mirror past rates of change. For example, if 2000 was the inflection point, meaning that technological change continues for a while at the same rapid progress but does not accelerate, then the 20$^{th}$ century might be a good indication of some of the changes we might see in the 21$^{st}$. In the 20$^{th}$ century there was such growth in population and resource use to move the world beyond sustainability. The major energy supply was from non-renewable fossil fuels. The expansion was driven by relatively inexpensive energy, new insights from physics leading to electrical, aerodynamic and material technology. These innovations led to creative destruction in capital formation and development as exemplified by the semiconductor industry which followed Moore's Law. The technology also caused problems such as arms races, environmental impacts, and expensive medical options. The $21^{st}$ century might adjust by slowing to a more sustainable society with more efficient energy use, a stable or declining population, reduction in the gap between incomes, and exploration of ways to mitigate global environmental impacts while maintaining robust fair trade.

While there are possible indications that a large transition such as a general technological slowdown is underway (LePoire 2014) there are reasons why we might be experiencing a transition inflection point in general evolution from a bootstrap natural evolution type system to a technologically design driven evolution which might show initial speed in development and then slow as leadership is assumed.

The problems with a bootstrap natural selection is that it has a difficult beginning and is stuck in historically determined structures, for example, the long period (billions of years) between the development of simple life and earth and multicellular life during the Cambrian explosion. The energy mechanisms, information storage and expression of biological systems were determined and mostly stable throughout further development. The systems also have difficulty scaling due to individual perspectives and limited information resources for collective action but instead are good at individual exploration, competition, and growth. The techniques for dealing with uncertainty are intuitive and based on evolutionary trajectories, for example, a simple intuitive fight or flight mechanism.

The assumption in the technological singularity is that technology will be able to quickly resolve human and biological constraints and continue an exponential growth path. However, this is unlikely as many constraints are tied to human systems and are also filled with uncertainty which might be better handled but will not be eliminated.

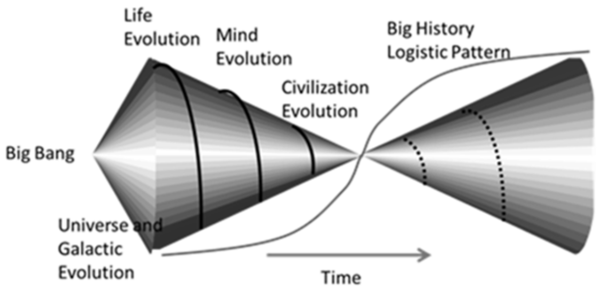


**Fig. 6.** Hypothesis of the Big History logistic growth pattern. The left hand side is what has been discussed in this paper. The trend towards shorter duration phases cannot continue. One way to extend the pattern is using an all-encompassing Big History logistic pattern which shows an inflection point where the rate of change is the largest

If the natural evolution is viewed as an ever quickening set of phases from molecular evolutions, cellular evolution, multicellular, primate, human civilization and technological stages then it might be expected that the technological evolution might show similar phases. Since the design of the technology is driven by humans there is a period where the two are tightly coupled. For example, the development of fundamental components similar to the molecular evolution for energy, information, and movement structures in organelles would be compared to the development of the understanding of theoretical logic, mechanical relays, electromechanical relays, transistor tubes, and isolated semiconductor transistors along with the resistors, capacitors, and inductors necessary for electronic designs. The next phase of integration, which might be compared with cellular evolution, was done at first in large computer rooms such as ENIAC, then IBMs with semiconductor transistors, but a major breakthrough in integration came with Texas Instrument's integrated chip technology which formed the ability for scalable integration and functionality. The network enabled quick growth of shared information and applications through the Internet, wireless and cellular networks might be compared to evolution of multicellular organisms. However, the Internet resulted in unintended consequences of malware, high dependence requiring high reliability, and ID theft. Concern over integrating with grids, decision support, and automated robotic support are leading to cautious rates of applications. It will be interesting if the artificial intelligence evolves at an accelerating rate or moves more cautiously as this artificial intelligence and robotics start complementing the intelligence that took billions of years to develop on Earth.

On a much longer time-scale the reflection of the rate of change would look something similar to Fig. 6. This paper focused on the left cone which includes the three phases (shown on a log time scale) of life evolution, human evolution, and civilization. If this follows the large logistic trends identified, the pattern in the future would look something like the cone on the right, again three phases with the characteristic slowing-down. However, it is not clear how and whether the logistic development pattern will continue

## Conclusion

The three major phases after cosmological development (*i.e.*, life, human, and civilization) had durations of about 1,000$^{th}$ that of the previous. Each might have six subtransitions with durations being reduced by a factor of 3. Energy and organization might qualitatively change between the transitions to handle the additional entropy flow through the systems. These characteristics seem to be consistent with the interpretation of a complex adaptive system with evolution through a sequence of bifurcations and logistic learning. A logistic accelerating rate of return logistic pattern, formed by combining the accelerating rate of return growth and the traditional logistic growth pattern shows similar exponentially shorter transitions. The pattern eventually reverses as has been observed in ecological systems. The decomposition of each phase into six transitions is motivated by the reorganization to maintain increasing energy flows. This nested logistic transition has been observed in the history of the discoveries in fundamental physics. While it is not known why a nested logistic transition would decompose into this number of subtransitions, it was observed that with seven subtransitions, the first step explores up to one standard deviation of the inflection point. Future inflection, symmetrical from boot-strapped to engineered system may gain more control over energy and physical systems.

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# 3
# Universal Darwinism and Human History*

*David Christian*

**Abstract**

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

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

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

James Joyce's strange masterpiece, *Finnegans Wake,* is fractal. You can read it at many different scales, but you always have the eerie feeling that you are hearing a story you have already heard somewhere else. A mathematician might say the stories are 'self-similar'. You may think you are reading about the wake for a drunken bricklayer who fell to his death from a ladder; but you are actually reading about the fall of humanity and the expulsion from Paradise; and then again the story is *really* about Dublin and the many rises and falls of that city's history, people and landscapes. Something similar happens in the

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emerging discipline of Big History (see Christian 2004, 2010). Big History surveys the past at the scales of cosmology, physics, geology, biology and human history. Each discipline tells its own story, but as you get to know the stories, they start to overlap, and we begin to see each discipline refracted in the others. Like *Finnegans Wake*, Big History is 'self-similar'. And like *Finnegans Wake,* Big History derives much of its power from the synergies that arise when you glimpse unexpected connections across different scales and domains.

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

## Universal Darwinism

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

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

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

> To apply natural selection to a population, there must be:
> • a space of parameters for each entity, such as the genes or the phenotypes;
> • a mechanism of reproduction;
> • a mechanism for those parameters to change, but slightly, from parent to child;

- differentiation, in that reproductive success strongly depends on the parameters (Smolin 2005: 34).

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

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

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

So powerfully does the Darwinian machinery steer biological change that many find it hard to avoid imagining that there must be a designer. Surely, organs as beautifully designed as wings or brains must have been, well, designed! Yet natural selection needs no cosmic project manager. This is what Daniel Dennett called 'Darwin's Dangerous Idea': operating without purpose, the Darwinian algorithm creates the appearance of purposefulness (Dennett 1995). From camels to chameleons, species fit their environments so precisely that they seem to transcend the laws of entropy. Yet they need no teleology and no driver. Darwin's ideas threatened theism because they explained the appearance of direction without needing a divine director (*Ibid.*).

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

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

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

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

Wojciech Zurek and his colleagues at the Los Alamos National Laboratory have even detected Darwinian mechanisms in quantum physics (Campbell 2011: 89ff.). When a quantum system interacts with another system, perhaps by being measured in a lab, just one of its many possible outcomes is selected and launched into the world, in the process known as 'decoherence'. We have variability of the initial possibilities, a selection from those possibilities, and a copying of the selected possibilities from the quantum to the non-quantum domain. 'This Darwinian process allows a quantum system to probe its environment searching for and selecting the optimal low entropy states from all those available, thus allowing greater complexity to be discovered and survive' (*Ibid.*: 154). (The author of this paper makes no claim to understand these processes except in the most superficial way. The point is that Darwinian mechanisms may be at work even at the quantum level.)

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

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

### Information and Universal Darwinism

Darwinian machines run on information: they replicate patterns, and that means replicating *information* about those patterns. So to understand their general properties, we need the idea of information. But information is a mysterious and ghostly substance that sometimes appears to float above reality, so we must define it carefully (accessible surveys include Floridi 2010; Gleick 2011; Lloyd 2007; Seife 2007).

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

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

We can also judge a transmission system by the amount of information it carries. Claude Shannon, the founder of 'Information theory', showed that information increases precision by reducing uncertainty (Floridi 2010: 37ff.). You can measure the amount of information in a message by the number of alternative realities it excludes. 'There is a tiger behind the bush' is helpful advice; it reduces uncertainty. But if a friend adds that the tiger is hungry and in a bad mood, that should eliminate any doubts you had about running away. If, from all the possible things that might have happened, a message selects a tiny, not-easily-predicted sub-set, then it eliminates a vast number of other possibilities and a huge amount of uncertainty. Each rung on a molecule of DNA can exclude three out of four possible futures; so the entire molecule, with billions of rungs, can exclude a near infinity of possible creatures. It tells you how to build just one, say, an armadillo. Not an amoeba, or an archaeopteryx, but an armadillo. In information theory, 'the amount of information conveyed by [a] message increases as the amount of uncertainty as to what message actually will be produced becomes greater' (Pierce 1980, Kindle edition, location 461).

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

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

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

## Three Darwinian Learning Machines

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

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

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

DNA preserves information because it acts like a ratchet (on the 'ratchet effect' in human history, see Tomasello 1999). Mechanical ratchets allow a gear-wheel to turn in only one direction because the 'pawl' catches on the cogs and prevents the wheel from turning backwards. By only copying information that works, DNA ensures that the gear wheel of evolution normally turns in the direction that accumulates viable variations. Without an information ratchet, the wheel of evolution could turn in either direction, viable variations would survive no better than any others, and biological change would drift with the flow of entropy. That is why it makes sense to suppose that life itself began with DNA or its predecessor, RNA. Before the evolution of DNA or RNA, parts of the Darwinian machine already existed: there was plenty of variation within pre-biotic chemistry, and variations could be selected for their greater stability. But only after DNA evolved (possibly preceded by RNA) could successful variations be locked in place so that genetic information could accumulate. With DNA preventing any backsliding, life was off and running.

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

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

I will call the second machine 'individual learning'. It works not across species or organisms but within the neurological system of a single individual. It is at work in species as varied as cephalopods, crows and chimpanzees. It works even in simple organisms, which can learn to detect and react to gradients of light or warmth or acidity. But individual learning is most impressive in animals with brains. Imagine our antelope glimpsing a lion near a waterhole. Was that really a lion? Should it make for another waterhole? With no guidance, it might have to choose randomly, as young animals often do. It will soon find out if its gamble succeeded. But intelligent animals also have better ways of choosing. They accumulate memories of past experiences associated with pain, fear, anxiety or with a sense of pleasure and ease. If any of those memories are similar to what is happening right now, they may provide guidance. Trying out possibilities in memory is less dangerous than trying them out in the real world, and the accompanying sensations, installed over time by genetic learning, will provide better than random criteria for repeating or avoiding particular experiences. Alasdair MacIntyre reports that if a young cat catches a shrew, it will eat it as if it were a mouse. It will then become violently ill, which is an unpleasant experience. But it has learnt a difference that matters and from now on it will avoid shrews (MacIntyre 2001: 37). A memory that should help the cat survive has outcompeted a memory that once caused it misery.

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

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

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

## Darwinian Machines in Human History: Collective Learning

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

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

Collective learning uses a new and more powerful information ratchet. Unlike individual learning, it stores information in many minds over many generations, so that information can outlive the individuals who created it. If a fraction of that information improves how individuals exploit their environments, collective learning will tend to increase the ecological power of whole communities. Like all animals, humans exploit their environments to extract the energy and resources they need to survive; but only humans keep discovering and sharing new ways of exploiting their environment, so that over time they can extract more and more energy and resources. Our ecological creativity explains why humans are the only species that has a history of long-term changes in behaviours, social structures and ecological adaptations. Like individual learning, collective learning also works much faster than genetic learning. That is why, within just a few hundred thousand years we have become more powerful than any single species in the 3.8 billion year history of life on earth, so powerful that some geologists argue we have entered a new geological epoch, the 'Anthropocene' (see Steffen *et al.* 2007).

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

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

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

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

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

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

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

When did our ancestors cross the threshold to collective learning? In paleontological time, the crossing took an instant, but in human time it was probably smeared out over tens of thousands of years (a paradox captured in the title of McBrearty and Brooks 2000, 'The Revolution that Wasn't'). And even when the engine of collective learning spluttered into action, it took time to pick up speed. So we cannot easily judge when human history began. But we do know what to look for. We should look for sustained evidence of humans adding ideas to ideas to form new ideas. We should look for sustained innovation and ever-increasing cultural diversity. We should look for new and more diverse tools, and signs that humans were exploiting many new niches. And if, as Terrence Deacon and others have suggested, the breakthrough was the acquisition of symbolic language, then we should also look for evidence of symbolic thinking in art, body painting or signing (Deacon 1998).

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

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

Language leaves no direct traces, but archaeologists have found many hints of symbolic thinking. More than 260,000 years ago, early humans near Twin Rivers in modern Zambia used hematite (red iron oxide), possibly to paint their bodies (Stringer 2012: 129). Later evidence is less equivocal (for a good survey see Pettit 2005; on Blombos cave see Henshilwood *et al.* 2011). At Pinnacle Point in South Africa, in sites dated to about 160,000 years ago, we find the earliest evidence for the use of shellfish, along with signs of composite tools and lots of hematite, of a particularly brilliant red, which points to symbolic uses (Stringer 2012: 129). By 115,000 years ago, similar evidence turns up in modern Israel, where, in Skhul cave, archaeologists have found evidence of symbolic burials. But the best evidence of all for rich symbolic activity comes from the marvellous South African site of Blombos cave, whose remains date from almost 100,000 years ago. Here, Chris Henshilwood and his team have found delicate stone tools, seashell beads, and lumps of ochre carved with wavy lines that could almost be an early form of writing (*Ibid.*: 129–130).

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

## Collective Learning as a Form of Universal Darwinism

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

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

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

Why does collective learning work so much faster than genetic learning? In part because it builds on the machinery of individual learning, which works with neurological impulses rather than entire organisms. A genetic mutation must wait a generation before it effects change; a suddenly triggered memory can have you swerving in a second. Collective learning also copies fast. It can transmit new ideas on the fly, as they evolve, and can broadcast them to many brains at once because it works with sound waves (in speech) or light waves (in signalling and imitation). Like genetic learning, collective learning is auto-catalytic, so it has generated better ways of storing and transmitting information, from writing to printing to the telegraph and internet. Auto-catalysis explains why collective learning generates not just change, but *accelerating* change. Finally, collective learning, like individual learning, builds on acquired as well as inherited variations. While genetic learning gropes randomly in the dark, collective learning can probe more purposefully.

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

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

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

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

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

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

## Conclusion: Different Versions of the Darwinian Machine

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

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

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# 4
# Collective Learning as a Key Concept in Big History

*David Baker*

**Abstract**

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

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

When I arrived in Sydney in 2010 to start my PhD in Big History, my original topic was long-term patterns in Malthusian cycles. However, it was only a few weeks before I noticed the strong connection between population dynamics, the rise of complexity that is central to Big History's grand narrative, and a concept known as cultural evolution, which is the transmission of cultural ideas, beliefs, and attitudes through an algorithm of variation and selection very similar to the evolution of genes in biology. Cultural ideas evolve and adapt far faster than genetics and this permits a much more rapid increase in complexity. Cultural evolution is, of course, one of many manifestations of the 'Darwinian algorithm' that is observed in cosmology, geology, biology, and even quantum physics, that seems to play a role in rising complexity (Baker 2011a, 2013, 2014; Christian in this volume). My dissertation has explored the Darwinian connection among these differing physical processes and I have explored them in a few other articles, but in this article I would like to focus on an aspect of cultural evolution that is crucial to human progress and the upper end of the immense complexity the Universe has generated so far.

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

The historian's view of all human history is no longer vague or boundless with a chaotic tangle of periods and research areas. Collective learning gives a clear and definite shape to the whole picture as well as an underlying theme. This is revolutionary not only for Big History, but for areas of conventional human history as well. The idea has its uses within archaeology, agrarian history, and within the study of the industrial era – not to mention our anxiety-fraught examination of the looming trials of the 21st century. For the concept of collective learning we are deeply indebted to David Christian for expounding it in his own works, and also anthropologists like Peter Richerson, Robert Bettinger, Michelle Kline, and Robert Boyd, for developing it mathematically and, in one case of a recent paper to the Royal Society, with a strong degree of empiricism (Christian 2005: 146–148; Richerson, Boyd, and Bettinger 2009: 211–235; Kline and Boyd 2010: 2559–2564).

In natural ecology, all organisms are slaves to some form of *S*-curve that restricts the amount of resources available to an individual and a species, enabling them to survive and reproduce. When the carrying capacity of a biological population is reached, the population undergoes strain, decline, and recovery. While potentially destructive to life-forms, it does have the merit of spurring along evolution by natural selection. Thomas Malthus' *Essay on the Principle of Population* (1798) illustrated how the human population growth always tended to exceed the resources capable of supporting its burgeoning numbers. Darwin read it in 1838 and extrapolated it to other organisms whereby species over-breed, compete, and change over time to possess the traits that are best able to extract resources from their environment and perpetuate their survival. It was an epiphany for him. At last, he said, 'I have finally got a theory with which to work' (Darwin 1887: 82). It also applies to human history. In his recent book, Big Historian Fred Spier identifies the unifying theme of our long story:

> If we want to prevent our bodily complexity as well as all the complexity that we have created from descending into chaos, we must

> keep harvesting matter and energy flows on a regular basis. *This is the bottom line of human history*. I will therefore argue that during most, if not all, of human history, the quest for sufficient matter and energy to survive and reproduce... has been the overriding theme (Spier 2010: 116; emphasis added).

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

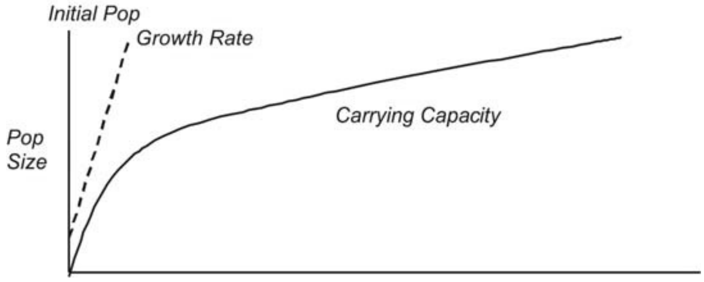


**Fig. 1.**

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

## I. Collective Learning in the Palaeolithic

What precise ability enables collective learning? How did it evolve? What selection pressures made it spring into being? This engages with a much larger and much older debate over the nature of human uniqueness – something to which a refined version of collective learning can contribute. These ideas are universal grammar *à la* Noam Chomsky *vs.* symbolic reference *à la* Terrence Deacon, the emergent thought *vs.* the computational model of the mind, the role of imitation and mimicry in the evolution of language, and the debate over group selection in humans that raged over a recent book by Edward O. Wilson and the counterblast of Steven Pinker (Wilson 2012; Pinker 2012). While the importance of collective learning and technological accumulation to human history has been clearly identified, it is much less clear what trait or a set of traits enabled it in the first place. A number of theories exist and they all seem to revolve around the gradual and the sudden. Chomsky argues against gradualism and considers universal grammar an all or nothing proposition that somehow flickered into being (Chomsky 2002: 80). Pinker argues for a more gradual evolution of a computational model of the mind similar to the evolution of the eyes (Pinker 1997: 21). Deacon argues for the appearance of symbolic reference as a sudden occurrence (Deacon 1997: 328–355). Dunbar claims that enhanced communication abilities and technological accumulation were the gradual result of selection pressures on complex interaction and coordination due to increasing group size and inter-group connectivity (Dunbar 1996: 3–17, 56–58, 62–64, 77; 2004: 28–29, 71–72, 125–126; 2010: 22–33). Finally, Corballis places gesticulation as the fundamental form of social learning with speech being the ultimate form – thus being a change of degree and not of kind (Corballis 2002: 41–65). Whatever the skill that allowed humans to accumulate more innovation with one generation than was lost by the next, it needs to have a clear explanation about how it evolved in real terms without recourse to metaphor and with identifiable selection pressures – whether sudden or gradual.

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

Similarly, the stagnant nature of stone tools 2.6–1.8 million years ago may potentially be dismissed as a 'sporadic learning', simply preserving knowledge but not accumulating it. Around 1.8 million years ago, however, the assertion grows more tenuous. Stone tool manufacture is less haphazard, with deliberate shapes being constructed that are passed on culturally. *Homo ergaster/erectus* also migrated into different environments in Asia, no mean feat, and there is evidence of a demographic boom in Africa that may have driven the migration. A demographic boom also indicates an enhanced ability to exploit niches in the ecosystem. There is also evidence of increased brain size and sociality (Stringer 2011: 25–26; Tattersall 2012: 123–124). All of these things are staple arguments for collective learning in *Homo sapiens* and the profound impact they had on the Palaeolithic world. There is no reason why the same arguments could not apply to *Homo ergaster/erectus*, albeit on a lesser scale. But this is a difference of scale, not a difference of kind.

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

Still, the assertion that *Homo ergaster/erectus* had crossed the threshold into mild collective learning can still be reasonably disputed and dismissed if the case is only based on such limited evidence. This argument is less feasible for the hominines of the last million years. *Homo antecessor*, *Homo heidelbergensis*, and the Neanderthals presided over the systematised and regular use of fire in hearths (790,000 years ago), the earliest wooden spears (400,000 years ago), the earliest use of composite tools (400,000 years ago), the first evidence of intricately constructed shelters (350–400,000 years ago), and the first prepared core tools (300,000 years ago) all before *Homo sapiens* was ever heard of (Goren-Inbar *et al.* 2004: 725–727; Tattersall 2008: 125). *Homo heidelbergensis* became the first pan-Old World hominine (600,000 years ago), showing signs of technological improvement, with the earliest specimens using simpler tools than later ones, and even evidence of pigments at Terra Amata, a site in Europe 350,000 years ago (Oakley 1981: 205–211). The Neanderthals adapted to climes that made clothing and other cultural innovations necessary for insulation and warmth. There is also limited evidence for use of pigments (Stringer 2011: 163–165). They used complex tool manufacture, with prepared stone cores, producing a variety of implements, sharp points, scrapers, teardrop hand-axes, wood handles, with deliberate use of good stone materials, and an endless supply of variations and signs of improvement over time (Tattersall 2012: 166–173; 2008: 150–158).

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

The question of a 'Palaeolithic revolution' is another point of contention. Did *Homo sapiens* undergo a biological change *c.* 50,000 years ago and does this explain the explosion of technological complexity that appears in the fossil record? Or did collective learning and population density achieve a point of saturation allowing for a faster pace of learning? Or did this complexity arrive in Africa prior to 100,000 years ago as McBrearty and Brooks have suggested (McBrearty and Brooks 2000: 453–563)? If the latter, it is probably the result of collective learning maintaining a faster rate of accumulation in denser African populations than disparate migrant ones. Collective learning may have also played a role in the Out-of-Africa migrations themselves. Recent DNA studies have shown exponential human population growth in Africa preceded our most successful migration out of that continent *c.* 60,000 years ago (Atkinson *et al.* 2009: 367–373). This coincides with evidence of an increase in the complexity of technology around the same time (Mellars 2006: 9381–9386). It is possible that there is a correlation between migration and population growth that may be explained by the gradual rise of collective learning. If such a connection exists for the ecological success of humans, it might also be applied to the prior migrations of *Homo ergaster/erectus*, *Homo heidelbergensis*, and the Neanderthals. The human correlation is also reinforced by genetic studies by Powell, Thomas, and Shennan that show population density in Africa may have reached a critical mass to allow more consistent technological accumulation without as many periods of loss (Powell *et al.* 2009: 1298–1301).

Decline in population and collective learning can also lead to a Tasmanian Effect, where technology disappears or undergoes simplification. Jared Diamond coined the term for the extreme disappearance of technology in Tasmania (Diamond 1978: 185–186). Kline and Boyd recently established a similar case in Oceania, where technology declined in groups that were isolated or lost density (Kline and Boyd 2010: 2559–2564). My own work has unearthed a similar occurrence of technological disappearance and simplification in the extreme and sustained population decline of isolated parts of post-Roman Western Europe in the 5th – 6th centuries (Baker 2011b: 217–251). Finally, Zenobia Jacobs, Bert Roberts, Hilary Deacon, and Lyn Wadley established two Palaeolithic Tasmanian Effects in Africa, at Still Bay 72,000 years ago and Howieson's Poort 64,000 years ago (Jacobs *et al.* 2008: 733–735; Wadley *et al.* 2009: 9590–9594). All are cases where technology disappears or is simplified in areas that suffered isolation and population decline – a phenomenon deemed more likely in the Palaeolithic due to lower populations and lower connectivity. It might explain why collective learning took tens of thousands of years to get off the ground, relatively speaking, before the explosion of agriculture.

## II. Accumulation of Innovations from Foraging to Agriculture

Culture evolves through an accumulation of small variations. Those ideas that are successful or useful, in whatever way, are selected and spread throughout a society. Every invention of technology or breakthrough in practice, like in agriculture, comes from a series of small improvements contributed by a long dynasty of innovators. The single innovation of a genius might be of revolutionary magnitude and repercussions, but would have been impossible without the hundreds of tiny innovations made by the hundreds of generations that came before it. Newton said he stood on the shoulders of giants. It might be fairer to say that every ordinary person stands on the shoulders of other ordinary people – some with more than ordinary perceptiveness and absolutely extraordinary timing. Our technologies, our institutions, our languages are far too elaborate for even the most gifted of geniuses to create from scratch. Human beings have a tremendous capacity for language. We can share information with great precision, accumulating a pool of knowledge that all people may use. The knowledge an individual contributes to that pool can long survive his death. If our populations are large and well-connected enough, more information is acquired by each passing generation than is lost by the next. It can be accessed and improved by countless generations.

From the origins of collective learning in the Palaeolithic, it is clear that from the rising carrying capacity and increase in cultural variants and innovations, that collective learning has great bearing on the historical narratives. Nowhere is this more relevant than the discussion of population cycles. The inception of the current arc of complexity is easily spotted. Around 74,000 years ago there was a catastrophic eruption at mount Toba, on the island of Sumatra, part of what is now Indonesia. It was worse than anything in recorded history.

The eruption drastically lowered temperatures on Earth for several years (Rampino and Self 1992: 50–52). Genetic studies show that the resultant decline in flora and fauna upon which humans could predate had reduced the population to near extinction. It is likely that in the aftermath of a period of starvation, on the entire face of the Earth there were scarcely more than 10,000 (and perhaps as few as 1000) human souls, which, as an aside, is what makes our long history of racism so abhorrent and absurd, particularly those ideological impulses inspired by Darwinism (Williams *et al.* 2009: 295–314; Rampino and Ambrose 2000: 78–80; Ambrose 1998: 623–651). Here is a low watermark for the current trend of human population dynamics. Evidently the starvation did not last long. In approximately the same amount of time that separates us from the dawn of agriculture, the human species had recovered and *c*. 60,000 years ago migrated out of Africa across the world. By 30,000 years ago, the foraging human population had risen to half a million. By 10,000 years ago, the innovation of hunter-gatherer bands had allowed them access to almost every environment on Earth, from Eurasia to Australia to the Americas. We must remember that the carrying capacity for a foraging band is quite low and they need a vast area to supply relatively small numbers. Nevertheless, by the dawn of agriculture the ranks of our species had swelled to six million people, approaching the full capacity for supporting hunter-gatherers of which the entire surface of the Earth is capable (Livi-Bacci 1992: 31). Innovations began to mount up. The earliest recorded evidence for herding goats and sheep in Southwest Asia is from 11–12,000 years ago, and one thousand years later, we have evidence for the farming of wheat, barley, emmer, lentils, and pigs. By 8,000 years ago, East Asia had begun using millets and gourds, and the Americas had domesticated llamas and maize. By 6,000 years ago, Southwest Asia had domesticated dates and the grapevine, while East Asia had domesticated water chestnuts, mulberries, water buffalo, and that mainstay of all Asian crops – rice (Roberts 1998: 136). All of a sudden, much larger numbers could be supported over a much smaller land area. The agrarian civilizations brought about a greater degree of connectivity, faster population growth, and a new rapid pace for innovation. Suddenly there were a lot more minds to generate ideas and a lot less space between those minds in order to conference. Agricultural efficiency gradually improved and practices slowly spread to new regions. From the upper limits of the carrying capacity for foragers, the population increased nearly tenfold by 3000 BC to 50 million people, and it took only another 2000 years to increase this number to 120 million (Biraben 1979: 13–25). But there was a problem. The tinkering of ideas in cultural evolution is random, after all. For nearly 10,000 years, the growth in the carrying capacity of agriculture was sluggish while population growth was exponential, and so there was a series of miniature waves of population collapse and recovery throughout the period of agrarian civilizations. From there came the advent of industry which has raised the carrying capacity and enhanced collective learning by leaps and bounds.

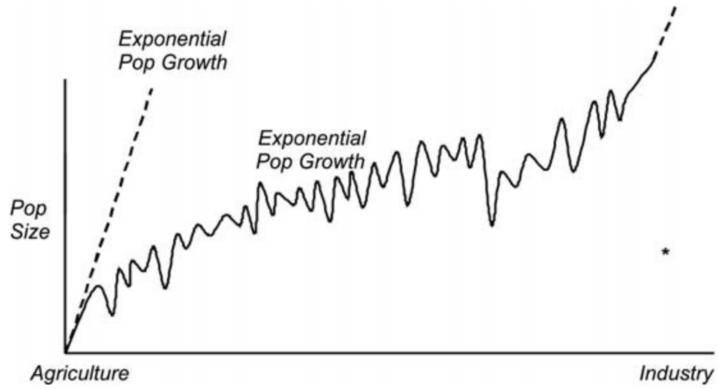


**Fig. 2.** The asterisk (*) marks a period of severe population decline where collective learning is lost

Bear in mind that each innocuous-looking downturn on the graph represents a period of intense starvation, suffering, and death. Every few centuries an agrarian civilization overshot its carrying capacity and countless famines, instability, poverty, and plagues ravaging a malnourished landscape, resulted. Each droop of the line represents the death of millions. Sometimes population loss would be so significant that it adversely affected the onward march of collective learning, as the asterisk simulates. If collective learning is lost, the carrying capacity falls, and the smaller group of innovators has to make up lost ground. This reversal of the process is known as the Tasmanian Effect.

## III. Collective Learning Undermined and Overthrown

When a catastrophe strikes and a population is reduced and isolated, the accumulation of knowledge slows down and a population's ability to retain information is weakened. The most extreme example of this is from Tasmania, which possessed many technologies shared by their Australian relatives to the north, but whose skills and technologies gradually disappeared after Tasmania was cut off from Australia *c.* 10,000 years ago. Jared Diamond famously observed that when the Europeans first visited Tasmania in the seventeenth century, the native population was small, isolated, and lacked many of the tools and methods that the aboriginal Australians on the mainland possessed. The Tasmanians could not produce fire in hearths, they did not have boomerangs, shields, spears, no bone tools, no specialized stone tools, no compound tools like an axe head mounted on a handle, no woodworking, no sewing of clothes despite Tasmania's cold weather, and even though they lived on the sea coast, they had no technology for catching and eating fish (Diamond 1978: 185–186). Diamond hypothesized that this was caused by the loss of the land bridge between Australia and Tasmania *c.* 10,000 years ago. A subsequent recent study of Tasmania's archaeological and ethno-historical evidence has borne out the same result (Henrich

2004: 197–218). The Tasmanians upon European contact had lost a great deal of technology that was enjoyed not only by their neighbours across the Bass Strait but also by most groups of *Homo sapiens* in the Palaeolithic. Humans probably arrived in Tasmania from Australia 34,000 years ago, across a land bridge, and were indeed cut off 12,000–10,000 years ago by the rising sea (Jones 1995: 423–446). The archaeological evidence shows that at the time of migration, the Tasmanians were producing bone tools, cold-weather clothing, fishhooks, hafted tools, fishing spears, barbed spears, fish/eel traps, nets, and boomerangs, and continued to do so even after the island was cut off by the rising seas. These tools gradually declined in frequency, variety, and quality between 8,000 and 3,000 years ago before completely disappearing from the archaeological record (Henrich 2004: 198). Thereafter, to hunt and fight, the Tasmanians used one-piece spears, rocks, and throwing clubs, and their entire toolkit consisted of 24 items, as opposed to the hundreds of tools possess by the Australians to the north (Ryan 1981). Bone tools are on the Tasmanian record from at least 18,000 years ago, just as they were in Australian records and also enjoyed by Palaeolithic man in Africa from 89,000 years ago (Webb and Allen 1990: 75–78). The archaeological record also shows that from 8,000–5,000 years ago, the Tasmanians relied heavily on fishing, second in their diet only to seal hunting, and much more than hunting wallabies. By 3,800 years ago, fish bones disappear from archaeological sites and it was not part of the Tasmanian diet when Europeans arrived (Henrich 2004: 199). All told, Jared Diamond's hypothesis forty years ago about a loss of knowledge due to connectivity and a shrinking population has been largely borne out by subsequent research.

It is not the only case where such a phenomenon has occurred, though it is undoubtedly one of the most extreme. Other Pacific groups have a history of losing canoe, pottery, and bow technology (Rivers 1926). The Inuit were decimated by a plague and lost knowledge to construct kayaks, bows and arrows, and the leister, until it was reintroduced by migrants from Baffin Island (Rasmussen 1908; Golden 2006). Michelle Kline and Robert Boyd detected a similar trend in Oceania (Kline and Boyd 2010: 2559–2564). The ecological similarity between these environments allowed Kline and Boyd to focus on fishing technology, preventing geographical differences from distorting the results. The groups also had a common cultural descent. The finding was that the number of tools and the complexity of them are higher in larger well-connected populations. Zenobia Jacobs, Bert Roberts, Hilary Deacon, and Lyn Wadley have determined that there was a Tasmanian Effect at Still Bay 72,000 years ago and Howieson's Poort 64,000 years ago (Jacobs *et al.* 2008: 733–735; Wadley *et al.* 2009: 9590–9594). At Still Bay, humans created highly complex flake technology, including finely shaped, bifactually worked spearheads. At Howieson's Poort, humans created composite weapons and stone artifacts, both of which were hafted. These two sites were more innovative than much else in Middle Stone Age Africa, and an increasingly complex social organization is implied by the use of bone tools, symbols, and personal ornaments. The strange thing is that these two industrious cultures are separated by several thousand years of stagnation and total disappearance of their technologies. And the differences between the way the technologies of Still Bay and Howieson's Poort are constructed implies that when Still Bay disappeared, the innovators of Howieson's Poort started from scratch. Both cultures intriguingly fall within the genetic bottleneck that occurred 80–60,000 years ago (Jacobs *et al.* 2008: 733). It would appear a relatively low carrying capacity for hunter-gatherers ranging across a territory, the small size of their groups, and their vulnerability to ecological changes and disasters made the disappearance of knowledge more common in the Palaeolithic. The Tasmanian Effect is not just confined to hunter-gatherer societies, however, though due to the low connectivity and small populations of those societies it may be more common. The Tasmanian Effect can also occur in agrarian civilizations. It occurred in the post-Roman West in the 4th, 5th and 6th centuries AD. We must make clear, however, that this trend was not mirrored in the Roman-Byzantine East, which underwent a different population trend, including growth through the 4th, 5th, and into the 6th centuries AD. The extreme settlement abandonment of the Roman West, started in 350, intensified by the Germanic invasions, and then further exacerbated by the bubonic plague of Justinian, reduced the already sparse and illiterate population to low levels. The loss of technology and expertise is reflected in the decline of various artisanal practices, pottery methods, military equipment and architectural knowledge (Murray-Driel 2001: 56–64; Pugsley 2001: 112–115; Ward-Perkins 1999: 227–232; Arthur 2007: 181; Mannoni 2007: xlv-xlvii; Knight 2007: 100; Rossiter 2007: 115; Bishop and Coulston 1993: 122–149; Coulston 2002: 23; Williams 2002: 45–49; Murray 1986: 31–32; King 2001: 26–28). It remained to subsequent generations to rediscover classical learning and devise new methods to make up for this shortfall and raise the carrying capacity once again. The process of recovery from the Tasmanian Effect took Western Europe more than 700 years.

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

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

The first great divergence was in Song China in the 9th and 10th centuries AD which led to something staggeringly similar to the rates of innovation and production seen in the Industrial Revolution. In the 6th century BC, the carrying capacity of China was already ahead of ancient Europe. China was already growing crops in rows, paying attention to weeding, and frequently employing iron ploughs. All of these innovations would not be employed in Europe for centuries. The Chinese also used horse harnesses by the $3^{rd}$ century BC, avoiding the risk of strangulation by a horse and permitting them to carry ploughs and heavy equipment. The seed drill came into use by the $2^{nd}$ century BC. In the $1^{st}$ – $2^{nd}$ century BC, the types of mouldboard ploughs that only became available in Europe after Charlemagne were already in use in China (Temple 1986: 15–20). At the time, the majority of the Chinese population concentrated in the north in the Yellow River valley where they farmed millet and wheat – not rice (Ponting 1991: 93). Even before the explosion of wet rice agriculture in China, these innovations served to create a higher agricultural output and carrying capacity compared with Roman Europe centred on the Mediterranean Sea, both in the East and especially the sparsely populated backwater that was the Roman West.

Until the $1^{st}$ millennium AD, both world zones had supported themselves mainly on grain products, with the Chinese sustaining a higher carrying capacity than Europe due to better agricultural practices. Even further divergence happened between 500 and 1000 AD with the spread of wet rice production in China, which has a much higher yield than grain. Per hectare, traditional varieties of rice support around 5.63 people compared to 3.67 people on a hectare of wheat (Fernandez-Armesto 2001: 105). Dry rice farming came first. However, it has a carrying capacity that is not much higher than wheat. The problem is that dry rice farming requires constant weeding (Woods and Woods 2000: 50). It was also ill-suited to the climate of northern China. In the north, millet farming in the Yellow River valley began in 6,000 BC (Higman 2012: 23). By 200 BC, the Han north was sustained by the farming of millet and wheat in an inefficient two-crop rotation. The inhospitable soils and temperatures of the Yellow River valley in the north usually permitted only one crop a year. From AD 1, wheat was immediately planted after millet or soy to increase crop frequency. In order to avoid too much loss of nutrients from repeated planting, the crop was often planted in alternating furrows, with new furrows being planted in between the old ones. The Han plough had limited depth of ploughing. Over-seeding was sometimes used to save labour at the expense of the yield (Hsu 1980: 112–114).

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

At the fall of the Han dynasty, the barbarian attacks forced more Chinese south to the Yangtze River basin. The reunification under the Sui in AD 589 made the region more stable, and rice expansion and the migration of the northern population to the south continued in earnest (Ponting 1991: 93). Gradually, migration between AD 500 and 1300 transformed the agricultural output and population distributions of China, particularly intensifying in the Song dynasty (AD 960–1276). The Song government initiated a set of policies to shift agricultural production from the northern millet and wheat regions to the wet rice producing south. In 1012, the Song introduced a strain of rice from Vietnam that allowed for multiple harvests per year, or the alternation of rice in summer and wheat in winter. The government appointed 'master farmers' from local communities, who were to disseminate new farming techniques and knowledge of new tools, fertilizers, and irrigation methods. The Song also introduced tax breaks on newly reclaimed land and low-interest loans for farmers to invest in new agricultural equipment and crops (Bray 1986: 203). The Song encouraged terracing, created fields that were evenly flooded and trapped fertile silts from being washed away. In 1273, the Chinese government distributed 3,000 copies of *Essentials of Agriculture and Sericulture* to landowners in order to improve crop yields. Wet rice farming by this method produced two-three crops a year compared to the meagre one-crop harvest of the millet-producing north (Headrick 2009: 51–52, 85).

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

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

## V. Collective Learning and the Rise of Complexity

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

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

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

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

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

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

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

We do not yet know where this tremendous capacity for collective learning will lead. It is likely to reveal even higher levels of complexity in the future, if we do not wipe ourselves out. When it comes to the broader trend in the Universe, it is fairly clear that the next rise of complexity will be down to animate rather than inanimate physical processes. As stars burn down, as planetesimals tumble through cold space, it may be that species like us, with a tremendous ability for collective learning and harnessing energy flows, will reveal even more remarkable phases of cosmic evolution. In that sense, collective learning tells us not only about human history, but about the overwhelming thrust of human destiny in a rising crescendo of complexity. That is, if we do not go extinct beforehand. An asteroid collision, a volcanic super-eruption, or a nuclear war could wipe the slate clean. Eventually the Sun will destroy the Earth. Even in the short term, as the 21st century appears to deepen further into crisis, the entire arc of collective learning could come very abruptly to an end. We shall then never know where collective learning might have led us or what we might have achieved as a population of billions of increasingly educated and well connected innovators. Mankind's great task in the 21st century is to survive it.

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# 5
# Collective Learning and the Silk Roads*

*Craig G. Benjamin*

## Abstract

*The Silk Roads are the quintessential example of the interconnectedness of civilizations during the Era of Agrarian Civilizations, and the exchanges that occurred along them resulted in the most significant collective learning so far experienced by the human species. The primary function of the Silk Roads was to facilitate trade, but the intellectual, social, and artistic exchanges that resulted had an even greater impact on collective learning. The Silk Roads also illustrate another key theme in Big History – evolving complexity at all scales. Just as the early universe was simple until contingent circumstances made it possible for more complex entities to appear, and that the relatively simple single-cell organisms of early life on the planet were able to evolve into an extraordinary, complex biodiversity, so human communities and the connections between them followed similar trajectories. The comingling of so many goods, ideas, and diseases around a geographical hub located deep in central Eurasia was the catalyst for an extraordinary increase in the complexity of human relationships and collective learning, a complexity that helped drive our species inexorably along a path towards the modern revolution.*

***Keywords:*** *Silk Roads, Collective Learning, Agrarian Civilizations, Afro-Eurasia, trade.*

## Introduction

During the Era of Agrarian Civilizations (*c.* 3000 BCE – 1750 CE) human communities did not exist in isolation. As confederations of pastoralists, states and large-scale agrarian civilizations expanded and stretched their boundaries, they joined together to form larger systems. Sometimes they joined up simply because their borders met and merged, but more often they joined in a looser sense as people from one region traded with, or traveled to, or borrowed ideas from, or fought with people from other regions within and beyond agrarian civilization. Because of this regular commingling the very idea of distinct agrarian civilizations with rigid borders is misleading. Borders that we identify

* Some of the material presented at the first IBHA Conference in this paper was later incorporated into *Big History. Between Nothing and Everything*, by David Christian, Cynthia Stokes Brown and Craig Benjamin.

on maps are, for the most part, modern inventions. The borders of agrarian civilizations were more often vague regions within which the control of rulers fluctuated or was contested by the claims of neighbors or local rulers.

Despite the complexity and fluidity of these processes, the slow linking up of different agrarian civilizations was immensely important because it facilitated a dramatic expansion in the size and diversity of collective learning, which can be described as the human capacity to share ideas so efficiently that they accumulate in the collective human memory from generation to generation. From the very beginning of human history the exchange of information and ideas between diverse peoples and cultures has been a prime mover in promoting change through this process of collective learning. As the smaller exchanges of the Early Agrarian Era began to expand, the enhanced collective learning that followed led to more and more significant changes in the material, artistic, social, and spiritual domains of human history. Eventually within the Afro-Eurasian world zone in particular, every human community was connected together within a vibrant web. This was true within each of the individual world zones, although not between them. Significant linkages developed during the era in the Americas, Australasia, and the Pacific, but the four zones were so isolated from each other that human populations in each remained utterly ignorant of events in the others.

The most influential of the intensified Afro-Eurasian exchange networks emerged around a trading hub located deep in Central Asia, along the Silk Roads. The trans-civilizational contacts that occurred through this exchange resulted in the most significant collective learning so far experienced by the human species. The first important period of the Silk Roads was between roughly 50 BCE and 250 CE, when material and intellectual exchange took place between the Chinese, Indian, Kushan, Iranian, steppe-nomadic and Mediterranean worlds. The demise of the Western Roman, Parthian, Kushan and Han Chinese empires resulted in several centuries of less regular contact, but the second 'Silk Roads Era' subsequently operated for several centuries between *c*. 600 and 1000 CE, connecting China, India, Southeast Asia, the Dar al-Islam, and the Byzantines into another vast web based on overland and maritime trade. The primary function of the Silk Roads during both periods was to facilitate trade. Not only material goods were carried along the Silk Roads, however, but intellectual, social, and artistic ideas as well, which together had an even greater impact on collective learning (Christian *et al.* 2013: 174–175).

An early example of intellectual exchange, which took place before the Silk Roads had started to operate with real intensity, was the spread of Greek and Hellenistic culture from the Eastern Mediterranean to Central Asia and India. This happened because Greek merchants and colonists followed in the footsteps of Alexander and spread Greek language, art, religion, philosophy, and law throughout much of the region. Perhaps, the most important spiritual consequence of material exchange was the spread of religions across Afro-Eurasia, particularly Mahayana Buddhism, which moved from India through Central Asia to China and East Asia. An example of cultural exchange that led to enhanced collective learning was the spread of artistic ideas and techniques, particularly the diffusion eastwards of syncretistic sculptural styles that developed in the second century CE in the workshops of Gandhara (in Pakistan) and Mathura (in India), where the first ever representation of the Buddha was conceived (*Ibid.*: 176).

The major biological consequence of Silk Roads trade was the spread of diseases and plague. Not only did the passing of disease bacteria along the Silk Roads by traders play a significant role in the depopulation and subsequent decline of both the Han and Roman Empires, but the exposure of millions of humans to these pathogens meant that antibodies spread extensively throughout the Afro-Eurasian world zone, and important immunities were built up within populations. These immunities proved of great significance in the pre-modern age, when Muslim, Chinese, and particularly European traders and explorers carried Afro-Eurasian diseases to the other world zones, with disastrous consequences for native populations (McNeil 1998). These four brief examples all support the claim that the Silk Roads profoundly affected the subsequent shape and direction of all human history.

Commercial and cultural exchange on this scale became possible only after the small river valley states of the early era had been consolidated into substantial agrarian civilizations, a process that was largely the result of warfare. Continuing expansion by the major civilizations meant that, by the first Silk Roads Era, just four imperial dynasties – those of the Roman, Parthian, Kushan, and Han Empires – controlled much of the Eurasian landmass, from the Pacific to the Atlantic. The consolidation of these states established order and stability over a vast and previously fragmented geopolitical environment. Extensive internal road networks were constructed, great advances were made in metallurgy and transport technology, agricultural production was intensified, and coinage appeared for the first time. By the middle of the last century BCE, conditions in Afro-Eurasia were ripe for levels of material and cultural exchange – and collective learning – hitherto unknown (Benjamin 2009: 30–32).

Also critical in facilitating these exchanges were the pastoral nomads, who formed communities that live primarily from the exploitation of domestic animals such as cattle, sheep, camels, or horses. The exact chronology of the origins and spread of pastoralism remains obscure, but certainly by the middle to late fourth millennium BCE the appearance of burial mounds across the steppes of Inner Asia indicates that some communities that were dependent upon herds or flocks of domestic animals had become semi-nomadic. There were varying degrees of nomadism, ranging from groups that had no permanent settlements at all to communities like the Andronovo that were largely sedentary and lived in permanent settlements. The highly mobile, militarized pastoralism of Inner Asia, associated with the riding of horses by the Saka/Scythians and other groups, probably did not emerge until early in the first millennium BCE (Christian *et al.* 2013: 177–178).

In Afro-Eurasia, by the time the first cities and states appeared, the technologies of the secondary products revolution had generated more productive ways of exploiting livestock, some of them so productive that they allowed entire communities to depend almost exclusively on their herds of animals (Sherratt 1981: 261–305). The more they did this, however, the more nomadic they had to be, so that they could graze their animals over large areas. The result was that there developed, over several millennia, entire lifeways based mainly on pastoralism, capable of exploiting the arid lands that ran in a long horizontal belt from northwest Africa through Southwest Asia and Central Asia to Mongolia.

By the middle of the 1st millennium BCE, a number of large pastoral nomadic communities had emerged with the military skills and technologies, and the endurance and mobility, to dominate their sedentary agrarian neighbors. Some of them, including the Saka, Xiongnu, Yuezhi, and Wusun, established powerful state-like confederations that formed in the steppe lands between the agrarian civilizations. These confederations demonstrated the ability of pastoral nomads to prosper in the harsh interior of Afro-Eurasia. Once such communities emerged, they facilitated the linking up of all the different lifeways and communities. Prior to the success of pastoralists in these more marginal zones, agrarian civilizations were considerably more isolated from each other. Ultimately it was the role of pastoralists as facilitators and protectors of trade and exchange that allowed the Silk Roads and other networks to flourish (Christian *et al.* 2013: 177–178).

## First Silk Roads Era (*c.* 50 BCE – *c.* 250 CE)

With these preconditions in place, it was the decision by the Han Chinese to begin to interact with their western neighbors and engage in long-distance commerce that turned small-scale regional trading activity into a great trans-Afro-Eurasian commercial network. The Han became involved in the late-second century BCE after Emperor Wudi dispatched envoy Zhang Qian on a diplomatic and exploratory mission into Central Asia. When Zhang Qian returned after an epic journey of twelve years, he convinced the emperor that friendly relations could be established with many of the states of the 'Western Regions' because they were 'hungry for Han goods' (Benjamin 2007b: 3–30). Those that were not eager to trade could be subdued by force and compelled to join the Han trade and tributary network. Within a decade the Han had established a tributary relationship with dozens of city-states of Central Asia, and mercantile traffic began to flow out of China along the ancient migration routes into Central Asia. Half a century after the Han began to engage with their western neighbors, Augustus came to power in Rome following a century of civil war. This restored peace and stability to much of Western Afro-Eurasia, leading to a sharp increase in the demand for luxury goods in Rome, particularly for spices and exotic textiles like silk (Benjamin 2009: 30–32).

The major Chinese export commodity in demand in Rome was silk, an elegant, translucent, sensual material that soon came to be regarded as the last word in fashion by wealthy patrician women. The Chinese, realizing the commercial value of their monopoly on silk, carefully guarded the secret of silk production, and border guards in Dunhuang searched merchants to make sure they were not carrying any actual silk worms out of the country. The Han iron was prized in Rome for its exceptional hardness. Fine spices were imported into the Roman Empire from Arabia and India, notably nutmeg, cloves, cardamom, and pepper, prized as condiments, but also as aphrodisiacs, anesthetics, and perfumes. Trade with China and Central Asia for such high-value goods cost the Romans a fortune. In 65 CE, Roman Senator Pliny the Elder wrote that trade with Asia was draining the treasury of some 100 million sestercii every year (*Ibid.*: 30–32). Even though Pliny's figure is undoubtedly exaggerated, it provides evidence of the incredible scale of Silk Roads commercial exchanges. In return for their high value-exports, the Chinese imported a range of agricultural products (including grapes), Roman glassware, art objects from India and Egypt, and horses from the steppes.

The major Silk Roads land routes stretched from the Han capital, Chang'an, deep into Central Asia by way of the Gansu Corridor and Tarim Basin. The animal that made Silk Roads trade possible in the eastern and central regions of Afro-Eurasia was the Bactrian camel. Native to the steppes of Central Asia, the two-humped Bactrian camel is a supreme example of superb evolutionary adaptation. To survive the harsh winters, the camel grows a long, shaggy coat, which it sheds extremely rapidly as the season warms up. The two humps on its back are composed of sustaining fat and its long eyelashes and sealable nostrils help to keep out dust in the frequent sandstorms. The two broad toes on each of its feet have undivided soles and are able to spread widely as an adaptation to walking on sand. The bulk of overland Silk Roads trade was literally carried on the backs of these extraordinary animals (Christian *et al.* 2013: 178).

In Western Eurasia, the major land route departed from the great trading cities of Roman Syria, crossed the Euphrates and Tigris Rivers, then climbed across the Iranian Plateau toward Afghanistan (then known as Bactria). Significant information on the geography of the western part of the Silk Roads has come to us from a document produced early in the first century CE – *Parthian Stations* – written by a Parthian Greek merchant Isodorus of Charax (Benjamin 2009: 30–32). Around the time *Parthian Stations* was being composed, the amount of trans-Afro-Eurasian trade taking place by sea was also increasing, particularly between Roman Egypt and the coast of India. The survival of the first century CE seaman's handbook, the *Periplus of the Erythrian Sea*, has provided historians with a detailed account of maritime commerce at that time (*Ibid.*: 30–32). The *Periplus* demonstrates that sailors had discovered the secrets of the monsoon 'trade' winds. The winds blow reliably from the southwest in summer, allowing heavily laden trade ships to sail across the Indian Ocean from the coast of Africa to India. In winter the winds reverse, and the same ships carrying new cargo would make the return journey to the Red Sea. Whether by land or by sea, however, no traders we are aware of ever made their way along the entire length of the Silk Roads during the first era of its operation. Instead, merchants from the major eastern and western civilizations took their goods so far, then passed them on to a series of middlemen, including traders who were operating deep within the Kushan Empire.

At the heart of the Silk Roads network, straddling and influencing both the land and maritime routes, was the Kushan Empire (*c.* 45–225 CE), one of the most important yet least known agrarian civilizations in world history (Benjamin 1998, 2009). By maintaining relatively cordial relations with Romans, Parthians, Chinese, Indians, and the steppe nomads, the Kushans were able to play a crucial role in facilitating the extraordinary levels of cross-cultural exchange that characterize this first Silk Roads Era. The Kushan monarchs were not only effective political and military rulers; they also demonstrated a remarkable appreciation of art and were patrons of innovative sculpture workshops within their empire. The output from these workshops reflects the sort of synthesis typical of the intensity of collective learning during the Era of Agrarian Civilizations.

The sculpture produced in the workshops of Gandhara and Mathura during the first two centuries of the Common Era was created by the combined talents of Central Asian, Indian, and probably Hellenistic Greek artists who placed themselves at the service of a resurgent Buddhist spirituality and created a whole new set of images for worship. Until this moment the Buddha had never been depicted in human form, but had instead been represented by symbols including an umbrella or footprints in the sand. The first ever representation of the Buddha, which appeared in Gandhara (in modern-day Pakistan), was influenced by depictions of Greco-Roman deities. This physical representation then spread along the Silk Roads, penetrating south to Sri Lanka and east to China, Japan, Korea, and Southeast Asia (Benjamin 1998, 2009).

An equally striking example of this cross-fertilization of ideas and traditions is the spread of Buddhist ideology along the great trade routes. Buddhism first emerged in northern India in the 6th century BCE. Eight hundred years later, according to ancient Chinese Buddhist documents, the Kushan king, Kanishka the Great (*c*. 129–152 CE?) convened an important meeting in Kashmir at which the decision was taken to rewrite the Buddhist scriptures in a more popular and accessible language. This helped facilitate the emergence and spread of Mahayana (or Great Vehicle) Buddhism, partly because the scriptures were now written in a language the common people could understand, and not one that could be read only by religious elites (Benjamin 2013).

The well-traveled trade routes from India through the Kushan realm and into China facilitated the spread of Buddhist ideas which, because they offered the hope of salvation to all regardless of caste or status, was already popular with India's merchants and businessmen. The Chinese merchants active in the silk trade became attracted to the faith, too, and returned home to spread the Buddhist message. Chinese edicts of 65–70 CE specifically mention the spread of Buddhism and opposition to it from imperial scholars devoted to Confucianism. By 166 CE, the Han emperor himself was sacrificing to the Buddha, and the Sutra on the 'Perfection of the Gnosis' was translated into Chinese by 179 CE. By the late fourth century, during a period of disunity in China, much of the population of northern China had adopted Buddhism, and by the sixth century much of southern China as well. The religion also later found ready acceptance in Korea, Japan, Tibet, Mongolia, and Southeast Asia (Benjamin 1998, 2009).

The Silk Roads also facilitated the spread of Christianity, Manichaeism and, later, Islam. Christian missionaries made good use of the superb Roman road and sea transportation networks. The Christian missionary, Paul of Tarsus, may have traveled as many as 8,000 miles along the roads and sea-lanes of the eastern Roman Empire preaching to small Christian communities. Christianity eventually spread further to the east along the Silk Roads, through Mesopotamia and Iran, into India, and eventually into China. One branch of Christianity, Nestorianism, became particularly strong throughout the central and eastern Silk Roads. The Central Asian religion of Manichaeism also benefitted from the silk routes after it emerged in Mesopotamia in the 3rd century CE. Its founder, Mani (216–272 CE) was a fervent missionary who traveled extensively throughout the region and also dispatched disciples. Like Buddhism, Manichaeism was particularly attractive to merchants, and eventually most of the major Silk Roads trading cities contained Manichaean communities (Christian *et al.* 2013: 180).

During the 3rd century of the Common Era, the Silk Roads fell gradually into decline as both China and the Roman Empire withdrew from the trans-Afro-Eurasian web. Ironically, Silk Roads trade itself was at least partly responsible for this disengagement, because it contributed to the spread of disastrous epidemic diseases. Smallpox, measles, and bubonic plagues devastated the populations at either end of the routes, where people had less resistance. Population estimates from the ancient world are always difficult, but the population of the Roman Empire may have fallen from 60 million to 45 million between the mid-1st and mid-2nd centuries CE. As smallpox devastated the Mediterranean world late in the second century, populations declined again, to perhaps 40 million by 400 CE. In China, populations fell from perhaps 60 million in 200 CE to 45 million by 600 CE (Bentley and Zeigler 2010: 282).

These huge demographic losses, which happened at the same time as the decline of previously stable agrarian civilizations (the Han Dynasty disintegrated in 220 CE, the Kushan and Parthian Empires collapsed under pressure from Sasanian invaders a decade or so later, and the Roman Empire experienced a series of crises throughout the first half of the 3rd century) meant that, for the next several centuries, the prevailing political situation in many parts of Afro-Eurasia was not conducive to large-scale commercial exchange. However, with the creation of the Dar al-Islam in the 8th and 9th centuries CE, and the establishment of the Tang Dynasty in China at the same time, significant Silk Roads exchanges along both land and maritime routes revived.

## Second Silk Roads Era *c.* 600 – *c.* 1000 CE

Both the Tang Dynasty (618–907 CE) and its successor, the Song Dynasty (960–1279 CE), presided over a vibrant market economy in China, in which agricultural and manufacturing specialization, population growth, urbanization, and infrastructure development led to high levels of internal and external trade.

New financial instruments (including printed paper money) were devised to facilitate large-scale mercantile activity. At the same time, Arab merchants, benefiting from the stable and prosperous Abbasid administration in Baghdad, began to engage with Chinese merchants in lucrative commercial enterprises. Large numbers of Muslim merchants actually moved to China where they joined communities of Byzantine, Indian, and Southeast Asian migrants in the great Chinese trading cities. As maritime trade gradually eclipsed overland trade in volume, merchants and sailors from all over Afro-Eurasia flocked to the great southern port cities of Guangzhou and Quanzhou (Christian *et al.* 2013: 180–181).

The recent discovery of a sunken ninth-century CE Arab ship – the so-called Belitung Wreck – in the waters of Indonesia has provided historians with tangible evidence of both the intensely commercial nature of Chinese-Muslim trade and the significance of maritime routes in facilitating it (Worrall 2003: 112ff.). The dhow was filled with tens of thousands of carefully packaged Tang ceramic plates and bowls, along with many gold and silver objects. The Tang bowls were functional and intended for the ninth-century equivalent of a 'mass market'. Their almost factory-like manufacture demonstrates the existence of a well-organized commercial infrastructure. The bowls required the use of cobalt for blue coloring, which was imported by the Chinese manufacturers in significant quantities from Iran. The firing date of the bowls was carefully noted in the ship's manifest. The cargo also included large quantities of standardized inkpots, spice jars, and jugs, clearly export goods manufactured for specific markets. Decorative patterns painted or glazed on the various items – including Buddhist, Iranian, and Islamic motifs – show the specific market the goods were intended for. China and the Dar al-Islam were clearly engaged in intense commercial exchanges during this second Silk Roads Era, and Arab mariners undertaking lengthy seagoing voyages were maintaining this vibrant trans-Afro-Eurasian web late in the 1st millennium of the Common Era.

As with the first Silk Roads Era, although the material exchanges were important and impressive, the cultural exchanges seem in retrospect of even greater significance. As noted above, long before the Tang came to power, many foreign religions had made their way into East Asia. With the advent of Islam in the 7th century and the establishment of substantial Muslim merchant communities in the centuries that followed, mosques also began to appear in many Chinese cities. Yet of all the foreign beliefs that were accepted in China, only Buddhism made substantial inroads against Confucianism. Between 600–1000 CE, thousands of Buddhist stupas and temples were constructed in China. With its promise of salvation, Buddhism seriously challenged Daoism and Confucianism for the hearts and minds of many Chinese, and in the end the syncretic faith of Chan Buddhism (Zen Buddhism in Japan) emerged as a popular compromise (Christian *et al.* 2013: 181).

## Conclusion

The Silk Roads, both the land and maritime variants, are the quintessential example of the interconnectedness of civilizations during the Era of Agrarian Civilizations. Along these difficult routes through some of the harshest geography on earth traveled merchants and adventurers, diplomats and missionaries, each carrying their commodities and ideas enormous distances across the Afro-Eurasian world zone. Each category of exchange was important, but perhaps the most significant consequence was the spread of religion, particularly Buddhism, which became one of the key ideological and spiritual beliefs of South and East Asia during the Era. To this day Buddhism remains one of the great cultural bonds shared by millions of Asian people, one of the many legacies that the modern world owes to the Silk Roads. As a result of this interaction, despite the diversity of participants, the history of Afro-Eurasia has preserved a certain underlying unity, expressed in common technologies, artistic styles, cultures and religions, even disease and immunity patterns, a unity that was to have profound implications for subsequent world history.

Silk Roads exchanges play an even more significant role in the Big History narrative. The physical contexts that made the Silk Roads possible were the product of billions of years of geological change and biological evolution. Geography made it possible for the first agrarian civilizations of western Eurasia and northeastern Africa to form cultural and commercial connections, but geography also prevented Chinese civilization from joining these developing networks in any substantive way. Only with the biological evolution and then human domestication of the silk worm and the Bactrian camel did the Chinese have an export commodity valuable enough, and a transport mechanism hardy enough, to justify and facilitate the expensive and complex expeditions necessary to allow the Chinese merchants to join the pre-existing Afro-Eurasian exchange network. This joining together of previously separated human communities led to a steep increase in levels of collective learning and complexity that had regional and global ramifications.

The development of the Silk Roads is also an example of another key theme in Big History – evolving complexity at all scales. In the same way that the early universe was simple until contingent circumstances made it possible for more complex entities to appear, and that the relatively simple single-cell organisms of early life on the planet were able to evolve into an extraordinary, complex biodiversity, so human communities and the connections between them followed similar trajectories. The commingling of so many goods, ideas, and diseases around a geographical hub located deep in central Eurasia was the catalyst for an extraordinary increase in the complexity of human relationships and collective learning, a complexity that drove our species inexorably along a path towards the modern revolution.

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# II. BIOSOCIAL EVOLUTION, ECOLOGICAL ASPECTS, AND CONSCIOUSNESS

## 6
## Modeling of Biological and Social Phases of Big History*

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

### Abstract

*In the first part of this article we survey general similarities and differences between biological and social macroevolution. In the second (and main) part, we consider a concrete mathematical model capable of describing important features of both biological and social macroevolution. In mathematical models of historical macrodynamics, a hyperbolic pattern of world population growth arises from non-linear, second-order positive feedback between demographic growth and technological development. Based on diverse paleontological data and an analogy with macrosociological models, we suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by non-linear, second-order positive feedback between diversity growth and the complexity of community structure. We discuss how such positive feedback mechanisms can be modelled mathematically.*

***Keywords:*** *social evolution, biological evolution, mathematical model, biodiversity, population growth, positive feedback, hyperbolic growth.*

### Introduction

The present article represents an attempt to move further in our research on the similarities and differences between social and biological evolution (see Grinin, Markov, and Korotayev 2008, 2009a, 2009b, 2011, 2012). We have endeavored to make a systematic comparison between biological and social evolution at different levels of analysis and in various aspects. We have formulated a considerable number of general principles and rules of evolution, and worked to

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develop a common terminology to describe some key processes in biological and social evolution. In particular, we have introduced the notion of 'social aromorphosis' to describe the process of widely diffused social innovation that enhances the complexity, adaptability, integrity, and interconnectedness of a society or social system (Grinin, Markov, and Korotayev 2008, 2009a, 2009b). This work has convinced us that it might be possible to find mathematical models that can describe important features of both biological and social macroevolution. In the first part of this article we survey general similarities and differences between the two types of macroevolution. In the second (and main) part, we consider a concrete mathematical model that we deem capable of describing important features of both biological and social macroevolution.

The comparison of biological and social evolution is an important but (unfortunately) understudied subject. Students of culture still vigorously debate the applicability of Darwinian evolutionary theory to social/cultural evolution. Unfortunately, the result is largely a polarization of views. On the one hand, there is a total rejection of Darwin's theory of social evolution (see, *e.g.*, Hallpike 1986). On the other hand, there are arguments that cultural evolution demonstrates all of the key characteristics of Darwinian evolution (Mesoudi *et al.* 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 the achievements of evolutionary biology to understanding social evolution and *vice versa*. In other words, we should search for productive generalizations and analogies for the analysis of evolutionary mechanisms in both contexts. The Universal Evolution approach aims for the inclusion of all mega-evolution within a single paradigm (discussed in Grinin, Carneiro, *et al.* 2011). Thus, this approach provides an effective means by which to address the above-mentioned task.

It is not only systems that evolve, but also mechanisms of evolution (see Grinin, Markov, and Korotayev 2008). Each sequential phase of macroevolution is accompanied by the emergence of new evolutionary mechanisms. Certain prerequisites and preadaptations can, therefore, be detected within the previous phase, and the development of new mechanisms does not invalidate the evolutionary mechanisms that were active during earlier phases. As a result, one can observe the emergence of a complex system of interaction composed of the forces and mechanisms that work together to shape the evolution of new forms.

Biological organisms operate in the framework of certain physical, chemical and geological laws. Likewise, the behaviors of social systems and people have certain biological limitations (naturally, in addition to various social-structural, historical, and infrastructural limitations). From the standpoint of Universal Evolution, new forms of evolution that determine phase transitions may result from activities going in different directions. Some forms that are similar in principle may emerge at breakthrough points, but may also result in evolutionary dead-ends. For example, social forms of life emerged among many biological phyla and classes, including bacteria, insects, birds, and mammals. Among insects, in particular, one finds rather highly developed forms of socialization (see, *e.g.*, Robson and Traniello 2002; Ryabko and Reznikova 2009; Reznikova 2011). Yet, despite the seemingly common trajectory and interrelation of social behaviors among these various life forms, the impacts that each have had on the Earth are remarkably different.

Further, regarding information transmission mechanisms, it appears possible to speak about certain 'evolutionary freaks'. Some of these mechanisms were relatively widespread in the biological evolution of simple organisms, but later became less so. Consider, for example, the horizontal exchange of genetic information (genes) among microorganisms, which makes many useful genetic 'inventions' available in a sort of 'commons' for microbe communities. Among bacteria, the horizontal transmission of genes contributes to the rapid development of antibiotic resistance (*e.g.*, Markov and Naymark 2009). By contrast, this mechanism of information transmission became obsolete or was transformed into highly specialized mechanisms (*e.g.*, sexual reproduction) in the evolution of more complex organisms. Today, horizontal transmission is mostly confined to the simplest forms of life.

These examples suggest that an analysis of the similarities and differences between the mechanisms of biological and social evolution may help us to understand the general principles of megaevolution[1] in a much fuller way. These similarities and differences may also reveal the driving forces and supra-phase mechanisms (*i.e.*, mechanisms that operate in two or more phases) of megaevolution. One of our previous articles was devoted to the analysis of one such mechanism: *aromorphosis*, the process of widely diffused social innovation that enhances the complexity, adaptability, integrity, and interconnectedness of a society or social system (Grinin, Markov, and Korotayev 2011; see also Grinin and Korotayev 2008, 2009a, 2009b; Grinin, Markov, and Korotayev 2009a, 2009b).

It is important to carefully compare the two types of macroevolution (*i.e.*, biological and social) at various levels and in various aspects. This is necessary because such comparisons often tend to be incomplete and deformed by conceptual extremes. These limitations are evident, for example, in the above-referenced paper by Mesoudi *et al.* (2006), which attempts to apply a Darwinian method to the study of social evolution. Unfortunately, a failure to recognize or accept important differences between biological and social evolution reduces the overall value of the method that these authors propose. Christopher Hallpike's rather thorough monograph, *Principles of Social Evolution* (1986), pro-

[1] 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 phases.

vides another illustration of these limitations. Here, Hallpike offers a fairly complete analysis of the similarities and differences between social and biological organisms, but does not provide a clear and systematic comparison between social and biological evolution. In what follows, we hope to avoid similar pitfalls.

## Biological and Social Evolution: A Comparison at Various Levels

There are a few important differences between biological and social macroevolution. Nonetheless, it is possible to identify a number of fundamental similarities, including at least three basic sets of shared factors. First, we are discussing very complex, non-equilibrium, but stable systems whose function and evolution can be described by General Systems Theory, as well as by a number of cybernetic principles and laws. Second, we are not dealing with isolated systems, but with the complex interactions between organisms and their external environments. As a result, the reactions of systems to 'external' challenges can be described in terms of general principles that express themselves within a biological reality and a social reality. Third (and finally), a direct 'genetic' link exists between the two types of macroevolution and their mutual influence.

We believe that the laws and forces driving the biological and social phases of Big History can be comprehended more effectively if we apply the concept of biological and social aromorphosis (Grinin, Markov, and Korotayev 2011). There are some important similarities between the evolutionary algorithms of biological and social aromorphoses. Thus, it has been noticed that the basis of biological 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 1987: 64–76).

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

A similar pattern is observed within social macroevolution. An example is the invention and diffusion of iron metallurgy. Iron production was practiced sporadically in the 3rd millennium BCE, but regular production of low-grade steel did not begin until the mid-2nd millennium BCE in Asia Minor (see, *e.g.*, Chubarov 1991: 109). At this point, the Hittite kingdom guarded its monopoly over the new technology. The diffusion of iron technology led to revolutionary changes in different spheres of life, including a significant advancement in plough agriculture and, consequently, in the agrarian system as a whole (Grinin and Korotayev 2006); an intensive development of crafts; an increase in urbanism; the formation of new types of militaries, armed with relatively cheap but effective iron weapons; and the emergence of significantly more developed systems of taxation, as well as information collection and processing systems, that were necessary to support these armies (*e.g.*, Grinin and Korotayev 2007a, 2007b). Ironically, by introducing cheaply made weapons and other tools into the hands of people who might resist the Hittite state, this aromorphosis not only supported the growth of that kingdom, it also laid the groundwork for historical phase shifts.

Considering such cases through the lens of aromorphosis has helped us to detect a number of regularities and rules that appear to be common to biological and social evolution (Grinin, Markov, and Korotayev 2011). Such rules and regularities (*e.g.*, payment for arogenic progress, special conditions for the emergence of aromorphosis, *etc.*) are similar for both biological and social macroevolution. It is important to emphasize, however, that similarity between the two types of macroevolution 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, yet there are enormous intellectual and social differences between chimpanzees and humans that arise from the apparently 'insignificant' variations between the two genomes (see Markov and Naymark 2009).

Despite its aforementioned limitations, it appears reasonable to continue the comparison between the two types of macroevolution following the analysis offered by Hallpike (1986). Therefore, it may prove useful to revisit the pertinent observations of this analysis here. Table 1 summarizes the similarities and differences that Hallpike (*Ibid.*: 33–34) finds between social and biological *organisms*.

While we do not entirely agree with all of his observations – for example, the establishment of colonies could be seen as a kind of social reproduction akin to organic reproduction – we do feel that Hallpike comes to a 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 in which institutions are similar to some organs. In this way, cells may be regarded as similar to individuals, central government similar to the brain, and so on. Examples of this kind of thinking can be found in the classic texts of social theory (see, *e.g.*, Spencer 1898 and Durkheim 1991 [1893]), as well as in more recent work (see, *e.g.*, Heylighen 2011).

**Table 1.** Similarities and differences between social and biological organisms, as described by Hallpike (1986)

| Similarities | Differences |
|---|---|
| Social institutions are interrelated in a manner analogous to the organs of the body. | Individual societies do not have clear boundaries. For example, two societies may be distinct politically, but not culturally or religiously. |
| Despite changes in membership, social institutions maintain continuity, as do biological organs when individual cells are replaced. | Unlike organic cells, the individuals within a society have agency and are capable of learning from experience. |
| The social division of labor is analogous to the specialization of organic functions. | Social structure and function are far less closely related than in organic structure and function. |
| Self-maintenance and feedback processes characterize both kinds of system. | Societies do not reproduce. Cultural transmission between generations cannot be distinguished from the processes of system maintenance. |
| Adaptive responses to the physical environment characterize both kinds of system. | Societies are more mutable than organisms, displaying a capacity for metamorphosis only seen in organic phylogeny. |
| The trade, communication, and other transmission processes that characterize social systems are analogous to the processes that transmit matter, energy, and information in biological organisms. | Societies are not physical entities, rather their individual members are linked by information bonds. |

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

(1) that, like societies, species do not reproduce;

(2) that both have phylogenies reflecting change over time; and

(3) that both are made up of individuals who compete against one another.

Importantly, he also indicates the following *difference*: '[S]ocieties are organized systems, whereas species are simply collections of individual organisms' (Hallpike 1986: 34).

Hallpike tries to demonstrate that, because of the differences between biological and social organisms, the very idea of natural selection does not appear to apply to social evolution. However, we do not find his proofs very convincing on this account, although they do make sense in certain respects. Further, his analysis is confined mainly to the level of the individual organism and the individual society. He rarely considers interactions at the supra-organism level (though he does, of course, discuss the evolution of species). His desire to demonstrate the sterility of Darwinian theory to discussions of social evolution notwithstanding, it seems that Hallpike involuntarily highlights the similarity between biological and social evolution. As he, himself, admits, the analogy between the biological organism and society is quite noteworthy.

Just as he fails to discuss interactions and developments at the level of the supra-organism in great detail, Hallpike does not take into account the point in social evolution where new supra-societal developments emerge (up to the level of the emergence of the World System [*e.g.*, Korotayev 2005, 2007, 2008, 2012; Grinin and Korotayev 2009b]). 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 to understanding biological evolution, though the differences between organisms and societies make the importance of this supra-level to understanding social evolution unclear. 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 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 (*cf.,* Lekevičius 2009, 2011).

In our own analysis, we seek to build on the observations of Hallpike while, at the same time, providing a bit more nuance and different scales of analysis. Viewing each as a process involving selection (natural, social, or both), we identify the differences between social and biological evolution at the level of the individual biological organism and individual society, as well as at the supra-organismic and supra-societal level.

### Natural and Social Selection

Biological evolution is more additive (cumulative) than substitutive. Put another way: the new is added to the old. By contrast, social evolution (especially over the two recent centuries) is more substitutive than additive: the new replaces the old (Grinin, Markov, and Korotayev 2008, 2011).

Further, the mechanisms that control the emergence, fixation, and diffusion of evolutionary breakthroughs (aromorphoses) differ between biological and social evolution. These differences lead to long-term restructuring in the size and complexity of social organisms. Unlike biological evolution, where some growth of complexity is also observed, social reorganization becomes continuous. In recent decades, societies that do not experience a constant and significant evolution look inadequate and risk extinction.

In addition, the 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. At another level of analysis, one can observe the formation of special suprasocietal systems that also tend to grow in size. This is one of the results of social evolution and serves as a method of aromorphosis fixation and diffusion.

### The Individual Biological Organism and the Individual Society

It is very important to note that, although biological and social organisms are significantly (actually 'systemically') similar, they are radically different in their capacities to evolve. For example, as indicated by Hallpike (see above), societies are capable of rapid evolutionary metamorphoses that were not observed in the pre-human organic world. In biological evolution, the characteristics acquired by an individual are not inherited by its offspring; thus, they do not influence the very slow process of change.

There are critical differences in how biological and social information are transmitted during the process of evolution. Social systems are not only capable of rapid transformation, they are also able to borrow innovations and new elements from other societies. Social systems may also be transformed consciously and with a certain purpose. Such characteristics are absent in natural biological evolution.

The biological organism does not evolve by itself: evolution may only take place at a higher level (*e.g.*, population, species, *etc.*). By contrast, social evolution can often be traced at the level of the individual social organism (*i.e.*, society). Moreover, it is frequently possible to trace the evolution of particular institutions and subsystems within a social organism. In the process of social evolution the same social organism or institution may experience radical transformation more than once.

### The Supra-organic and Supra-societal Level

Given the above-mentioned differences, within the process of social evolution we observe the formation of two types of special supra-societal entity: (1) amalgamations of societies with varieties of complexity that have analogues in biological evolution, and (2) elements and systems that do not belong to any particular society and lack many analogues in biological evolution.

The first type of amalgamation is rather typical, not only in social but also in biological evolution. There is, however, a major difference between the two kinds of evolution. Any large society usually consists of a whole hierarchy of social systems. For example, a typical agrarian empire might include nuclear families, extended families, clan communities, village communities, primary districts, secondary districts, and provinces, each operating with their own rules of interaction but at the same time interconnected. This kind of supra-societal amalgamation can hardly be compared with a single biological organism (though both systems can still be compared functionally, as is correctly noted by Hallpike [1986]). Within biological evolution, amalgamations of organisms with more than one level of organization (as found in a pack or herd) are usually very unstable and are especially unstable among highly organized animals. Of course, analogues do exist within the communities of some social animals (*e.g.*, social insects, primates). Neither should we forget that scale is important: while we might compare a society with an individual biological organism, we must also consider groups of organisms bound by cooperative relationships (see, *e.g.*, Boyd and Richerson 1996; Reeve and Hölldobler 2007). Such groups are quite common among bacteria and even among viruses. These caveats aside, it remains the case that within social evolution, one observes the emergence of more and more levels: from groups of small sociums to humankind as a whole.

The multiplication of these levels rapidly produces the second kind of amalgamation. It is clear that the level of analysis is very important for comparison of biological and social evolution. Which systems should be compared? Analogues appear to be more frequent when a society (a 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 systemic organization. This might entail comparisons 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; or with groups of highly organized animals (*e.g.*, cetaceans, primates, and other social mammals or termites, ants, bees and other social insects).

Thus, here we confront a rather complex and rarely studied methodological problem: which levels of biological and social process 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 in every situation. The comparisons should be operational and instrumental. This means that we should choose the scale and level of social and biological phenomena, forms, and processes that are adequate for and appropriate to our intended comparisons.

Again, it is sometimes more appropriate to compare a society with an individual biological organism, whereas in other cases it could well be more appropriate to compare the society with a community, a colony, a population, or a species. At yet another scale, as we will see below, in some cases it appears rather fruitful to compare the evolution of the biosphere with the evolution of the anthroposphere.

## Mathematical Modeling of Biological and Social Macroevolution

The authors of this article met for the first time in 2005, in the town of Dubna (near Moscow), at what seems to have been the first ever international conference dedicated specifically to Big History studies. Without advance knowledge of one another, we found ourselves in a single session. During the course of the session, we presented two different diagrams. One illustrated population dynamics in China between 700 BCE and 1851 CE, the other illustrated the dynamics of marine Phanerozoic biodiversity over the past 542 million years (Fig. 1).

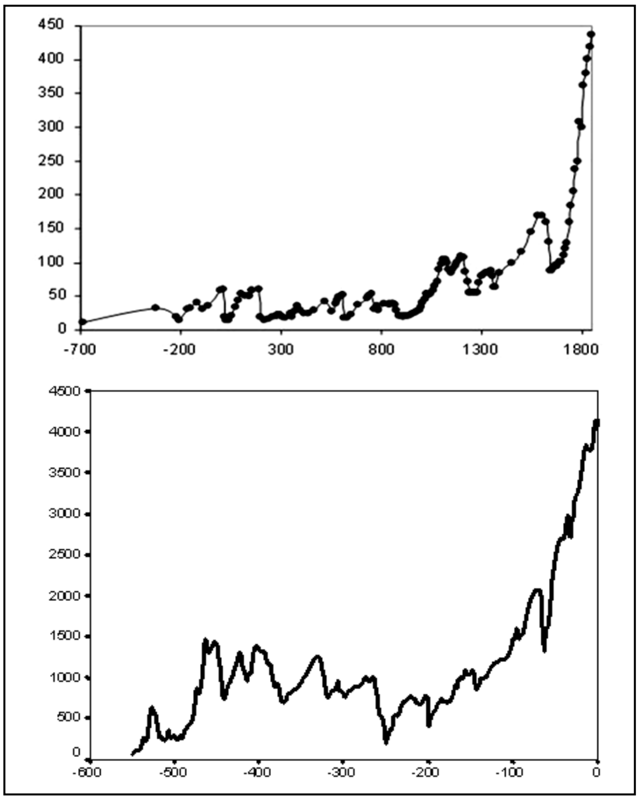


**Fig. 1**. Similarity between the long-term population dynamics of China (top: millions of people, following Korotayev, Malkov, *et al.* 2006b: 47–88) and the dynamics of Phanerozoic marine biodiversity (bottom: number of genera, *N*, following Markov and Korotayev 2007)

The similarity between the two diagrams was striking. This, despite the fact that they depicted the development of very different systems (human population *vs.* biota) at different time scales (hundreds of years *vs.* millions of years), and had been generated using the methods of different sciences (historical demography *vs.* paleontology) with different sources (demographic estimates *vs.* paleontological data). What could have caused similarity of developmental dynamics in very different systems?

* * *

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

$$N_t = \frac{C}{(t_0 - t)}, \qquad \text{(Eq. 1)}$$

where $N_t$ is the world population at time $t$, and $C$ and $t_0$ are constants, with $t_0$ corresponding to an absolute limit ('singularity' point) at which $N$ would become infinite. Parameter $t_0$ was estimated by von Foerster and his colleagues as 2026.87, which corresponds to November 13, 2026; this made it possible for them to supply their article with a title that was a public-relations masterpiece: 'Doomsday: Friday, 13 November, A.D. 2026'.

Of course, von Foerster and his colleagues did not imply that the world population on that day could actually become infinite. The real implication was that the world population growth pattern that operated for many centuries prior to 1960 was about to end and be transformed into a radically different pattern. This prediction began to be fulfilled only a few years after the 'Doomsday' paper was published as World System growth (and world population growth in particular) began to diverge more and more from the previous blow-up regime. Now no longer hyperbolic, the world population growth pattern is closer to a logistic one (see, *e.g.*, Korotayev, Malkov *et al.* 2006a; Korotayev 2009).

Fig. 2 presents the overall correlation between the curve generated by von Foerster *et al.*'s equation and the most detailed series of empirical estimates of world population (McEvedy and Jones 1978, for the period 1000–1950; U.S. Bureau of the Census 2013, for 1950–1970). The formal characteristics are: $R = 0.998$; $R^2 = 0.996$; $p = 9.4 \times 10^{-17} \approx 1 \times 10^{-16}$. For readers unfamiliar with mathematical statistics: $R^2$ can be regarded as a measure of the fit between

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

the dynamics generated by a mathematical model and the empirically observed situation, and can be interpreted as the proportion of the variation accounted for by the respective equation. Note that 0.996 also can be expressed as 99.6 per cent.[3] Thus, von Foerster *et al.*'s equation accounts for an astonishing 99.6 per cent of all the macrovariation in world population, from 1000 CE through 1970, as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2013).[4] Note also that the empirical estimates of world population find themselves aligned in an extremely neat way along the hyperbolic curve, which convincingly justifies the designation of the pre-1970s world population growth pattern as 'hyperbolic'.

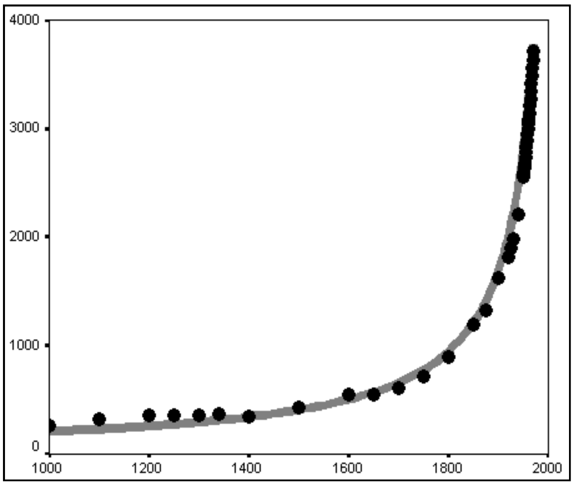


**Fig. 2.** Correlation between empirical estimates of world population (black, in millions of people, 1000–1970) and the curve generated by von Foerster *et al.*'s equation (grey)

[3] The second characteristic ($p$, standing for 'probability') is a measure of the correlation's statistical significance. A bit counter-intuitively, the lower the value of $p$, the higher the statistical significance of the respective correlation. This is because $p$ indicates the probability that the observed correlation could be accounted solely by chance. Thus, $p = 0.99$ indicates an extremely low statistical significance, as it means that there are 99 chances out of 100 that the observed correlation is the result of a coincidence, and, thus, we can be quite confident that there is no systematic relationship (at least, of the kind that we study) between the two respective variables. On the other hand, $p = 1 \times 10^{-16}$ indicates an extremely high statistical significance for the correlation, as it means that there is only one chance out of 10,000,000,000,000,000 that the observed correlation is the result of pure coincidence (a correlation is usually considered statistically significant once $p < 0.05$).

[4] In fact, with slightly different parameters ($C = 164890.45$; $t_0 = 2014$) the fit ($R^2$) between the dynamics generated by von Foerster's equation and the macrovariation of world population for 1000–1970 CE as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2013) reaches 0.9992 (99.92 per cent); for 500 BCE – 1970 CE this fit increases to 0.9993 (99.93 per cent) with the following parameters: $C = 171042.78$; $t_0 = 2016$.

The von Foerster *et al.'s* equation, $N_t = \frac{C}{t_0 - t}$, is the solution for the following differential equation (see, *e.g.*, Korotayev, Malkov *et al.* 2006a: 119–120):

$$\frac{dN}{dt} = \frac{N^2}{C}. \qquad \text{(Eq. 2)}$$

This equation can be also written as:

$$\frac{dN}{dt} = aN^2, \qquad \text{(Eq. 3)}$$

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

What is the meaning of this mathematical expression? In our context, *dN/dt* denotes the absolute population growth rate at a certain moment in time. Hence, this equation states that the absolute population growth rate at any moment in time should be proportional to the square of world population at this moment. This significantly demystifies the problem of hyperbolic growth. To explain this hyperbolic growth, one need only explain why for many millennia the world population's absolute growth rate tended to be proportional to the square of the population.

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

> (1) 'the Malthusian (Malthus 1978 [1798]) assumption that population is limited by the available technology, so that the growth rate of population is proportional to the growth rate of technology' (Kremer 1993: 681–682),[5] and
> (2) the idea that '[h]igh population spurs technological change because it increases the number of potential inventors… In a larger population there will be proportionally more people lucky or smart enough to come up with new ideas', thus, 'the growth rate of technology is proportional to total population'(Kremer 1993: 685).[6]

Here Kremer uses the main assumption of Endogenous Technological Growth theory (see, *e.g.*, Kuznets 1960; Grossman and Helpman 1991; Aghion

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

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

and Howitt 1998; Simon 1977, 2000; Komlos and Nefedov 2002; Jones 1995, 2005).

The first assumption looks quite convincing. Indeed, throughout most of human history the world population was limited by the technologically determined ceiling of the carrying capacity of land. For example, with foraging subsistence technologies the Earth could not support more than 8 million people because the amount of naturally available useful biomass on this planet is limited. The world population could only grow over this limit when people started to apply various means to artificially increase the amount of available biomass that is with the transition from foraging to food production. Extensive agriculture is also limited in terms of the number of people that it can support. Thus, further growth of the world population only became possible with the intensification of agriculture and other technological improvements (see, *e.g.*, Turchin 2003; Korotayev, Malkov *et al.* 2006a, 2006b; Korotayev and Khaltourina 2006). However, as is well known, the technological level is not constant, but variable (see, *e.g.*, Grinin 2007a, 2007b, 2012), and in order to describe its dynamics the second basic assumption is employed.

As this second supposition was, to our knowledge, first proposed by Simon Kuznets (1960), we shall denote the corresponding type of dynamics as 'Kuznetsian'. (The systems in which the Kuznetsian population-technological dynamics are combined with Malthusian demographic dynamics will be denoted as 'Malthusian-Kuznetsian'.) In general, we find this assumption rather plausible – in fact, it is quite probable that, other things being equal, within a given period of time, five million people will make approximately five times more inventions than one million people.

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

$$\frac{dT}{dt} = kNT \ . \qquad \text{(Eq. 4)}$$

This equation simply says that the absolute technological growth rate at a given moment in time ($dT/dt$) is proportional to the technological level ($T$) observed at this moment (the wider the technological base, the higher the number of inventions that can be made on its basis). On the other hand, this growth rate is also proportional to the population ($N$): the larger the population, the larger the number of potential inventors.[7]

When united in one system, Malthusian and Kuznetsian equations account quite well for the hyperbolic growth of the world population observed before the early 1990s (see, *e.g.*, Korotayev 2005, 2007, 2008, 2012; Korotayev, Malkov *et al.* 2006a). The resultant models provide a rather convincing expla-

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

nation of *why,* throughout most of human history, the world population followed the hyperbolic pattern with the absolute population growth rate tending to be proportional to $N^2$. For example, why would the growth of population from, say, 10 million to 100 million, result in the growth of *dN/dt* 100 times? The above mentioned models explain this rather convincingly. The point is that the growth of world population from 10 to 100 million implies that human subsistence technologies also grew approximately 10 times (given that it will have proven, after all, to be able to support a population ten times larger). On the other hand, the tenfold population growth also implies a tenfold growth in the number of potential inventors, and, hence, a tenfold increase in the relative technological growth rate. Thus, the absolute technological growth rate would expand 10 × 10 = 100 times as, in accordance with Eq. 4, an order of magnitude higher number of people having at their disposal an order of magnitude wider technological base would tend to make two orders of magnitude more inventions. If, as throughout the Malthusian epoch, the world population ($N$) tended toward the technologically determined carrying capacity of the Earth*,* we have good reason to expect that *dN/dt* should also grow just by about 100 times.

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

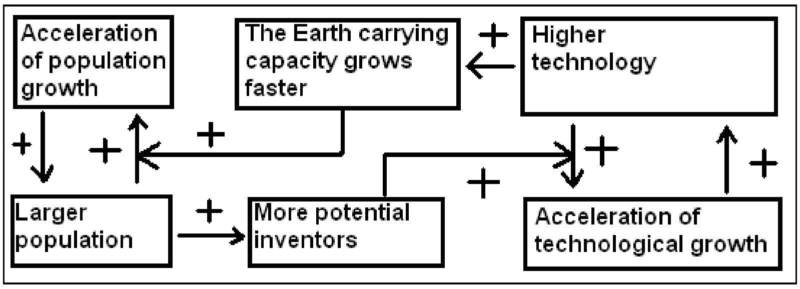


**Fig. 3.** Cognitive scheme of the nonlinear second order positive feedback between technological development and demographic growth

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

The feedback system described here should be identified with the process of 'collective learning' described, principally, by Christian (2005: 146–148). The mathematical models of World System development discussed in this article can be interpreted as models of the influence that collective learning has on global social evolution (*i.e.*, the evolution of the World System). Thus, the rather peculiar hyperbolic shape of accelerated global development prior to the early 1970s may be regarded as a product of global collective learning. We have also shown (Korotayev, Malkov *et al.* 2006a: 34–66) that, for the period prior to the 1970s, World System economic and demographic macrodynamics, driven by the above-mentioned positive feedback loops, can simply and accurately be described with the following model:

$$\frac{dN}{dt} = aSN, \qquad \text{(Eq. 5)}$$

$$\frac{dS}{dt} = bNS. \qquad \text{(Eq. 6)}$$

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

$$G = mN + SN, \qquad \text{(Eq. 7)}$$

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

The mathematical analysis of the basic model (not described here) suggests that up to the 1970s, the amount of $S$ should be proportional, in the long run, to the World System's population: $S = kN$. Our statistical analysis of available empirical data has confirmed this theoretical proportionality (Korotayev, Malkov *et al.* 2006a: 49–50). Thus, in the right-hand side of Eq. 6, $S$ can be replaced with $kN$, resulting in the following equation:

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

Recall that the solution of this type of differential equations is:

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

which produces a simple hyperbolic curve.

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

$$S = \frac{kC}{t_0 - t}. \qquad \text{(Eq. 8)}$$

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

$$SN = \frac{kC^2}{(t_0 - t)^2}\,. \qquad \text{(Eq. 9)}$$

This suggests that the long-term world GDP dynamics up to the early 1970s must be approximated better by a quadratic hyperbola, rather than by a simple one. As shown in Fig. 4, this approximation works very effectively indeed.

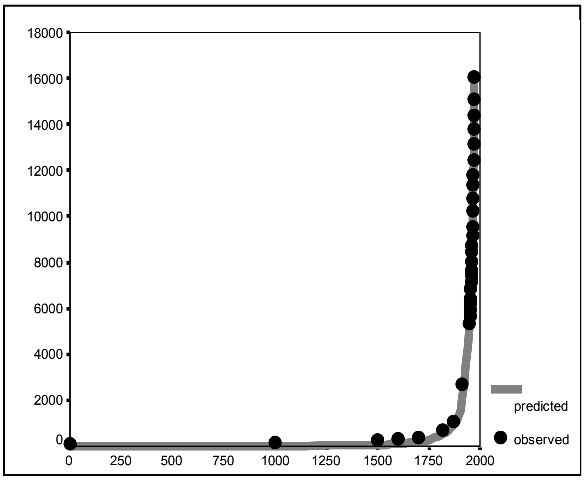


**Fig. 4.** The fit between predictions of a quadratic-hyperbolic model and observed world GDP dynamics, 1–1973 CE (in billions of 1990 international dollars, PPP)

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

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

Thus, up to the 1970s the hyperbolic growth of the world population was accompanied by the quadratic-hyperbolic growth of the world GDP, as suggested by our model. Note that the hyperbolic growth of the world population and the quadratic-hyperbolic growth of the world GDP are very tightly connected processes, actually two sides of the same coin, two dimensions of one process propelled by nonlinear second-order positive feedback loops between the technological development and demographic growth (see Fig. 5).

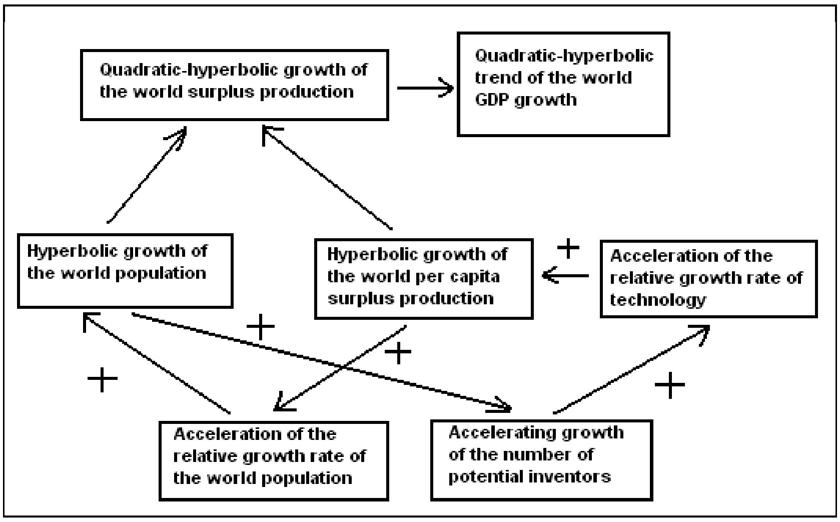


**Fig. 5.** Cognitive scheme of the world economic growth generated by nonlinear second-order positive feedback between technological development and demographic growth

We have also demonstrated (Korotayev, Malkov *et al.* 2006a: 67–80) that the World System population's literacy ($l$) dynamics are rather accurately described by the following differential equation:

$$\frac{dl}{dt} = aSl\ (1 - l), \qquad \text{(Eq. 10)}$$

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

It is important to stress that with low values of $l$ (which correspond to most of human history, with recent decades being the exception), the rate of increase in world literacy generated by this model (against the background of hyperbolic growth of $S$) can be approximated rather accurately as hyperbolic (see Fig. 6).

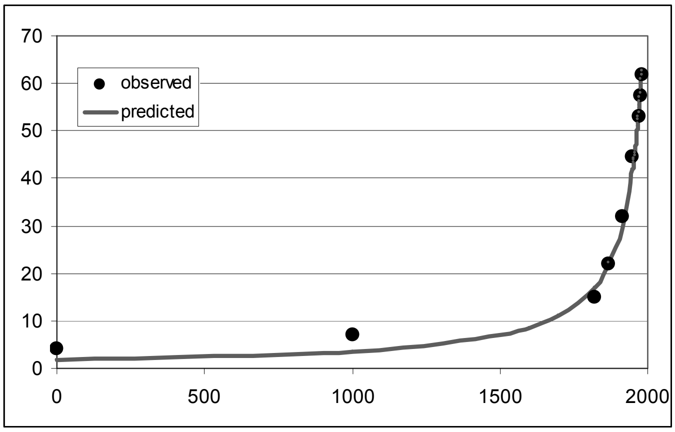


**Fig. 6.** The fit between predictions of the hyperbolic model and observed world literacy dynamics, 1–1980 CE (%%)

*Note:* $R = 0.997$, $R^2 = 0.994$, $p << 0.0001$. Black dots correspond to World Bank (2013) estimates for the period since 1970, and to Meliantsev's (2004) estimates for the earlier period. The grey solid line has been generated by the following equation:

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

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

The overall number of literate people is proportional both to the literacy level and to the overall population. As both of these variables experienced hyperbolic growth until the 1960s/1970s, one has sufficient grounds to expect that until recently the overall number of literate people in the world ($L$)[8] was growing not just hyperbolically, but rather in a quadratic-hyperbolic way (as was world GDP). Our empirical test has confirmed this – the quadratic-hyperbolic model describes the growth of the literate population of this planet with an extremely good fit indeed (see Fig. 7).

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

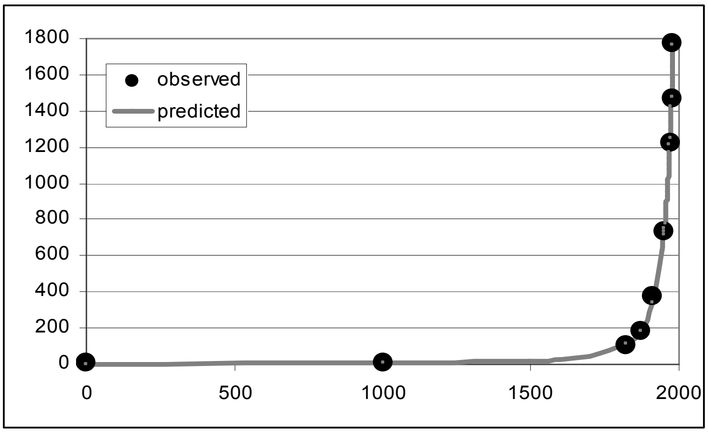


**Fig. 7.** The fit between predictions of the quadratic-hyperbolic model and observed world literate population dynamics, 1–1980 CE ($L$, millions)

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

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

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

Similar processes are observed with respect to world urbanization, the macrodynamics of which appear to be described by the differential equation:

$$\frac{du}{dt} = bSu\,(u_{\lim} - u)\,, \qquad \text{(Eq. 11)}$$

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

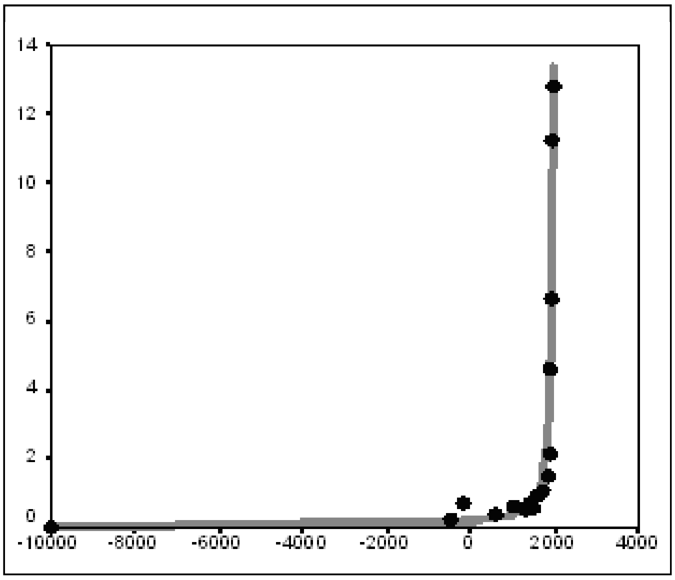


**Fig. 8.** The fit between predictions of the hyperbolic model and empirical estimates of world megaurbanization dynamics (% of the world population living in cities with > 250,000 inhabitants), 10,000 BCE – 1960 CE

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

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

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

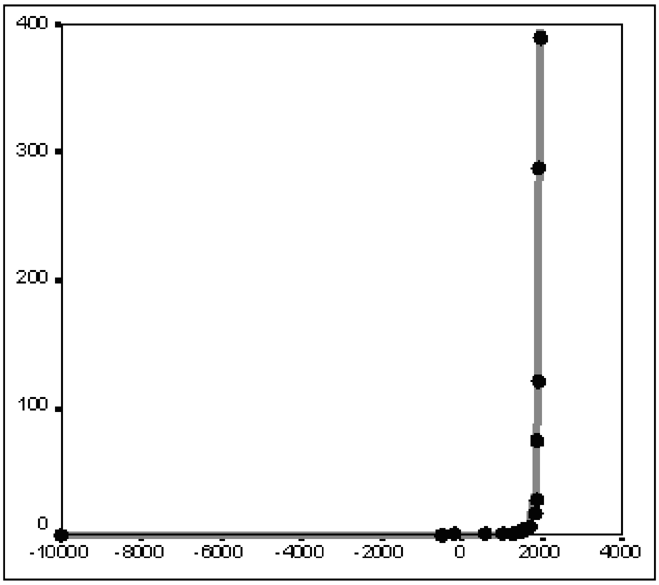


**Fig. 9.** The fit between predictions of the quadratic-hyperbolic model and the observed dynamics of world urban population living in cities with > 250,000 inhabitants (millions), 10,000 BCE – 1960 CE

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

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

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

Within this context it is hardly surprising to find that the general macrodynamics of largest settlements within the World System are also quadratic-hyperbolic (see Fig. 10).

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

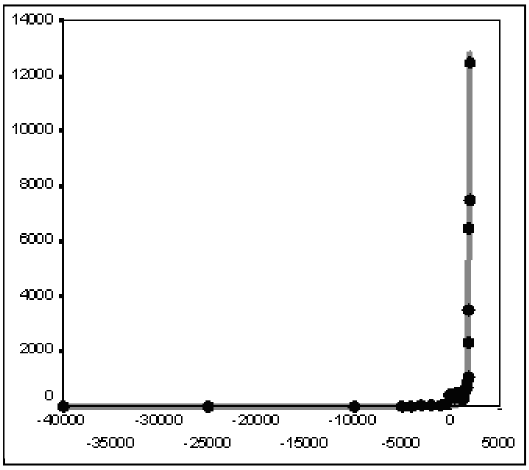


**Fig. 10.** The fit between predictions of the quadratic-hyperbolic model and the observed dynamics of size of the largest settlement of the world (thousands of inhabitants), 10,000 BCE – 1950 CE

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

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

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

Turning to a more concrete case study, as suggested at the beginning of this section, the hyperbolic model is particularly effective for describing the long-term population dynamics of China, the country with the best-known demographic history. The Chinese population curve reflects not only a hyperbolic trend, but also cyclical and stochastic dynamics. These components of long-term population dynamics in China, as well as in other complex agrarian societies, have been discussed extensively (see, *e.g.*, Braudel 1973; Abel 1980; Usher 1989; Goldstone 1991; Chu and Lee 1994; Komlos and Nefedov 2002; Turchin 2003, 2005a, 2005b; Nefedov 2004; Korotayev 2006; Korotayev and Khaltourina 2006; Korotayev, Malkov *et al.* 2006b; Turchin and Korotayev 2006; Korotayev, Komarova *et al.* 2007; Grinin, Korotayev *et al.* 2008; Grinin, Malkov *et al.* 2009; Turchin and Nefedov 2009; van Kessel-Hagesteijn 2009; Korotayev, Khaltourina, Malkov *et al.* 2010; Korotayev, Khaltourina *et al.* 2010; Grinin and Korotayev 2012).

As we have observed with respect to world population dynamics, even before the start of its intensive modernization, the population dynamics of China were characterized by a pronounced hyperbolic trend (Figs 11 and 12).

The hyperbolic model describes traditional Chinese population dynamics *much* more accurately than either linear or exponential models.

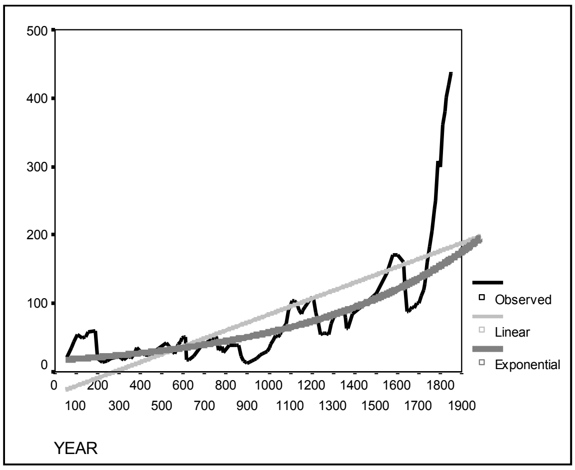


**Fig. 11.** Population dynamics of China (million people, following Korotayev, Malkov, *et al.* 2006b: 47–88), 57–1851 CE. Fit with Linear and Exponential Models

*Note:* Linear model: $R^2 = 0.469$. Exponential model: $R^2 = 0.600$.

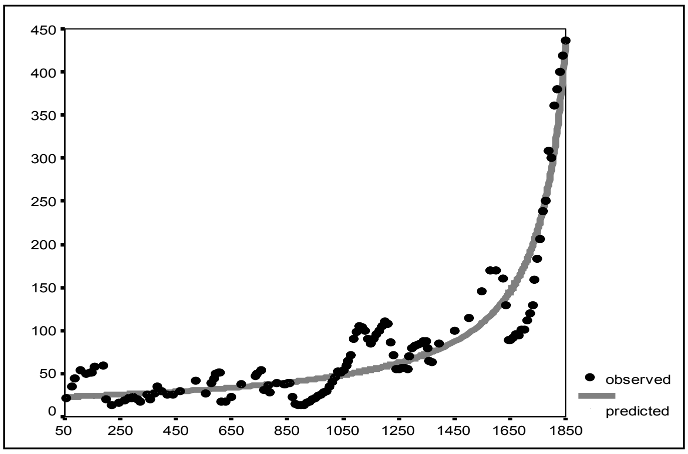


**Fig. 12.** Fit between a hyperbolic model and observed population dynamics of China (million people), 57–1851 CE

*Note:* $R^2 = 0.884$. The grey solid line has been generated by the following equation:

$$N_t = \frac{33431}{1915 - t}.$$

The hyperbolic model describes the population dynamics of China in an especially accurate way if we take the modern period into account (Fig. 13).

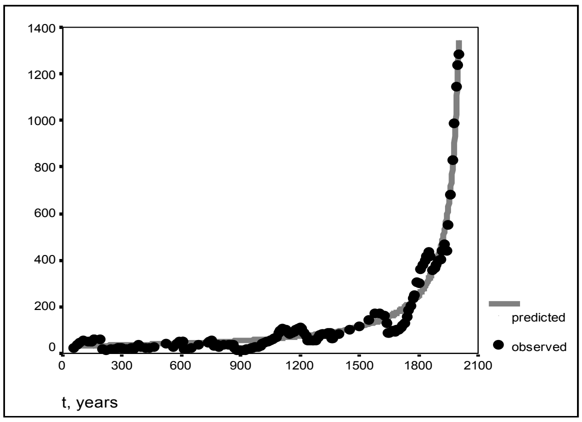


**Fig. 13.** Fit between a hyperbolic model and observed population dynamics of China (million people, following Korotayev, Malkov, *et al.* 2006b: 47–88), 57–2003 CE

*Note:* $R^2 = 0.968$. The grey solid line has been generated by the following equation:

$$N_t = \frac{63150}{2050 - t}.$$

It is curious that, as we noted above, the dynamics of marine biodiversity are strikingly similar to the population dynamics of China. The similarity probably derives from the fact that both curves are produced by the interference of the same three components (the general hyperbolic trend, as well as cyclical and stochastic dynamics). In fact, there is a lot of evidence that some aspects of biodiversity dynamics are stochastic (Raup *et al.* 1973; Sepkoski 1994; Markov 2001; Cornette and Lieberman 2004), while others are periodic (Raup and Sepkoski 1984; Rohde and Muller 2005). In any event, the hyperbolic model describes marine biodiversity (measured by number of genera) through the Phanerozoic much more accurately than an exponential model (Fig. 14).

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

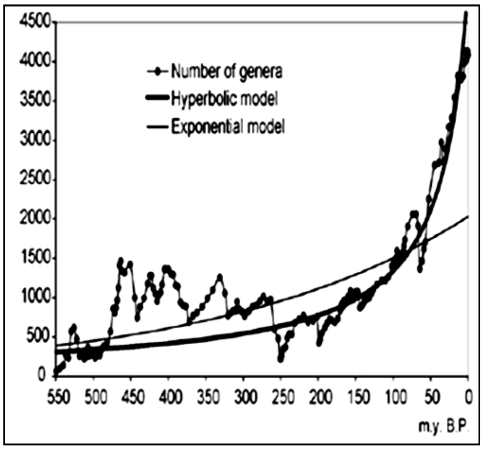


**Fig. 14.** Global change in marine biodiversity (number of genera, *N*) through the Phanerozoic (following Markov and Korotayev 2007)

*Note:* Exponential model: $R^2$ = 0.463. Hyperbolic model: $R^2$ = 0.854. The hyperbolic line has been generated by the following equation:

$$N_t = \frac{183320}{37 - t}.$$

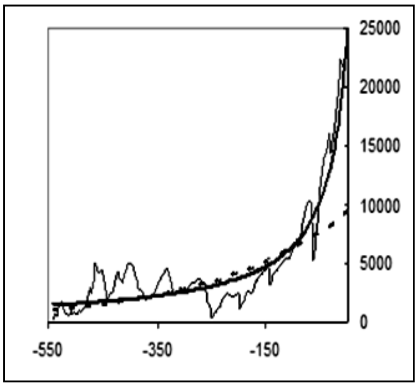


**Fig. 15.** Global change in marine biodiversity (number of species, *N*) through the Phanerozoic (following Markov and Korotayev 2008)

*Note:* Exponential model: $R^2$ = 0.51. Hyperbolic model: $R^2$ = 0.91. The hyperbolic line has been generated by the following equation:

$$N_t = \frac{892874}{35 - t}.$$

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

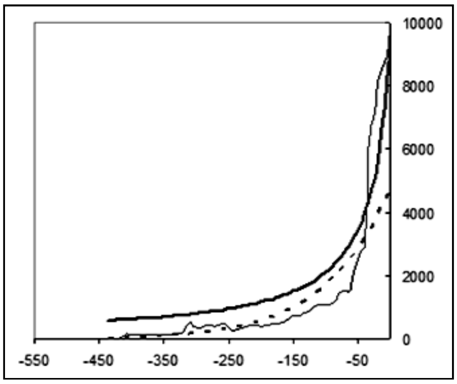


**Fig. 16.** Global change in continental biodiversity (number of genera, *N*) through the Phanerozoic (following Markov and Korotayev 2008)

*Note:* Exponential model: $R^2$ = 0.86. Hyperbolic model: $R^2$ = 0.94. The hyperbolic line has been generated by the following equation:

$$N_t = \frac{272095}{29 - t}.$$

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

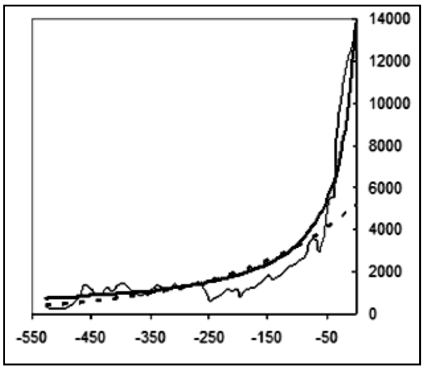


**Fig. 17.** Global change in total biodiversity (number of genera, *N*) through the Phanerozoic (following Markov and Korotayev 2008)

*Note:* Exponential model: $R^2$ = 0.67. Hyperbolic model: $R^2$ = 0.95. The hyperbolic line has been generated by the following equation:

$$N_t = \frac{434635}{30 - t}.$$

The hyperbolic dynamics are most prominent when both marine and continental biotas are considered together. This fact can be interpreted as a proof of the integrated nature of the biosphere. But why, throughout the Phanerozoic, did global biodiversity tend to follow a hyperbolic trend similar to that which we observed for the World System in general and China in particular?

As we have noted above, in sociological models of macrohistorical dynamics, the hyperbolic pattern of world population growth arises from non-linear second-order positive feedback (more or less identical with the mechanism of collective learning) between demographic growth and technological development. Based on analogy with these sociological models and diverse paleontological data, we suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by non-linear second-order positive feedback between diversity growth and the complexity of community structure: more genera – higher alpha diversity – enhanced stability and 'buffering' of communities – lengthening of average life span of genera, accompanied by a decrease in the extinction rate – faster diversity growth – more genera – higher alpha diversity, and so on. Indeed, this begins to appear as a (rather imperfect) analogue of the collective learning mechanism active in social macroevolution.

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

Most authors agree that three major biotic changes resulted in the fundamental reorganization of community structure during the Phanerozoic: Ordovician radiation, end-Permian extinction, and end-Cretaceous extinction (Bambach 1977; Sepkoski *et al.* 1981; Sepkoski 1988, 1992; Markov 2001; Bambach *et al.* 2002). Generally, after each major crisis, the communities became more complex, diverse, and stable. The stepwise increase of alpha diversity (*i.e.,* the average number of species or genera in a community) through the Phanerozoic was demonstrated by Bambach (1977) and Sepkoski (1988). Although Powell and Kowalewski (2002) have argued that the observed increase in alpha diversity might be an artifact caused by several specific biases that influenced the taxonomic richness of different parts of the fossil record, there is evidence that these biases largely compensated for one another so that the observed increase in alpha diversity was probably underestimated rather than overestimated (Bush and Bambach 2004).

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

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

Selective extinction leads to the accumulation of 'extinction-tolerant' taxa in the biota (Sepkoski 1991b). Although there is evidence that mass extinctions can be nonselective in some aspects (Jablonski 2005), they are obviously highly selective with respect to the ability of taxa to endure unpredictable environmental changes. This can be seen, for instance, in the selectivity of the end-Cretaceous mass extinction with respect to the time of the first occurrence of genera. In younger cohorts, the extinction level was higher than that of the older cohorts (see Markov and Korotayev 2007: fig. 2). The same pattern can be observed during the periods of 'background' extinction as well. This means that genera differ in their ability to survive extinction events, and that extinction-tolerant genera accumulate in each cohort over the course of time. Thus, taxa generally become more stable and long-lived through the course of evolution, apart from the effects of communities. The communities composed of more stable taxa would be, in turn, more stable themselves, thus creating positive feedback.

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

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

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

$$(N_o - N_e)/\Delta t \approx kN, \qquad \text{(Eq. 12)}$$

where $N_o$ and $N_e$ are the numbers of genera with, respectively, first and last occurrences within the time interval $\Delta t$, and $N$ is the mean diversity level during the interval. The same is true for the hyperbolic model. It does not predict the exact way in which origination and extinction should change, but it does predict that their difference should be roughly proportional to the square of the current diversity level:

$$(N_o - N_e)/\Delta t \approx kN^2. \qquad \text{(Eq. 13)}$$

In the demographic models discussed above, the hyperbolic growth of the world population was not decomposed into separate trends of birth and death rates. The main driving force of this growth was presumably an increase in the carrying capacity of the Earth. The way in which this capacity was realized – either by decreasing death rate or by increasing birth rate, or both – depended upon many factors and may varied from time to time.

The same is probably true for biodiversity. The overall shape of the diversity curve depends mostly on the differences in the mean rates of diversity growth in the Paleozoic (low), Mesozoic (moderate), and Cenozoic (high). The Mesozoic increase was mainly due to a lower extinction rate (compared to the Paleozoic), while the Cenozoic increase was largely due to a higher origination rate (compared to the Mesozoic) (see Markov and Korotayev 2007: 316, figs. 3a and b). This probably means that the acceleration of diversity growth during the last two eras was driven by different mechanisms of positive feedback between diversity and its growth rate. Generally, the increment rate $((N_o - N_e)/\Delta t)$ was changing in a more regular way than the origination rate $N_o/\Delta t$ and extinction rate $N_e/\Delta t$. The large-scale changes in the increment rate correlate better with $N^2$ than with $N$ (see Markov and Korotayev 2007: 316, Figs 3c and d), thus supporting the hyperbolic rather than the exponential model.

## Conclusion

In mathematical models of historical macrodynamics, a hyperbolic pattern of world population growth arises from non-linear second-order positive feedback between the demographic growth and technological development. Based on the analogy with macrosociological models and diverse paleontological data, we suggest that the hyperbolic character of biodiversity growth can be similarly accounted for by non-linear second-order positive feedback between the diversity growth and the complexity of community structure. This hints at the presence, within the biosphere, of a certain analogue to the collective learning mechanism. The feedback can work via two parallel mechanisms: (1) a decreasing extinction rate (more surviving taxa – higher alpha diversity – communities become more complex and stable – extinction rate decreases – more taxa, and so on), and (2) an increasing origination rate (new taxa – niche construction – newly formed niches occupied by the next 'generation' of taxa – new taxa, and so on). The latter possibility makes the mechanisms underlying the hyperbolic growth of biodiversity and human population even more similar, because the total ecospace of the biota is analogous to the 'carrying capacity of the Earth' in demography. As far as new species can increase ecospace and facilitate opportunities for additional species entering the community, they are analogous to the 'inventors' of the demographic models whose inventions increase the carrying capacity of the Earth.

The hyperbolic growth of Phanerozoic biodiversity suggests that 'cooperative' interactions between taxa can play an important role in evolution, along with generally accepted competitive interactions. Due to this 'cooperation' (which may be roughly analogous to 'collective learning'), the evolution of biodiversity acquires some features of a self-accelerating process. The same is naturally true of cooperation/collective learning in global social evolution. This analysis suggests that we can trace rather similar macropatterns within both the biological and social phases of Big History. These macropatterns can be represented by relatively similar curves and described accurately with very simple mathematical models.

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# 7
# Prebiological Panspermia and the Hypothesis of the Self-Consistent Galaxy Origin of Life

*Alexander D. Panov*

## Abstract

*We argue that panspermia can mean not only the other place of the origin of life but also another mechanism of the origin of life that increases the probability of the origin of life to many orders of magnitude compared to a single-planet prebiological evolution. The prebiological evolution can be an all-Galaxy coherent process due to the fact that prebiological panspermia and the origin of life are similar to Galaxy-scale second-order phase transition. This mechanism predicts life to have the same chemical base and the same chirality everywhere in the Galaxy.*

**Keywords:** *prebiological evolution, panspermia, origin of life, phase transition, Galaxy.*

Life was to appear in the process of a natural chemical prebiological evolution. Nobody can estimate now a 'natural' duration of the prebiological evolution on a single planet like Earth proceeding from the 'first principles' or the experiment. We will show how an independent phenomenological estimation of its time scale can be obtained from the timescale of the Earth biosphere evolution.

Let us consider a number of the first great steps of the biological evolution (hereinafter 'phase transitions').

**Phase transition 0.** *The origin of life* – about $3.9 \times 10^9$ years ago (Orgel 1998: 91). After the biosphere appeared, it was presented by anucleate anaerobic unicellular organisms – prokaryotes (and, possibly, viruses). Evidently, it existed in such a form without considerable shocks during the first 2–2.5 billion years.

**Phase transition 1.** *The Neoproterozoic revolution* (Rozanov 2003: 41). Anaerobic cyanobacteria enriched atmosphere in oxygen which was a strong poison for the anaerobic prokaryotes. This caused an ecological crisis. Apparently, the first one in the history of the Earth. Extinction of the anaerobic prokaryotes started, and the anaerobic prokaryote fauna gave place to the eukaryote and primitive multicellular.

**Phase transition 2.** *The Cambrian explosion (the beginning of the Paleozoic Era)* – 570×$10^6$ years ago (Carroll 1992, vol. 1: 10). Most modern phylogenetic branches of multicellular organisms (including vertebrates) appeared during tens of millions of years. In the Paleozoic Era the land was gradually inhabited by living creatures. When it was totally inhabited and all corresponding ecological niches were filled, the next evolution crisis occurred.

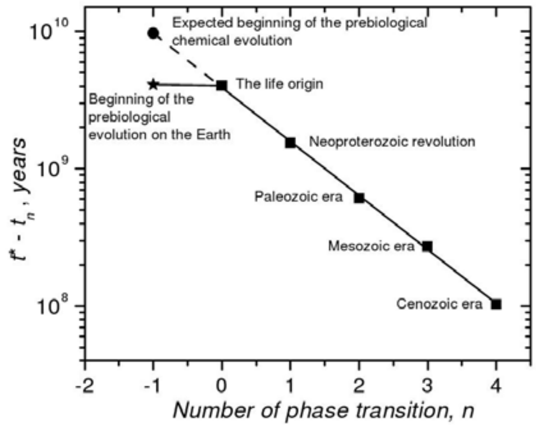


**Fig. 1.** Extremely short time of the prebiological chemical evolution on the Earth produces a 'hockey' stick anomaly in the exponential scale of time of the evolution

**Phase transition 3.** *The revolution of reptiles (the beginning of the Mesozoic Era)* – 235×$10^6$ years ago (Carrol 1992: V. 1, V. 2). Practically all species of Paleozoic amphibia die out. Reptiles become leaders of evolution on land.

**Phase transition 4.** *The revolution of mammals (the beginning of the Cenozoic Era)* – 66×$10^6$ years ago (Carrol 1992: V. 2, V. 3). Dinosaurs die out. Mammals and birds become the leaders of evolution on land.

It is not difficult to see that the duration of the phases of biosphere evolution steadily decreases from the past to the present. Furthermore, the sequence of durations of the phase transitions forms a geometric series $T_0/\alpha^n$ with $\alpha \approx 2.7$ in good approximation (and the limit point $t^*$ of the series fits very good the present moment of time – we are living near the point of the singularity of evolution [Panov 2005: 220–225]).

We see that the higher is the organization level of the biosphere, the higher is the evolution rate. Since any prebiological system has a lower organization level than the biological one, then it seems that the prebiological evolution rate must be even lower than the rate of the subsequent evolution of the biosphere. Furthermore, one can speculate that the duration of the prebiological evolution belongs to the same geometric series of the phases of the biosphere evolution and estimate expected duration of the prebiological evolution by its extrapolation back in time. It is clear that this is only an incomplete induction; our speculations are not a proof; this estimation should be considered as a conjecture.

Using the duration of the first step of the biological evolution $3.9\times10^9 - 1.5\times10^9 = 2.4\times10^9$ years, we get an estimation of the duration of the last phase of the prebiological chemical evolution to be $\tau_{chem} = 2.4\times10^9 \times 2.7 = 6.4\times10^9$ years. This is the lower limit of the total duration of the prebiological evolution since the latter can consist of many phases.

The value $\tau_{chem} \approx 6\times10^9$ years is very large. At the same time, there is evidence that the duration of the prebiological chemical evolution on the Earth did not exceed $0.2\times10^9$ years (Orgel 1998: 91). An obvious contradiction is present and this contradiction is clearly seen in Fig. 1. It can be solved in the following way. The duration of the 'natural' prebiological chemical evolution actually is of order of 6 billion years (or even more), but it occurred not on the Earth, but on the other planets near stars that are much older than the Sun. Life appeared on the Earth as a result of the process of interstellar panspermia from these old planets. However, if the biological panspermia took place, then the prebiological panspermia could be quite possible as well. The products of the prebiological chemical evolution must be less sensitive to difficulties of cosmic missions (hard radiation, cold and vacuum) than any biological systems. What is a typical time scale of expansion of a prebiological or biological 'infection' over the Galaxy?

Let us refine some details of the panspermia mechanism. Suppose the question is on expansion of a biological or prebiological product characterized by a high elasticity and competitiveness. Upon getting to a planet suitable for adaptation, such a product must expand over the planet surface in some thousands of years or even faster, replacing local weaker systems. As a result, the planet itself becomes a source of panspermia of this advanced product of evolution. If its host star flies near another star, then the latter can be infected and become an object of panspermia too. Then the spread of the product of evolution would have not the diffusion character, but the character of an autowave propagating at a constant velocity, approximately as it occurs in epidemics. The typical velocity of peculiar chaotic motion of stars is decisive. Its value – about 30 km per second – is the typical velocity of the panspermia wave in the Galaxy. To model it, the pure Huygens principle can be used. Of course, the model contains a lot of simplifications. So, for instance, the typical peculiar velocities can differ at different distances from the Galaxy center, *etc.* But the model is suitable to make a rough estimate of the time scale of the process.

Fig. 2 shows the results of digital simulation of panspermia wave propagation in the Galaxy fulfilled with the above assumptions taking into account differential rotation of the galactic disk. It can be seen from Fig. 2 that due to this rotation the process is practically finished in two galactic years (one galactic year – the period of rotation of the Sun around the Galaxy center – is equal to 216 million years), and 70 per cent of the Galaxy volume is inhabited for about 300 million years.

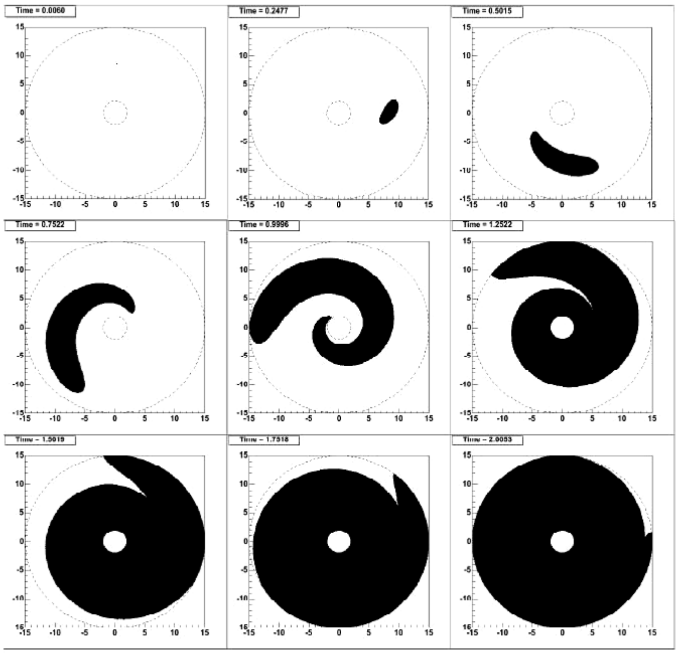


**Fig. 2.** Digital model of propagation of panspermia wave in the Galaxy disc. Time in figures is shown in galactic years. The subsequent times of the phases are (from upper-left to top-down): 0.0060, 0.2477, 0.5015, 0.7522, 0.9996, 1.2522, 1.5019, 1.7518, 2.0053. The Galaxy rotates clockwise

So, we get two time scales: one long scale of $\tau_{chem} \approx 6\times10^9$ years (or more), this is a scale of natural duration of the prebiological chemical evolution on an isolated planet; the other short scale of $\tau_{pansp} \approx 0.3\times10^9$ years is a scale of duration of the process of galactic panspermia. From the two very different time scales it follows that the prebiological chemical evolution on separate planets could not occur independently of processes on other planets.

Let us suppose that a stable and competitive prebiological system appears on a planet at the prebiological evolution stage of the Galaxy (*i.e.* before life appeared for the first time). This is quite a random event. Then, during a short time, of order $\tau_{pansp}$, this prebiological system spreads over the whole volume of the Galaxy displacing less effective local prebiological systems because of the ordinary natural selection. This is a mechanism of natural selection at the prebiological level on a scale of the whole Galaxy. Due to the condition $\tau_{pansp} << \tau_{chem}$, this process must synchronize (with an accuracy of $\tau_{pansp}$) the prebiological evolution in the whole volume of the Galaxy. As a result, life originates almost simultaneously on all planets having suitable conditions for its existence, with one molecular basis (in terms of the basis of genetic code, *etc.*) and with one chirality. This event resembles the non-equilibrium phase transition of second order. Thus, the prebiological chemical evolution and the origin of life can be a self-consistent collective process, but not a process located on separate planets as is usually supposed.

If the mechanism of the self-consistent Galaxy origin of life operated, then a gigantic burst of inhabitance of planets with life must have taken place in the Galaxy soon after life appeared somewhere for the first time. After that life could not arise anywhere in the process of the natural prebiological evolution since the natural prebiological process cannot compete with much faster processes of panspermia.

It is widely believed that the probability of self-generating life on any separate planet is vanishingly small. For instance, the origin of life on an isolated the Earth-type planet with suitable conditions can take a billion of billions years or some so absurdly long time. If the prebiological evolution proceeded independently on different planets, then, at present, life would not exist at all or would be a quite unique phenomenon. However, if an effective process of the prebiological panspermia is possible, then any random success of the prebiological evolution on one of about $10^9$ planets of the Galaxy becomes the property of other planets practically immediately. In other words, the probability of such an event on any separate planet increases $10^9$ times! And the rate of the prebiological evolution increases as well. Thus, even if the self-generating origin of life is practically improbable under the conditions of an isolated planet, it can be quite probable because of prebiological panspermia (the last idea is taken from G. A. Skorobogatov, 2004, private communication). Panspermia provides other place of the origin of life of course, but it also does provide other mechanism and other way of the origin.

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# 8
# Social Evolution of Humankind as an Integral Part of the Evolution of the Biosphere

*Olga A. Sorokina and Rendt Gorter*


## Abstract

*A theoretical reconceptualization of social evolution is proposed in order to construct the principles for socio-economic governance that can expand the resilience of global systems that in turn determine the world's carrying capacity for the human population. The Big History approach shows how world societies are in a transition phase that can be explained using evolutionary laws with the understanding that the development of human civilization is considered as an integral part of the evolution of the Earth's biosphere.*


**Keywords:** *Big History, anthropocoenosis, biocoenosis carrying capacity, demographic imbalance, demographic transition, ecosystem carrying capacity, Flynn effect, macroecological approach, social evolution, sustainable development, urban millennium, youth bulge.*

## Introduction. The Need for a Socio-Evolutionary Understanding

Since Thomas Malthus first published his *Essay on the Principle of Population* in 1798, the problem of the overexploitation of accessible resources by humans has bothered intellectuals, philosophers, and scientists alike. Unfortunately, in the 20$^{th}$ century these intellectual speculations were often misinterpreted by political thinkers, since theoretical explanations affect the choice of principles that guide decision-makers and, hence, the direction of political development. This ideological misunderstanding among political actors increased the difficulties in the governance of human socio-ecological systems.

To facilitate the communication among the involved parties, in 1968 the Club of Rome was founded. It is an informal association of independent but influential personalities from politics, business and science – men and women who are long-term thinkers and interested in contributing in a systematic interdisciplinary and holistic manner to the betterment of the world. The Club of Rome members share a declared concern for the future of humanity and the planet (Meadows 1972).

In 1972 the report *The Limits to Growth* (*Ibid*.), a computer modeling of unchecked economic and population growth with finite resource supplies, was presented at the Club of Rome. In that report it was argued that the limited store of non-renewable resources forces global civilization into a transition to re-organize the contemporary resource consumption model. This provided the basis for the call for sustainable growth and as such that has characterized commentary and economic development since then.

But the global socio-economic model has changed little since that time even in the face of resource consumption growing unabated. Then, in 2004 *The Limits to Growth: The 30-year Update* was presented by Donella Meadows, Jorgen Randers, and Dennis Meadows. In this work it was shown that the time of turning to a model of 'sustainable development' had already passed at least to prevent catastrophic overexploitation. However, Dennis Meadows *et al.* (2004) argued that humankind still had an opportunity to increase resilience in the face of accelerating change, *i.e.* to increase the ability to cope with change.

Even if despite the warnings of the authors of *The Limits to Growth: The 30-year Update*, the political-economic steps that were taken achieved little to change the path of growth-based development, there has in fact been a shift of public opinion in the Western world and hence motivation for scientific research in the relevant fields of geography, environmental sciences and ecology has increased. The scientific achievements made between the publications of the two books were arguably actually underestimated by Meadows *et al.* (2004). That work has made the expansion of the socio-economic system's resilience more realistic, provided our socio-evolutionary understanding can be brought to bear on this effort, we argue here. We assume that without closer attention to the laws of evolutionary ecology and evolutionary psychology the specific increase of system resilience may not be achieved. But this requires an application of a Big History approach (on this approach see, *e.g.*, Christian 2005a, 2005b; Spier 1996, 2005, 2010; Hughes-Warrington 2005; Carneiro 2005; Nazaretyan 2005; Snooks 2005; Markov, Korotayev, and Grinin 2009; Grinin, Carneiro, Korotayev, and Spier 2011; Grinin, Korotayev, and Rodrigue 2011).

## An Evolutionary View of Social Development

In a seminar which was held at the Stockholm Resilience Center in 2012, Lance Gunderson, a Beijer Institute of Ecological Economics Fellow, reminded the audience in his presentation *Learning by Doing*[1] (see also Holling, Gunderson and Light 1995) of the importance of experimenting, developing alternative visions and to recognize opportunities in sustainable natural resources man-

[1] URL: http://www.stockholmresilience.org/21/research/research-news/11-13-2012-learning-by-doing.html.

agement. He called for a new theoretical reconceptualization of the social evolution theory to build the principles for socio-economic governance that can expand the resilience of global systems that determine the world's carrying capacity for the human population.

However, carrying out the social experiments on the scale required in reality is costly and potentially indeterminate, let alone entailing the risk of meeting public resistance. This, however, can be avoided. By now the history of humankind has accumulated enough empirical data, especially during the 20$^{th}$ century, so that the theoretical reconceptualization that Dr. Gunderson is looking for may be carried out just by analyzing a 'Big History'.

The development of human civilization seen with a Big History lens brings focus to the interrelations between local demographic density and local ecosystem carrying capacity. Excess of local habitat carrying capacity switches on the population's density autoregulation mechanisms, evolutionary biology tells us (Diggle *et al.* 2007). There are three in particular – migration to some new area, mass suicides of a Lemmings' type effect, and exploration of new ecological areas, *i.e.* ecological specialization.

While migration is no longer an option for human populations, at least from a global perspective, and clearly mass suicide has to remain off the agenda, then implementation of the third alternative will require deep relevant changes in social and economic organization. Specifically, the values and ideas that both motivate the policy goals and that have to be uppermost in the minds of the public and the media must reflect an evolutionary view. In other words, this reality is a Cognitive Policy for Socio-Economic Development which the following article presents in an attempt at the theoretical reconceptualization that Dr. Gunderson is looking forward to having in place.

## Demography and Evolution

Demography (*i.e.* population density, gender and age structures) strongly affects the pattern of social and economic organization. Many observers consider that demographic imbalances are the main reason for the intensification of armed conflicts in the modern world. Here it is assumed that trends of modern conflicts cannot be regarded outside the context of the evolution of global human population and hence, the evolution of the global ecosystem. Globalization, urbanization, and economic development together with the development of appropriate means of communication are regarded here also as integral parts of the evolution of social structures and behavioral patterns.

Simultaneously, globalization, urbanization and economic development significantly increase demographic imbalance. This imbalance seriously impedes the process of the transition to the next evolutionary stage.

Till now there is no single term for this new pattern of society – some researchers call it the Informational World, others – the postmodern society.

However, it would be more logical to call this newly developing era 'after-postmodernism'. The transition to this type of society is the key for solving the overpopulation problem within the context of the future global Earth ecosystem evolution. It would not be possible to facilitate this process without working out and applying sensible natural science based methods of social engineering – in other words, without initiating a Marshal Plan at a global scale, as Sergei Kapitza recommended to the Club of Rome (Kapitza 2006).

Therefore, a new vision of the widely discussed relation between fertility and socioeconomic development is presented in this paper.

## The Hypothesis

To understand and interpret the mechanisms driving social evolution, the hypothesis is put forward that the development of human civilization is an integral part of the evolution of the Earth's biosphere. That means social development is affected by various identifiable factors and processes just like the evolution of other social species. These biological species are co-integrated in one global ecosystem, the biosphere. The evolution of their populations' density follows a certain pattern of balancing energy and matter budgets throughout the system. Hence it may be assumed that the species, *Homo Sapiens*, is integrated within ecosystems from local to global scales and thus follows the same pattern.

## Population Growth

With the *Gapminder Project*, Rosling *et al.* 2005 explained why ending poverty – over the coming decades – is crucial to stop population growth and argues that only by raising the living standards of the poorest with humanitarian aid and by increasing the child survival rate would it be possible to limit the population level at 9 billion people by 2050. But the question remains, to what extent development aid can change the underlying social pattern and thus change human 'mindsets'?

Rosling is not alone. Global overpopulation and related processes of population aging and demographic imbalances are considered to be the central global problem by many scholars (*e.g.*, Magnus). The term 'youth bulge' was coined by the German social scientist Gunnar Heinsohn in the mid-1990s to identify the excessive share of jobless young people in the general population. That term has gained greater currency in recent years, for instance, thanks to the work of American political scientists Jack A. Goldstone and Gary Fuller, who in 1995 introduced the term 'youth bubble', and in Europe by the work on demographic imbalance of Si Frumkin. It has been observed that when the share of 15 to 29 year olds makes up more than 30 per cent of the population, violence tends to increase (Beehner 2007).

Thus, the inflation of youth populations contributes to increasing population density in human aggregations, and hence the shrinking of individual security space. That reduction of individual space increases stress, and hence it causes an increase of unavoidable intraspecific aggression. In modern societies that pressure of aggression is heavily suppressed with material appeasement and institutions that enforce social conformity. This constant internal suppression feeds psychological stress which leads to different psychological and behavioral disorders and perversions.

One of the mechanisms that human societies have evolved for self-preservation from these disorders is to channel that increased aggression outwardly. Currently many demographic experts speak of the threat of this deep imbalance for the sustainable future of humankind. However, according to the data of the Department of Economic and Social Affairs of the United Nations, the growth of the general population is slowing down and is expected to reach a peak in the near future (UN 2014). But social and age structures are changing too due to increasing longevity and the consequences of increasing longevity affecting the economic development of an increasingly older and more unproductive population.

The changes in the gender roles of females as well as the level of female education together with the spreading of birth control methods significantly influenced the Total Fertility Rate in developing countries (Martine 1996). Aside from those cultural and sociological reasons, there is also a simple biological explanation equally affecting non-human populations.

The modern market-based and mobile society model is based on competitive principles and so is the source of constant stress for individuals which affect reproduction rates. For instance, research into reproductive activity in mice populations showed that the increased stress that pregnant mice experienced affects the reproductive activity of their offspring (Christian and LeMunyan 1958).

Many observations have indeed noted the negative correlation between individual well-being and low birth rates (Diener 2000; Bradshaw *et al.* 2007; Sellström and Bremberg 2006). But it would not be possible to find the solution to a specific demographic imbalance without understanding the reasons of that observed correlation, although this should not be realized outside the process of general evolution of the Earth's biosphere. If the stress levels have increased evolutionary processes, then we see a transfer from a K-strategy of the affected populations' reproduction to an r-strategy (Kondratyev 2004). However, species do not only differ in reproductive strategies. The resistance of their social complexes to the mid-level fluctuations of the surrounding environmental conditions differs a lot. The r-strategy species are called opportunistic species. These species usually start the succession process of invading and inhabiting new habitat area. The results of their activity transform living conditions in these areas into those accessible for the species of the next stage, more environmentally robust K-strategists. The outcome of the biological reproduction of such populations is high, but later the outcome of total biological production slows down. The communities occupying a given habitat would reach a plateau, at which the incoming and outgoing energy-matter flows are more or less balanced and the sustainable existence of the community is limited only by some sharp change of surrounding conditions. It may also be slightly shifted by the results of species life activity. However, in this perspective the systems will remain in dynamic equilibrium as a whole.

## Demographic Transition

For this purpose, considering a reproductive strategy in response to the surrounding conditions, allows the analogue with respect to human population evolution to be constructed and to predict a sequence of consecutive formations which differ from each other by memetic structure. We should thus consider in detail the problem of demographic imbalance and demographic transition.

In the beginning of the demographic transition the total fertility rate (TFR) decreases. This can be observed in Western countries, *i.e.* in the More Economically Developed Countries (MEDC), and also in Europe. The experts of the Max Planck Institute for Demographic Research even call this decrease in fertility 'lowest-low fertility' (Costa-Font *et al.* 2008). At first sight these observations show that fertility is negatively correlated with well-being. Many hypotheses have been put forward to explain this decrease in fertility such as the changes in female social life, female education, crises of the family, *etc*. However, the phenomenon of falling fertility has been observed worldwide, while in the MEDC countries experts now speak of the 'end of lowest-low fertility' (Goldstein *et al.* 2009). In this article the authors compare the total fertility rate (TFR, the average number of children that would be born to a woman over her life time), for several European and South-West Asian countries. In the end of the 20$^{th}$ century, *i.e.* in the 1990s, these countries experienced serious declines in TFR, called by some researchers the 'lowest-low fertility period' (Kohler *et al*. 2002). However, recent data confirms that the relationship between fertility rate and wellbeing has turned backward within the first decade of the 21$^{st}$ century. The authors emphasize that this has occurred due specifically to sensible state social policies that were introduced**.** However, this phenomenon is still quite new. To explain the occurrence of these 'sensible state social policies', various explanations were put forward, ranging from economical to cultural-political ones.

The above mentioned studies and in particular the works of Gunnar Heinsohn demonstrate that the process of demographic transition is highly risky (Korotayev *et al.* 2011). And following Heinsohn's recommendations, would just increase those risks connected with the demographic transition and youth bulge.

To understand the inherent reasons of this transition, biological laws can be applied to demographic data which reveals the main problem of social evolution. The problem of population blow-up is simply a direct consequence of demographic imbalances. Beside the increase of intraspecific aggression levels, there is the second, more serious threat raised by the Club of Rome – of exceeding the Earth's ecosystem carrying capacity – which means that at some point in time the non-renewable resources will run out, and people would have neither room to live nor resources to use to support life. Competition would severely increase and lead to resource wars, thus turning sub-populations against each other resulting in the 'survival of the strongest'. A terrifying prospect.

This Malthusian forecast is actually just one of a number of rising problems. However, as stated, in the developing countries despite the population blow-up, the total fertility rate is falling as a whole. The global human population is now experiencing a demographic transition which would reach a peak by the middle of the 21$^{st}$ century.

This actual transition rate differs a lot over the world. As a consequence, this makes the population structure in various countries very imbalanced. It has been found that this imbalance brings new problems (Kapitza 2006; Ediev 2001). The data from this work confirms the imbalance between the birth rates of the MEDC and the developing countries. This observation raises the question of its relationship to the level of a given country's development. Are the MEDCs indeed losers? Let us consider this question in more detail to understand the reasons of this imbalance.

In the past 300 years, there has been an increase in the number of innovations in the fields of science, technology, medicine, and in business management. At the same time, the corresponding social circumstances gradually evolved too, leading to a form of social evolution. Critical to both processes were the growing fertility rates and the falling incidence of child mortality. In the 20$^{th}$ century the autocatalytic changes in surrounding conditions accelerated so much that disruption of the processes of social evolution became evident. In the most rigid state systems, for example in Russia, this resulted in revolutions, while the rest of the world also became embroiled in dramatic change through two World Wars and a Great Depression. Even the 'sexual revolution' of the 1960s – although it was not so bloody – was part of this systemic rebalancing of social systems.

The social pattern of these modern states evolved step-by-step from the traditional societies that preceded them. The traditional pattern of societies is characterized by a rather steady social class stratification with low mobility of people. The most important factors for demography are high mortality rate, high birth rate and correspondingly low life expectancy. The transition to the Industrial Age led to the development of new means of production, followed by increased urbanization. Thus, the structure of the market-based society had to become more flexible in order to function. As a result, against the background of many failed attempts and crises, the modern Western-style democracies developed, and the social structures in those countries adapted correspondingly.

While the traditional state was based mostly on the use of natural resources – mainly agricultural resources in the past – these states fundamentally evolved as social structures due to the innate human problem-solving power and drive to improve its living conditions in those states, or in evolutionary perspective, due to human 'foraging activity'.

And due to geographical separation of these fragments of population – named sub-populations below – distinctive behavioral patterns formed among their members. Behavioral patterns are formed mainly in the time of childhood and adolescence – in other words, we mean here imprinting. The differences that evolved aggravated misunderstanding among sub-populations often provoking conflicts. We assume here, that it may be regarded as an analogue to interspecies struggle in the course of ecological allopatric specialization. So, in the course of sociocultural development within each of these separated sub-populations a unique social mindset developed (Valsiner and Van der Veer 2000).

However, since these different patterns are not innate, they are open to change if certain efforts are made. The work of the *Earth and Environmental Sciences Program* (New York) has demonstrated that. Cindi Katz (1998) considered social reproduction and the production of space, place, and nature; the consequences of global economic restructuring for everyday life; the politics of knowledge; children and the environment; the intertwined spatialities of homeland and home-based security; the changes in social structure and behavioral patterns of use of natural resources in an educational agriculture project in the Sudan. She also analyzed the reasons why these changes caused little resistance in local communities. Unexpectedly, she found that individual interests turned out to be more powerful than those held in the name of the traditional commune, in particular the call for preserving the traditional structure of the local commune. While stress increased for individuals with the many changes in the structure of local life, few people were looking backwards, because the project significantly increased their quality of life, independently of traditional social structures, social change became possible.

Unfortunately Katz pays little attention to the resistance from the higher levels of the local social structure. Their authority has a large influence on the behavioral patterns in such sub-populations, explaining resistance to changing the traditional modes of life.

## The Threat of Violence in the Urban Millennium

According to the UN Report *State of the World Population* (Salas 1981), the year 2007 was the year when the majority of the human species would be living in towns or cities, for the first time in history. This is referred to as the arrival of the 'Urban Millennium' or the 'tipping point'. In regard to future trends, it is estimated that 93 per cent of urban growth will occur in developing nations, with 80 per cent of urban growth occurring in Asia and Africa.

The beginning of the new millennium was also the tipping point for mass communication, as the Digital Age began. By now there is a lot of factual confirmation that many political breakdowns were strongly facilitated by the development of electronic means of information exchange. Due to this information exchange, human horizons broadened significantly – people who used to be considered distinct sub-populations were involved in diverse and significant information exchanges with the rest of humankind. It can be argued that as a result social systems of the subpopulation are unable to maintain resilience, *i.e.* capability for change. Probably, this led to the collapse or transformation of many autocratic states which were more or less isolated in the past.

The changes to living conditions are like environmental change and will precede the corresponding changes to social pattern. The adaptation of behavioral patterns coalesced into a social mindset that must follow this, even if the abandonment of the traditional mindset is very stressful for commune dominants and hence can be rather risky for any society. The traditional mindset of the privileged and dominant state citizens can be expected to underlie the state apparatus power, cementing their social position and causing resistance to change or poor resilience and hence heightened risk. Such an apparatus is naturally predisposed to preserving the social mindset shared by citizens and to prevent that mindset from changing. Thus, state structures will naturally be resisting change from the outside arriving as conflict or as foreign culture. Simultaneously, that stress at the individual level can easily result in violence, *i.e.* an increase in interspecies aggression.

In order to reduce the increase in the level of violence, its nature has to be understood as resulting from the rise of social stress levels due to the transition of societies from the traditional pattern of resource consumption, social structure, and mindsets. Given the inevitability of this process, the general evolutionary rules of any maturing ecosystem therefore must be taken into account.

## The Importance of Foraging Activity

Until the 20th century, high child mortality rates were normal. A high fertility rate compensated for and ensured a slow but gradual population growth. Meanwhile, science and technological innovations grew as an expression of human foraging or Searching Activity (Rotenberg 2009). Foraging activity is common for any living species with a feedback response and evolved together with the animal nervous system. As *Homo sapiens* developed, foraging activity integrated with human cognitive activity. Together, these became the human ability to alter human surroundings in favor of current requirements necessary for survival.

The merging of foraging activity together with cognitive analytical activity made possible science and technical innovations. The level of human development depends not only on the individual brain physiology but also on the individual socialization and the level of education. To suppress this activity would mean to suppress further development of humankind. That is the strongest argument contra the evolutionary trend of human eusociality. The evolution of eusociality for other social animal species had been considered by Andersson, and the results of the studies look very interesting (Andersson 1984).

However, this may not apply to human evolution. Following that way of evolution proactively would require significantly decreasing the individual ‘foraging’ activities of a society's members, but that activity is still required to meet the constant changes in surrounding conditions. And these changes are autocatalytic, *i.e.* sustained through the result of human cognitive activity.

All such innovations have occurred, since they were driven by economic conditions and resulted in social developments in those countries where evolution could take place. The determining conditions include not only living conditions but also the social structures as, for example in the Most Economically Developed Countries (MEDC) – in other words, in those countries with a stable state pattern, which developed on the ground of modern economic systems, together with regulated markets. Hence, the population of those countries experienced correspondingly gradual changes. Both those processes, *i.e.* fertility and child mortality rates, stayed more or less in balance. This long-term development period gave the social structures in these advanced countries enough time to adjust to changing conditions.

The initial assumption made here was that the global human population is an integral part of the Earth's biosphere and hence follows an evolutionary pattern characteristic of populations. Thus, the widely discussed problem of overpopulation and *Limits of Growth* would be expected to be resolved soon simply because the laws of evolutionary ecology are now affecting this global population at the social organization level. As the social structure becomes more complex, the total fertility rate reduces, repeating the evolutionary sequences of K- and r-reproductive strategies of living forms in the course of colonizing new biotopes.

This hypothesis is confirmed by laboratory data, obtained in research of the genetics of behavior and the neurophysiological influence of stress on reproductive behavior and fertility rate among populations of laboratory rats (Rhen and Crews 2002). The research into human reproductive medicine confirms that fertility is falling (Auger *et al.* 1995). So it was seen that the Total Fertility Rate (TFR) in the MEDCs in the 20$^{th}$ century was falling (Waugh 2003).

Since human fertility/mortality/longevity figures are strongly affected by other factors of the sociocultural environment, it is not easy to distinguish social and biological factors and to determine the main causes. However, the experiments on rat populations allow distinguishing the reproductive behavior from the influence of social factors (Holson *et al.* 1991). These experiments prove the key role of prenatal maternal stress level during pregnancy on their further reproductive behavior.

This research confirms the purely neuroendocrine character of this effect. However, at the social level or organization this factor becomes seriously affected by other factors, those that depend on state social policy, *i.e.* on the anthropogenic factors. Again the experiments on laboratory rats allowed the estimation of the degree of influence of anthropogenic factors (Popova *et al.* 2011; Amstislavskaya *et al.* 2004). However, the birth rate depends not just on sexual behavior but also on the individual fertility rate, and most importantly on male sperm quality. An analytical review showed the consistent gradual decreasing of male sperm quality in recent decades (Carlsen *et al.* 1992; see also Irvine 1997).

Female fertility is also decreasing under the influence of stress. The relation of stress and fertility is now widely discussed in many corresponding public sources (*e.g.*, Braverman 2012; Rodriguez *et al.* 2012). This data from reproductive medicine confirms the intrinsic reasons for reproduction decreasing under the influence of stress. The authors assume that those innate reasons are determined by the ecological conditons of the environment that sustain environmental carrying capacity. However, this does not mean any deliberate activity of this complex subject-object system. It is not animated (*i.e.*, this complex has no free will). That activity is just the result of the interaction of numerous components interrelated by the endless number of complex feedbacks, which follow the main evolutionary law of complication increasing complexity. This complex system makes it impossible to make a definite fixed forecast. However, it is possible to work out some general strategy based on the probabilistic crisis analysis. The authors assume that in order to work out a general strategy, the motivation of people has to be considered more closely, and this cannot be done without taking into account evolutionary ecological – or macroecological – trends.

Since human behaviour is the result of the interaction of both biological and social components, the social factor must be considered to asess people's drive to reproduce. As this motivation strongly depends on the social environment, and the social environment in its turn is determined by measures being taken by the state.

The current article confirms the purely innate nature of declining fertility along with the increasing complexity of social structures, which provides for the enlarging of ecosystem carrying capacity. This increase of social complexity imposes ‘unnatural’, artificial requirements on individuals' social behavior.

Together with the abnormal increase in population density, which is especially high in urban areas, stress levels increase as well. This stress increase leads to numerous socio-psychological effects, related with the changing social roles of family partners and gender social status. All those factors decrease fertility potential and result in the significant decline of TFR.

However, the most crucial example of declining fertility in tandem with increasing population density is observed in experimental populations of laboratory rats, animals that have no signal inheritance at all. Unlike rats, in human society the fertility rate is determined by both the intrinsic ability of conception and the people's motivation, which is socially determined. The latter depends on the social environment and on signal heredity as well.

All the above makes the authors come to the following conclusion: the social evolution of human beings is an integral part of the Earth-Biosphere evolution. This system follows the same pattern of evolutionary population ecology in which the prevalence of r-strategy species changes to K-strategy species. This happens together with an increase of system complexity. And the latter is unavoidable, as it provides for the increase of human habitat carrying capacity.

## A Transition to the Anthropocoenosis

When the 20$^{th}$ century was well under way, a transition into a new stage had begun. By this stage of evolutionary development the activity of human societies determined the direction of energy and matter exchanges in the global biosphere complex. This stage may be called the *anthropocoenosis*, an interactive community of living organisms centered on humans (Scott 1996).

In the current essay the authors suggest choosing a macroecological approach to the study of the cognitive development of social structures and policy. The macroecological approach allows considering particularly the evolutionary factors that influence the motivation of a social group's behavior. In modern social circumstances the changes of public moods – in other words, the changes in individual motivations – are manifested in powerful social trends and are realized in international political agendas.

In the course of the evolution of human civilization, the heterotrophic nature of *H. sapiens* stimulated economic development. This has made the economy in the MEDCs move from those based on agriculture, or other forms of natural resource use, to the industrial production of economic goods. So stateled social patterns had to change from traditional modes to the social patterns of industrial society. This process was burdened by many conflicts – local and international, revolutions of various kinds, and the two World Wars, in particular. The development of social patterns of less industrially developed countries was different, however, as generally traditional social patterns were more resistant to change of external conditions.

## The Imbalance in the Development Level of Global Human Civilization and the Demographic Transition

Given that the ecosystem carrying capacity for the human population depends on the productive activity of humans that may be significantly increased by industrialization. The productive activity of humans occurs together with increasing levels of urbanization and shift of people employed in economic production from agriculture to industries first and to services later on. According to the UN Conference on Trade and Development, in 2012 the share of services in world economics has increased to 70 per cent, while the agricultural share decreased from 10 per cent in the developing countries to less than 3 per cent in the MEDCs. This shift in economics occurs together with the process of urbanization. This shift from agriculture to industrial production marked the beginning of modern times. The next shift, the current one, is characterized by an increase in the share of the services sector in economics and marks the transition to the next stage of social and economic development. This stage is called the *Innovation Economy* (Scott 1996) and is defined by an economic doctrine that reformulates the traditional model of economic growth so that knowledge, technology, entrepreneurship, and innovation are positioned at the center of the model rather than seen as independent forces that are largely unaffected by policy. At this stage the economic demand for non-renewable material resource gradually decreases, and innovation economics becomes the main human resource for economic development (Holling *et al.* 1998).

While change in external conditions is followed by changes in social pattern, the rate of adaptation of new behavioral patterns – described as social mindsets further on – varies due to different factors that social science addresses. Radical change of the traditional mindset is very stressful and simultaneously risky. However, that transformation is the only way to avoid a catastrophic mode of population density autoregulation that evolutionary processes impose (Haidt 2007).

So, employing this rationale in order to overcome that developmental imbalance together with avoiding the threats described in the *Limits to Growth*, the crucial factor is an updating of the traditional community model.

## Towards a New Community Model

A low individuality level is the most crucial feature of a 'Hive Psychology' that describes the important behavioral patterns of all social species. *H. sapiens* is clearly an ultra-social species. Hence, it can also be expected to be affected by the Hive Psychology effect. Prof. Jonatan Haidt considers in his work the questions of Hive Psychology and its effects on human socio-psychology, particularly its relation to happiness and religion (Haidt *et al.* 2008). He emphasizes the crucial moments for achieving 'public happiness' are not some divine, some spiritual ideas, but rather the common interpretation of Hive Psychology used in 'mass ritual'. These mass rituals are also typical for any authoritarian state or a totalitarian ideology, for mass rituals strongly facilitate the individuality of the human mind being undermined and hence crowds of different peoples uniting around their leaders and falling under the Hive Psychology effect.

The most severe and intractable conflicts are taking place right at the border of two social patterns – the traditional pattern and the modern one – as they meet each other. The social mind of the traditional communities is effectively less fit, that is in evolutionary terms, than is the social mindset of the MEDCs, to meet the uncommon social changes of this new milieu that intensifies the links within these groups and also increases the Hive effect.

Under the current conditions of constantly increasing population density in the developing countries, Hive Psychology then favors the so called Suicidal Lemming effect (Chitty 1996). Hence the increase in wellbeing associated with social traditions would not guarantee that the population growth rate would decrease.

Another convincing case-study is the example of changes in Russian demography. They show that the correlation between wellbeing and birthrate may as well be inverse at times. In Russia the general mortality rate – not just that of children – exceeded the birth rate for a long period of time. The wellbeing of Russians after the USSR collapse fell significantly. However, instead of rising, the birth rate fell too, so nowadays Russia is gradually depopulating with the low rate of 0.465 per cent (CIA 2010). In order to fight that threat, the government in 2007 launched a federal program for reducing child mortality and increasing the wellbeing of females in connection with the number of children a female can raise. But the conclusion of Rosling's report suggests that these steps would reduce the birthrate instead. However, for the first half of 2009, the index of infant mortality decreased by 10 per cent and simultaneously the birth rate for the same period increased by 4.7 per cent.

Still, using a Big History approach, another evident example is the difference between North and South Korea. Both countries are populated by the same people with historically the same traditions, mindsets, *etc.* but have been strictly separated about 60 years ago under contrasting ideological regimes. Now the income of the North Korean people is much lower than that in the South Korea, but the population growth rate is just slightly higher than its neighbor (0.398 per cent *vs* 0.25 per cent according to the *CIA World Factbook* of 2010). And this is despite all the efforts of the North Korea government to control this aspect of their demographics.

The infant mortality rate there is very high, with 50.51 infant deaths per 1000 birth, while in South Korea it is just 4.25 deaths per 1,000 births. With Rosling's assumptions that would also strongly contribute to the increasing birth rate. However, it does not help the North Korean government to overcome its rival significantly with respect to fertility rate. Even the strict state control over the distribution of contraceptive means proved unable to increase the population fertility rate, while the day-to-day stress, people are experiencing, is extremely high anyway.

Popular authors often claim that the access to female education, independence, and the contraceptives in the Western countries has led to a decrease in fertility rates. However, the example of North Korea shows that at least access to education and contraceptives are sufficient for the fertility rates to drop. Contraceptives are available in North Korea, but they are distributed under strict state control, and hence they are not easy to get. Cultural input could also be expected to play a role.

First, with the use of statistical data from published sources, we are going to look at the correlation between infant mortality rate and the birth rate. The data analysis proves that the relation between infant mortality rate and birth rate is not that direct. For instance, in Israel the infant mortality rate is very low, 4.17 deaths per 1,000 live births, but the total fertility rate (TFR) is 2.72 children per woman in general (CIA 2010). Among Haredi Jews the TFR is very high. For Ashkenazi Haredim, the TFR rose to 8.51 in 1996 from 6.91 in 1980. The figure for 2008 is estimated to be even higher. TFR for Sephardi/Mizrachi Haredim rose from 4.57 in 1980 to 6.57 in 1996. Israel infant mortality rate is one of the lowest in the World. So, apparently the influence of infant mortality rate on the birth rate is also not that critical.

This does point to the important influence of cultural background on the fertility rate. However, further on it will be shown that the cultural background is not that crucial as it may have seemed at the first sight.

Let us return to the Korean examples to clarify the reason for declining fertility rate. Apparently the stratification of production forces in the society – and hence the social patterns of this country – are more important for the birth rate than the infant mortality.

The distribution of workers in the economy in North Korea is the following: 37 per cent of people are working in agriculture and 63 per cent – in industries. In the meanwhile in South Korea only 3 per cent of people are working in agriculture, 39 per cent – in industries and 57.5 per cent – in the services sector. So, the community sectoral stratification in North Korea is in fact much more archaic and restrictive than that in South Korea. Even so, the TFR is still very low. Why?

In the example of both Koreas, we have previously already regarded and excluded the influence of the female education, contraceptives access, and even the common folk's cultural origin. The only factor that remains to be considered is individual stress level.

This scenario is also confirmed by demographic data from China, Singapore, and Taiwan. Despite comparable cultural origins, their fertility rates differ a lot. However, in China there was the impact of strong state control, so these data are not valuable without thoughtful analysis.

So neither cultural factors nor fertility rate are that crucial for to cause a decrease in population growth.

## Possible Reasons for the Decrease in Population Reproductive Rates in the Most Economically Developed Countries

So, in summary, we have found that the increased economic wellbeing of populations was the result of economic development and corresponding social evolution from the traditional community social patterns. Simultaneously, as the economy grew, the citizen's wellbeing grew as well. This economic growth was caused by industrialization. Industrialization also caused increasing urbanization. Urbanization makes peoples live in naturally abnormal living conditions, in high density aggregations and in other highly abnormal conditions of life style. Both industrialization and economic growth all lead to a higher level of psychological stress. That general stress increases due to the increasing level of urbanization (*i.e.* living in abnormal stressful conditions) leading to a general deterioration in human reproductive function, which seems to have dropped considerably during the past 4–5 decades even without any means of contraception. This process has created circumstances in which individuals constantly encounter challenges, both social challenges and those from new environmental conditions. And that stress causes a significant decrease in fertility rates at the same time as longevity increases.

The assumption that change in population autoregulation mechanisms are influenced by the increase of within-population stress is confirmed by the results of research on reproductive activity in experimental mice populations of the Laboratory of Behavioral Neurogenomic of the Institute of Cytology of the Siberian Department of the Russian Academy of Science, which proves that the increased stress that is experienced by pregnant female mice affects the reproductive behavior of their offspring. Aside from those experimental results, there is a set of similar experimental confirmations of the effects of the relationship between negative stress and reproduction for human beings that studied male sperm quality under stressful conditions (Clarke *et al.* 1999).

There are also other factors that affect social and mindset adaptations. For instance, the developing countries that have not had enough time for social and mindset adaptation, have seen important instances of a ‘Youth Bulge’. Professor Heinsohn, a historian and economist at the University of Bremen in Germany, argues that wars, insurrections, contemporary and historical terrorism, and internal violent insurrections are the result of a surplus of 15- to 29-year-old men in the total population (see also Urdal *et al.* 2006).

It is important to take into account that 'youth bulges' may result in rapid economic growth, but their occurrence may also risk the possibility that adaptation of social patterns may not follow pace. Navaneetham (2002) described how this was historically manifested in South and South East Asia where a demographic transition has given these countries an opportunity for economic development.

This means that in the case of providing only humanitarian aid, the child mortality rate in the developing countries would fall much faster than mindsets of the populations of those countries could adapt. So those population would still be increasing instead of falling. For instance, if 30 years ago a woman in these developing countries had 6 babies and 3 of them – 50 per cent – died as infants, currently she might have only 4 children, but modern child mortality rates would ensure that at least 3 of them – or even all 4 of them – would reach adulthood. This would simply increase that 'Youth Bubble', which is considered one of the main reasons for civil conflicts after the Cold War (Cincotta *et al.* 2003).

Therefore, increasing well-being alone that is not accompanied by a corresponding social and mindset development would only make the situation worse. So we can come to the following conclusion: traditional mindsets and the provision of humanitarian aid while increasing child survival rates alone would contribute to the prevention of overpopulation without stressful psychological changes. Insisting on preserving 'indigenous, unique' archaic social and mindsets as well as that of traditional communities, would risk making the situation significantly more difficult.

However the archaic mindset – or the mindset of the commune-oriented traditional society member –is very hard to overcome without any efforts from subduing side of this process and also with no required assistance from the leaders of social evolution. Due to many quite natural psychological reasons people normally cling to their habitual traditions (Aronson 2003).

Solving the overpopulation problem is thus not possible without changing the archaic mindsets in place, or in other words – without the social mindsets of traditional community members adapting.

This means it would not be possible without the transmission of fragments of various subpopulations, characterized by traditional community patterns into this global population with its updated mindset.

However, it is easier to say than to do. The unavoidable necessity of that transition raises many questions. The current work can give no answers – not only for moral reasons but simply because it is impossible within the scope of such multi-factored and complex problem. But it does suggest a strategy to adopt. The main challenge here for the subpopulations in question is to preserve sustainability while remaining able to change at a social level. But how could that be achieved, using a macro-ecological perspective?

The populations of MEDC's experience an extreme level of narcissism and a seemingly unlimited will to individual autonomy – due to the very nature of the modern economic model. But as discussed above, this strongly contradicts the flow of the process of social evolution. This Market Autocracy, *i.e.* the 'invisible hand of the market' of Adam Smith, may be one of the most powerful reasons causing the reverse Flynn effect in the MEDC. The Flynn effect is the substantial increase in average scores on intelligence tests recorded all over the world. It was measured in 1949, 1974 and 1991. However, the consequent investigations in some MEDC countries showed unexpected reverses of this effect. So in the United Kingdom, tests carried out in 1980 and again in 2008 show that the IQ score of an average 14-year-old dropped by more than two points over this period. However, children aged between five and 10 saw their IQs increase by up to half a point a year over the same three decades. Professor James Flynn (2009), the author of the latest study, believes the abnormal drop in British teenage IQ could be due to the youth culture having 'stagnated' or even dumbed down. Teasdale and Owen (2008) report intelligence test results from over 500,000 young Danish men, tested between 1959 and 2004, showing that performance peaked in the late 1990s, and has since declined moderately to pre-1991 levels. In another study on young adult males in Denmark (2009), they found that there was a modest increase between 1988 and 1998, but a modest decrease between 1998 and 2003/2004. The difference was approximately 1.5 IQ points in both cases.

But that relative decrease of the mind control over free will results in the flourishing of asocial behavior among the young population of MEDC countries. We assume that the reverse of the Flynn Effect occurred due to the same Market Autocracy effects. The market offers and social politics of modern states remove the negative limit for random allocation of human intellectual ability. Simultaneously, the excess of market offers together with the progress of marketing technologies strongly decrease people's Searching Activity. If the Searching Activity is not required to ensure normal living over an extended period of time it either decreases or focuses on non-material matters of highly private, individual understanding. That affects the selection of goals for cognitive activity, which may be the reason for the Flynn effect reverse and for superstitions flourishing.

The reverse of the Flynn effect means that the social mind control over people's motivation decreases. People's mindsets become more governed by media and advertising, and simultaneously social behavior becomes more asocial.

Unfortunately these effects are thoroughly intermixed with the ritual understanding of religions. The current conditions or globalization lead to a 'crisis of sovereign states' and thus competing non-state self-identification gains more influence. The most evident parameter people of various social development levels use for self-identification is the ritual parts of religion, and especially those with extremist tendencies.

## Conclusion: Towards a Science-based International Politics

In order to be sustainable, social patterns have to remain both able to adapt to change while keeping an internal equilibrium. That is a fundamental requirement of any system, but especially of the biological ones, which apply to macro-ecological systems.

But as the individualization of behavior grows more extreme, so does behavior subordination which obstructs social mind development. Realizing this problem alone would not help provide the transition described above, but it does offer an understanding that can facilitate working out specific and sensible steps to overcome it. We assume here that the real way to solve this problem is not only by providing humanitarian assistance. It would rather require specific assistance in adapting social mindsets. This step would require the sensible and deliberate efforts by social leaders.

The resistance to an evolutionary transition would come from many sources – as, for instance, from powerful mass psychology factors and also from established political interests. People benefiting from preserving a given situation can normally be found at the top economic level of developing countries.

The growth of asocial behavior has made some Western philosophers even look back to the commune-oriented traditional lifestyles and look for some way of returning the values of those lifestyles. However, all the previous discussion proves that it would be hardly possible, – if not just disastrous – under modern conditions.

So despite all these problems, there seems no other way to solve the problem of enlarging the global biocoenosis carrying capacity than the transition from a narcissistic market autocracy to an evolutionary goal, which is developing social mindsets for modern populations. And that conclusion increases the importance of natural science-based social engineering by political leaders during the current transition.

The transition to the 8$^{th}$ threshold of Big History started in the second half of the 20$^{th}$ century along with the transitions in international trade and communication means. This article shows that this development is an integral part of the Earth-biosphere system evolution. The upcoming 9$^{th}$ threshold is also a part of that evolution.

However, the carrying capacity of the Earth-biosphere system is still limited by the planet's boundaries. To provide further ecological specialization and the evolution of social mindsets that allow a demographic transition, a system of obligatory social feedback has to be developed to sustain the balance between various social groups and countries that make up the global population.

The most important conclusion from the above is that the sustainability of the Earth will depend on the deliberate actions of human leaders, by taking into account the general rules of the evolution of our biosphere.

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# 9
# The 'Ahimsa Factor': Ecological Non-Violence Process Analysis in China and Its Implications for Global Paradigmatic Shifts

*Michael Charles Tobias and Jane Gray Morrison*

## Abstract

*The world is witnessing the sixth extinction spasm in the annals of 4.2 billion years of life on Earth. We lose some 40,000 discrete populations of organisms every day. Species and habitat loss exceeds anything comparable during the last 65 million years. The human population is poised to hit between 9.5 billion and – in the absolute worst case scenario, 15 billion – with all of its accompanying consumption. A new global paradigm that can set the gold standard for ecologically-humble human behavior is urgently required and the nation of China – the largest country in human history, by far – has the potential to set in motion the global processes that are a prerequisite to a new gold standard for rectification of ecological violence. This will be no easy challenge, to be sure.*

*In this essay the authors examine some of the comprehensive biodiversity, global trade, ecological degradation, demographic and animal rights challenges facing the China of 2013 and suggest some solutions.*

***Keywords:*** *biodiversity, ecological degradation, human population, species, China.*

## What is at Stake?

China's environmental predicament represents some of the best, but also the most vulnerable, of circumstances. In this precarious and dialectical regard it is not alone. The human condition has awakened, as if from a long slumber, to divine in its current situation both peril and promise.

Ecological schizophrenia captures both the upside and colossal downside of human affairs. We are all, each of us, free to choose our destinies. Evolution neither condemns nor liberates us. We alone must be the agents of inspired change.

In May of 2006, The European Environment Agency embraced a concept whose time is long overdue: that of 'halting the loss of [global] biodiversity by 2010'.[1] This announcement echoed the avalanche of data and widespread alarm throughout the world's scientific communities by firmly acknowledging that we are now in the midst of the Earth's sixth massive extinction spasm in the known 4.2 billion history of known life on this planet. The recent acceleration in species extinctions is occurring some thousand times more rapidly than the presumed 'natural rate' of extinctions, which is estimated to be one out of every million species, or, between 10 and 100 extinctions annually. The rate of loss varies from location to location, of course. But in some areas we could be looking at literally hundreds of thousands of species wiped out forever in a day.[2]

As species disappear, their link to other populations is shattered, thus triggering larger and larger collapse of habitat, migratory viability, and the critical genetic robustness of interdependent communities, all of whose breakup can happen as rapidly as in a forest fire, or the calving of an ice shelf in Antarctica, where the root causes are deep within the texture, often beneath the radar screen of detection. 'Whether it's forests, marine systems, grasslands, you name it, they are in disrepair. For the sake of the planet, the biodiversity science community has to create a way to get organized, to coordinate its work across disciplines, and together with one clear voice advise governments on steps to halt the potentially catastrophic loss of species already occurring', said Dr. Watson, former chairman of the Intergovernmental Panel on Climate Change (IPCC) (CBD 2006).[3]

Little wonder, then, that approximately 40,000 discrete populations of organisms across the planet are being extinguished every day.[4]

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[1] URL: http://epaedia.eea.europa.eu/pag.php?pid=584.

[2] This assertion is born of three empirically driven sets of data. First, the astonishing revelations of Terry L. Erwin. In a study of one hectare (2.4 acres) of Ecuador's Yasuni National Park tropics, Erwin and colleagues extrapolated a reliable index of invertebrate abundance, and determined as many as 60,000 different species per hectare, many of them endemic within those very few acres of rainforest (Erwin 1988, 1966). Add to Erwin's findings the inevitability of biological codependents. Navjot Sodhi and Lian Pin Koh of the National University of Singapore, in a study focusing on some 12,200 plants and animals that are threatened or endangered, discovered that for every endangered species (often an invertebrate) two other known species appear to be equally imperiled. See http://www. planetark.com/dailynewsstory.cfm/newsid/27082/story.htm. Place this remarkable combination of species vulnerabilities beside the fires and bulldozers of development now accounting globally for as much as 200,000 acres of rainforest lost every day, and the loss in this generation becomes incalculably large. See http://www.rain-tree.com/facts.htm; www.satyamag.com/novdec00/keating.html.

[3] 'A majority of the nation's biologists are convinced that a "mass extinction" of plants and animals is underway that poses a major threat to humans in the next century, yet most Americans are only dimly aware of the problem, a poll says' (Warrick 1998).

[4] See Michael Tobias' interview with Paul Ehrlich at URL: http://www.forbes.com/sites/michaeltobias/2013/01/16/the-ehrlich-factor-a-brief-history-of-the-fate-of-humanity-with-dr-paul-r-ehrlich/.

## Ecological Renaissance

Along with the European Environment Agency, China, too, has long embraced an environmental calling. Eco-science, biodiversity protection, renewable energy R&D, pollution mitigation, reforestation and many other ecological sectors have seen a true coming-of-age across the People's Republic. China is well on its way – notwithstanding enormously complex challenges – to becoming a leader in that universal predilection to engender a global ecological civilization. Cutting-edge environmental restoration has been much discussed in Chinese academic and civil engineering circles for years. Eighteen months ago, an important case study of ecopolis, beginning with Hangzhou City, was published by the Research Center for Eco-Environmental Sciences at the Chinese Academy of Sciences in Beijing. Therein, the author Rusong Wang described the 'ten big eco-infrastructure projects and 1250 eco-engineering projects [that] have been carried out in areas [such] as free-bicycle service system, eco-agriculture and eco-industrial transformation, sustainable consumption, eco-community, wetland restoration, rural sewage treatment, municipal wastes regeneration, eco-cemetery, eco-mapping'. Wang adds, 'Up to now, 30 per cent and 70 per cent of its townships have met the State and Provincial ecopolis standards respectively, and 6 counties/districts were granted as eco-counties'.[5]

Many of the most provocative implications and exciting opportunities inherent to the ecopolis sustainability design concept are discussed on the Harvard Business, and Harvard Design Schools website devoted to ecopolis.[6] In a recent article, the vertical sustainability and 'best practices' approach being employed in the world's second highest building, the Shanghai Tower, are examined.

Among the numerous other indicators of a Chinese ecological renaissance are the country's recent National Strategy for Plant Conservation (BGCI 2007) aimed at safeguarding the future of nearly 5,000 specifically identified threatened plants within the country, to her efforts to expand an in situ network of protected areas. China's massive 10-year reforestation project is aimed at covering 97 per cent of the country, the largest initiative of its type in any country in history. Initially, an area twice the size of Colorado was planted.[7] By 1998 commercial logging in China's one designated biological hotspot – the Hengduan Shan, or Mountains of the Southwest – had been halted.[8]

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[5] See URL: http://www.eco.confex.com/eco/2011/preliminaryprogram/abstract_27375.htm.

[6] See URL: http://www.sustainablecitiesfinance.wordpress.com/.

[7] See URL: http://www.china.org.cn/english/2002/May/32599.htm; www.fadr.msu.ru/rodale/agsieve/txt/vo14/issue1/1.html; www.eurekalert.org/pub_releases/2006-09/ci-uac091406.php.

[8] A 'hotspot' so defined refers to a region that has at least 1500 endemic vascular plants (indicator species) in terrain of which at least 70 per cent has been lost from its original extent. See Tobias *et al*. n.d.

## Ecological Challenges

Here is where the much discussed inherent contradictions within Chinese tradition have been pointed out, namely, a reverence for nature in ancient Daoist tradition – seen in so much of Chinese aesthetic appreciation on canvass, in literary and other art and philosophical forms – but, alas, a simultaneous predilection to undermine that very spirituality, in some instances (Wenhui 1997). To date, for example, many individuals continue to ignore the government ban on cutting down forest and data suggests that as little as 5 per cent of the overall forests in Hengduan Shan remain (Mittermeier *et al.* 2004).

Similarly, in spite of major botanical restoration work with endemics and floristic medicinals, it is likely that Chinese wild rice could disappear in little over a decade from now. 'Chinese wild rice will become extinct in fifteen years', says Peking University Professor Dr. Lu, in a new report detailing the country's fast disappearing natural heritage and just some of what is at stake (Yardley 2007). These are just two examples out of many. Such ecological contradictions are rife within every nation, but for China – that has so much wilderness yet to lose – such contradictions could prove heartbreaking if the challenges they pose are not overcome.

## Halting the Loss of Biodiversity

The crisis of disappearing biodiversity cannot be understated: it is the core loss that a nation and her people must fear the most, lest they end up like the extinct culture of Easter Island. As with every economy, China's spectacular growth is altogether dependent on the vast treasure troves of her natural heritage, no matter how hard it, or any other country, tries to cover-up in situ depletion by trying to import natural resources from outside her political borders, ecologists call a syndrome of 'the Netherlands Fallacy': an equation that correlates sustainability with carrying capacity.[9]

Should China see its natural heritage go bankrupt to any demonstrable extent, it would be bereft of more than its soul: China herself would be lost.

History has not been kind to the twenty-two great civilizations of the past that ignored the ecological warning signs, as outlined all too clearly by such notable historians as Arnold Toynbee and Jared Diamond (Toynbee 1976; Diamond 2005; Tobias 1994). In *Collapse*, Diamond points to three developmental leviathans in China that together emblemize 'the world's largest development projects, all expected to cause severe environmental problems'. They are the Three Gorges Dam in Hubei Province, the South-to-North Water Diversion Project, and the overall runaway development across much of Western China (Diamond 2005: 367).

[9] See URL: http: www.pregnantpause.org/overpop/nethfall.htm.

As previously indicated, The People's Republic has as much or more to lose in terms of biodiversity than any country in history. Consider some of the nation's ‘basal ecological metabolism’: nearly 18 per cent of the country remains clad in forest, or 175 million hectares (420 million acres or nearly 700,000 square miles). At least 6,347 vertebrate species including 581 mammals, 1,244 bird species, 284 species of amphibian, 376 species of reptile and at least 20,000 marine species exist within that vast and scattered canopy (SEPA 2005). In addition, nearly 8 per cent of the Earth's plant species are represented in China, or some 30,000, a third of which are endemic (found nowhere else). From the summit of Everest to the Turfan Depression 154 m below sea level, China's altitudinal variations are the largest in the world, ensuring an astonishing turnover rate of species diversity across the vast arrays of China's numerous mountain ranges, deserts, tropical, temperate and marine biota.

Among the country's most critically endangered iconic species are not only the highly threatened Giant Panda, but lesser known creatures, not least of which, the world's ‘greatest concentrations of endangered primate species’, including the snub-nosed monkeys of the genus Rhinopithecus, and the Hainan gibbon (Mittermeier R., Gil, and Mittermeier C. 1997). Other astonishing ‘Chinese citizens’ include Yangtze river dolphins and Père David's deer, snow leopards, Chinese alligator, and the world's largest number of endemic pheasants, not to mention a quarter of the world's unique Rhododendron species, plus some of the most diverse lichens, ferns and other bryophytes on Earth.

Like the countries of the European Union, the People's Republic has committed to halting biodiversity loss, with ever-present benchmarks. The Conservation International authors of the critical book *Hotspots* in their assessment of China write, ‘...time is short ... pressures on fragmented natural habitats from grazing, clearance, hunting, and collection of forest produce remain, and new threats, such as dam building on all main rivers in the hotspot, mining, and unplanned mass tourism development accompanied by road expansion and wildlife consumption are emerging. This means that the extinction of many of the restricted-range species of plants and animals is a realistic and immediate possibility’ (Mittermeier *et al*. 2004: 160).

These warnings are being countered by strong collective endeavors evidencing China's awareness of, and resolve to counter biological degradation with significant sustainability initiatives, as heretofore referenced. While China – like most other nations – has realized the vulnerability of its indigenous flora and fauna, it also knows well the spectacular global scope and importance of such biodiversity. And unlike, say, a place like Yasuní National Park in Ecuador, where insects and spiders have been tracked uniquely for nearly two decades, the invertebrates of China have enjoyed only preliminary research, yet the indications suggest an even more astonishing array of creatures yet to be discovered (Xu MuQi and Zhang ZhiBin 2002).

This generation of young Chinese ecologists has much to be hopeful about. But, as is consistent with any mixed record, it will not be an easy path. For example, the 2005 Environmental Sustainability Index (ESI) ranked China 133 out of 146 (with North Korea being 146).[10] By 2008, the Environmental Performance Index showed some improvement: China had risen to a ranking of 105 out of 149 nations listed. China fell behind Myanmar and was just barely ahead of Uzbekistan.[11] But last year, China fell again to 116 out of 132.[12] Much of this can be attributable to China's air and water pollution issues, but also to biodiversity loss.

### Ecological Costs/Benefits

The approximated cost/benefits accompanying ecological damage in a country the size of China is unambiguous. With net annual losses far exceeding the nation's US$ 10 billion monthly trade surplus average (see Lardy 2008; BBC 2008) and a general demographic reversal in terms of increasing preferred family size (2 rather than 1), consumerism in China is taking a terrible toll, in spite of the country's trillion dollar plus 'cash hoard' (Mukherjee 2007). Metropolitan statistical areas, with their tally of low sulfur coal-fired power plants, spring up virtually overnight, and the fast-growing number of automobiles is outstripping even the human population explosion. Increasingly, more and more landscapes are being converted to sacrifice areas.

Of course, the targeting of China's growing surplus at an environmental safety net is no less critical than a nation-wide pension fund. While China's official press agency *Xinhua* cited former Vice Premier Zeng Peiyan, as declaring 'coal, iron and oil' to be the purchases of choice with all of China's cash surpluses (*Ibid.*), two other looming realities must sound a wake-up call for the country: 1.45 billion Chinese by 2050, a large percentage of whom will be elderly; and vastly truncated natural capital (Zhou 2006). These represent a potentially lethal combination for biodiversity.

### The Agricultural Conundrum

One of the most problematic areas of concern, when speaking of a green future amid environmental disparity and biodiversity loss, involves agriculture. In a provocative Washington Post editorial in March 2011, Lester Brown asked, 'Can the United States feed China?' It raised many eyebrows and also provided ample opportunity to reflect on current grain import/export dilemmas, desertifi-

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[10] See http:www.infoplease.com/ipa/A0930889.html.

[11] Environmental Performance Index Summary for Policymakers, Yale Center for Environmental Law and Policy; Center for International Earth Science Information Network, Columbia University, in Collaboration with the World Economic Forum, Geneva, Switzerland, and Joint Research Centre of the European Commission, Ispra, Italy, 2008.

[12] URL: http://epi.yale.edu; http://epi.yale.edu/epi2012/rankings.

cation and falling water tables across the North China Plain. Brown writes, 'Just as China is America's banker, America could become China's farmer'. He explains this scenario by examining how 'China requires 80 million tons of grain each year to meet just one-fifth of its needs'. If, as Brown speculates, China 'charges into the US grain market, American consumers will find themselves completing with nearly 1.4 billion foreign consumers'. Politically-destabilizing spikes in agricultural prices would not make for the best diplomacy. Brown says, 'If China pushes US food prices higher, tensions between the two countries may escalate' (Brown 2011).

That is one bad side of the equation. Another concerns the basic ecological overshoot and what such consumption, if predicated upon a scenario of exhausted Chinese soils and watersheds, bodes, namely, additional biodiversity fragmentation. Considering that the aforementioned IUCN in China has already published information attesting to the fact that 'more than 27 per cent of species are considered threatened'.[13] That adds yet another whopping dimension to the challenge of engendering a global ecological civilization with China at the helm, given its size, population, wealth accumulation and biological diversity. Then add the animal rights side of the equation and there are further difficulties. Indeed, as many luminaries from China's own Lao Tzu, Confucius, and Hseigh Ling-Yun, to Leonardo Da Vinci, Mahatma Gandhi and Einstein have said, a human civilization can be judged according to its treatment of other animals. Animal rights are the most telling mirror of the ethical and spiritual challenges facing any nation. For China, the myriad of animal rights and basic animal protection issues are mired in a web of insufficient legislation, monitoring, or regulatory statutes guaranteeing any nation-wide coverage. Even across its 31 Provinces, and at least 50 widely varying cultures and language groups, a singular lack of homogeneous ethics in China militates against the likelihood of any surge in empathy towards non-human animals anytime soon.

This constitutes probably the severest crisis in process-formulation that China must contend with, for it underscores all other ecological malfunctions; placing the nation on a path towards those many other civilizations in past centuries and millennia that have actually gone extinct. Twenty-two such civilizations were chronicled by the late British historian Arnold Toynbee. Clarence Glacken, from the University of California-Berkeley made similar strides, as did men like Oswald Spengler, Jared Diamond, and the author of this essay in his 1994 book (and film), *World War III: Population and the Biosphere at the End of the Millennium*.

[13] URL: http://www.iucn.org/about/union/secretariat/offices/asia/asia_where_work/china/iucnch_work/iucnch_biodiversity/. See Population Reference Bureau Data Comparisons at URL: http://www.prb.org/Datafinder/Topic/Bar.aspx?sort=v&order=d&variable=92, and 93.

## Chinese Animal Rights Issues

In a Forbes interview with Peter J. Li, Associate Professor of University of Houston, Dr. Li has gone into many details specific to China's not entirely unique situation. Dr. Li says that, 'The sheer number of farm animals in China suggests the world's great number of farm animal are raised in welfare compromised farming conditions in China'. He also speaks about the crisis of Chinese bear farming, 'shocking farming and slaughter practices', 'dog slaughter', 'a collective fear of hunger in the minds of people over the age of 50 in China' that might add to what is, in essence, a stark abnegation of traditional Chinese ethical and aesthetic values; and the overall situation across China given that, as Dr. Li puts it, the country has 'lagged behind the industrialized nations in animal protection law-making for more than 180 years'. Dr. Li writes, 'Never in its 5,000 year history did China ever raise and keep hundreds of millions of wildlife species in captivity as it is today'.[14]

Indeed, Dr. Li reminds us that China surpassed the USA as the world's biggest meat producer in 1990. And he adds that, 'While Westerners greet each other by asking "how are you", Chinese people traditionally greeted each other by saying "Have you eaten?"' (*Ibid.*). Dr. Li remembers how, when he 'met some of [his] old classmates back in China 30 years after graduation, [he] was some 40 pounds lighter than they were. They actually wondered if [he] got enough to eat in the US' (*Ibid.*). In terms of food, Dr. Li points to the fact that 'China's rapid industrialization has threatened the survival of 398 species of vertebrates' across China. And he has examined traditional Chinese medicine in terms of its exploitation of Chinese biodiversity, for tiger bone wine with its 'dubious curative effect' and Dr. Li goes on to ask 'whether all these allegedly indispensable and life-saving ingredients for illnesses ranging from eye irritations to cancers, coma, severe acute respiratory syndrome (SARS) and even liver transplants are really nothing more than the wildlife farming industry capitalizing on the anxiety of patients' (*Ibid.*).

And it is not just Chinese medicine, but a penchant for all things ivory, yet another disastrous cultural addiction that is the primary engine for destruction of African and Asian elephants – the largest land mammals on Earth who share with us, humans, deep self-awareness, emotional and cognitive bonds.

Dr. Li concludes that, 'Animal suffering is unprecedented in China in magnitude in both numerical terms… and in welfare conditions. With regard to China's ranking on a global report car, so to speak, I would not hesitate to say that it [China] may be at the bottom…' (*Ibid.*)

And yet, he is not all despair and pessimism, pointing out that today, China 'has an estimated 130 million dogs, many of whom are household pets. As a re-

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[14] See interview with Michael Charles Tobias for Forbes, at URL: http://www.forbes.com/sites/michaeltobias/2012/11/02/animal-rights-in-china/.

sult, China's animal protection community is expanding. Some Chinese activists estimated that as many as 30 to 50 million Chinese are animal lovers, bigger than the total population of Canada' (*Ibid.*).

## China's Profound Ecological Opportunity

Conversely, despite the aforementioned difficulties, these 'negative externalities' could actually – if reversed – pose the greatest opportunity in Chinese history to conserve biological heritage so as to guarantee all the basics for a huge population: clean water, clean air, healthy soils, ample storehouses of grain, home grown fruits and vegetables, not to mention a legacy of ecological nonviolence and enthrallment for future generations. With such opportunities come the most exciting and noteworthy prospects for ecological entrepreneurs ever, within any country.

For this to happen, Chinese conservation and business need to work hand-in-hand, while the Government hopefully continues to proactively urge the adoption of smart, nation-wide strategies for identifying biodiversity rarity; setting priorities for large scale ecosystem protections to mitigate corresponding economic progress; allocating significant ecological resources; distributing the 'green benefits' of virtuous engagement with the natural world; implementing national 'polluter pays' protocols and precautionary principles; and exacting much stricter monitoring and enforcement of current environmental and animal rights legislation.

The challenges are exacerbated by the time-frame, which is short. China's position vis à vis other countries is one of significant loss: among those nations with the largest number of threatened and endangered plant and animal species, China is one of the worst, ranking 14$^{th}$ and 7$^{th}$ from the bottom, respectively. And while the country has focused considerable attention on the prospects of ecotourism, it has done so without any overall sustainability plan (Han and Zhuge 2001).

Conversely, with her increasing economic success, and vast opportunities for international carbon credits by mitigation within China, the economics of environmental remediation suggest an industry that will transcend all others in the country, thus providing a win-win for one of the last standing aggregates of critical biodiversity on Earth. In this spirit, China's National Environment Protection Agency has long avowed that 'the survival of mankind cannot be separated from that of other species' (NEPA 1998).

## On Point

To this end, China appears clearly on point: recognizing her unique threatened endangered species status since signing on to the Convention on Biological Diversity in 2004, China has endeavored to put in place such groundbreaking legislation as its Law on the Protection of Wildlife, while engendering an in-country network of protection mechanisms.[15]

Ten years ago, the Chinese Academy of Sciences embarked on saving endangered vascular plant varieties throughout the country in a grid of gardens with the ultimate goal being some 458 square kilometers of plant protection, the largest collective botanic garden network in the world.

Hundreds of wildlife breeding stations have been created, and measurable progress noted with rare species like the Panda, the Chinese alligator, Eld's deer and Tibetan antelopes.[16] These biological and endangered species endeavors should be viewed as a kind of barometric reading; the baseline for assessing environmental amelioration. Because all economics are a sub-set of Mother Nature, what is good for the Giant Panda is good for all of China.

## What is Good for China Should be Good for the World

When Jeremy Rifkin spoke last year before the European Commission, treating of what he has characterized as the 'third industrial revolution', he described how Germany 'is expected to produce 35 per cent of its electricity from renewables by 2020'; how 'Daimler, the company that invented the internal combustion engine that ushered in the Second Industrial Revolution, is readying hydrogen fuel stations in preparation for the mass production of its fuel cell automobiles in 2015'. He described a new vision for the EU's, putting forth the prospect of [the European Union] becoming the largest and wealthiest internal commercial market in the world.

'The key, – said Rifkin, – was in creating a seamless distributed renewable energy régime, a green electricity Internet, and a communication and transport network that will allow one billion people to engage in sustainable commerce and trade across the European continent and its periphery. By such means the European Union will come of age' (Rifkin 2012).

Now, consider China's future. I, too, have a dream for a nation that can also seamlessly fulfill a similar promise as that divined by Rifkin for the EU. That dream involves China that is ecologically compassionate in her embrace of regional biological integrity, and brilliantly proactive in terms of the responsibilities and duties attendant upon every nation in what is, as never before in human history, a globally interdependent environmental commons.

This was well stated during the December 2012 IUCN China roundtable on what was called 'Nature Based Ecological Civilization'. The IUCN Chair of the Commission on Education and Communication, Dr. Juliane Zeidler, brought forth the concept of 'Love, Not Loss', suggesting that the 'best way to rekindle our connection with nature' was by remembering not just all that which has gone

[15] URL: http://www.china.org.cn/english/features/China2004/107041.htm.

[16] *Ibid.*

extinct or is threatened with extinction, but also, and critically, that which ‘we loved in the first place… [to] reconnect our daily lives with nature’. Moreover, the new IUCN President, Mr. Zhang Xinsheng, has long been committed, as he has put it, to ‘building consensus among all stakeholders for development of a green and sustainable future’. Considering that he has also recognized the continuing plight of poverty throughout much of the world, and a myriad of environmental crises, Zhang Xinsheng's optimism and resolve to create a better world speaks not only to the mission of the IUCN, but to that of China, as well (IUCN 2012).

## Conclusion

The necessary global processes that might transform China as a whole into a champion of ecological non-violence will necessitate a vision of one of the most ancient, powerful and elegant countries in the world setting the highest possible benchmark for all things green, sustainable, compassionate, and tolerant; a nation that – were it to do so – has every reason to become an ecological beacon for world civilization and harmony.

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# 10
# Situational Binding and Inner Speech: Cross-Sectional Evidences

*Ilya V. Ponomariov*


## Abstract

*Different evidences of inner speech development are gathered and discussed from the perspective of situational binding – a conception developed within the framework of cultural and historical tradition of L. S. Vygotsky. This conception explains and systematizes many facts which have otherwise caused much perplexity to scientific knowledge. It predicts that the future neurobiological research of inner speech in non-school societies should discover that it has fragmentary and sympractical character.*


***Keywords:*** *inner speech, developmental science, sympractical culture, linguogenesis, Vygotsky.*

## 1. Development of Inner Speech

The foundations for development of inner speech are laid from the birth of a child. His/her first words cannot appear from nowhere and the long period of their adoption is necessary. Those children raised by animals (feral children) or deaf-blind ones do not develop speech themselves and if the first sensitive period for language acquisition is over, they have almost an insurmountable impediment to adopt it from other humans (see Meshcheryakov 1979). Let us consider the forerunners of inner speech to find its role in the human development.

Inner speech has the latent, overt and covert periods of development. From the moment when a baby hears the first words, the latent period of speech development is open. That period is characterized with the child being gradually more and more involved in a verbal milieu. Up to one year the averaged child cannot pronounce words, still s/he communicates with adults by means of crying and other sounds. With time infant sounds become more emotionally differentiated, approaching in that respect the speech. Being not able to speak, the child already learns verbal phonemes and semantic structures from adult's developed speech (Vygotsky 1984a).[1]

[1] For references of partial English translations of Vygotsky's works published in Russian and referred here, see Mahn 2003. For the critique of English translations quality see Veer and Yasnitsky 2011.

The overt period of inner speech development begins approximately from the age of one year when a first infant word appears on the background of an unarticulated flow of sounds that s/he actively produces. From this time, the overt speech is beginning to execute more functions in psychic development; but it is evident that embryonic inner speech processes also take place as it was during infancy. Hence, we can speak about the inner speech development from the birth. During the second year of life, the more adult-like speech appears. From three years of age, the overt stage of inner speech development is characterized with the differentiation of private speech from social speech (Vygotsky 1984a, 2001). The former is usually defined as a speech directed more to oneself than to others (see Berk and Landau 1993).

The history of private speech internalization, *i.e.* turning of it into inner thoughts, evidences that it plays a central role for planning and directing child's behaviour (*e.g.*, Fernyhough 2008). Approximately about three years of age this type of speech is yet weak and rather accompanies child's activities than directs them. The situation changes gradually to the age of five when private speech becomes more complex and more involved in self-control. If in three- and four-year-old children one can observe long phrases of private speech, which help them in their activities but often directed to both an interlocutor (often an imagined one) and oneself, towards six years of age the phrases of such type are compressed to one-two words (Vygotsky 1984c). It is very important to notice that the child can now express a meaning of long sentences to oneself with one or two words, because this meaning is clear to him from the context of his past and present verbal experience (Vygotsky 1934), which can also be called a semantic field of speech (Luria 1981; Luria and Vinogradova 1959). The shortening and compacting of private speech is proportionally counterbalanced with the development of partially and fully internalized covert speech operations. The dynamics of speech internalization found in experiments shows how the private speech turns into the inner speech passing the stage of covert one. In this process the private speech loses the verbal structures specific for overt, interpersonal speech, but preserves the sense, planning and directing functions (Winsler *et al.* 2003; Martinez *et al.* 2011).

The crucial role of speech for the development of all major psychic processes can be found in children with atypical development (ADHD, autistic, *etc.*) (Winsler *et al.* 2007a; Akbar *et al.* 2013). These children usually have some deviations in the development of private speech that correlate with some impairment in the genesis of self-control, social competence, emotional regulation, abilities to learn, *etc.* If these children have the private speech of normal estimates, there can still be found some additional, usually organic, factors (mental retardation, memory dysfunction, *etc.*) preventing them from using their speech functions properly (Winsler *et al*. 2007b; Kopecky *et al*. 2005).

The covert speech, which is almost the inner speech, begins to predominate from the age of seven years and marked with the developmental crisis (Vygotsky 1984a, 2001). If some manifestations of private speech are investigated in the age periods between seven and thirteen years, they prove only that this type of speech has been replaced by inner speech operations and that it can only be initiated under conditions of increasing demands on performance (Lidstone *et al.* 2011; Ostad and Sorensen 2007; Lidstone *et al.* 2010). In this age period the learning of literacy (and science) is especially essential for the quantitative and qualitative changes of inner speech to occur (Vygotsky 1934, 2001). Hence, it can be suggested that the potential for inner speech development is initially constrained by the available means and social background. But after thirteen years of age the sensitive period for literacy learning is mostly over which means that many opportunities for the development of inner speech in future are lost (Tulviste 1991).

## 2. Situational Binding

After the path of inner speech in ontogenesis has been briefly considered, its connections with situational binding can now be analyzed.[2]

Developing consciousness from the birth to the crisis of one year old can be characterized as a sensorimotor unity (Vygotsky 1984a). This unity means that perceptions and actions of a child are united in such a system that any visual stimulus initiates an immediate reaction. This reaction is mediated but only with the system of instinct consciousness, which allows reaction to be very fast and adequate. Thus, the situational binding of this age period can be described as a binding with a visual field (Vygotsky 1984a; Bozhovich 2006). When speech is not yet fully adopted by child, in some cases adult's words are already disturbing the sensorimotor unity splitting infant perceptions from actions. The arising speech further dissociates the sensorimotor unity helping to overcome the situational binding with a visual field. Speech creates a psychic space/field between perceptions and actions which Vygotsky called ‘functional barrier’ (Vygotsky 1984c). This barrier is a path from animals' instinct movements to human planned actions. The Pavlovian unconditioned reflex evolves into a tool-mediated action and a word is a tool that reorganizes all natural processes of instinct life (Vygotsky 1984a, 1984c).

Central aspect of the overcoming of situational binding after the age of three years is the development of time perspective. As Vygotsky noted, ‘No one have ever met a child under three-year-old age who would like to do something over several days' span’ (Vygotsky 1966: 63). But in four- and five-year-old children such intentions become gradually more obvious. Speech raises a child above actual affective situations by creating a semantic field in his/her

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[2] For the origin of this conception in Vygotsky's works see Ponomariov 2013.

consciousness beside a visual field (Vygotsky 1984c). The perception of actual situation, memories relevant to this situation, and possible consequences of child's actions in future can be combined in a conscious experience only in the semantic field of speech. *Thus, speech creates the inner space and time of consciousness, or the semantic field.* This inner space-time continuum has a potential to differentiate a child's consciousness from the external space and time. Once it has appeared, the situational binding shifts more and more from the binding with a visual field towards the binding with speech operations.

The latest fMRI studies confirm the close connection between speech and memory processes from the perspective of their localization in the brain regions (Marvel and Desmond 2012); this connection also finds wide support in psychometric investigations (Al-Namlah *et al.* 2012; Akbar *et al.* 2013). The semantic field, being a part of organic speech process, has a physiological correlate – 'neural clusters' (Tononi and Edelman 1998), or may be better to say *the localized branches of neurons*. These bunches of neurons develop with age and exercise, each for carrying some specific psycho-physiological operation like reading or imagining a specific event, but they can also substitute each other to some extent. For all the described processes of situational binding, affect is not a determinate but one of the elements in the developing consciousness (Vygotsky 2004, 1934: 191). Some experiments demonstrate the role of private speech in children's emotion regulation (Day and Smith 2013; Winsler *et al.* 2003).

Vygotsky (1984a, 2001) related the emergence of inner speech to the seven-year-old crisis and explained the symptoms of this crisis from that perspective. Studying his works and other scientific data compels us to consider the development of inner speech, or its forerunners from the birth. As we have here tried to show his works and other scientific data compel us to regard the development of inner speech, or its forerunners, from the birth. One of the most specific results of his experimental explorations is the conclusion that from seven to thirteen years of age the central line of psychic development is the growth of 'scientific concepts', or the systems of operations with scientific word meanings (Vygotsky 1934, 2004). It should be noticed that the researcher used the terms 'concept' and 'word meaning' synonymously, as he underlined himself (Vygotsky 1935b: 133; 1934: 114, 131). The operations with word meanings which are developing in the semantic field of inner speech are not purely linguistic or logical (Luria and Vinogradova 1959). They are a part of organic inner speech process with its functions for planning and directing behaviour. They can become purely linguistic or logical only when they are torn from the brain by means of written speech. The development of operations with 'scientific concepts' is slow and painful; it spurs due to schooling as opposed to the genesis of 'everyday concepts' developed by child in his preschool experience (see for other experimental confirmations: Tulviste 1991, 1985). Step by step this process leads to the crisis of the age of 13 years.

Self-esteem and self-examination were already the symptoms of seven-year-old crisis but only the development of inner speech, driven by learning of literacy and science, can bring self-awareness, or reflexion, to a new level. The reflexion develops first in the domain of scientific word meanings, being their immanent feature, and gradually becomes a part of inner speech operations. The reflexion is initially transferred to the functions of consciousness, which are most developed to the age of seven: perception, action, memory, and, to a less extent, will and emotion. According to Vygotsky (2001), thinking (cognition) can become a leading function, which organizes other functions of consciousness in a system, only after perception and memory played that role, the former from the one-year-old crisis to three-year-old crisis and the latter from three to seven years of age. After the crisis of seven years old, thinking becomes a leading function, organizing other functions in a system, but it is not yet developed enough to become a self-aware process itself. Still, thinking can stepwise bring reflexion to other psychic processes, especially if it is subject to schooling. The essence of thirteen-year-old crisis will be that the reflexion of thinking will appear in the inner speech (*Ibid.*). Thus, the system of consciousness becomes with time based more and more on the systems of operations with word meanings in the semantic field of inner speech.

The great paradox of the age development is that after the thirteen-year-old crisis the operations of inner speech, which liberated consciousness from impulsive sensorimotor behaviour and reorganized all its processes, become a central factor of binding. The systems of operations with word meanings in the semantic field of inner speech can now determine the course of individual life more than genetic factors and, to some extent, more than social surrounding (Luria and Yudovich 1956). The 'situational binding' of consciousness with 'scientific concepts' (Vygotsky 1935b: 107) is a characteristic feature of all post-school societies. The semantic binding with word meanings and terms, not less determined with affect than with verbal logic, can be found in most scientific texts, especially in humanities. Many scientists believe in the semantic constructions that they actively create in their minds – in the semantic field of inner speech. They have belief in them because *it is an affective state that characterizes any speech operation of consciousness*. These speech operations, initially maintained to drive behaviour in some direction, can themselves become a single factor dominating the individual consciousness. The semantic binding with these operations greatly precludes further psychic development and it cannot be overcome by means of scientific studies.

In the last months of his life Vygotsky tried experimentally to investigate the systems of operations with word meanings in the semantic field of inner speech, which he called the 'dynamic sense systems', on the samples of both adult patients with frontal dementia and mentally retarded children (Samukhin *et al.* 1934; Vygotsky 1935a; Ponomariov 2012). The centrality of inner speech systems for all psychic processes was also explored by him in the studies of schizophrenia (Vygotsky 1956, 1981; 1984b: 188–189), which finds some support in the current neurobiology.

John H. Gruzelier's (2003) researches of brain hemispheric asymmetry in schizophrenia and schizotypy allow formulating two types of inner speech dysfunctions. The overproduction of inner speech correlates with the brain hemisphere balance shifting to the left (speech-located for right-handed) hemisphere and such symptoms as behavioural over-activity; manic, grandiose and paranoid ideas; exaggerated or inappropriate labile affect and affective delusions. These symptoms were called by Gruzelier an 'activated syndrome'. The underproduction of inner speech correlates with the brain hemisphere balance shifting to the right, non-speech hemisphere and such symptoms as social and emotional withdrawal, blunted affect, and motor retardation. These symptoms are united by Gruzelier under the title of a 'withdrawn syndrome'. Both syndromes are in agreement with the wide scope of schizophrenia studies (*e.g.*, Liddle 1987; Gordon *et al.* 2001; Gruzelier 2002). The recent fMRI studies also evidence that the hyperintensity of functional networks connected with speech-selective cortical regions is related to such symptoms as hallucinations and Schneiderian delusions in schizophrenia (Rapin *et al.* 2012).

## 3. Sympractical Culture

The conception of situational binding has already found application in social sciences. The pioneering works belong to Indologist Vladimir N. Romanov (2003) who analyzed many facts gathered from anthropological, linguistic, psychological and cross-cultural studies using this conception.

Rethinking the ideas of Vygotsky, A. R. Luria and P. Tulviste, the psychologists of the cultural-historical school, Romanov managed to explain some practices and social activities preserved in the descriptions of ancient texts. Referring to Luria's distinction between two types of psychological activity (visuopractical *versus* theoretical, the latter being based on scientific concepts), he writes, 'Starting from this distinction, whose accuracy had been proved both through the ontogenetic analysis of abstract conceptual thinking and the ethnopsychological studies of "traditional" societies, psychologists suggested the hypothesis (Tulviste 1977, 1978) that historical roots of abstract conceptual thinking (characterized by awareness not only of relations among the subjects of those concepts, but of relations among the concepts themselves) should have connection with the emergence of new types of "theoretical" social activity in Ancient time' (Romanov 2003: 64).

It is obvious that only the historian and linguist prepared to work with ancient languages can excavate such forms of 'theoretical' social activity, moulded in written sources. Romanov worked with those coined in Sanskrit. Using the example of Ancient India, he showed that such theoretical social activity can initially emerge in a non-school society via creating a theoretical type of learning on the basis of the oral tradition (*Ibid.*). The latest findings by social scientists like Barnes and Carmichael (2006) also support the already long-standing idea that oral cultures have been underestimated, as compared to written cultures. There is now more evidence that oral cultures can effectively transmit exact knowledge across many centuries and preserve social structures and values.

Romanov's data allowed him to distinguish between sympractical and theoretical cultures (Romanov 2003), the proposal deeply rooted in the cultural-historical tradition:

*Sympractical culture* – the type of socio-individual interaction involved in transferring skills, knowledge, moral/ethical norms and principals of behaviour in a less verbalized, more visuopractical manner. In sympractical culture the practical and theoretical information is little divided and completely received through personal contacts; for this reason the personal authoritativeness of a source is predominant when such information is retrieved, and the individual reflexion is generally constrained to this authoritativeness.

*Theoretical culture* – the type of socio-individual interaction involved in transferring skills, knowledge, moral/ethical norms and principles of behaviour through formalized and institutionalized verbal activity, through constructing categorical algorithms and plans – that is, theoretically. In theoretical culture the practical and theoretical information are relatively well-divided and the latter obtained mainly at school. Due to the verbal awareness, there is more individual reflexion in socio-individual interactions and in different types of activity; these, in turn, are more fully realized and more voluntary than is possible within sympractical socio-individual interaction.

In any concrete society both types of culture coexist and dialectically supplement each other through their mutual development and realization.

The works of the cultural historian Vladimir V. Glebkin (2000, 2002) were followed in Romanov's footstep. Exploring texts of Ancient Greece and Mesopotamia, Glebkin traced how 'theoretical thinking' emerged within the more general context of developing a theoretical culture. His conclusions confirm and further support the idea of distinguishing between theoretical and sympractical cultures.

The comparison of socio- and ontogenetic data was one of the cornerstones of Vygotsky's cultural-historical school from its foundation (Vygotsky 1934, 1984c; Vygotsky and Luria 1993; Tulviste 1977, 1991). And the experimental investigations of the historical development of psychic processes were carried out (Luria 1976; Tulviste 1991; see for comments Cole *et al.* 2011; Ponomariov 2013). Following these works, the concept of situational binding will be applied to anthropological, psycho- and palaeolinguistic data in the next sections.

## 4. Inner Speech Development in Non-School Society

If the thirteen-year-old crisis is possible only as a result of schooling, what characteristics would the inner speech have in the societies where schooling is completely absent? What effect would the absence of schooling have on the behaviour and practices of people in such societies? Particularly, are there concrete examples of transferring of skills and knowledge from one generation to another in a sympractical society? Answering these questions will help to understand some additional aspects of situational binding in relation to the adolescent education in a process of sympractical socio-individual interaction. To approach this aim, the analysis of adolescent initiations and age group institutions in a non-school society will be presented in this section. The initiation procedures have common and specific characteristics in different societies. The comparison of them allows to define the characteristics that are common for the most of non-school societies where the sympractical culture predominates (*e.g.*, Gilmore 1990).

The process of adolescent initiation has usually many stages and unfolds in time for several years in non-school societies. In turn, each stage consists of several phases, the most important of which is the temporal isolation of adolescents from society lasting from several days to the half of year. During this phase under the supervision of adults and older youths, adolescents experience starvation, humiliation, physical impairment and punishments, hurting changes or amputation of body parts, drug abuse and other dreadful practices that are unsavoury even to mention. In different societies and for two genders, the set of calamities is different but their purpose is always the same: to inculcate in adolescents ethical and social norms and to transfer them skills and knowledge (Ponomariov 2009). The training of life-important techniques is deeply interwoven in initiation procedures with the moral restructuring of adolescent consciousness obtained by both emotional and intellectual intervention. The hectic dancing, drum beating, singing and reciting are successfully used for the same purposes in the second phase of adolescent initiation (for detailed description see, *e.g.*, Nadel 1954). The terrific effectiveness of emotional, intellectual and physiological intervention is achieved with adolescents' attention being firmly and constantly held during initiation rituals on sexual and death stimuli.

The initiation procedures should not be torn from age group institutions in societies where they exist. These institutions provide social scaffolding for the borrowing and developing of new psychological skills, besides initiation rituals. Age groups give structure and sense to the process of social interaction. With the help of these institutions, adults create new motives and satisfactions in the zone of proximal development of adolescents, not less than by means of initiations (for comments on Vygotsky's concept of the zone of proximal development see, *e.g.*, Veer and Valsiner 1991). These social institutions make it easier to transmit skills, knowledge and ethical norms from one generation to another. Let us consider the example from social anthropology.

Social anthropologist and psychologist Siegfried F. Nadel (1954, 1961) made the description of age groups and initiation rituals based on his living for several years among the Nupe of Nigeria.[3] The small societies of those Nupe who did agriculture in the 1930s were strictly divided in age groups or 'age-grade associations', as Nadel called them. People of one age group went from one age grade (class) to the next through initiation procedures. In this sense, the age group is a group of people united by the time of initiation and common interests of everyday life: economic, political, intellectual. Thus, it is not age but the time of initiation that is the main criterion of participation in a concrete age group. Still, the age plays a central role for the inclusion in a concrete age group and it was so particularly in the past when the institutions of age groups were strong. If there were enough adolescents, several age groups in each grade were formed, equal in most respects, but competitive with each other and older age groups in respect of society benefits.

Nadel describes two types of collective labour among the Nupe: *egbe* and *dzolo*. The *egbe* is agricultural work carried out by adolescent members of several age groups. During the work, age groups compete with each other for the title *sode* that will be given to a group that performed best. The *egbe* is accompanied by loud music (playing drums and flutes) and ends with a feast prepared by an adult owner of the field tilled. Adults play a major role in the organization, maintenance and accomplishment of the work, 'Older men stand at the side, watching, criticizing, commenting. Often you can see them call one of the workers by name, exhorting him to ever greater efforts, or shouting impatiently: "Quicker, quicker!" When one field is finished, some of the young men, the captains of the age-grade association among them, will execute a short dance, balancing their heavy hoes in the air and heavily stamping on the tilled field…' (Nadel 1961: 249). Nadel underlines the role of external rhythmic accompaniment for accomplishing the work, linked with the speech practices of adolescent's supervisors and young workers, who 'were shouting with deep hoarse voices at every stroke of their hoe. The speed with which they worked, the whole atmosphere of the *egbe* – the constant drumming, the shouts from audience – had something deeply exciting, almost feverish. I have seen a team of fifteen young men, the oldest between 19 and 20, the youngest 14, clear and till a farm-plot of one acre in two and a half hours' (*Ibid.*).

In contradistinction to the *egbe,* the *dzolo* is collective work performed by the adult members of a Nupe society who come groupwise to each other's

[3] Nadel was a prominent English scientist of Austrian origin in 1930–1950s. He took PhD in psychology and then in anthropology. His teachers were Karl Bühler and Bronislaw Malinowski. The Nupe are one of Nigerian peoples and the Nupe language belongs to West-African Niger-Congo family.

households. There is no music, no competition, no verbal commands or overt speech, and only the preparing of modest food by the host is preserved. All adult members of society can benefit from the *dzolo* while the help of the *egbe* is predominantly reserved for old men and less so for the heads of extended families.

In the examples given, the use of speech and other cultural means can be traced in the cross-generation interaction of the Nupe. The adolescents give themselves external rhythmic signals with their own voice and are subject to the verbal commands of adults. The structure of age groups creates a competition with all the vigor and enthusiasm that it implies, hence the short dances in the conditions of 40–50 °C during the work transfer that would be hard to explain from other perspective. The rhythmic accompaniment with drums and flutes helps to maintain the tempo and force of works. Such cultural tools as adults' supervision, competition, collectiveness, musical tone and rhythm are clearly needed for organizing adolescents' behaviour during the work, because this scaffolding is completely absent when the work is performed by the adult Nupe alone. The self-voice external signals and adults' verbal commands are even more directly point to the character of inner speech processes that occur in adolescence in the non-school society.

All that was said about the inner speech development in the previous sections suggest that there is the developmental lagging of inner speech functions in the non-school society, as compared to the inner speech development in the post-schooled society. The underdeveloped inner speech means the insufficiency of behavioural control in adolescence (see Section 2). If the existence of some cultural tools can be explained by ecological hardship and/or tradition, the necessity of additional speech control more firmly links to the inner psychological processes. But the concept of situational binding makes ecological or other explanations superfluous. The adolescents' work is organized by adults in such a scaffolding system that helps them to overcome the situational binding. The absence of schooling slows the development of inner speech and in the non-school society adolescents cannot effectively overcome the situational binding, *i.e.* they cannot cope with their own physiological state in the physical situation of the work alone. The insufficiency of behavioural control in adolescence is widely discussed in contemporary neuroscience, the data being obtained from schooled samples (*e.g.*, Davey *et al.* 2008; Ernst *et al.* 2006). These data do not contradict to the present discussion but confirm that the degree of self-control is higher in school-based societies.

Furthermore, because the adult Nupe do not use external voice commands, musical and vocal rhythm, competition to overcome the situational binding during the agricultural work, it can be concluded that with advancing age the need for such outer scaffolding system is diminishing even in the non-school society. This system becomes the part of the inner speech control according to

Vygotsky's law of internalization (*e.g.*, Vygotsky 1984c). The developed inner speech has immanent rhythm and continuity, voluntary motives and control that replace external rhythm and voice support, competition and submission to adults. The overt speech and scaffolding, being transformed into the inner speech, become a part of inner organization. In the process of internalization the overt speech loses much of its interpersonal characteristics, but preserves communication, control, and voluntary motives as its basis. Vygotsky analyzed the historical development of inner speech in sociogenesis and even found a similar example (but much less clear one due to the scattered data) of overt speech scaffolding for performance of agricultural works (Vygotsky 1984c: 84; Vygotsky and Luria 1993).

The data about the sympractical nature of learning processes in the non-school society could be supported with many examples from Africa (*e.g.*, Turner 1953, 1957, 1967; Ponomariov 2009) and other world regions (*e.g.*, Gilmore 1990; Ponomariov 2012). It is confirmed by many facts in the works of V. Romanov (2003, 2008), and with many cross-cultural evidences of situational binding (Ponomariov 2013). In the last section, the article turns to the facts that can be explained only from the perspective of the historical development of inner speech and linguogenesis.

## 5. Historical Development of Language

British linguist Daniel Everett and his wife spent many years living with a Brazilian tribe, called the Pirahã, in remote areas of the Amazon basin. The main characteristic of the Pirahã language and culture is its binding with immediate experience and sympractical context. As Everett notes, 'Grammar and other ways of living are restricted to concrete, immediate experience (where an experience is immediate in Pirahã if it has been seen or recounted as seen by a person alive at the time of telling), and immediacy of experience is reflected in immediacy of information encoding – one event per utterance' (Everett 2005: 622). The immediacy of personal experience, found by Everett, speaks in favour of the limitation of time perspective in the Pirahã consciousness due to the underdevelopment of inner speech. The binding with personal experience in the Pirahã culture and language can be supported by many linguistic examples, presented in Everett's article and in the supplement on the website. As Everett stresses, 'What I propose, again, is that Pirahã culture avoids talking about knowledge that ranges beyond personal, usually immediate, experience or is transmitted via such experience' (*Ibid.*: 623). The analysis of cross-cultural researches allows to find experimental confirmations of the situational binding with personal experience in non-school societies (Ponomariov 2013). This type of binding is fundamentally different from those that were described above on the developmental material.

Summarizing his ethnographic and linguistic data, Everett explains many features of Pirahã culture by the absence of abstract word meanings ranging beyond immediate experience:

> 'Pirahã culture constrains communication to nonabstract subjects which fall within the immediate experience of interlocutors. This constraint explains a number of very surprising features of Pirahã grammar and culture: the absence of numbers of any kind or a concept of counting and of any terms for quantification, the absence of color terms, the absence of embedding, the simplest pronoun inventory known, the absence of "relative tenses", the simplest kinship system yet documented, the absence of creation myths and fiction, the absence of any individual or collective memory of more than two generations past, the absence of drawing or other art and one of the simplest material cultures documented, and the fact that the Pirahã are monolingual after more than 200 years of regular contact with Brazilians and the Tupi-Guarani-speaking Kawahiv' (Everett 2005: 621).

The traditional Pirahã way of life resembles that of other small tribes (some fewer than one hundred members) populating the vast territory of Amazonian tropical forests. But the characteristics of their culture, as outlined by Everett, seem rare and demand further explanation. Such an attempt was made by the psychologist Peter Gordon who conducted several series of numerical test-trials with the Pirahã. Based on his findings, Gordon describes the Pirahã words for counting as follows, 'The Pirahã counting system consists of the words: 'hói' (falling tone = 'one') and 'hoí' (rising tone = 'two'). Larger quantities are designated as 'baagi' or 'aibai' (= 'many'). <…> Of particular interest is the fact that the Pirahã have no privileged name for the singular quantity. Instead, 'hói' meant 'roughly one' or 'small', which precludes any precise translation of exact numerical terms' (Gordon 2004: 496–498).

Gordon refers to Whorf's (1956) hypothesis, of which there are two versions: (1) the type of language you speak *influences* the way you think (the weak linguistic determinism); (2) the type of language you speak *determines* the way you think (the strong linguistic determinism). Discussing the results of his experiments, the scientist supports the strong version:

> 'The results of these studies show that the Pirahã impoverished counting system limits their ability to enumerate exact quantities when set sizes exceed two or three items. For tasks that required additional cognitive processing, performance deteriorated even on set sizes smaller than three. <…> The present experiments allow us to ask whether humans who are not exposed to a number system can

> represent exact quantities for medium-sized sets of four or five. The answer appears to be negative. The Pirahã inherit just the abilities to exactly enumerate small sets of less than three items if processing factors are not unduly taxing. <…> The present study represents a rare and perhaps unique case for strong linguistic determinism' (Gordon 2004: 498).

Agreeing with Gordon that the Pirahã neither count nor understand the concept of counting, Everett offers an alternative explanation, 'Gordon (2004) alludes to a Whorfian approach to the matter by claiming that Pirahã's lack of counting might derive from their lack of number words, but many societies in the Amazon and elsewhere have borrowed number words as they develop economic ties that require numerical abilities. The hypothesis of this paper, which explains both the lack of counting and the lack of borrowing, is that Pirahã's counting 'deficiency' and their failure to borrow number words (in spite of commercial contact with Brazilians and in spite of borrowing their pronouns) are due to cultural constraints' (Everett 2005: 634).

Thus, if Gordon explains his findings from the perspective of language constraints, Everett points to cultural constraints. But both culture and language are created in a semantic field of speech; they are not parallel processes (Vygotsky and Luria 1993; Cole 1985). The same is true of Whorfian parallelism between language and thought. Famous psychologists Patricia M. Greenfield and Jerome S. Bruner, who conducted cross-cultural studies confirming some of Luria's findings, evidence, 'We have asked first the naive question: where in a culture should one find differences in the processes of thought? The anthropological linguists (*e.g.*, Whorf) suggested a concrete answer: where there are language differences, there may (or should?) be cognitive differences. Our results have led us away from the parallelism of Whorf toward the instrumentalism which is more typical of Vygotsky (1961) and Luria (1961)' (Greenfield and Bruner 1966: 91). Language cannot be regarded only as a cultural phenomenon or only as an individual one. Not only language and literacy influence the development of speech but the latter has a deep impact on the linguogenesis via the development of operations with word meanings. And the linguogenesis is an axis of cultural development.

Vygotsky experimentally proved that the operations with word meanings are developing in ontogenesis and he tried to find as many evidences as possible that this process occurred also in sociogenesis (Vygotsky and Luria 1993). His experimental research showed that there are *three major stages* in the development of operations with word meanings: proper names, complexes, and concepts (Vygotsky 1934). Each of these stages comprises a different system in the development of the semantic field of speech. The Pirahã speech and thinking are so bound to the non-abstract system of operations that it is mostly incompatible with system of other languages based on more abstract operations. The development of language and the development of speech is a mutual process and each stage of this process means the gradual overcoming of situational binding (Vygotsky 2001). Therefore, it can also be said that a different level of liberation from situational binding constitutes a main impediment for Pirahã's understanding and borrowing of systemic operations with word meanings from other languages. These speech operations can radically differ in different languages correlating with a level of word meaning development and a degree of the situational binding of language speakers.

It does not mean that the Pirahã cannot develop their speech operations to make them more compatible with those of other languages. To achieve this, they have to change both their cultural practices and the verbalization of these practices – the processes, which go hand in hand. But as Everett's experiment of practical teaching proved, the Pirahã adults could not change to different speech operations because the sensitive period for language acquisition is over. But if the Pirahã child were in the bilingual situation from the birth, the language with more developed speech systems would take more preferable position in her/his consciousness. This adds one of the reasons why many peoples in history changed to radically different languages, when exposed to the bilingual situation with more developed speech systems, and why some contemporary languages continue to die.

The historical development of psychological operations with word meanings was also understood by Vygotsky as 'the historical development of language' (Vygotsky 1934: 263). His conclusions may raise some doubts because they were the result of extrapolation of experimental ontogenetic findings on the data obtained from ethnopsychology and anthropology of the beginning of the 20th century. Verifying his position with new data obtained from neuroscience, neurolinguistics, cross-cultural psychology and anthropology, A. R. Luria supported it many years later (Luria 1976, 1981). Besides being confirmed with contemporary psychological and ethnolinguistic data, linguogenesis can to some extent be verified by current palaeolinguistics.

The assyriologist Igor M. Diakonoff (1995) notes that there is a shortage of words with abstract meanings in archaic languages and that is the reason why less abstract meanings were initially used as a trope (*i.e.* metaphorically, metonymically) to express more abstract meanings. For example, in the Sumerian language, on the base of which one of the earliest writing system was developed after 3000 BC, 'tenderly' was written *mí-dug,* (*i.e.*, 'to speak like a woman'); 'open' was written *ik-kid* (*i.e.*, to push a door), even when it was referred to an opening of a trade route from one sea to another; 'to kill' was *sang-ngiš-rah* (*i.e.*, 'to strike the head with a stick'), even when a different way of killing was described; 'wise' was *ngeštu(g)-sum-(m)* (*i.e.*, 'having the ear'); 'in front of' was *igi* (*i.e.*, 'the eye'); 'liberation' was *ama-r-gi* (*i.e.*, 'coming back to mother'), *etc.* (Diakonoff 2004: 24–40).

Though Diakonoff gives many sophisticated examples from different ancient languages, demonstrating how the first abstract meanings were gradually formed in a non-linear way, further studies are needed to obtain a detailed picture of language development (cf. Romanov 2008). Diakonoff's examples only in the first approximation show how abstract meanings were created with the help of less abstract ones. But they implicitly suggest that the expressing of abstract through tropes generated many metaphorical associations, 'Such tropes as a consequence of their wide associability can induce further tropes, producing semantic chains, bunches, and the whole semantic fields' (Diakonoff 2004: 39). Verifying many historical and linguistic data by some psychological and physiological findings, Diakonoff suggested that science and art were not divided, when the first systems of writing appeared. This explains why the most ancient texts are full of poetry and emotionally loaded semantic chains.

Diakonoff's conclusions about the functioning of word meanings in archaic languages are close to those formulated at the beginning of the 20th century (Cassirer 1955; Frank-Kamenetsky 2004), although based on much more extended and better-verified linguistic material from several ancient languages, and consulting the works of other palaeolinguists that has since appeared. They are consistent with Vygotsky's ideas of historical development of language, or linguogenesis, and confirm Everett's arguments that there can be languages with the shortage of abstract word meanings. From the perspective of inner speech development and the overcoming of situational binding, they sound even more plausible.

The main reason for both linguogenesis and inner speech development lies to some extent in the necessity to control one's behavior more effectively and rationally. For example, when preparing a lecture, classes or public speech, we can elaborate the whole future monolog in our inner speech. In the semantic field of inner speech a schooled individual can produce prolonged and emotionally intensive dialogues with oneself trying to reach that or other behavioural decision (Ponomariov 2012: 126–134). The schooled individual can write down or remember his own monologic or dialogic inner thoughts to check introspectively their logic or absurdity, morality or ugliness – that is what is referred to as reflexion, or metacognition. Now let us ask whether an individual without school education can effectively maintain these speech processes? All the data regarded suggest that the inner speech of unschooled people has much more reduced and fragmentary character than that of schooled ones. To check this hypothesis, the complex neurobiological study of unschooled individuals' inner speech along with psychometric measuring is necessary.

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# III. PROJECTS FOR THE FUTURE

## 11
## Governing the Time Will Govern Development – or, 'Territory of Faster Development: Everything for People' Megaproject Realization Proposals*

*Valentina M. Bondarenko*

### Abstract

*In the present article the author substantiates the thesis that the contemporary scientific knowledge has exhausted its explanatory potentials and does not contribute to definition of the objective causes of the emerging systemic crisis in Russia and in the world. Hence, such knowledge does not help to conduct the search and to substantiate transition to the new economic growth model, although Russia in its current situation is doomed to stagnation, further slowdown of growth rates, increase in unemployment and poverty. As argued further on in the article, only by reaching the visionary level of understanding the roots of the emerging systemic crisis and all other problems, it has become possible to form the methodology for cognition of regularities in the human system development, and then, basing on the given methodology, to substantiate the need and possibility to realize the megaproject of 'Territory of Faster Development: Everything for People'.*

***Keywords:*** *new methodology for cognition, specific human person, goal, time, single efficiency criterion, systemic nature, cross-disciplinary nature, integrity, systemic crisis, main task of governance, two development paradigms, megaproject.*

### Introduction

The scholars in different parts of the world have long contemplated the ways to transform the world order to improve ecological situation, to get rid of poverty, to resolve the food problem, eliminate the very possibility of periodically arising wars, resolve many other problems and make the crises shaking all the fun-

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damentals of human existence to sink in the oblivion once and forever. Many well-known scholars focused their studies on the search for the solutions for these difficult problems.

As many economists believe, everything that happens in the world at present proves amply that the second wave of the crisis has already started. However, the solution of the problems via the monetary means, *i.e.* emission of money and investment thereof in all kinds of assets (shares, resource assets, real estate, *etc.*) for the purpose of their resale becomes the prevailing way compared to investments in fixed capital, and thus causes the further growth impairment. Thus, the old models which countered the crisis by money injections into economy do not work any longer; and therefore, this path is hardly the remedy which could defeat the crisis by eliminating the primary cause of its emergence. Moreover, on the one hand, it is recognized that at present there are no serious debates over the measures to eliminate the crisis. However, on the other hand, at the last two World Economic Forums in Davos as well as the G-20 summits in 2013, we observed an increasing number of people stating that the 2008 crisis and its current second wave actually represent the crisis of the contemporary economic model. Thus, until the cause of the crisis of the economic model has been identified, any system of institutions and mechanisms aimed at elimination of pressure in realizing the anti-crisis measures will turn useless at best.

So, we should point that, on the one hand, at present the rhetoric of the subjects discussed by the academic community has changed dramatically. The focus of discourse shifted from specific issues (how to improve, accelerate, modernize, reform, *etc.*) to the comprehensive agenda. As never before, it has become necessary to develop a worldview approach to the current crisis situation in the world as well as to undertake the search for new models of economic evolution and new concepts of economic growth. However, in order to move to the new model of economic growth, one should have a theoretically verified and practically feasible idea of such a model.

On the other hand, we also have to admit that the global systemic crisis affects all spheres of human community's life and growing in scale, and nobody knows its deeper causes and where the remedy is to be found.

The failure to find the prescription to overcome the crisis makes us turn to history and search for the answers there. The findings, however, are not at all spectacular. For example, Dr. Geffrey Sommers (Professor of Political Economy and Public Policy at the Wisconsin-Milwaukee University (USA) and participant of the first Moscow Economic Forum held in March 2013) when commenting on the strict saving measures to be taken in the context of the looming recession in the Russian economy, warns that with respect to such measures, the point of his gravest concern was expressed best by Mark Twain, ‘History doesn't repeat itself, but it does rhyme’, and the result can be most unfavorable.

Sommers points that the last case of strict economizing took place in Germany, Italy and Japan in the period between the two world wars and resulted in fascism. Without stating that the same may happen now, Sommers suggests that the outcome would be most unpleasant, because economizing cannot be imposed on people all the time, as in the end, they will respond and nobody knows in which particular way (Astashenkov 2013).

It is exactly due to the methodological vacuum that many scholars, experts and policy-makers fail to comprehend the root causes of the crisis and to find the way out. Therefore, they can hardly find a proper mechanism to overcome the crisis and to move to a crisis-free evolutionary path of the transition from the asocial model of economic growth to the adoption and realization of the economic-growth concept and strategy that would allow the prior development of the real sector and the development of any human individual and his/her qualities.

The question, which many scholars pose in this connection is whether we should consider the crisis in development of the global civilization, as well as the wars, terrorism, man-made and natural disasters as transient phenomena and casual events, or this is a chain of cause-and-effect relationships between phenomena and events and a result generated by the effects of inherent and objective laws that apply equally to nature and society and underlie the co-evolutionary development of the world system.

Therefore, the major prerequisite for the transition to the crisis-free development is to obtain and master the knowledge on the objective causes of the global systemic crisis, to find the path of the crisis-free development and to understand the implications of each decision made. The time of development by try-and-error method has gone into the past irreversibly.

### New Methodology for Learning the Regularities of the Human System Development

For many years I have been studying the objective causes of the crisis in the human-system development and try to make some forecasts for the future. Over thirty years ago, while trying to explain the contradictions within the Soviet economy, I found out that the then existing economic theories and general scientific knowledge at large had exhausted their inherent explanatory potential in the search for the ways to overcome negative phenomena. However, it became also clear that in order to solve those problems it was necessary to find what could be described in Marxist terminology as the only possible form of production relations and thereto new relevant production forces. Since then, I have been searching for the theoretical approach at the level of political economy and for the methodological instruments that would help to disclose the objective idea of the human-community development and to reveal the objective causes of crises and find the only possible model of human relations for the present time and future.

At that stage of the afore-mentioned political-economic study, which is also supposed to include the philosophical understanding of the problem, the methodological and theoretical platform was formed by the materialist dialectical method supplemented by the tools of economic cybernetics. Having realized that the major forms of being are space and time, and that the being without time is as great nonsense as the being without space, time was taken as the colligating index (criterion) characterizing the positive or negative movement towards the goal.

The scientific novelty of the introduced criterion consists in the fact that it allowed providing a periodization for the possible forms of development of the production relations in terms of reduction or prolongation of time needed to achieve the developmental goal. That goal was formulated similar to the concepts in the majority of literature sources on political economy – the satisfaction of constantly growing human needs as well as the creation of conditions for comprehensive and harmonious development of an individual.

The major political and economic conclusion drawn at that stage of research which was presented in my thesis, was as follows: (1) another step forward was made in the development of the Marxist methodology. It was a particular human individual (rather than a commodity as drawn by Marx) which I took as a cell of society; (2) socialism had not been achieved in any country of the world yet; (3) socialism would only emerge when property becomes both private and public – that is, when the private production becomes connected with a particular human person and commodities will be produced by demand (order) of a particular individual, and thus, the redundant and unneeded commodities will not be produced, while the consumed resources will be used in an efficient and rational way.

But by the early 1990s, the then existing form of production relations became correlated with the phase of initial capital accumulation, and hence the production forces were becoming even more primitive. The innovations were rejected, while the development took the retrogressive course.

Again, there arose the question of whether that conclusion was incidental. So, it was necessary to achieve a new level of understanding the problem, and the research was reoriented to a new target – to achieve the worldview level. As a result, the new methodology was devised for the cognition of regularities in the human community development.

This methodology is innovative since it helps to reveal the regularities of the human community development in any context – whether in the context of civilization, or in terms of the complex dynamics of long-term historical development, or at the local, regional and global levels, or in terms of socio-economic and political system, or as an integral system. The main novelty is that all these aspects are considered, studied, examined and analyzed in terms of achieving the single and objectively set ultimate goal of development – that is, in the framework of the systemic approach.

Here one should note that as early as in 1784, Immanuel Kant in his *Idea for a Universal History with a Cosmopolitan Purpose* considered the world history as a purposeful process. He searched for means to bring history under a law and believed that the law of history is meant to be the law of development. Kant found the solution in connecting history with its initial goal what would give it a regular character. To bring history under a law would mean to make it move towards a certain goal. In other words, he meant to conceive history in terms of teleology and 'to try to see if we can discover a natural purpose in this idiotic course of things human. In keeping with this purpose, it might be possible to have a history with a definite natural plan for creatures, who have no plan of their own' (Kant 1963–1966, vol. 6: 8). Thus, according to Kant, the reason and purpose of history are to bring to the full the development of human reasonable natural properties. And this purpose of history is as well the purpose of nature, while the development of reasonable human properties would be expressed in the growth and accumulation of knowledge and use of this knowledge by a human individual for reasonable organization of his/her life. In Kant's view, the ultimate purpose of the world existence is the highest good in the world, and in the notion of the highest good he combines the full realization of the moral law with physical welfare of humans as natural creatures.

Many authors of the reports to the Club of Rome also sought to formulate the goal of the global community development and, proceeding therefrom, to articulate new proposals for reorganization of the international order (RIO) as well as to find a new and perfect social organization of people. For example, in the third report to the Club of Rome its authors, basing on universal human values defined the main goal of the world community (in which equal opportunities would be provided within and between countries) as providing the dignified life and moderate wealth for all citizens of the world (Tinbergen *et al.* 1976). However, the hopes that these authors will be heard did not come true.

Another report, in which the global problems were addressed through the prism of a system of goals and values and which contributed to a cardinal transition from the quantitative to qualitative analysis, was entitled *Goals for Mankind*. Here the fore position was taken by the concept of 'new humanism' and the idea on the primacy of personal human qualities that would provide for the 'human revolution' as well as for the 'revolution of consciousness' and societal transformation. Another cornerstone in the basis of this report was the concept of global solidarity, when the norms of human behaviour and norms of state policy would determine the 'new standard of humanism'. According to the report authors headed by Dr. Ervin Laszlo (the world-known professor of philosophy, systemic sciences and political science, honorary doctor at several universities, program director at the UN Institute for Training and Research, and President of Vienna Academy of Futurology), it would be necessary to formulate the global development goals and to present them to the global community.

Inspired by the assigned task, Dr. Laszlo and his group undertook the national- and transnational-level analysis of the 'atlas of goals' set by different regions, countries, churches, multinational corporations, United Nations and other international organizations, and, having interviewed many representatives of all spheres and directions of human activities, set forth the following four global goals: (1) global security (ending the arms race, elimination of wars and conflicts, and renunciation of violence); (2) the global-scale solution of the food problem, elimination of famine, and building the global system that would be instrumental in satisfying food needs of all people on the Earth; (3) global control over the use of energy and raw resources that would help to proceed to the rational and ecologically safe energy consumption, control of technologies, and economically efficient nature management; and, (4) global development oriented to the qualitative growth – that is, to the better quality of life and social justice in distribution of material and spiritual goods (Laszlo *et al.* 1977).

Proceeding from these objectives, the authors of this report offered several scenarios of the 'global solidarity revolution', in which the main role, in different combinations, is to be played by religious communities, intellectual groups, political leaders, government circles, businesspeople, *etc*. They hoped that scientific community, religious leaders, or business representatives of one country would be able to render influence on their counterparts in other countries and then 'all together' they could consider the critical issues and jointly work out the general solutions. Unfortunately, this idea has not been realized so far.

I selected a somewhat different way to define the global developmental goal. The task was to identify the initially and objectively set goal of development. Here the ultimate goal is the one that cannot serve as a means to attain a goal of higher level and at the same time serves the starting point (and a feedback) for a qualitatively new phase in the development of the whole system and of its every subsystem.

The logic is as follows. If any socio-economic and political system can be evaluated from the position of the ultimate goal realization, then the given goal is of the planetary, global nature. From this it follows that when correlating the present practices of economic and political development in any country with the theoretically outlined or, rather, objectively preset ultimate goal, then it would be possible to find the redundant or missing links in the mechanism of such goal realization and to identify the shortest-term and hence the most efficient and sustainable ways to its attainment.

Therefore, the essence and scientific novelty of the new methodological tools is expressed by the fact that it is based on the objectively preset goal identified within the human community development. To make this conclusion, it was necessary, as said above, to define not just the development goal of the human system, but also to define the ultimate goal which should not be a subgoal of the higher goal within the lifetime of a human individual. That is, to define the objective reason of the human system development means to understand that any human individual lives not to provide the GDP growth or to produce more weapons for his/her own annihilation. Any human individual must and can live for no other goal than the maximal development and realization of his/her own moral and intellectual potential with the concomitantly growing level of consciousness and physical perfection.

In other words, the objectively set goal is that any specific human individual in the course of his/her development must and can reach his/her own perfection or the Supreme Reason. Otherwise, development can proceed along the opposite path and lead to such optional outcomes as the blind alley, retrogressive development in order to start again, or a catastrophic outcome in the form of the apocalypse.

The second element of the new methodological 'tool-kit' which includes the integrity, systemic nature and cross-disciplinary approach is based on the premise that the world is integral and nature and society are subject to the same laws, and the integral world as a system can be only cognized through the integration of all disciplines and spiritual knowledge into one systemic, integral cross-disciplinary or, rather, trans-disciplinary knowledge. Therefore, it was necessary to integrate them systemically through the identification of the target function in development of the system and any of its parts in any framework (civilizational, formational, national, confessional, territorial, natural-scientific, socio-economic, socio-engineering, socio-cultural, political, organizational, *etc.*), and irrespectively of the prevailing development model (neo-liberal, Keynesian, totalitarian one or their combination). Only due to this knowledge, one can understand that the financial, economic, social, organizational, science-tech and, generally, systemic crisis in the world as well as all existing negative phenomena are the links of one and the same chain. Therefore, the solution must also be integral, systemic and unified for the whole world and at the same time must take into account the maximal variety of interests of all people living on the planet.

It is fair to say that the scholars learned long ago how to borrow or combine different disciplines for the study of various processes and phenomena. The spiritual knowledge, however, is a different story. But, we also observe some positive shifts. For example, Fritjof Capra, an American physicist of Austrian origin, in his book *The Tao of Physics*: *An Exploration of the Parallels between Modern Physics and Eastern Mysticism* as well as in his other bestsellers, states that physics and metaphysics invariably lead to one and the same knowledge. All his works bear the implicit message that 'inherent connections exist between everything'. Seeking to find a scientific resolution for the mystery of life, Fritjof Capra applies the theory of systems in his books to synthesize the latest achievements and discoveries of physics, mathematics, biology, sociology and other disciplines with spiritual knowledge of the East (Capra 1975).

The novelty of the methodology elaborated for identification and cognition of regularities in the development of the societal system also consists in the selection of the basic criterion which would help to express all the variety of processes, to separate the essence from the phenomenon as well as the objective from the subjective, and to make a generalized assessment characterizing the positive or negative development of the human system with respect to the ultimate goal.

For example, the GDP/GNP indices, human potential development index, happiness index, *etc*., do not help to reveal the regularity, essence, objectivity and direction of the whole variety of processes because, first, the economic reality tends to change faster than it is studied. Second, as contemporary analysts note, the reliability of the global statistical data raises big doubts. Third, the larger part of statistical information involved in the studies of economic processes represents a certain extrapolation of basic parameters constructed on the platform of certain models. Meanwhile most of those models were developed during the 'boom' of mathematic programming, in the late 1950s – early 1970s. Therefore, they cannot describe the condition of the contemporary economy in relevant terms at least because the current economic growth rates extend beyond the minute-errors field of the given models. Even the authors of the reports to the Club of Rome noted that in the course of computer simulation it was found that any model would inevitably reflect views, ideas and preferences of the researchers developing it, and this would become evident already in the selection of uploaded data. Therefore, such a model can hardly serve a means to learn the objective processes and cause-effect relations. And, fourth, to forecast the future and to make prediction is known to be an unrewarding and sometimes a dangerous matter, because the negative scenarios and therein laid 'forms of thought' tend to come true. Science has proved many times that thoughts are material and can be operated in order to create, cure, raise crops, correct weather, *etc.*, as well as to kill a person or to force someone to commit unusual actions up to the criminal ones.

In other terms, today the existing model of the human-community development (with all its transformations) conflicts with the scientific and technological achievements. Today the humanity is on the brink of self-annihilation by means of its own intellectual R&D. Meanwhile, the human community still remains a probabilistic society, which is insufficiently predictable and controllable, featured by a high-degree of uncertainty, and is absolutely incompatible with the concept of sustainable development proclaimed by the UN and other organizations at the highest level, with the 'Millennium Declaration', as well as with the concept, strategy and principles of building an informational civil society. Therefore, we may state that as never before we need a new approach to examination and identification of the laws of human existence, a new methodology for the cognition of regularities of the human system development and a new measure of all processes.

These examples are presented in order to show the scale of responsibility for consequences of the decisions made in order to create the global community and its institutes, especially, if such decisions neglect the inherent common laws underlying the human system development. Therefore, to create proper conditions for the evolutionary development of the human system in terms of achieving the goal and to bring the whole humanity into common temporal space are the main tasks whose resolution will help to overcome the crisis in the global community development as well as to streamline and unite the whole range of knowledge and theories.

This leads us to the conclusion that from the prospective of the systemic view of such factors as the human community development status and of the selected means and mechanisms to achieve the goal, time can become such a universal index (criterion). Today the human knowledge, with its avalanche-like growth, immediately becomes outdated. The knowledge, based on the empirical analysis and generalization of the past and present, lags behind since when a conclusion is drawn, the picture of the world is completely different and does not represent the actual reality.

So, the third provision of the new methodology of cognition defines time as the only positive index, which can be applied to measure and juxtapose all processes and phenomena. By means of time, we may measure and juxtapose the phenomena that are non-measurable or non-commensurable in terms of other indices, and, what is more, to temporally juxtapose all spheres of human and societal life with the target ideal and to define at what stage of human progress they are with respect to the goal.

The only opportunity and the only precondition to prevent knowledge from becoming outdated is to make it develop proactively, ahead of the actually unfolding socio-economic and political processes. This can be achieved only if knowledge is obtained on the basis of the cybernetic, systemic and cross-disciplinary approaches to the study of the actual reality, through the prism of the theoretical approach 'from the future to the present and past', rather than on the base of empirical analysis and/or subjective assessments and thereon based theories built along the pattern 'from the past to the present and future'. We must know *a-priori* which socio-economic and political structures and which technological system are relevant to the given goal and what is the mechanism to achieve it. Provided we find the socio-economic/political structure, technological system and mechanism of realization relevant to the goal, the closer we are to the goal, the faster the processes proceed. Hence the time interval between the emergence of a material and/or spiritual need of any individual or a whole society and the satisfaction of the given need becomes the only criterion of efficiency in attainment of the final or ultimate goal.

Thus, the fourth provision of the new methodological tool-kit is that there was found a uniform criterion of the human system development, which is the time between the necessity to achieve the single goal of development, and the reality, in which a society (in whatever aspect) and a particular human individual are located in relation to the achievement of the given goal. If the time between the emergence and satisfaction of any particular individual's need tends to continuously and evolutionary reduce to zero, then it means that the human system develops sustainably and efficiently in terms of achieving the goal. The application of the given criterion gives opportunity to control (manage) the time between the emergence and satisfaction of a particular individual's need. Meanwhile, to manage time means to control development in a way which will provide an evolutionary, irreversible and continuous reduction in time and bringing it to the zero criterion value. Only in such case the human system will start to develop sustainably and efficiently towards the achievement of the goal and in the interests of every particular individual.

## Brief Fundamental Conclusions from the Application of the New Cognition Methodology

It is not possible to dwell on the detailed description of the results obtained from the application of the new methodology; however, they are presented in such books as *Forecasting the Future: A New Paradigm* and *Crisis-Free Development: A Myth or A Reality*, as well as in many articles and conference papers published in Russia and abroad. A smaller part of such publications is presented in the bibliography (Fetisov and Bondarenko 2008a, 2008b; Bondarenko 2008, 2009, 2011a, 2011b, 2012, 2013a, 2013b, 2014).

To summarize, the new methodological tool-kit enabled us to make the following:

∗ to exceed the limits of the human system and view it as an integral entity of 'the past/present/future' in relation to the objectively set development goal – to satisfy the highest human need to become spiritually, intellectually and physically perfect and at the same time to achieve a high level of consciousness;

∗ to evade the reliance upon empirical data and subjective judgments on the past and present;

∗ to comprehend in time and space the objective picture of the human-system development, depending on the positive (sustainable) or negative (unsustainable) orientation towards achievement of the single goal.

This has made it possible to see that the whole centuries-long history of human community development offers only two paradigms of the human-system development, namely:

- **the first paradigm:** there existed short-time and short-space connection between production and consumption. It started when humankind consumed everything that was produced at the respective level of manual labor development. So, the time between the emergence and satisfaction of a particular individual's need was minimal. That was the pre-industrial mode of production for individual needs and by order, for a particular consumer at the household level (craftsmen);
- **the second paradigm:** production and consumption are connected indirectly. This development paradigm originated with the development of primitive technology, labor division, market, class of intermediaries, and the universal equivalent of exchanging the results of the labor – money. As a result of the gradual territorial expansion and foreign-trade development, the direct interconnection between production and consumption would be transformed into the indirect one. Thus, the second paradigm of development was formed. Its development in time and space would be accelerated by the transition to the industrial mode of development. Hence, the mass industrial production of the assembly-flow type develops as well as domestic and foreign trade together with the territorial expansion up to the global scale and mass consumption. This type of production is oriented at satisfying the demands and needs of an abstract end-consumer through a spontaneous, archaic and market-type form of communication (prolonged in time and space) with a specific individual. In such circumstances, the uncertainty of consumption led to the emergence and further global growth of disproportion and even complete de-synchronization between the time of production and the time of the circulation of commodities and money. The time of circulation becomes much larger than the time of production. Despite the multiple growth of material and physical factors of production, there was a tremendous breakaway of dynamics of their circulation from the real and, especially, virtual monetary form. The monetary methods to cope with the financial crisis would only strengthen this breakaway between circulation of real product and money, and would increase the disproportion between the time for production and time for circulation of commodities and money. As a matter of the chain reaction, the financial crisis rapidly grew into the systemic crisis, and today this has become the predominant model of development.

The essence of the second paradigm of development consists in the mass belt-line mode of production oriented at maximal profits rather than at satisfying human needs and comprehensive development and perfection of human individuals. The basic relationship among people is an indirect and desynchronized (in time and space) interconnection between various technologies of production of commodities and intangible values, on the one side, and the consumption by an abstract consumer rather than a particular individual, on the other side. The current systemic crisis signifies the peak, agony and inevitable collapse of this paradigm of development. That is, the model of human relations based on the indirect connection between production and consumption has entirely exhausted itself.

At this long-time and long-space road for movement of ideas, commodities, money, and information, when the time between the emergence and satisfaction of a particular individual's need is unknown, the conditions are objectively formed for different kinds of negative phenomena. Poverty and inequality, recession, skyrocketing prices and inflation, deindustrialization, primitive production and commerce, terrorism and corruption, natural abnormalities and disasters, *etc.* – all these are the links of one and the same chain and a result of the mediated development model. In this model of human relations, the factor of time plays the most negative role.

The current development model represents the mediated human relations that do not correlate with the started era of cosmic speeds and use of digital, informational, cognitional, nano- and other technologies. Due to the development of these high technologies, the economic and other realities change rapidly and become incompatible with the mode of production and consumption, and, especially, with the mediated-type interconnection among individuals which makes it impossible to coordinate interests.

The new methodological tool-kit allows an objective consideration of the formation pattern of another life-organization model capable of eliminating the primary cause of the systemic crisis and allowing taking the crisis-free development path.

## Proposal for the Development and Realization of 'Territory of Faster Development: Everything for People' ('Megaproject')

Objective grounds for the development and realization of this Megaproject include:

∗ availability of the new developed methodology for cognition of regularities in the human-community development (in brief, new cognition methodology of 'Everything for People'), proven several times in Russia and abroad;

∗ constructive application of the new methodological tool-kit for analysis, comparison and measurement of the global and Russian trends reflecting the deeper processes that so far are invisible to researchers;

∗ existence of the new paradigm of 'forecasting from future' that was obtained by means of the new methodological kit and provides the unambiguous assessments of the objective reasons that cause the global systemic crisis as well as the need and possibility to proceed to the crisis-free development road on the basis of the development strategy for Russia and the world;

∗ existence of the solid Megaproject structure as predetermined by the New Cognition Methodology of 'Everything for People': (1) *the goal defini-*

*tion*: the single goal objectively set for the long-term, mid-term and short-term perspectives; (2) *the single measure for all processes*: time; (3) *the single efficiency criteria:* continuous, evolutional and irreversible reduction of time between the goal and reality; (4) *cross-disciplinary nature*: at the juncture of all disciplines and spiritual knowledge;

∗ use of the new methodological resource serves a guarantee of successful contacts among all researchers in the RAS institutes as all of them would be able to speak the same language. This, in turn, will contribute to development of high professional level of research and to obtaining the results for resolution of the most complex problems in formation and practical realization of the Megaproject.

**A brief outline of the Megaproject: the resolution of strategic and tactical tasks:**

1. ***Formation of new production relations means*** to change the content of the economic and social policy of the state and to reorient it to the transition to the reproduction trajectory of development inside a country. This must only be achieved through the orientation of the whole reproduction complex to the ultimate result – that is, attaining of the development goal by means of evolutionary reduction of the time interval between the emergence and satisfaction of every individual's needs. This can be attained if commodities are manufactured only under the demand (order) from a particular individual, without manufacturing any redundant items.

2. ***Simultaneous formation of new production forces*** means to realize digital revolution in production and thus to make production personalized, that is, manufacturing of products for the one-person 'market'. To this end, it is necessary to draw and realize the subprogram for digital production. The minor high-tech forms of production with distributed systems, re-tunable in the real time depending on the demand (order) of a particular individual with respect to the whole range of his/her needs, must be the final link in such production at each local level (at the given individual's place of residence).

3. For all kinds of production and for all consumers at local level, simultaneous formation of the intercommunication infrastructure that would be based on digital ICT, broad-band television and other innovations.

4. At each local level, formation of the mechanism for real-time conciliation of interests of all actors (the state, business, and society) with interests of ultimate consumers (particular individuals). It is not a human individual, who must be digitalized, but rather the direct human communication and the whole interest-conciliation mechanism that would make it possible to provide everyone with equal and free access to all the variety of goods and benefits at each local level.

5. Providing the transfer of the new life-organization model to the entire territory of Russia, its EurAsEC partners (as a prerequisite for achieving

a communicative effect) and, may be throughout the planet (probably under the UN auspice).

6. *Tactical task*: Within the framework of the Russian Academy of Science and under the lead of its Institute of Economics, to build the inter-academy, cross-institutional and cross-disciplinary team of scholars and practical workers; to provide for participation of all science-towns and innovation-towns of Russia and the whole global intellectual community, united by network interaction in Internet, in the development of the herein offered model, with due account of special tax preferential regime and acts of law.

7. *Tactical task*: To understand and to accept the provision that the subjects of Megaproject implementation will include the state, business, society and each particular human individual, as all of them will be united by the shared interest in realization of the shared development goal.

8. *Tactical task*: Conceptualization of the need and possibility to develop and realize efficiently at each local level the 'Comprehensive target program of forming the new life-organization model and new technologies of the 21st century (new production relations and thereto relevant production forces'). The pilot project of this entirely new environmental approach can be realized at the local level of Russia's different regions and then proliferated throughout the country.

The major effects expected from the realization of the Megaproject:

➢ The establishment of digital equality among particular individuals. Equal access to the benefits of civilization provided under the made order and without producing anything redundant. Conciliation of the individuals' interests at each local level in the self-governance mode. All these effects will help to eliminate disproportions and de-synchronization in the movement of commodities, money and all processes in time and space, and thus to eliminate the primary root-cause of the systemic crisis, as well as to remove all systemic shortcomings in socio-economic, science-tech, institutional, organizational and other aspects of Russia's development. In turn, this new environment of human habitation and the higher-level consciousness will enable us to build secure and strong digital economy that would not depend on the state of affairs in the outside world. This only possible condition will provide security of a human personality, his/her residential community, his region, country and the entire world.

➢ Consideration of each particular individual's interests at each local level and conciliation of such interests in the real-time regime shall be the only available driving force that would provide motivation 'here and now' for the higher labor productivity. This, in turn, would make it possible to resolve the task of reducing dependence of the Russian economy on the raw-resource exports and would acquire the long-expected intellectual dimension, because any human individual would generate new knowledge in the societal and his/her own interests. Therefore, each local community can become the Silicon Valley and at the same time the BioEcopolis, and spiritual Mecca, and the Skolkovo Center for development and commercialization of innovative technologies. (The case in point is available in Rwanda, Africa, where they create their own Silicon Valley that will enable them to step over the centuries-long backwardness straight to the $21^{st}$ century.) Only in such conditions, by reducing manufacturing of redundant products and by generating the new ideas of each particular individual, it will be possible to create all conditions for accelerated realization of projects for modernization of infrastructural and technological bases of the economy and to resolve, for example, the problems of mono-towns, as well as to provide for the rise of Siberia and the Far East and to resolve other so far unresolved tasks. Investments will return in the real time rather than in half-century periods (*e.g.*, BAM).

Realization of this Megaproject in Russia and the entire global world as well as the transition to control (management) of time should become a breakthrough to the future. The main thing now is not to miss time and to prevent the destructive wave of the new crisis!

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# 12
# The Noospheric Concept of Evolution, Globalization and Big History

*Vasily N. Vasilenko*

*The followers of Vladimir I. Vernadsky's ideas claim that the relevance of the biospheric concept is increasing, as well as the biosphere-noosphere transition, thereby providing public safety and reaching sustainable development. Philosophical, ontological and futurological nationwide recognition of Vernadsky's legacy is proved by including the 150th anniversary of Vladimir Vernadsky in the UNESCO calendar of anniversaries under the title 'Noospheric Thinking – the 21st Century Thinking'. The author considers the issues of evolution, globalization and Big History from the perspective of noospheric paradigm. The issues deal with future development of the civilization within the Earth's biosphere. In order to take into account ecological threats for citizens in different regions of the planet, the criterion of noospheric approach to globalization challenges was chosen.*

***Keywords:*** *biosphere science, biosphere-noosphere transition, the unity of the noospheric nature of Man, noospheric status of an individual, noospheric functions of citizenship in the biosphere, noospheric imperative of humankind viability, noospheric anthropology and psychology, noospheric ethics, pedagogy and futurology.*

> The noosphere we live in is the sphere of human cognition.
> The noosphere is the last of many stages in the evolution of the biosphere in geological history, the condition of our times. The noosphere for me is neither a mystery nor faith creation, but empirical generalization.
> I realized yesterday, that human thought is a part of the noosphere, *i.e.* in terms of real life the freedom of thought should equal the economic freedoms of socialism.
> I am looking ahead to the future that represents transition to the noosphere.
> (V. I. Vernadsky, 1863–1945)

Noospheric Thinking – the 21st Century Thinking
(the motto of the 150th anniversary of Vladimir Vernadsky)

## The Origins of the Noospheric Realism: The Missed Lessons of Academician Vladimir Vernadsky

An award-winning journal *American Scientist* published an article of Academician V. I. Vernadsky 'The Biosphere and the Noosphere' in early 1945 which was translated by the author's son, Dr. George Vernadsky (Yale University). In the preface the editor claims that the publication presents the general intellectual outlook of one of the most distinguished scholars of the present century. The frontispiece depicted the photo of the scientist and the quote from his letter to Professor Alexander Petrunkevich, 'I *look forward with great optimism. I think that we undergo not only a historical, but a planetary change as well. We live in a transition to the noosphere. Cordial greetings, V. Vernadsky*'[1] (Vernadsky 1989: 139–150; italics mine. – *V. V.*).

The article draws relevant conclusions, 'The noosphere is the last of many stages in the evolution of the biosphere in geological history… Now we live in the period of a new geological evolutionary change in the biosphere. *We are entering the noösphere.* This new elemental geological process is taking place at a stormy time, in the epoch of a destructive world war. But the important fact is that our democratic ideals are in tune with the elemental geological processes, with the law of nature, and with the noösphere. Therefore we may face the future with confidence. It is in our hands. We will not let it go. July 22, Borovoye – December 15, 1943, Moscow' (*Ibid.:* 150; italics mine. – V. V.)

The article gave an account of Vernadsky's book of life entitled *The Chemical Structure of the Earth's Biosphere and Its Surroundings* and evaluation of the confrontation of the Soviet people and countries of anti-Hitler coalition with 'animal ethics' of Nazism. The greeting of the Presidium of the USSR Academy of Sciences (occasioned by the 80$^{th}$ anniversary of Academician) ran as the following, '…We admire your unwavering optimism. During the hardest days of the Great Patriotic War you, Vladimir Ivanovich, stated that the one who propagates the wild ideas of the Middle Ages will never succeed. You also mentioned that fascism was doomed and that *reason, goodness and justice should gain victory*. This winter ***your prediction is beginning to fulfill. We will be looking forward to the day when mankind starts living in the Noosphere, the sphere of thought after eradicating fascism'*** (Vernadsky 2007: 28; emphasis mine. – *V. V.*).

Giving response to Stalin's greetings, V. Vernadsky sent a telegram, 'Our cause is just and it spontaneously coincides with the advent of the noosphere – a new sphere of life, biosphere – the fundamentals of the historical process, where the human mind turns into a powerful geological force' (Aksyonov 1993: 271–272). Later on Vernadsky sent an article entitled 'What One Should Know about the Noosphere' (*Ibid.*: 271) to editorial board of *Pravda* newspa-

[1] An explanatory note to the publication mentions the death of the scientist on January 6, 1945.

per and to the Commander-in-Chief. The second telegram ran as follows, '07/27/1943, Borovoye. Dear Joseph Vissarionovich! I am sending you my article, which I have sent to the editors of *Pravda* as well, it would be worthy of publishing due to the fact that I point to the natural process which ensures our ultimate victory in this world war. In the telegram I sent you I point out the value of the noosphere and inform you that I shared half of the prize, named after you, with the Red Army. With deep respect and devotion. V. Vernadsky. I am sending you the article, as I do not know whether it will be published or not'.

Vernadsky made the following diary entry of 4/9/1943 in Borovoye, 'Today I have sent a telegram to Stalin informing him of RUR 100,000 award donation which is meant for defense. In the letter ***I am writing about the noosphere and I am wondering whether I would get a reply.*** This is the first broad statement about the noosphere in real life conditions. I expect it to be published widely. It remains to be seen what happens next' (Vernadsky 2010: 428; emphasis mine. – *V. V.*). The expectations have not been fulfilled.

The article was published in the short-run journal *Advances in Modern Biology* in 1944 (No. 18) in isolation from real-life situations. It had an impersonal title 'Some Words about the Noosphere'. After the victory of the USSR and other countries over fascism, the conclusions of the Academician about the causes of world wars, and the threat of 'animal ethics' of Nazism were relegated to the periphery of political interests of the ruling and those staying in power of the class life of the nations of the world. The time has shown that humanity pays off 'hot' and 'cold' wars of geopoliticians, and as a result we observe the upsurge of fascism in Central Europe, for example in the Ukraine. Here Vernadsky created the doctrine of the biosphere, hatched the concept of development of the biosphere into the noosphere. In 1918 V. Vernadsky organized the Academy of Sciences and was elected its first President.

However, the majority of the analysts of the scientist's legacy consider his life imperative, 'What and Why a Person Should Know about the Noosphere' to be minimized to 'Some Words about the Noosphere'. The danger of neglecting the lessons of Vernadsky is becoming more obvious: the study of the biosphere identifies the imperatives of ecologizing science, knowledge, education of generations, functions and powers of state control in the regions of the world. The study based on the biosphere-noosphere transition allowed devising the theory of sustainable human development. The diary entry of 05/26/1938 drew the following substantive conclusion, '***Science is a natural phenomenon – an active expression of geological manifestation of humanity, transforming the biosphere into the noosphere.*** It mandatorily expresses real correlation between the human living matter – the totality of people's lives and the environment, and primarily the noosphere. The human and his genome can be removed from the noosphere only mentally. The man ⇆ noosphere relationship is inseparable' (Vernadsky 1988b: 81, emphasis mine).

The concept of the noosphere derives from Édouard Le Roy (1870–1954), 'If we mean to introduce a Human being in general life history without distorting and disrupting his role, it is of vital importance to place a Human being at the top of the pyramid, where he rules. It comes down to the idea that wildlife biosphere finds continuation in human biosphere, the sphere of consciousness, thought, free and conscious creativity, thinking per se, in short: the sphere of consciousness or the noosphere' (Le Roy 1928; Aksyonov 1993: 656). He was attending seminars taught by Vladimir Vernadsky at Sorbonne (Paris 1923–1925) and was familiar with his research.

For V. I. Vernadsky the sphere of thought, labor and the sphere of human mind coincide with the noosphere concept of living generations of Individuals, Citizens in the planetary community, '*The thinking man is a measure of everything.* He is a huge planetary phenomenon' (Vernadsky 1988b: 276). The global geological power of mankind and planetary scientific thought was generalized. Taking into account the universal role of science, Vernadsky managed to establish the Committee for the study of natural productive forces (1915) in the Academy of Sciences and was elected its Chairman. Analyzing the 'imperialist threat of bloody application of scientific achievements' to peoples and states (1914–1915), he explained the strategic role of 'protective and defensive strength of scientific creativity', 'that should be the top priority in order not to bring mankind to self-destruction' (Vernadsky 2003: 545–546). In the article 'The Goals of Science in Connection with the State Policy in Russia' (June 1917) Vernadsky (the member of the State Council and the Provisional Government) makes generalizations expressing the prognostic potential of science, education, the neglect of which reduces the viability of the state, 'Revolution should not lead to the disintegration of Russia. The majority of people do not take into account the fact that **there is a commonality more powerful than the state; there is scientific unity of the territory. Preservation of a unified state and national revival – do not contradict each other, if resolved in a scientific way**. Science significantly contributes to international understanding. It connects people and nations in a non-violent and solid way. It reveals the enormous benefits of the country-continent. For the time being, we are not taking the advantage of it' (Aksyonov 2001: 201; emphasis mine. – *V. V.*)

The research 'Scientific Thought and Work as Geological Powers in the Biosphere' (1937–1938) shows the role of scientific knowledge in socially equitable life of citizens in the state, the necessity to take the knowledge into account while providing welfare and preempting the threat of danger, '**Outbursts of scientific creativity take place and partly, to a certain extent provide transition from the biosphere to noosphere.** However, apart from this, a person has continuous social, individual and material-energetic connection with the biosphere. The connection is uninterrupted and lasts as long as the person lives; it is no different from other biospheric phenomena' (Vernadsky 1988b: 46; emphasis mine. – *V. V.*).

Human scientific thought, creativity of nations, Academies of Sciences, education system, fields of knowledge, the culture of countries – all of these constitute the noosphere. Thinking man is the subject, factor, and participant in the evolution of the mind of ethnic groups in a global society, the attractor of the culture of geo-civilizational existence. The scientist defined 'the measure' of Man in nature at the new level of knowledge, 'the measure' as Man sees it in terms of the biosphere, offered by Protagoras (490–420 B.C.). Ancient Greek philosopher, the founder of the sophist school claimed, 'Man is the measure of all things: of things which are, how they are, and of things which are not, how they are not. Many things prevent knowledge including the obscurity of the subject and the brevity of human life'.[2]

Carl Linnaeus (1707–1778), natural philosopher, singled out Man from the 'realm of nature' and called him using the nooname *Homo sapiens*. 20,000 species had been described before Linnaeus started doing his research. He described 4,000 species of animals and 10,000 plants along with *Homo sapiens* in *The System of Nature*. By the epoch of V. Vernadsky, E. Le Roy and P. Teilhard de Chardin the Register of biospecies in regional ecosystems of the Earth's biosphere had exceeded 1,000000. At the beginning of the 21st century 1,7 – 2 million biodiversity species had been described. However, extinction threatens 1/10–1/2 of species. Firstly and foremost it threatens *Homo sapiens* who does not show reasonable attitude to his House. Researching the basics of ecosystem sustainability in the biosphere, describing biodiversity species lags behind the growth of anthropogenic threats, especially those on the borderline of replacing the biosphere by technosphere. The UNO adopted a series of environmental conventions (on biodiversity, climate change, combating desertification, *etc*.), the 21st century agenda, all of these come true in all countries on planet Earth.

Why? The answer is simple*: globalization of human existence proved that Homo institutus, making economic choices, dominates at the level of government bodies and UN officials. Impersonal Homo economicus institutius of a global society* acts ethnoecologically, culturologically**,** *under the name of Man,* while developing regions of the planet's biosphere, the settlements of mankind, structures of civilization (Inshakov 2004: 39–44; 2005: 13–14).

As for the concept of *thinking man*, Protagoras, Aristotle, Linnaeus, Smith, Darwin, Marx and other scientists are right. But in terms of real attitude to the biosphere it is not noospheric functions of Man, gained through scientific institutions, education system, culture of generations (nous potential of Homo sapiens institutius[3]), that prevail globally, but particular human qualities. The quali-

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[2] URL: http://www.brainyquote.com/quotes/quotes/p/protagoras2055402.html

[3] Scientific name *Homo sapiens institutius* (the original name of the Man, Personality, Citizen as a reasonable being) expresses a sense of belonging of ethnic groups to the institutions of social ac-

ties express *the measure* of zoological, social, political, military, economic, geological, technical, informational, and other manifestations. Fundamentally, the nooname *Homo sapiens institutius* expresses: 1) **the ability** of generations to conceive the noospheric nature of Man in the Earth's biosphere, Here/Now; 2) **the competence** to take into account the noospheric nature of Man (adhering to the ethnoecological laws) in relation to the nature of the planet – the environment, thought, citizen activities Yesterday – Today – Tomorrow; 3) **mandatory compliance** with the noospheric functions of science, knowledge, education, culture in life of all people of the Global Community. But the growth of threats, risks, and challenges of globalization for humanity in the House of nature show that scientific *thought has become dependent on the subjects of authorities – authorities of the blind force, but not the power of the mind of generations.*

During the 125th anniversary of V. I. Vernadsky at conference in Kiev, Nicholas Polunin (English botanist, environmentalist, educator, 1909–1997) and Jacques Grinevald, ahistorian (University of Geneva) stated, 'There is a question whether we should **ponder over 'Vernadskiansky revolution' as a term encompassing the entire range of its concepts.** The revolution can effectively lead to progress in education, with regard to the environment, and as a result to improving people's lives. To a certain extent it should have constituted an important and distinctive facet of the global movement for environmental protection' (Polunin and Grinevald 2000: 550; emphasis mine. – *V. V.*).

They point out, 'While developing this all-important concept and comprehending the Earth's Biosphere, it is of vital importance to take into account the historical figure of Vladimir Ivanovich Vernadsky, a far-sighted pioneer. **Yet it is a striking and deplorable fact that Western scientific culture, of which the English language is now by far the most-used vehicle, until recently disregarded Vernadsky's work and much that is symbolized by it'…**(*Ibid.*: 551, 548; emphasis mine. – *V. V.*); 'And now The Biosphere is emerging as a vital overall reality that we need to maintain intact and cherish perhaps even more ardently than any particular part or factor of our planet's terrestrial or aquatic surface' (*Ibid.*: 551).

René Descartes (1596–1650), a French philosopher, mathematician, physicist and psychologist expressed the intellectual 'measure'of human being in the proposition I think, therefore I am (cogito ergo sum). The proposition implies self-consciousness of Man and Personality in terms of nature, society, and civilization. It is also *the measure of our self-determination* among other living beings in the natural habitat on Earth. Vernadsky considers the life of *Homo sapiens faber* on Earth to be a biogeochemical function of the living matter in

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tors' existence in the social and natural reality of the planet, *i.e.* in the biosphere of the Earth, Space and Universe.

the biosphere of nature, cultural biogeochemical energy of the living matter: Man, Person, Citizen in the global existence of society. Therefore, *thinking man is the subject of the noosphere in the Earth's biosphere, the subject of Big Science in generations* (the source of developed and educated mind). Thus, thinking man is the guarantee of abiding by biospheric laws in life, thought, the choice of deeds by ethnic groups Here/Now in the cycles Yesterday – Today – Tomorrow of the Big History in the House of Nature.

Hence, in the *socio-natural reality* – the history of human existence in the regions of the Earth's biosphere, the function of ethno-ecological conscious unity of citizens with the nature of Yesterday – Today – Tomorrow (in terms of the quality of life, thoughts, acts in the institutions of global society) should be implemented. It constitutes the *Big History* of ethno-ecologically reasonable, ontologically, futurologically sustainable development of generations of mankind in the House of Nature. It is written by *minds of the Big Science – noospheric personalities*, world citizens, mastering the basics of noosphere safety (Vasilenko 2007: 657–663). The noosphere imperative of *Homo sapiens institutius* viability in the biosphere of nature is expressed by observing the principle of presuming ethnic-environmental hazard of mankind activity in the regions of the Universe.

The 3rd International Congress 'Globalistics 2013', held under the auspices of UNESCO and the International Consortium of Global Studies, was hosted to commemorate the 150th anniversary of the scientist at Lomonosov Moscow State University.

The participants of the 1st section of the Congress discussed the following issue 'V. I. Vernadsky's Research on the Biosphere and Noosphere: Modern Interpretation and Global Evolutionism'. Within the forums the following issues were discussed: 'V. I. Vernadsky and the Noospheric Paradigm of the Development of Society, Science, Culture, Education and Economics in the 21st Century' (Subetto and Shamakhov 2013), 'Scientific Legacy of Vladimir Vernadsky – the Fundamental Basis of Scientific and Educational Revolution of the 21st century, and the Global Strategy of Sustainable Development', 'Vernadskiansky Revolution in Scientific-Educational Learning Environment of Russia'. The anniversary events in many universities and institutes of the Russian Academy of Sciences were held under the motto 'Noospheric Thinking – the 21st Century Thinking'.

The biographies of V. I. Vernadsky, E. Le Roy, P. Teilhard de Chardin and their contemporary followers show the *ascension to the noospheric mission of man* in science, education, the culture of global society, mankind incentives. They provide real-life examples of citizens' service to the native land and interests of all mankind. Noospheric personalities crystallize noospheric thinking in institutions of society, the consciousness of people, and shape the noospheric ethics, pedagogy, psychology of life that are required for decision-making to eliminate the threats of globalization. Noospheric personalities of Man, Citizen in socio-being of the peoples of the Earth's biosphere are *the entities, the actors of the noosphere* (after the nooname *Homo sapiens institutius*), expressing the joint wisdom of mankind in the evolution of nature, co-evolution of nature and society. They consider the noospheric function of the science of generations as of planetary, cosmic (universal) scale within reasonable development of civilization. Therefore, noonames (the measure of scientific thought of Man, 'the logic of the noospheric phenomena' are to be considered basic for the noospheric paradigm of sciences, the knowledge of mankind. They express the binding nature of biospheric laws in the life of mankind on the Earth.

How can contradictions of mankind development in the House of nature be overcome, if reasonable self is not supported by adequate acts of citizens of the country (strategically, futurologically) and *there is a threat of depopulation, 'reduction' in the number of people?*

## Noospheric Personality in the Global Society: The Imperatives of Life, Deeds, Choice

Karl Marx assumed, 'Natural science will in time incorporate into itself the science of man, just as the science of man will incorporate into itself natural science: there will be one science' (Marx and Engels 1956: 596). But his followers and critics have neither proposed the name of the new science, nor identified the topic, subject, object, and the possible limits of the 'competence' of the scientists in the sphere of knowledge expressing the unity of *Homo sapiens institutius* with nature. Marx showed why under the conditions of the class and formation model of social and economic development a Man of social and economic development acts egoistically and unwise (despite the name) in political, economic, social, and other forms of managing people's life.

From the standpoint of the theory of the Earth's biosphere, the concept of the biosphere – noosphere transition, global and planetary conditions of life, thoughts, deeds of the generations of mankind (aggregate *Homo sapiens institutius*) coincide. V. I. Vernadsky noted down on 8.XI.1941, '…The memory of Hitler will stay forever. He was the man who managed to set goals of the world domination of one race and one person prior to the noosphere – the single reign of *Homo sapiens*, created as a result of a geological process' (Vernadsky 2010: 66). A year later (August 20, 1943) he drew conclusions about the nature of fascism and Hitler, the most urgent threats of social darwinism for citizens of the global society of the 21st century, 'Scientific thought turned out to be compared with animal ethics of Hitler, Mussolini and their gang' (*Ibid.*: 443).

If one tailors his assessment to realities of life in the 21st century, 'scientific thought turned out to be weak', as citizens of the countries are still divided by class organization of socio-economic development. Professor O. V. Inshakov expressed capital centrist tendency of the global political economy of countries: *Homo sapiens* is the institutional Man (*Homo institutius*), making economic choices – *Homo economicus institutius* (Inshakov 2004: 39–44; 2005: 13–14). Subordination of the works of scientists, science development, education, and society to the interests of the market contradicts 'the logic of the noospheric phenomena', capable of providing ethnoecological safety of citizens in the regions of the biosphere.

The interests of *Homo economicus institutius* prevailing in the countries and the UN structures aggravate the danger of selfish approaches of the subjects of the capital and authorities to life in countries of the Earth. Therefore, ideological, institutional, prognostic issues of the noospheric nature, the noospheric status of *Homo sapiens institutius* are at the forefront. The status functions in the noospheric mission of Man, Person and Citizen in native lands of the global society. 'Vernadskiansky revolution' (experienced by the author of the biospheric science, biosphere-noosphere evolution) in the worldview, consciousness of the people and aims of creative people are crucial for eliminating ethno-ecological danger to generations, overcoming threats of class-formation confrontation in the global society.

Vernadsky pointed out, 'The biosphere of the 20th century is turning into the noosphere, created primarily by the growth of science, scientific understanding, and social labor of mankind that is based on it. I will turn hereinafter to **the analysis of the noosphere.** Currently it is of vital importance to emphasize **the inextricable connection of its creation with the growth of scientific thought, which is the first prerequisite of the creation**. **The noosphere can be created only under this condition'** (Vernadsky 1991: 37–38; emphasis mine. – *V. V.*). Exploring the planetary function of the aggregate Man (generations of mankind) in the regions of the Earth's biosphere, he drew the following noospheric conclusion, *'An outburst of scientific creativity occurs and partly, to a certain extent, creates the biosphere transition into the noosphere*' (*Ibid.*). But, apart from this, man in his individual and social aspect is closely connected (in a natural, material and energetic way) with the biosphere. This connection lasts as long as man exists and is no different from other biospheric phenomena.

Summing up these scientific and empirical generalizations:

1. Man, as he is observed in nature, like all living organisms, and like every living substance, is a *function of the biosphere* in specific space-time.

2. Man, in all kinds of manifestations, is an integral part of the biosphere structure.

3. 'An outburst' of scientific thought in the 20th century was stipulated by the history of the biosphere and has deep roots in its structure. **The noosphere – the biosphere, processed by scientific thought** and prepared by hundreds of millions or probably billions of years **(by the process creating *Homo***

***sapiens faber),*** is not a short-term and transient geological phenomenon (Vernadsky 1991: 39–40; emphasis mine. – *V. V.*).

Vernadsky, researcher of the planet (geochemist), sees his participation in the 'outburst' of scientific thought in the 20th century, considering the global geological force of mankind (natural phenomenon), a planetary phenomenon of scientific thought of man (noospheric factor of the scholar in the Earth's biosphere) as a functional dependence on the environment, thoughts and deeds of generations:

1) *Homo sapiens faber* – a spontaneous factor of the aggregate humanity functioning in the Earth's biosphere (the environment of the social type of thinking man, *Homo sapiens*) in the nature;

2) *Homo sapiens faber* – a rational factor of man in the noosphere of generations, *i.e.* developed by science, education, culture and creativity in the global society;

3) *Homo sapiens faber* is to transform into an institution, a tool, a mandatory mechanism taking into account biospheric laws in terms of ethno-ecological laws of life of the citizens of the Earth – into the noospheric function of *Homo sapiens institutius*.

This means that in the life of nations abiding by the scientific name *Homo sapiens institutius* of the global society must be confirmed by the potential of the noosphere of Human nature, the noosphere status of an Individual, the noosphere function of the Citizen in the world. According to Vernadsky, a thinker, a researcher, a figure in the generations is the subject of the noosphere in the biosphere, function-factor of cultural biogeochemical energy of the living matter in the nature of the planet. It is in this sense that a scientific thought of Man, Person and Citizen in the generations of the native land is the measure of everything, the measure of intelligent life, thoughts, deeds in the regions of the planet, the institutions of governance within the state. That is why he paid attention to the 'traps' of 'divorcing' philosophers from the realities of human existence, society in nature, 'Philosophers proceeded from free ideas (as it seemed to them), searching for the tormented human mind, human consciousness and not accepting the reality. People, however, built their ideal world inevitably within the violent surrounding nature, the environment of life, the biosphere. Man did not and does not conceive the deep connection with it (independently of his will)' (*Ibid.*: 30).

The analysis of the biography and scientific legacy of V. I. Vernadsky, a thinker, researcher, planetary-scale personality, suggests that the scientist ascended from *Homo sapiens faber* status in geology to understanding the noospheric mission of Man, Person and Citizen in the institutions of science, education, the authorities of the countries of the world. Therefore, the nature, the phenomenon, substance and the top mission of 'Vernadskiansky revolution' in the consciousness of mankind, its significance for humanity cannot be understood apart from the creative biography of a person, bringing about a revolution in. He was devoted to developing institutions of science, education system, and enhancing their role in the native land. That means he lived 'in tune ... with the laws of nature, corresponding to the noosphere'. This allowed him 'to look forward to the future with confidence', with no fear of losing it.

Here are the key noospheric generalizations of the scientist from recent works – they are the criteria of noospheric thinking, consciousness, civil acts of a Person in the biosphere. They constitute *the core of the noospheric paradigm* of knowledge among generations of mankind.

The noosphere we live in is the major result of my understanding the environment (Vernadsky 2010: 27).

The noosphere is the last of many stages in the evolution of the biosphere in geological history, the condition of our times (*Ibid.*).

The noosphere for me is neither a mystery nor faith creation, but empirical generalization (*Ibid.*: 53).

Democracy means *the freedom of thought* and faith (*Ibid.*: 41).

I realized yesterday, that human thought is a part of the noosphere, *i.e.* in terms of real life the freedom of thought should equal the economic freedoms of socialism (1941) (Vernadsky 2007: 119).

I am looking ahead to the future that represents transition to the noosphere (1942).

Our cause is just and it spontaneously coincides with the advent of the noosphere – a new sphere of life, biosphere – the fundamentals of the historical process, where the human mind turns into a powerful geological force (excerpt from V. I. Vernadsky's telegram to I. V. Stalin, 1943).

Being the part of the living matter of planet Earth we feel the mystery of life instinctively and unconsciously vividly, our existence and the existence of life. I would say that the most profound manifestation of consciousness happens when the thinking man tries to find his place not only on Earth, but in Space. In a scientific empirical way he comes to understand the unity of all living things – from bacteria (and even viruses) to man – and to the impossibility of doubting the existence of microbes and such manifestations of consciousness that we identify in a scientific way (from infusoria, invisible to the naked eye, to man). There has been an unresolved mystery for thousands of generations, but the mystery of life is solvable (1943) (Vernadsky 1987: 141).

I am optimistic about the future. ***The noosphere is a real thing*** (2.II.1944) (Excerpt from the letter to B. L. Lichkov. Vernadsky 1989: 242; emphasis mine. – *V. V.*).

There is a tendency to the unification of mankind in history, to the noosphere – the future unity of the human organization as a single planetary efficient structure (16.II.1944) (*Ibid.*).

For me it is obvious the noosphere is a planetary phenomenon, a historical process taken in a planetary scale, a geological phenomenon as well (11.IV.1944) (from a letter to Vernadsky's son).

I am glad you expressed my idea of the noosphere as the synthesis of natural and historical process vividly and clearly (11.VII.1944) (from a letter to Vernadsky's son; *Ibid*.).

He saw the highest meaning of Faust's life in the mastery of nature with the help of the power of science for the benefit of the masses, in creating the noosphere (using the term of the 20th century) with the help of the science. He perceived it as the main mission of any state, the mission which had been non-existent for the statesmen of his time (1938–1944) (Vernadsky 1988a: 251).

I am putting the archive in order and preparing the storyline of '*Experienced and Thought over*'<...> I am eager to finish this work and live in the noosphere for a longer period of time ... (13.IV.1944). (From a letter to his daughter, N. V. Vernadsky-Toll) (Vernadsky 1945: 242).

In terms of growth of ethnoecological threats to generations, the moral imperative of Vernadsky 'to live in the noosphere for a longer period of time' expresses confrontation of the noospheric Person, Citizen of the global era with the myopic consumerism of market entities whose interests dominate over the institutions of the countries of the world. In the monograph *Scientific Thought as a Planetary Phenomenon* section 'Scientific thought and scientific work as a geological force in the biosphere' showed the relationship between the deepest manifestations of the scientist personality and the main motives of his scientific work, 'It would be impossible not to mention the newly emerging types of scientific fraternity – *non-state run forms of international scientific environment ... which will have a great future.* Establishing Gosplan in our country used to be the structure of a similar kind (by idea, not by performance). The idea of "scientific think tank" has been proposed by life'. '**The issue of planned, consistent activities for mastering nature and proper distribution of wealth, connected with acknowledging the unity and equality of all people**, **the unity of the noosphere**, is on the agenda' (1938) (Vernadsky 2007: 302, 303; emphasis mine. – *V. V.*).

Understanding the unity of the noosphere is expressed in noonames of Man, Person, Citizen and is *the basis of the noosphere anthropology*, the core of citizenship noospherology, noosphere futurology, and other sections of mankind noospherology. *Noospherology* is an integral science, formed on the basis of development the doctrine of the biosphere, evolution of the biosphere into the noosphere, studying the origins of the noosphere, the origins of nature in Man in the biosphere, the structure, characteristics of the noosphere status of an Individual, noospheric functions of the Citizen, forms of development, and implementation of citizenship mission for the generations of people in the countries of the world. In philosophical, scientific and applied value, the scientific name *Homo sapiens institutius* recognizes the unity of the noospheric nature (starting point) of Man, the noospheric status (role) of Personality, the noospheric function (mission) of the Citizen in the Earth's biosphere, society (native land), which is implemented in the noospheric function of geocivilizational mankind. The language of noospherology of ethnic groups identifies understanding of *the unity of Big Science and Big History as a unity of the noosphere*, implemented as a reasonable interaction of society with nature.

Here we come to the problem of *noospheric futurology, which constitutes the core of the noospheric globalistics,* – the science of intelligent, harmonious interaction of mankind generations with the biosphere of nature Here/Now, in the relay Yesterday – Today – Tomorrow civilization. *Noospheric globalistics* (a new scientific area, the subject of research, the area of knowledge, education) is being formed nowadays (Ursul A. D., Kaznacheyev A. I., Subetto A. I., Vasilenko V. N., Ilyin I. V., Smirnov G. S., Chumakov A. N. and others). I distinguish ideological, conceptual, and applied aspects in it. The aspects express the relevance of taking into account the noospheric nature, noostatus, noofunction of Man in cooperation of the subjects of a global society with the nature of the planet. In the report for the summit on sustainable development 'Rio+20' (Rio de Janeiro 2012) 'Viable planet for viable people: the future that we choose' the experts admitted, *'The current model of global development is unsustainable.* We can no longer assume that our joint actions will not reach the critical point with indicator threshold of environmental condition rising. It creates a risk of causing irreparable damage to ecosystems and human society'. But Vernadsky's conclusions on functional non-replaceability of the biosphere in the human destiny, during transition from the biosphere to the noosphere, the necessity of 'Vernadskiansky revolution' in the minds of citizens are not generally accepted. They are not accepted in terms of assessing the processes of globalization, bearing threats, risks, challenges to the biological species of the biosphere, calling themselves sapiens (*Homo sapiens institutius*).

The scientific ternary Space – Time – Life in the biosphere of mankind generations, discovered by V. I. Vernadsky (the author of the biospheric science, noospherologist-empiricist), is ethnoecological space-time of life, thoughts, deeds of Man, Personality and Citizen in a global society. The choice of measures of the quality of our lives should be adequate to the noospheric nature, noostatus, noofunctions of *Homo sapiens* and *institutitus* in the Biosphere, History, Civilization of the planet.

## Noospheric Mission of Man, Citizen in Culture, Civilization, History

For V. I. Vernadsky the sphere of thought, social labor, the sphere of *Homo sapiens institutius* mind coincide in the concept 'noosphere of mankind in native land'. Therefore, the history of science, history of knowledge is the history of 'the greatest creative power of *Homo sapiens*. It is the history of being a free personality, one of the greatest manifestations of cosmic forces' of mankind thoughts (Vernadsky 1988b). In his opinion not only a scientific thought of a free creative personality, but also the institutes of the Academy of Sciences and the knowledge system constitute the structure of the noosphere. Hence, the history of scientific knowledge of generations is *the history of forming the noosphere of mankind.* Vernadsky as a personality ascended to perceiving himself as the subject of the noosphere in the Earth's biosphere, to understanding the scientific work of *generations* of Citizens in the institutions of science and also as the factor of scientific thought in the structure of the noosphere of mankind. If 'the correlation people-noosphere is inseparable', 'a thinking man is the measure of everything, a huge planetary phenomenon', it means that it is *WE*, who are the generations of nations are the entities in the biosphere (Vernadsky 1988b). We should comply with security fundamentals of settlements in the life of a global society. *It comprises ethnoecological substance, measure, the noospheric vector of 'Vernadskiansky revolution' in science, education, deeds and institutions, managing citizens of a global society.*

Noospheric hypostasis of the life of ethnic groups of mankind in the nature are represented in the nooname *Homo sapiens institutius* – scientific self, social identity, political self-identification of Citizens of the states in the regions of the Earth's biosphere. In its turn the nooname of Man, Person, Citizen in the countries of the global society expresses the following:

1) belonging of the social species of biodiversity – *Homo sapiens* (Lat.) to those with the highest form of reason, developed by the system of education. This Personality implements the value of knowledge in the quality of life of generations in the nature (biosphere of the planet Earth), society (country), civilization of mankind; society of intellect, Personality, realizing the value of knowledge in the quality of life of generations in the nature (biosphere of the planet Earth), society (country), civilization of mankind;

2) the nooname acknowledges the ternary of the noospheric nature, noospheric status, noospheric function of *Homo sapiens institutius* in the Earth's biosphere – environment, thoughts, citizen actions, non-replaceable for the vitality of mankind generations in the nature;

3) the nooname *Homo sapiens institutius* (Person-individual in the family, ethnic group, society) consolidates understanding of the basics (foundations) of the rational nature in the ecosystems of the biosphere of the planet. The term implies potential belonging of the Individual to the subjects of the realm of the mind (the subjects of the noosphere in humanity generations), able to recognize, develop, and implement individual noospheric status of a Citizen in the family, society, nations of the world;

4) the nooname *Homo sapiens institutius* recognizes the presumption of environmental hazards, economic, and other types of human activity; its princi-

ple (measure) in the nature, country, states of the global society. The measure acts as the noospheric imperative of generations' viability.

*The noospheric hypostasis of a Citizen of the Native Land is implemented in the core of status-functional interaction of ethnic groups' generations with the biosphere in the regions of the planet.* The terms ‘Citizen’ and ‘Native Land’ are capitalized, as they express basic aspects of Man, Personality in the life of the subjects of a global society. Belonging to *Homo sapiens institutius*, *WE* can qualify for Surname (by family, generations), Name, Patronymic, which give the grounds for citizenship in the countries of the Earth's biosphere. And the nooname of *Homo sapiens institutius* generations has no constitutional, legal (lawful), or other forms of recognition, status confirmation in the institutions of society.

The threat of species depopulation, calling themselves *sapiens* (*Homo sapiens*), raises the following questions:

– Do the living peoples of the planet have a Past, but perhaps no Future History?

– If *WE are INTELLIGENT*, why do we not force the mind to increase the vitality?

– What basis makes it possible to overcome the irrationality of the current model of global development of society, generations of mankind in the Earth's biosphere as a whole?

During the evolution of *Homo sapiens faber* of ethnic groups in *Homo sapiens institutius*, the global philosophical problem of the transition from unsustainable (unstable) global development to ontologically reasonable, futurologically sustainable is resolved. Hence, the scientific name *Homo sapiens institutius* of the global society should be seen as a *means of recognizing* the functional unity of the noosphere of Human nature, the noospheric status of an Individual, the noospheric function of the Citizen. They are to be implemented in cooperation of the population of states with the nature of biospheric regions of the planet.

Disregard of the noospheric bases in the biospheric nature is expressed by the fact that *WE*, the population of the native land, take into account the stability of ecosystems in the regions of the Earth, inadequate to threats of life and health. The threads of processing the inert expand (up to 50 tons per year per person, out of these 1 per cent to 0.5 per cent is beneficial, the rest pollutes the territory of the settlements). Civilization technosphere turns from local to regional, global and cosmic, poisoning the hydrosphere, atmosphere, soil and suppressing all living things. One should use a preemptive tactic in considering the fundamental connection between social and biological, ecology, biology, genetics and health of generations. ‘Public health has always been regarded as the indicator of well-being of the nation and the backbone factor that links culture, economy, ecology, education, policy, bio- and noosphere' (Shevchenko 2004: 399).

By the beginning of the 21st century clinical medicine (23.53 per cent) had been ranked first in the structure of scientific knowledge, it is followed by physics (12.16 per cent), chemistry (11.89 per cent), engineering (9.03 per cent), biology and biochemistry (8.12 per cent), the science of plants and animals (6.47 per cent), neurosciences (3.89 per cent), materials technology (3.52 per cent), molecular biology and genetics (3.05 per cent), geosciences (2.60 per cent), pharmacology (2.38 per cent), agronomy (2.38 per cent), microbiology (2.35 per cent). 2.31 per cent of publications account for works devoted to the problems of environmental protection (Marshakova-Shaikevich 2000: 139–149). The World Health Organization recognized the connection between the quality of life, health, longevity and the environmental condition of the regions of the Earth's biosphere. The top ten scientific breakthroughs of the 20th century: recognition of ethno-ecological criteria of viability of generations: 50 per cent of health depends on lifestyle, 20–25 per cent on the quality of the natural environment, 15–20 per cent – on state genetic and immune potential of the people, 8–10 per cent – on status, access to health care for the citizens of the state. According to noospheric anthropology, it is a formula of *ethnoecological viability* of mankind generations of the native land in the Earth's biosphere. Its indicators are in poor demand in science; forecasts for civilization development: by the 21st century there had been unfavorable ratio of human knowledge in the structure of science about the past (95 per cent), about the present (4 per cent) and about the future (up to 1 per cent). The ratio of citizens' knowledge on the environment of life is more disturbing: scientific knowledge of the subjects of the society on inanimate nature make up 95–98 per cent; on the nature of the living matter – 2–5 per cent; on the nature of Man (*Homo sapiens institutius*) in the biosphere – less than 1 per cent (Spasibenko 2007: 3).

In the era of globalization the moral responsibility of the Individual and Citizen is the noospheric imperative of ethnoecological security of humanity in the biosphere of nature. It is the imperative of evolution, globalization and the Big History of the Earth, in which Man, educated by institutions of science, culture, and power, is a Measure of noospheric co-evolution of society and the biosphere, the planetary entity, factor, attractor of Universal History.

## Noospheric Imperatives of Evolution, Globalization and Universal History

**An interdisciplinary and synergetic approach** to finding scientific methods of 'softening' the growing threats, risks, challenges of civilization to the present and future generations of *Homo sapiens institutius* dominates in conference proceedings of the International Congress 'Globalistics' which was held in 2009, 2011, and 2013, the anthology *Universal and Global History. The Evolu-*

*tion of the Universe, Earth, Life and Society'*, in collection of articles *Where does the Age of Globalization Go?* and other publications devoted to the urgent issues of mankind development. The noospheric concept of globalization allows us to deliver futurological predictions for the science base and *'remove' the problem of the future shock* (Toffler 2001: 23–24, 501). From the standpoint of the noospheric anthropology and applied noospherology, *the causes of the future shock* are disregarding the noospheric principles (nature) of Man in the biosphere, the noospheric status of the Individual, the noospheric mission of citizenship in society. All of these allow to increase the viability in nature, life of the country, civilization of the global era. Ontologically WE are not the victims of the future shock, but the hostages of the past knowledge, 'lagging behind' the processes of science globalization, education of citizens. From the standpoint of the noospheric futurology WE are the victims of a cosmopolitan, ethno-ecological impersonal attitude of the subjects of state authorities, UN entities of the planet to strategic decision-making.

Performing a biospheric function, *Homo sapiens institutius* is involved into ethno-ecological processes of the planet while implementing the biospheric function of *Homo sapiens* in the nature, noospheric status of Human being who is rational in the institutional sense (bearing wisdom of nations). It is necessary to understand in order to overcome our ethno-ecological and civil impersonal attitude to the biosphere in the following aspects of generations' existence.

1) In terms of social and natural reality of a global society we are included in the core of *status-functional interactions* (SFI) on life support of mankind – the triad 'ecological functions of the biosphere – ecological reproduction of ethnic groups – the viability of civilization'. The SFI triad 'ecology of the region of the planet – ecology of ethnic groups – ecology of civilization' performs *ethnoecotechnopolis functions of life* of the population on the territory of the state in the global community (the UNO). *Ethnoecotechnopolis* 'the Earth's biosphere – ethnic groups of mankind – ecology of civilization' performs biosphere-ecological, ethnoecological function of the unity of the people with the state. The noospheric measure, ethnoecological criteria for the safety of the citizens of the native land are expressed by *the formula of generations' viability* in the regions of the biosphere (50 per cent – 20–25 per cent – 14–20 per cent – 8–10 per cent).

Territories of the states of the global society should be simultaneously taken into account in their life supporting, viable and life arranging functions:

a) The noospheric potential of Human nature, Person and Citizen (scientific name *Homo sapiens institutius*), implemented during the longevity of the generations of the native land in the regions of the biosphere;

b) the noospheric status of Personality performing eco functions of Citizens in the countries of the world;

c) the noospheric mission of citizenship in institutions of culture, civilization, environmental management in local, regional and planetary scales of society.

Vernadsky showed that the biosphere of the planet is the living environment, environment for thoughts, acts and solutions. The latter can and/or cannot take into account the laws of nature for life, life activity of the state population. *The presumption of ecological risk* principle threatening economic and other kinds of activity implies the necessity of taking into account the foundations of the biosphere theory. Along with the above mentioned, *ethnoecological norms* (ethnoecotechnopolis requirements) of citizens' settlements on the planet should be followed. Assessing the *presumption of ecological risk* principle implies the scientific (environmentally conscious) unity of ethnic groups on the planet. Therefore, it is of vital importance to take into account the standards of environmental safety within the process of exchange between Man and nature with substance, energy, information (nature management functions of society).

Noospheric imperatives of ethnoecological safety of mankind generations (within the core of status-functional interactions) determine the need of overcoming *social selfishness of class relations* in the life of the countries where short-sighted interests of the property entities and state authorities prevail.

The noospheric potential of ethnoecological security of the Man, Personality, Citizen is implemented in the core of local, regional, planetary, cosmic scale of status-functional interactions of *Homo sapiens institutius* and the ecosystems of the nature's biosphere Here/Now, the vector of Yesterday – Today – Tomorrow of humanity. Irreplaceability of the biosphere is confirmed by human mastery of space technology and access to the Space.

The subjects of the noospheric anthropology are those of *the noosphere in the planet's biosphere* – the living environment, environment of thought, deeds of all generations of Man, Personality, and Citizens of states. Therefore, they are subjects of the evolution of *Homo sapiens institutius* of the biosphere into the noosphere. But this is only possible in favorable social conditions, revealing the noospheric ability of peoples within generations. The main priority of society is developing the noospheric ethics, pedagogy, psychology of Personalities. This science is capable of forming the noospheric potential of citizens, that is designed to create conditions for implementing the noospheric imperative of vitality Here/Now and in the succession Yesterday – Today – Tomorrow of the civilization.

2) Status-functional interactions on providing life support of mankind generations in the Earth's biosphere are controlled in the triad of status-functional institutions (SFI) of world states, ‘noospheric institutions of civil society – noospheric institutions of the native land – the noospheric institutions of the civilization’. Regional, planetary and other governing bodies (subjects of the UNO) constitute the noospheric institutions of civil society. The noospheric personality of the citizen of the native land (source, subject, nationality) is a

generic beginning of society, state institution, managing function of territorial authorities. The noospheric development potential, the highest values of life quality, way of thinking, and the power of creativity of citizenship subjects constitute the genetic core, the cultural code of noospheric civilization representatives in the native land among generations of peoples. The noospheric values of the subjects of civilization are formed due to *noospheric education of Personality, implementation of the foundations of the noospheric ethics, pedagogy, and psychology* in civil institutions.

From the standpoint of noospheric anthropology, general and applied noospherology primarily aim at compliance with ethnoecological requirements of citizens in the institutions of government, governance structures of states of the planetary society. Formation, development of noospherology, its applied areas determine the level of realizing the potential of the noospheric anthropology – *noospheric imperative* of mankind viability in nature. The triad, SFI 'noospheric institutions of civil society – noospheric institutions of the native land – the noospheric institutions of civilization' requires formation of *the structures for noospheric monitoring of generations.* The process aims at determining the direction of proactive strategic planning, forecasting, risk management, risks of globalization.

In the global era there is a prior issue for advanced development of science, knowledge, education, proactive ethno-ecological threats, risks, and challenges for citizens of the states in the biosphere Here/Now, in the succession Yesterday – Today – Tomorrow. This is the top priority of preventing 'irreparable harm to ecosystems and human society', set by the UN report 'Resilient People, Resilient Planet: A Future Worth Choosing'.

3) If the noospheric level of ethnoecological threats to generations is chosen within status-functional interactions (the core of SFI 'the Earth's biosphere – ethnic groups of mankind – ecology of civilization'), and the noospheric imperatives of civilization viability are controlled by the status-functional institutions (SFI triad 'noospheric institutions of citizenship – the noospheric functions of power – noospheric institutions of civilization'), then the actual reasonable control should be achieved in the system of *status-functional relations* (SFR) of the constituent entities of the state: 'generation of Citizens in the country – the authorities of the sovereign territory of the subjects of the Russian civilization'.

The noospheric human nature and the noospheric status of an Individual are formed by noospheric ethics, pedagogy and psychology. Noospheric education of citizens contributes to this process as well. The above mentioned concepts are implemented in the values of the noospheric cultural life of the subjects of a global society. The noospheric function of the Citizen (noomission of the citizenship) is implemented in the social sphere, cultural institutions and governing structures of society. The noospheric mission of governmental civil functions should contribute to the safety purpose of human generations, the strategy of sustainable development of society. These problems are solved by the methods of noospheric futurology (Vasilenko and Imanov 2010).

*The biospheric core* of status-functional interactions, institutions, relations of citizens in the processes of globalization contains the noospheric potential of *Homo sapiens institutius* viability in ecosystems of the regions of the planet. The generations of *Homo sapiens institutius* of the global society are *the subjects of the noospheric civilization* in the biosphere. The latter should enhance vitality potential of Man, Personality, and Citizens of states in the regions of the Earth. The criterion used to noospherically monitor strategic planning, forecasting, and management is in compliance with the noospheric imperative of mankind security, sustainable development of states in a global society.

*The noospheric core of* status-functional interaction of the biospheric subjects, the noospheric triad of status-functional institutions, the noospheric regulatory principles of status-functional relations of individuals imply understanding of *Big Science and Big History unity* in the biosphere.

In times of ethnoecological threats, risks, challenges of globalization to the fundamentals of peoples' lives in the regions of the Earth's biosphere, the noospheric concept of status-functional interactions, status-functional institutions and status-functional relationship allows to remove the trap of class models of states. These traps are controlled by the owners of world capital and create the patterns of noosphere formation, therefore it is essential to establish *noospheric structures* that will ensure the safety of generations, sustainable development of civilization. In accordance with the motto 'Noospheric Thinking – the 21st Century Thinking', foundations of 'Vernadskiansky revolution' in science, education, government institutions, management of global society, there is a need for *ethno-ecological examination (interpretation)* of the UN report at the Summit on Sustainable Development (Rio de Janeiro 2012) 'Resilient People, Resilient Planet: A Future Worth Choosing'. The relevance of the noospheric expertise is confirmed by the fact that in the final UN document at the summit Rio+20 'The Future We Want' (designed to implement the goals of the Millennium Declaration), did not include the problems of depopulation. The document lacked designs, recommendations and projects of scientists representing the noospheric schools of Russia.[4]

The first group of theses (13 out of 283) of the final document 'The Future We Want', adopted by the participants of Rio+20 Conference, expressed the following common vision:

'1. We, the Heads of State and Government and high-level representatives, having met at Rio de Janeiro, Brazil, from 20 to 22 June 2012, with the full participation of civil society, renew our commitment to sustainable development and to ensuring the promotion of an economically, socially and environ-

[4] Over 110 countries took part in drafting the UNO final document.

mentally sustainable future for our planet and for present and future generations.

2. Eradicating poverty is the greatest global challenge that the world faces today and an indispensable requirement for sustainable development. In this regard we are committed to freeing humanity from poverty and hunger as a matter of urgency.

3. We therefore acknowledge the need to further mainstream sustainable development at all levels, integrating economic, social and environmental aspects and recognizing their interrelation, so as to achieve sustainable development in all its dimensions'.[5]

The final thesis of the conceptual section in the final document at the Summit on Sustainable development which was held in 2012 describes obligations of the member entities of the United Nations:

'We recognize that people's opportunities to influence their lives and future, participate in decision making and voice their concerns are fundamental for sustainable development. We underscore that sustainable development requires concrete and urgent action. It can only be achieved with a broad alliance of people, governments, civil society and private sector, all working together to secure the future we want for present and future generations'.[6]

From the perspective of the noospheric approach, 'providing people with opportunities to influence their lives and their future, participate in decision making and voice their concerns' is essential at the UN institutions level and institutions of states. It is crucial to acknowledge ideological, institutional, the noospheric nature (fundamentals), the noospheric status (role), the noospheric function (mission) of *Homo sapiens institutius – noospheric citizenship* in the family of humanity in the Earth's biosphere. Ethnoecological involvement of *Homo sapiens institutius* into life-sustaining functions of regions of the Earth's biosphere expresses the ontological and futurological irreplaceability of habitat, thoughts, actions of citizens in the nature of the planet. From the perspective of the biospheric approach, evolution of biosphere to noosphere, we are the citizens of sovereign UN Nations – noospheric subjects, ethno genesis factors in the biosphere genesis in local and regional conditions of life of the Earth's countries. Therefore, we should realize that *we are noospheric personalities* in the families, institutions of power, management of settlements and we must comply with ethnoecological restrictions, regulations in life realities, acts of the subjects of a global society.

Thus, the noospheric potential of individuals in families, generations of the native land – reasonable subjects of ethno genesis in biosphere genesis

[5] See e-almanac 'Noosphere of the 21st Century' at URL: // http://www.socionauki.ru; http://www.vgi.volsu.ru/

[6] *Ibid.*

of the planet – should be aimed at ensuring the safety of citizens of sovereign states, *their sustainability in Big History of Humankind and the natural House (the Universe).* Vernadsky, being several generations ahead, pointed out that as long as citizens do not acknowledge the doctrine of the Earth's biosphere and the evolution of the biosphere into the noosphere, mankind has no future. In his diary dating back to 1940 he identified an alternative to social Darwinism in geopolitics, 'the 20th century is the age of the noosphere' (Vernadsky 2007: 109). The motto 'Noospheric Thinking – the 21st Century Thinking' is considered to be ideological, conceptual, institutional recognition of the doctrine of the biosphere, evolution of the biosphere into the noosphere, relevant to human nature. If the 20th century was the age of the noosphere, the 21st century is to become the age of the noospheric forestalling of ethnoecological challenges of globalization to citizens, transition to sustainable development of civilization.

Russia, the USSR, Russian Federation – the naturalistic birthplace of the theory of the biosphere and evolution of the biosphere to the noosphere. Together with China, India, Euroasian, G20, SCO partners and other neighbors, it has the necessary civilization potential to initiate the preparation, host the UN Summit on Sustainable Development, RIO+25 in 2017 and accept the futurologically valid political strategy.

In conclusion, ontologically and conceptually crucial finding for the peoples of the Earth: implementation of *the noospheric mission of Big Science in Big History* of the global society is possible due to compliance with the criteria of noospheric anthropology, the principles of basic and applied noospherology, the imperatives of noospheric futurology of mankind.

The noospheric approach allows to find relevant measures of the conflict resolution in the Ukraine the citizens of which appeared to be the victims of social Darwinism in geopolitics, the theory imposed by the adherents of capitalocratic lifestyle in states of the Earth.

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# 13
# Cybernetic Revolution and Forthcoming Technological Transformations (The Development of the Leading Technologies in the Light of the Theory of Production Revolutions)*

*Anton L. Grinin and Leonid E. Grinin*

**Abstract**

*The article analyzes the technological shifts which took place in the second half of the 20th and early 21st centuries and forecasts the main shifts in the next half a century. On the basis of the analysis of the latest achievements in innovative technological directions and also on the basis of the opportunities provided by the theory of production revolutions the authors present a detailed analysis of the latest production revolution which is denoted as 'Cybernetic'. The authors give some forecasts about its development in the nearest five decades and up to the end of the 21st century. It is shown that the development of various self-regulating systems will be the main trend of this revolution. The authors argue that at first the transition to the beginning of the final phase of the Cybernetic Revolution will start in the field of medicine (in its some innovative directions). In future we will deal with the start of convergence of innovative technologies which will form the system of MBNRIC-technologies (i.e. the technological paradigm based on medicine, bio- and nanotechnologies, robotics, IT and cognitive technologies). The article gives a detailed analysis of the future breakthroughs in medicine, bio- and nanotechnologies as well as some other technologies in terms of the development of self-regulating systems with their growing ability to select optimum modes of functioning as well as of other characteristics of the Cybernetic Revolution (resources and energy saving, miniaturization, individualization, etc.).*

**Keywords:** *production revolutions, Neolithic revolution, Agrarian Revolution, Industrial Revolution, cybernetics, Cybernetic Revolution, science-informational epoch, medicine, biotechnology, nanotechnology, robotics, cog-*

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*nitive technologies, self-regulating systems, epoch of self-regulating systems, miniaturization, individualization, information, control.*

## Introduction

Our article presents the analysis of contemporary technological shifts and forecasts the future technological transformations on the basis of the *theory of production principles and production revolution* which was introduced elsewhere (*e.g.*, Grinin 2006a, 2006b, 2007b, 2012b; Grinin L. E. and Grinin A. L. 2013; Grinin A. L. and Grinin L. E 2015; the history of the main technological changes is presented in these works). These new explanatory concepts are relevant for the analysis of causes and trends of major technological breakthroughs in the historical process and for the forecasting of new technological shifts. The article presents a general outline of this theory and analyzes its predictive capacities. The main part of the article is devoted to the analysis of the last production revolution – the Cybernetic Revolution – and the changes which took place in its course starting from the 1950s. The focus is on the changes which will most probably occur due to the Cybernetic Revolution in the next 30–60 years; for some aspects we have made forecasts up to the end of the 21st century.

## Section 1. THE CYBERNETIC REVOLUTION: THE MAIN CHARACTERISTICS, JUSTIFICATION, AND THE METHODOLOGY OF FORECASTING

### 1. The Main Ideas and Implications of the Theory of Production Revolutions

*According to the theory we have developed* (Grinin 2006a, 2006b, 2007a, 2007b, 2012a; Grinin L. E. and Grinin A. L 2013; Grinin A. L and Grinin L. E 2015*), the most fundamental causes of transition from one stage of historical development to a subsequent one are global technological transformations which create an essentially new level of productivity and initiate a new technological epoch. We propose that these basic technological levels and epochs can be defined in terms of* production principles.

We single out four **production principles**:

**1. Hunter-Gatherer.**
**2. Craft-Agrarian.**
**3. Trade-Industrial.**
**4. Scientific-Cybernetic.**

Among large technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian or Neolithic Revolution; 2) the Industrial Revolution; and 3) the newest Cybernetic one.

Each production revolution launches a new production principle; so the three production revolutions represent the borders between four production principles (see Fig. 1).

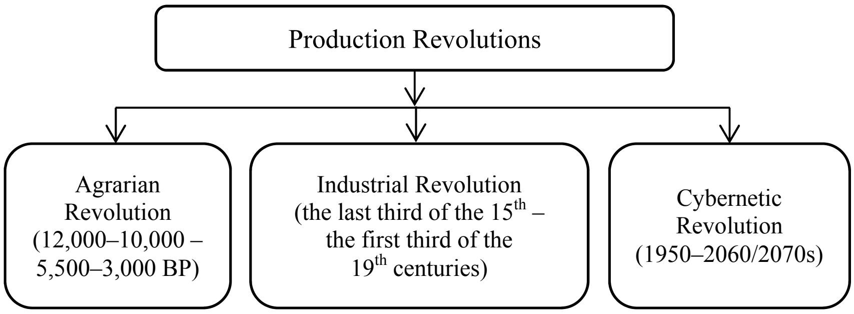


**Fig. 1.** Production revolutions in history

Each production revolution has its own cycle consisting of three phases: two innovative phases and between them – a modernization phase (see Fig. 2).

At *the initial innovative phase* a new revolutionizing productive sector emerges. The primary system for a new production principle emerges and for a long time it co-exists alongside old technologies. *The modernization phase* is a long period of distribution and development of innovations. It is a period of progressive innovations when the conditions gradually emerge for the final innovative breakthrough. At *the final innovative phase* a new wave of innovations dramatically expands and improves opportunities for the new production principle, which, at this time, attain full strength. As the final phase of the production revolution unfolds, the 'essence' of the production principle, its opportunities and limitations are revealed, as well as the geographical borders of its expansion in respect different climates, soils, diets, *etc*.

The production revolutions also bring about:

1. The development of fundamentally new resources.
2. A vigorous growth of production output and population.
3. Substantial complications to society.

(For more details see Grinin 2006b, 2007b, 2012b; Grinin L. E. and Grinin A. L. 2013; about Industrial Revolution see Grinin and Korotayev 2015a).

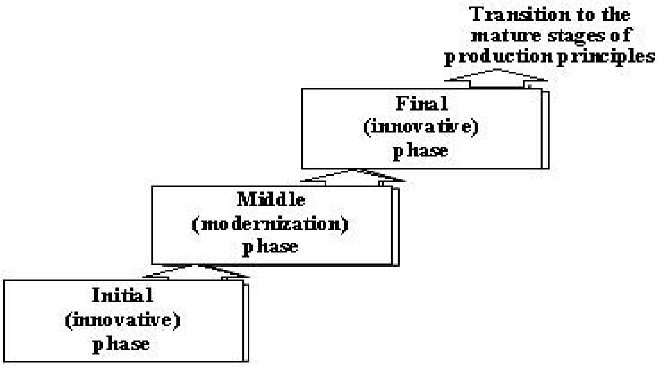


**Fig. 2.** The structure of production revolutions (phases and their types)

*The Agrarian Revolution was a great breakthrough from hunter-gatherer production principle to farming.* Its **initial innovative phase** was a transition from hunting and gathering to primitive hoe agriculture and animal husbandry (that took place around 12,000–9,000 BP).[1] The **final phase** was a transition to intensive agriculture (with large-scale irrigation and plowing) which started around 5,500 years ago. These changes are also presented in Table 1.

**Table 1.** The phases of the Agrarian Revolution

| Phases | Type | Name | Dates | Changes |
|---|---|---|---|---|
| Initial | Innovative | Manual agriculture | 12,000–9,000 BP | Transition to primitive manual (hoe) agriculture and cattle-breeding |
| Middle | Modernization | No designation* | 9,000–5,500 BP | Emergence of new domesticated plants and animals, development of complex agriculture, emergence of a complete set of agricultural instruments |
| Final | Innovative | Irrigated and plow agriculture | 5,500–3,500 BP | Transition to irrigative or plow agriculture without irrigation |

*Note:* * In this and Table 2 below the titles are given only to the innovation phases; the modernization phases do not need special designation.

[1] Following Gordon Childe (1950), the Agrarian Revolution is often called the Neolithic one. However, this notion is not quite satisfactory. First, it actually started during the Mesolithic era; second, it completed already in the Iron Age. One should not confuse the Agrarian Revolution as a global phenomenon with the British Agrarian Revolution of the 17th – 18th centuries (on the latter see, *e.g.*, Overton 1996; see also Grinin and Korotayev 2015a ).

*The Industrial Revolution was a great breakthrough from craft-agrarian production principle to machine industry, marked by intentional search for and use of scientific and technological innovations in the production process.*

Its **initial phase** started in the 15th and 16th centuries with the development of shipping, technology and mechanization based on the watermill as well as with a 'more organic' (Durkheim 1997 [1893]) division of labor. The **final phase** was the well-known breakthrough of the 18th and 19th centuries with the introduction of various machines and steam energy (for more details about Industrial Revolution see Grinin 2007b; Grinin and Korotayev 2015a). These changes are presented in Table 2.

**Table 2.** The phases of the Industrial Revolution

| Phases | Type | Name of the phase | Dates | Changes |
|---|---|---|---|---|
| Initial | Innovative | Manufacturing | 15th – 16th centuries | Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization |
| Middle | Modernization | No designation | 17th – early 18th centuries | Formation of complex industrial sector and capitalist economy, increase in mechanization and division of labor |
| Final | Innovative | Machinery | 1730–1830s | Formation of sectors with the machine cycle of production using steam energy |

*The Cybernetic Revolution is a great breakthrough from industrial production to the production and services based on the operation of self-regulating systems.*

Its **initial** phase dates back to the 1950–1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. We assume that the **final** phase will begin in the nearest decades, that is in the 2030-s or a bit later, and will last until the 2070s.

We denote the initial phase of the Cybernetic Revolution as **a scientific-information** one, and the final – as **a phase of self-regulating systems**. So now we are in its modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous phase (*e.g.*, computers, internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough. *We suppose that the final phase of the Cybernetic Revolution will lead to the emergence of many various self-regulating systems*.

The scheme of the Cybernetic Revolution is presented in Fig. 3.

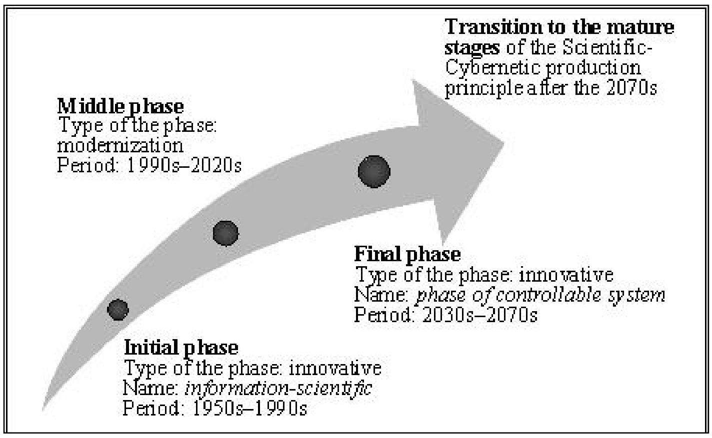


**Fig. 3.** The phases of the Cybernetic Revolution

## 2. Characteristics of the Cybernetic Revolution

### 2.1. The main characteristics of the Cybernetic Revolution

Below we enumerate the most important characteristics and trends of the Cybernetic Revolution and its technologies. One can observe them today, but they will be realized in mature and mass forms only in the future. These features are closely interconnected and corroborate each other.

**The most important characteristics and trends of the Cybernetic Revolution:**

1. The increasing amounts of information and complication of the systems of its analysis (including the ability of the systems for independent communication and interaction);

2. Sustainable development of the system of regulation and self-regulation;

3. Mass use of artificial materials with previously lacking properties;

4. Qualitatively growing controllability a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic and using tiny particles as building blocks);

5. Miniaturization and microtization[2] as a trend of the constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*;

6. Resource and energy saving in every sphere;

[2] See: http://www.igi-global.com/dictionary/microtization/18587.

7. Individualization as one of the most important technological trends.

8. Implementation of smart technologies and a trend towards humanization of their functions (use of the common language, voice, *etc.*);

9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[3]

**The characteristics of the technologies of the Cybernetic Revolution:**

1. The transformation and analysis of information as an essential part of technologies;

2. The increasing connection between the technological systems and environment;

3. A trend towards autonomation and automation of control is observed together with the increasing level of controllability and self-regulation of systems;

4. The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies) as well as capabilities for *choosing optimal regimes in the context of certain goals and tasks*;

5. A large-scale synthesis of the materials and characteristics of the systems of different nature (*e.g.*, of animate and inanimate nature).

6. The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system;[4]

7. The self-regulating systems (see below) will become the major part of technological process. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution can be called **the epoch of self-regulating systems** (see below).

*Various directions of development should generate a system cluster of innovations*.[5]

### 2.2. Why is the latest production revolution denoted as 'Cybernetic'?

The theory of production revolutions proceeds from the assumption that the essence of these revolutions can be most clearly observed only during the fi-

[3] For example, the control of human insufficient attention in order to prevent dangerous situations (*e.g*., in transport) as well as to prevent human beings from using means of high-risk in unlawful or disease state (*e.g*., not allow driving a motor vehicle while under the influence of alcohol or drugs).

[4] During the Industiral Epoch these elements existed separately: technologies were preserved on paper or in engineers' minds. At present, thanks to informational and other technologies the technological constituent fulfils the managing function. And this facilitates the path to the epoch of self-regulating systems.

[5] Thus, for example, the resource and energy saving can be carried out via choosing optimal modes by the autonomous systems that fulfil specific goals and tasks and *vice versa*, the choice of an optimum mode will depend on the level of energy and materials consumption, and a consumer's budget. Or, the opportunities of self-regulation will allow choosing a particular decision for the variety of individual tasks, orders and requests (*e.g*., with 3D printers and choosing of an individual program as the optimal one).

nal phase. One can retrospectively outline the future features in initial and middle phases, but they do not form a clear system yet. Thus, the designation given to the third production revolution is based on our forecasts concerning its final phase. We suppose that *the most important thing about this phase will be a wide use of* ***the principle of self-regulation and self-controlling in different technological systems*** *which as a result will transform into self-regulating systems. At the same time in the systems of new type, the characteristics of living matter will combine with technological principles.* We denote this revolution as 'Cybernetic' as it will lead to the transition to a wide spread of self-regulating systems. The analysis of such systems can be based on the ideas of cybernetics which is a study in controlling different complex regulated systems via the processes of receiving, transformation and transfer of information (see, *e.g.*, Wiener 1948; Ashby 1956; Beer 1959; Foerster and Zopf 1962; Umpleby 1999; Tesler 2004).

Cybernetics can also be defined as a study of general laws of receiving, storage, and transfer of information in complex controllable systems. In any case the notions of regulation and information are considered as the most important ones for cybernetics, as it is impossible to control anything without transforming information. Within the Cybernetic Revolution, the technologies connected with information processing and more complex systems of control become of utmost importance. That is the reason why it makes sense to consider the changes in information technologies as the initial phase of the Cybernetic Revolution since information technologies are the basis of a transition to regulating technologies. Regulation and self-regulation (as the highest form of regulation) in systems are also the most important categories in cybernetics.

### 2.3. What are self-regulating systems?

Thus, *the main characteristic of the Cybernetic Revolution is a transition to creation and wide distribution of the special kind of systems: controllable systems (in some respect they can be denoted as standalone systems, i.e. systems which are able to operate independently), and the systems of higher level – self-regulating ones*.

Let us explain. *Controllable (standalone) systems are based on* ***the principle of controllability****, this means a higher level of control which is not a direct human control but a control via some inanimate system or subsystem of control (technical or of some other kind). In fact such kind of regulated systems should have a greater autonomy.* Just as even a primitive machine differs from a mechanical appliance, so the control by the autonomous systems differs from human control or control by means of primitive appliances. The highest level of controllability will be denoted as ***self-regulation.***

***Self-regulation and self-regulating systems.*** Self-regulating systems are systems that due to the embedded programs and intellectual (and other) components can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment[6] as well as independently operate (or suggest alternatives) in a wide range of variations, having opportunities for *choosing optimum regimes in the context of certain goals and tasks*. They are the systems that operate with minimal to zero human intervention.

On the whole, this refers to the type of regulation via the technologies which allow the systems: a) to work most of the time without human interference as a part of control; b) to have more opportunities to independently respond to changes and to make operative decisions (and in future responsible decisions as well); c) to self-regulate and to self-adapt. In other words, due to special technologies one can allow the required processes to proceed autonomously, intervening only in the case of unexpected deviations from the predetermined parameters or in the case of some important reset of the parameters (of course, it is necessary to provide the signal about changes in parameters and a message inquiring the permission for some changes, or a number of possible options will be provided). Let us emphasize that this refers not only to technical but also to biological, compound or some other kind of systems.

*Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suitable mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (as robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and consumption of resources. Human life will become organized to a greater extent by such self-regulating systems (e.g., by monitoring of health, regulation of or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, etc.).* As a result, the opportunity to control various natural, social and industrial production processes without direct human intervention (which is impossible or extremely limited at present) will increase.

[6] The connection with the environment and the 'selection' of this or that 'decision' by the system on the basis of environment changes are also the most important ideas in cybernetics.

Nowadays, there are a number of so-called 'smart' technologies and things which in a proper and rather flexible way respond to external impacts. The simple but very illustrative example here can be mattress or pillows which take (or remember) the form of body (head) of a user; another example is chameleon sunglasses which change the intensity of sun protection depending on the brightness of the sunlight. However, in such technologies as well as in some automatic systems like auto-open doors, auto-switch light, *etc.* only some elements of self-regulation are applied. Within self-regulating systems, the processes of identification, memorizing and selection of regime should proceed on a much larger scale; it will often be the choice within the framework of uncertain opportunities. One can say that 'smart' technologies with the elements of self-regulation have the reaction amplitude within the predetermined spectrum. In such device like temperature regulator (connected through WiFi to Internet) which memorizes the climatic habits of an individual in a given period of time, the amplitude of preferences is rather small. Whereas for self-regulating systems, the amount of variations is largely unlimited, such a system is capable of choosing a proper action model in any combination within the framework of its opportunities. Let us consider the navigator. There are usually several routes to reach the destination, but since navigators can get direction from every point the number of routes is practically not limited. That is why navigator is supposed to lead the driver to the destination from any place. This is an example of self-regulation system of rather high level, though the device itself is not too complicated. The number of routes to reach the destination is not limited (as even when there are several possible routes the amount of variations becomes large). However, in any situation the navigator should bring the driver to the point of destination from any place. Here the degree of self-regulation can be considered as a higher one, though the device itself is not too complicated.

### 2.4. The main directions of the Cybernetic Revolution

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends should produce the effect of a system cluster of innovations as is often the case with the innovative phases of production revolutions*. Thus, if we consider the forecasts for the final phase of the Cybernetic Revolution in our opinion *the general drivers of the final phase of the Cybernetic Revolution will be medicine, bio- and nano- technologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulating production.* We can denote this complex as **MBNRIC-technologies.**[7]

Another question is in what sphere will the final phase of the Cybernetic Revolution start? Which one will be the first? First of all, one should remember

[7] As is known, there is a widely used abbreviation of NBIC-technology (or convergence), that is nano-bio-information and cognitive (see, *e.g.*, Lynch 2004; Dator 2006; Akayev 2012). However, we believe that this complex should be expanded.

that the 'breakthrough' sphere will be narrow as it happened during the Industrial Revolution (when the breakthrough occurred in a narrow field – cotton industry). In a similar way, we assume that the Cybernetic Revolution will start first in a certain area. Given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area should be highly commercially attractive and have a wide market, we predict that the final phase (the one of self-regulating systems) of this revolution will begin in one of the new branches of medicine. Perhaps, it has already formed (as biomedicine or nanomedicine) or it can form as a result of involving other innovative technologies into medicine. However, the development will follow the path of spreading the self-regulating systems into different new fields, their integration and development of the complex of MBNRIC-technologies.

Our assumption that the first field will be a new branch in medicine is based: a) on the analysis of the latest achievements in technologies; b) on a number of demographic and economic trends (see below); c) on the regularities obtained from the theory of production revolutions which we analyze in the following section. This section will define these regularities and the way they can be used in forecasting.

## 3. The Logic of the Production Revolution: The Analysis of Utility and Correlations between the Phases

Let us remind that the fundamental idea of the proposed conception of production revolutions is that *for every production revolution each of its three phases plays functionally the same role and the ratio between the duration of phases within the framework of each cycle remains approximately the same*. Thus, on the basis of the regularities identified within the Agrarian and Industrial Revolutions, one can make assumptions about the following factors:

*first*, about the duration of the middle (modernization) phase of the Cybernetic Revolution;

*second*, about the beginning and approximate duration of the final phase of the revolution;

*third*, about the sectors and directions that will be affected by the new technological breakthrough.

Therefore, the theory of production revolutions provides with methodological approach to ground our forecasts about the future technological shifts within the Cybernetic Revolution. Let us remind the reader that the initial phase of the Cybernetic Revolution has already been completed (lasting from 1950 to the early 1990s) and the modernization one is approximately half way through its development (it started in the 1990s and presumably will last till the end of the 2020–2030s). So we can compare the forecasts of the theory concerning each phase of the production revolution with present-day reality, and we can also infer the role that technologies will play in the final phase of the Cybernetic Revolution.

To give a better explanation to such a methodology, we formulate a number of functional and processual relations between the initial and final phases of the production revolution, between the initial and middle phases, and between the middle and final phases of the production revolutions. Knowing the algorithm of how processes manifested in the initial phase of the production revolution can be transformed in the middle and final phases, we provide forecasts of the Cybernetic Revolution development for the upcoming decades proceeding from the study of its initial and uncompleted middle phase.

### 3.1. The peculiarities of the initial phase: Amalgamation of non-system tendencies into a system and the development of new ones

**The initial phase of the production revolution is marked by the following peculiarities:**

1. *A number of tendencies and innovations that used to be non-systemic within the previous production principle get a systemic character.* The non-systemic character means that within the previous production principle these phenomena did not play a crucial role and did not result from its main characteristics, whereas within a new production principle the role of these characteristics significantly increases. This can be shown by the example of automatization which to a certain extent was developed within industrial production long before the Cybernetic Revolution. One of the main characteristics of the industrial production principle is that the production process is carried out by means of machines which are operated by humans using their sense organs, power and qualification. At the same time, some operations were performed without human involvement, in other words automatically. But the automatization of processes was not essential, in other words it was not a necessary characteristic of the industrial production principle but an extra bonus. In the early 20$^{th}$ century, automatization started to develop vigorously (*e.g.*, in electrical engineering for the prevention of accidents, in engines for convenient control, *etc.*). But still it had no decisive importance as it was not generally used for the automatization of technological processes.

Therefore, in that period automatization can be regarded as a hyper-development of such essential characteristic as mechanization. Besides, in the first half of the 20$^{th}$ century, automatization was not the leading direction of the industrial production principle. On the contrary, the leading position was taken by the processes of the latest division of labor including the wide distribution of assembly-flow production (a constant intensifying division of labor is an essential and transparent characteristic of the industrial production principle, strikingly manifested already in manufactures). The development of automatization in the second half of the 20th century is quite a different matter. It has become the most important characteristic of the scientific-cybernetic production principle (in its initial stages), finding new forms of application and expression in releasing human costs in process control (especially in Information and Communications Technology [ICT]).

Thus, *the initial phase of the production revolution develops the non-system elements of the previous period to the highest degree.* In this regard, automatization was the continuation of mechanization (see *e.g.*, Lilley 1966; Philipson 1962; Bernal 1965); as the chemistry of synthetic materials was the continuation of organic chemistry (Zvorykin *et al.* 1962); and as the Green Revolution in agriculture was the continuation of agronomy (Thirtle *et al.* 2003). The development of radio and television technologies was the continuation of the trend of new methods of information transfer which had emerged earlier. Such continuity can hide the intensity of the transition from one epoch to another. So it is not surprising that in the 1950–1970s the scientific and technological development was considered as the continuation of the Industrial Revolution, and at best it was defined as a new industrial revolution (scientific and technical revolution [Bernal 1965]). However, this super-development possessed some qualitative characteristics which will be described below.

2. *The former non-system characteristics together with newly emerging ones now merge into a unified system representing a new production principle.* Automatization, the chemical production of synthetic materials, the powerful development of non-computer electronics and means of communication, the emergence of various engines, the general transition to a new type of energy and fuel, the breakthrough in selection and plant protection, the discharge of a million workers previously employed in agriculture and industry and their transition to the service sector; together with a number of new directions in technology, informatics and science – all this creates a principally new situation in economy and also evidences the start of a new production revolution, namely, the Cybernetic one.

3. *An important factor with a powerful synergistic effect is the temporal density (the cluster pattern) of the formation and development of a number of directions which, to a greater or lesser extent, is typical of a new production principle.* Such directions in the 1950–1960s were the nuclear power industry, space exploration and usage of space frequencies for communication and other purposes, deep-sea exploration, information and computer technologies, multiplying equipment, laser technologies, and other areas (*e.g.*, in genetics, medicine and biotechnology).

4. *However, the future of these innovative spheres can be different*: some of them get particular and important development in the second half of the initial phase and in the middle phase; and other areas will not develop so intensively. Some can turn (at least, temporally) into dead-ends. Thus, at present the atomic energy industry faces severe constraints due to environmental problems,

the hopes to master thermonuclear energy fell short of expectations and deep-sea exploration (except for shelf sea) still remains exotic. At the same time, the development of ICT has become the leading trend.

5. *The change of the leading sector in the course of the production revolution.* The leading role of the peculiar characteristics and sectors of a new production principle becomes especially obvious by the end of its initial phase or during its modernization phase (as in the case with ICT). These sectors need some time to reach maturity and acquire a systemic character. *Thus, during these two first phases of the production revolution there is a constant alteration of the leading branches and sectors as well as the formation of new sectors.* One of the branches of a new production principle starts to dominate over the other branches for quite a long period of time (from the end of the initial phase until the middle phase). This branch becomes a key symbol of the production revolution and its driving force. *But later its role as a driving force decreases.* Thus, the wool industry (the most important branch of the initial phase of the Industrial Revolution) appeared to be unimportant in the final phase when it was replaced by the cotton industry.[8] So one can make an assumption that ICT will not remain the most important sphere of the final phase of the Cybernetic Revolution. Besides, advancements in this field will become only one constituent (albeit an important one) of the breakthrough which will be made in other fields.

Later, in the course of the final phase of the Cybernetic Revolution (approximately in the 2040–2050s) one can expect a new qualitative breakthrough in ICT. For example, one can assume that sooner or later serious changes will inevitably occur in programming itself. At present this process is labor-intensive and slow. It will most likely develop in the direction of simplification and robotization of some part of programming and especially in implementation of programs. In other words, machine programming will mainly substitute human programmers and 'the self-programming' trend will be developed.

6. *Already in the initial phase there emerges a prototype of the sectors which will become the leading ones in the final phase. But in the initial phase they do not play the leading role* (see below).

### 3.2. The characteristics of the middle (modernization) phase: accumulation of innovations and the search for a breakthrough point

1. *The large scale of already existing tendencies and the formation of new ones.* On the one hand, in this phase many processes develop (to a varying degree) that were formed in the initial phase of the production revolution. On the other hand, in the modernization phase we can trace the roots of those forms which

[8] Animal husbandry which developed in the modernization phase of the Agrarian Revolution did not become the leading direction of the final phase of this revolution.

will emerge as leaders in the final phase of production revolution. Therefore, it is important to distinguish between the tendencies which have already appeared to be mature and the tendencies which are only formed.

2. *The expanded development. Need for profound social and political changes.* The expansion of new technologies is especially noticeable in the first half of the modernization phase. In its second half this expansion faces certain saturation and slows down and this increases activity in the field of innovations. There appears an anticipation of something important. But the decisive component for the formation of a new system is still lacking. Besides, this gap can be manifested not only in the absence of basic technological innovations but also of the social conditions for its implementation. One of the most important characteristics of the modernization phase is that *during this period some profound changes or even breakthroughs in social and political relations should take place*. As regards the Industrial Revolution, the period between the seventeenth and eighteenth centuries is the time of social revolutions in England, the Netherlands, the USA, and France which changed the world. It was also the time of changes in the world policy: The Thirty Years' War (1618–1648) and the subsequent Piece of Westphalia laid the foundations of international relations for a long time. Globalization and the period which we denoted as the epoch of new coalitions (Grinin 2009, 2012c; Grinin and Korotayev 2010, 2015a) will also significantly change the world and this process is already underway.

3. *The idea of a decisive component*. During the modernization phase opportunities and improvements accumulate that will play a role in making the final phase of the revolution possible. All components should be ready before it starts. However, we emphasize that the innovations will form a new system only as soon as the key component emerges. At the same time the reconstruction of the relationships within the framework of a whole production system (fields, branches and innovations according to their value) will be considerable.

4. *The emergence of the decisive innovation in the new field.* Basing on our analysis of production revolutions one can conclude that the decisive innovation will appear not within the most important sector of the economy. Thus, irrigated agriculture failed to become the most important sector of agriculture in pre-state barbarian societies; while the cotton industry was not the most important industrial sector in the first half of the $18^{th}$ century. Moreover, in this field there should appear certain conditions which should include high commercial profitability and attraction, thus producing a steady demand for a long period of time. Nevertheless, the emergence of the decisive innovation can remain underestimated for some time.

The decisive innovation for the final phase of the Cybernetic Revolution to begin can appear in different fields of bio- or nanomedicine (or some other new branch of medicine). There can be a series of innovations which will turn the growing number of innovations into a qualitatively new system. It is quite possible that such a breakthrough will be connected with the invention of successful methods to fight cancer as this disease differs significantly from other diseases and requires solutions at the genetic level as well as the application of fundamentally new technologies.

### 3.3. The peculiarities of the final phase

1. *The main characteristics of the production revolution come to maturity.* One can find all the basic characteristics of the final phase of the revolution already in its initial phase though in undifferentiated, incomplete or undeveloped state. These characteristics of the future system are revealed in the middle phase when the production principle takes a relatively complete although undeveloped form.

**Thus, one may infer about the main characteristics of the Cybernetic Revolution on the basis of an analysis of the initial and middle phases, through a focus on their features and the dynamics of development.** This analysis allows for a singling out of the most important characteristics of the Cybernetic Revolution including resource savings, miniaturization, individualization, wider use of artificial and smart materials, *etc.* These characteristics already show up in our epoch but they will absolutely dominate in the next epoch.

2. Given the *numerous directions that will appear during the initial phase, there will be some that will necessarily become leading directions in the final phase.* At the same time in the initial phase they play a less significant role. Thus, while in the final phase of the Industrial Revolution the main point is mechanisms, machines, replacement of manual labor by machinery, in its initial phase machinery was only a part of this new direction. In the beginning of the Industrial Revolution, the technical innovations (replacement of manual labor by machines) were not so important and the main point was the process that intensified the division of labor. If you consider the Agrarian Revolution, the leading direction of manual (hoe) agriculture was the use of fertile areas with the help of manual labor (*e.g.*, with the help of a sharp stick or stone hoe). The soil fertility was natural or was achieved by burning of plants. As to irrigation technologies, in the initial phase of the Agrarian Revolution they were not so widespread and were linked to the local environment. But in the final phase they became the leading factors and remained such during the whole period during which the craft-agrarian principle dominated production.

**Therefore, the leading sector of the final phase of the Cybernetic Revolution has already formed, but it is one of those sectors which do not, as yet, play a decisive role in the economy.** In our opinion, medicine (one of its new branches) will play the leading role in the unfolding final phase of the Cybernetic Revolution (see below).

3. *The mutual integration of innovative sectors starts after the formation of the decisive innovations or their group.* This process especially intensifies in

the final phase of the production revolution. Innovations are mutually integrated and form a fundamentally new system. That was the case with the invention of the power spinning loom in the 1760s (which was then constantly being improved). The important inventions and directions of industrial production such as primitive steam engines, steam energy, new types of machines, the principles of management at large enterprises, the current institution of inventions and different technical innovations which had already existed before, after the invention of the power spinning loom allowed during two decades to form the fundamentally new sector of cotton mills (as well as the great idea that all manual operations can be mechanized). This caused the cumulative effect of rapid invention of missing innovations in the field of cotton carding (*i.e.*, the separation of cotton fibers), painting, printing, *etc.*

**Thus, the breakthroughs in medicine and allied technologies will cause the 'catching up' and an amalgamation of different innovations into a system which might bring about the completion of the Cybernetic Revolution** (see below).

4. One should *distinguish between the field of breakthrough and the essence of a new system of production.* The field of breakthrough just initiates profound transformations. The production revolution will fully gain its logic and 'sense' or 'essence' only later when the transformations become profound and expanded. However, one can try to guess this 'meaning', 'sense' and 'essence' on the basis of the processes occurring during the initial and middle phases of the production revolution.

**Thus, the general idea of the Cybernetic Revolution can be connected with a constant and comprehensive saving of energy, resources and materials which will start due to mass development of self-regulating systems at a fundamentally new level.** In fact, without the breakthrough in saving there will be no growth of living standards of the world's population whose number will increase at least until the 2070s (according to most forecasts, see, *e.g.*, Population Division 2012).

### 3.4. The determination of the future sector of the breakthrough. Why medicine?

Thus, an assumption from the theory of production revolutions entails that one of the number of directions defined in the initial and middle phases of any production revolution becomes a breakthrough area by the beginning of its final phase. But this factor does not play a leading role in the economy until the beginning of the breakthrough.

The analysis of the actual development of production revolutions also suggests the following characteristics of the future sector:

- the commodity produced in this sector should be of prime necessity. Thus, cereal in the period of the Agrarian Revolution and cotton in the period of the Industrial Revolution were basic necessities;
- the direction of development of the sector should conform to the leading tendencies and problems in the society (irrigation agriculture could support and increase the sudden exponential population growth; the cotton industry met the needs of increasing urbanization and made use of the surplus labor force which had emerged in the agrarian sector);
- the sector can influence a significant number of spheres and integrate them (*e.g.*, in the period of the Agrarian Revolution the irrigation facilities required joint actions in society; and in the period of the Industrial Revolution the transition to machines and steam-engine in the cotton industry caused a rapid growth of economy, the reconstruction of transportation routes and trade);
- technological conservatism in this sector is relatively weak;
- the breakthrough sector should provide high profits and rely on steady demand, otherwise it will fail to attract major investments. Besides, borrowing from this sector new technologies which arose in the advanced society will face no obstacles (*e.g.*, government's ban, *etc.*) in other societies;
- the sector must have a great potential for the growth of its productivity and the need for the growth of productivity must remain high for a long time to stimulate the innovations and investments.

Let us consider these conclusions in the context of the Cybernetic Revolution. It is evident that the future breakthrough sector of the final phase of this revolution should have already developed. But which of the existing ones meets the mentioned characteristics? We argue that there will be no breakthrough, for example, in the field of green (low-carbon) energy sector (despite the fact that at present wind power demonstrates high growth rates) because green power will be unable to completely replace traditional energy resources but it will coexist with it just as hydro- and nuclear power coexist with carbon energy. We think that robotics could become the break through direction if there were created robots that could perform different functions in the services sector. Not without reason the future scientific and technological progress was thought to be connected with developments in the sphere of robotics. At present robotics finds wide application and is rapidly developing (see, *e.g.*, Makarov and Topcheev 2003; Gates 2007). But still one can hardly say that robotics will become the breakthrough direction judging by the current volume of investments in this sphere which grows slowly, and there are much less investments in the biotechnology field. However, it will play a very important part in the final phase of the Cybernetic Revolution and should achieve outstanding results though somewhat later, perhaps in the middle of the final phase of the Cybernetic Revolution or even at the end of it (see Conclusion).

On the basis of the analysis of the current situation one can conclude that the only field which meets all the requirements is medicine. That is why medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, the development of self-regulating systems will cover the most diverse areas of production, services and life. We treat medicine in a broad sense, because it will include (and already actively includes) for its purposes a great number of other scientific-technological branches (*e.g.*, the use of robots in surgery and taking care of patients, information technologies in remote medicine, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor an organism; new materials for growing artificial organs and many other things to become a powerful sector of economy).

Let us consider in detail why medicine is to become the breakthrough sphere.

a) Medicine is unique because it inspires constant activity in the field of new high technologies.

b) There are far fewer social, cultural or structural obstructions to the application of these technologies in medicine than in other fields (as well as the obstacles to adoption of innovations).

c) The commercial prospects of new technologies in this sphere are huge since people are always ready to pay for them.

d) In the nearest decades not only the developed but also developing countries will face the problems of population ageing, shortage of labor resources and the necessity to support a growing number of elderly people. The progress in medicine can contribute to the extension of working age (as well as to the general increase of the average life expectancy) of elderly people and to more active involvement of disabled people into labor activities. *Thus, elderly people and people with disabilities could more and more subsist for themselves.*

e) A rapid growth of the world middle class and population education level, especially in the developing countries (NIC 2012) is anticipated in the nearest decades and these two factors mean that there will be a sharp growth in the demand for health services.

f) The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. Many spheres (including but not limiting to biotechnologies, nanotechnologies, robotics, use of the latest ICTs and various devices, cognitive technologies, synthesis of new material) will be integrated in this field.[9]

[9] It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the Sixth Kondratieff Wave (according to his approach, this wave began in the end of the 1990s and will last until the 2050s) (Nefiodow 1996; Nefiodow and Nefiodow 2014a, 2014b). We do not agree with him about the date of the Sixth Kondratieff Wave, which, according to our estimates, will start in 2020s and will last until the 2060s (Grinin L. E. and Grinin A. L. 2014). Never-

Thus, given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area is to be highly commercially attractive and have a wide market, we predict that the final phase of the Cybernetic Revolution will begin in medicine.

By the 2030s there can appear unique opportunities for a breakthrough in medicine:

– by that time we will face the problem of population ageing (by 2030 the number of people aged 65 and over will amount one billion (see Fig. 4). Moreover, this problem will be typical not only of the developed countries where it will become crucial for democracy, but also for a number of developing countries, in particular, China and India. Pension issues will become more acute (as the number of retirees per worker will increase) and at the same time a shortage of qualified labor force will increase (which is very critical in a number of countries, *e.g.*, in Russia). *Thus, we will have to solve the problem of labor force shortages and pension contributions by increasing the retirement age by 10 or 15 years (of course, it is necessary to solve complex social problems at first).* It also refers to the adaptation of people with disabilities for their full involvement in the working process due to new technologies and achievements of medicine;

– simultaneously by that time, the birth rates in many developing countries will significantly decrease. Therefore, the government will start to be concerned about the health of the national population and not about population control;

– by the 2030s great changes will occur in the opportunities of billions of citizens of the developing countries due to leveling of peripheral and developed countries, formation of a huge middle class, and reduction in poverty and illiteracy. As a result, the focus will be shifted from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc*. So, there is a great potential for the development of medicine.

However, primarily the breakthrough will not necessarily occur in all spheres of medicine but in its one or two innovative fields (similar, the final phase of Industrial Revolution occurred not in all branches of textile industry but in its innovative sector, namely in cotton industry). As for other branches of medicine, revolutionary transformations will begin there later. Moreover, some branches of medicine would be unable to transform due to their conservatism. Thus, more radical reforms will occur in these fields in the future. So when

theless, we generally support his ideas about the role of medicine (including the ideas about a new type of medicine), but it is important to point out that Nefiodow believes that it is biotechnologies that will become an integrated core of a new mode. However, we suppose that the leading role of biotechnologies will consist, first of all, in their ability to solve the major medical problems. That is why, it makes sense to speak about medicine as the core of new technological paradigm.

speaking about medicine, one should keep in mind that with respect to potential revolutionary transformations medicine is a very heterogeneous sphere.

However, in the process of the final phase of the Cybernetic Revolution and after its end the *development of medicine will follow the path of correction or even modification of our biological nature*. In other words, it will be possible to extend opportunities to alter a human body, perhaps, even its genome, to cultivate biological materials for regeneration, as well as to use artificial organs and tissues for it (for more detail see below).

*Along with many other medical innovations (e.g., minimizing invasive operations) it will be possible to dramatically increase life expectancy and improve physiological abilities of people as well as health-related quality of life (HRQoL).*

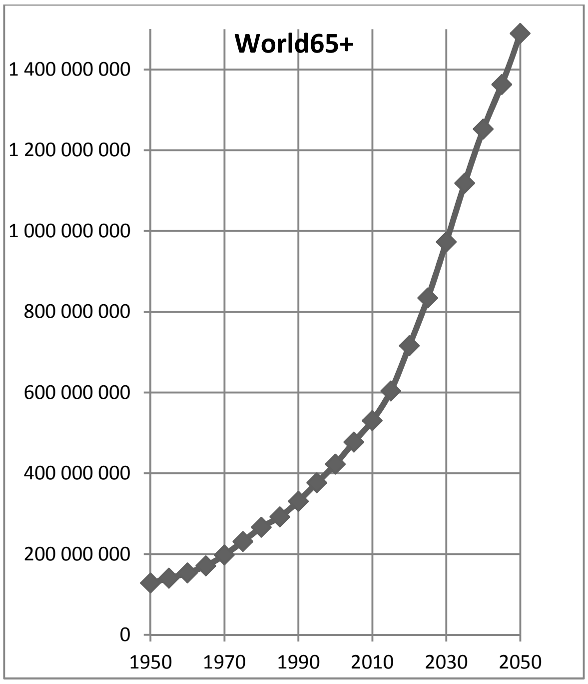


**Fig. 4.** Predictable increase in the number of people aged 65+, estimated for 1950–2015 and projected to 2050.

*Source:* UN Population Division 2015 (Grinin and Korotayev 2015b).

**Medicine as a sphere of the initial technological breakthrough and the emergence of MBNRIC-technology complex.** It is important to understand that even though the final phase of the Cybernetic Revolution will be connected with great transformations in the opportunities to influence the human health, life expectancy, quality of life, as well as human biology itself, the revolutionary changes will be much wider. Many spheres of production and life will be affected by these changes. They will include very many spheres of production and life. *On the whole, the final phase of the Cybernetic Revolution will result in the convergence of technologies and development of MBNRIC-technologies (i.e. of a complex of medicine, bio- and nanotechnologies, robotics, ICT, cognitive sciences). Together they will form a sophisticated system of self-regulating production.*

## Section 2. MEDICINE IN THE CYBERNETIC REVOLUTION

We have no opportunity to describe the whole range of MBNRIC-technologies with the equal attention. So in this paper we will focus more on describing current and future transformations in medicine. With less scrupulousness we will analyze the future transformations in the fields of bio- and nanotechnologies. Unfortunately, robotics and other technologies of the final phase of the Cybernetic Revolution will be briefly described.

### 1. Medicine in the Initial and Modernization Phases of the Cybernetic Revolution

**In the initial phase of the Cybernetic Revolution (the 1950–1990s)** there was a rapid growth of medicine as an increasingly important service sector. *At the same time the growth of health services constituted the general process of a rapid increase in service sector, which became the leading sector in terms of GDP in developed countries.*

During this initial phase of the Cybernetic Revolution new directions of medicine emerged while those directions that had emerged earlier reached a certain level of maturity (among them are electroencephalography, electric shock therapy, transplantology, active use of electronics, laser and new methods of diagnostics such as ultrasound, *etc.*). Substantial progress has been achieved in the sphere of child mortality reduction, infertility treatment, gerontology, psychiatry, development of contraceptive methods, and transplantation of organs and the creation of artificial organs, gender reassignment surgery, *etc.* Sport medicine, space medicine and other directions in medicine appeared during this time. On the whole, due to medicine people learned about controlling their bodies and maximizing their health.

To better understand the breakthroughs which took place in medicine during the initial phase of the Cybernetic Revolution, it makes sense to refer to the most prestigious award in the field of science. In the period from the 1930 to the 1980s the authors of discoveries in the field of vitamins, hormones, antibiotics, nervous regulation, enzymes were awarded the Nobel Prize. All of these discoveries began to be used in pharmacology. After 1958 genome researchers were awarded the Nobel Prize.

**Medicine in the modernization phase.** The period from the 1990s till the present represents the modernization phase of the Cybernetic Revolution.

At this phase the major direction of medicine underwent dramatic changes. In the 19th and 20th centuries many fatal diseases were defeated (cholera, yellow fever, typhoid, tetanus, polio, whooping cough, measles, malaria, diphtheria, *etc.*). It would seem that fatal highly infectious diseases except for AIDS (which is widespread in African countries) have been defeated. At the initial phase of the Cybernetic Revolution the fundamental task was to increase the life expectancy. As a result, when the task was accomplished, the main concern of the last period of the initial phase and the modernization phase of the Cybernetic Revolution became the struggle against the diseases of aged people.

According to WHO, in 2012 the most frequent causes of death in the world were respiratory diseases – 6.2 million (14 per cent), ischaemic heart diseases – 7.4 million (11.1 percent), stroke – 6.7 million (11.9 per cent), HIV/AIDS – 1.5 million (2.7 per cent) (WHO 2014).

As a result of the Cybernetic Revolution the changes in the general trend in medicine led to the emergence of new pharmaceuticals. One of the peculiarities of contemporary medical development is a constantly increasing production of drugs. For example, in the USA, from 1950 to 2000, the number of firms producing drugs increased more than seven times (Demire and Mazzucato 2008). By 2006, the production of drugs doubled, and the total global market volume of drugs was estimated at US$ 640 billion, about half of which was accounted for in the USA (Kondratieff 2011). This field remains one of the most profitable fields with a sales profitability of 17 per cent (*Ibid.*). Every year the volume of consumed drugs increases by several percent. Over the last 15 years the revenue of the worldwide pharmaceutical market has increased more than twice.[10]

Now medicine is closely related to biotechnologies (through pharmaceuticals, gene technologies, new materials, *etc.*). The distinctive feature of modern medical science is its 'bio-related trends' – a wide use of approaches based on the methods of molecular and cell biology. Note that the growing importance of medicine is shown in the phenomenon of medicalization. It is expressed in the fact that many aspects of human behavior (especially deviant) and psyche which have never been related to medicine, start to be described in medical terms and require medical observation and intervention (see Yudin 2008).

The process of differentiation of medicine which started many years ago in many branches has intensified. At present there are about one hundred medical branches and relative scientific disciplines. Among others, nanomedicine, biomedicine, stem cell research and generative medicine are declared as formed branches (see Strategy… 2013; Wagner *et al*. 2006; Minger 2006). It is also

[10] See URL: http://www.statista.com/statistics/263102/pharmaceutical-market-worldwide-revenue-since-2001/

worth mentioning such new directions as shockwave therapy and control of cholesterol levels. The directions which emerged earlier have been actively developing, for example, those which are related to artificial fertilization, maintenance of pregnancy and obstetrics, *etc.*

At present medicine is highly computerized especially in the field of diagnostics, various automatic control systems have been developed; for example, for the control of breathing, nutrient supply to specific organs, blood pressure, control over the functioning of some internal organs, *etc.* A large range of drugs have been developed which over time decrease in price and become more available to the general public. Surgery connected with the transplantation of organs and the replacement of certain human organs by artificial organs, endoscopic surgery providing operations without incisions, and rehabilitation medicine are all developing rapidly. Surgical methods have become less invasive and require less time for rehabilitation.

The current stage is represented by the prevalence of innovations accumulated over the last decades since most of the latest technologies are based on improvements to previous discoveries and inventions. Starting with the 1980–1990s we observe considerable progress in the struggle against the most common causes of mortality – heart attacks, strokes, orphan diseases and other diseases including hereditary. Significant progress has been made in technologies for diagnosing internal organs and tissues using such methods as X-ray computed tomography, nuclear magnetic resonance introscopy, X-ray photography and others (Mirsky 2010: 19). At present the fastest developing fields of medicine (in its broad sense) are the fight against incurable diseases, implantations, reproductive medicine, gene therapy, pharmaceutics and aesthetic medicine which we will consider below.

On the whole, medicine (supported by both government and private funding) has been a major influence on GDP. The distribution of medical technologies is a very expensive process. Despite that cost, there still has been a steady increase in funds allocated to medicine by the state. Generally, its growth is comparable to the GDP growth rate. But in the developed countries spending on health care per capita is 10–20 times larger than in the developing countries. Taking into consideration the anticipated faster growth rates of GDP in the developing countries and a rapid formation of the middle class there, one can suppose that in general, spending on health care will increase significantly. Ageing of the population together with growing prosperity will lead to a situation where health care spending will outpace the general GDP growth. And this tendency is likely to increase.[11] It is not strange because in the developed coun-

[11] One can prove this by the fact that even in the periods of insignificant GDP growth, the expenses for health care increase very fast. In particular, in the OSCE countries in the period of the last crisis (2008) the growth of GDP per capita was very low – 3 per cent (correspondingly in 2007 – US$ 35,855, in 2010 – US$ 36,994), and expenses for health care per capita increased by 13 per

tries a significant part of population is involved in medicine. For example, in Germany a number of health care personnel constitute 22 per cent of the total number of employed people while the share of automobile industry is only 2.3 per cent (Nefiodow and Nefiodow 2014b). The level of medical development has significant impact on such popular development indicators as the human development index (HDI).

**The development of aesthetic medicine.** At present aesthetic and cosmetic medicines are vigorously developing and their main task is to correct defects or alterations which concern the person and improve attractiveness (eliminate wrinkles, provide attractive rejuvenation, different types of face lift, liposuction, body shaping, transplant hair, wide spread of already proven technologies, *etc.*). According to *Forbes*, the global cosmetic surgical and aesthetic medical market amounts to 180 billion dollars (Zhokhova 2011).

One of the highest achievements of plastic surgery is the face transplantation. The first full face transplant was performed in France in 2005 on a woman who was mauled by her dog. Recently, details of the most extensive face transplant performed in March 2012 were presented. The doctors from the University of Maryland Medical Center gave a new face including jaw, teeth and tongue, to 37-year old Richard Norris.

During the next two decades cosmetic and aesthetic medicines are supposed to rapidly develop (though it can cause rather serious psychological problems including those connected with individual's self-identification). This will be achieved through the emergence of new technologies, as well as the living standard growth in the developing countries. The wealthier a society, the more money people spend on health and beauty. Taking into account the growth of the world middle class, this direction and all types of aesthetic medicine are expected to develop rapidly. Once the new technologies based on the achievements of medicine and genetic engineering have been established, aesthetic medicine will be able to become the correction medicine of the future, one of the most important tasks of which will be to correct birth defects and acquired defects.

cent (correspondingly in 2007 – US$ 3,858, in 2010 – US$ 4,364) [calculated on the basis of World Bank 2012a]).

## 2. Forecasts Regarding Developments in Medicine. In What Way will the Characteristics of the Cybernetic Revolution Appear in the Development of the Medical Sphere?

### 2.1. Two decades before the beginning of the final phase of the Cybernetic Revolution

As we predict within the medical sphere some major innovations will reach maturity in two or three decades (some of them even earlier). Below we will consider some important trends of medicine.

**Systemic problems of the Pharmaceutical industry.** As we have already mentioned, at present the pharmaceutical industry has made considerable progress.

For example, we observe a rapid development of so called generics which are the drugs whose patent protection on the production is no longer valid. It is supposed that the global market of generics will double in the period from 2010 to 2018 and will reach US$ 230 billion. One can explain such a rapid growth by the fact that the vigorously growing economies of developing countries, like India and China, actively enter this market. Such growth is typical of the modernization phase of the production revolution as well as an opposite tendency which will be described below. In the securities market pharmaceutics also shows rapid growth (Williams 2014).

However, the number of serious systemic problems in pharmaceutics is increasing. In particular, in the recent decade there is a reduction in the amount of officially approved biopharmaceuticals protected by patent. On the other hand, a number of clinical trials of drugs steadily increase (Woollett 2012). Despite the rapid growth of capitalization at the markets of bio-technological (pharmaceutical) corporations in 2013–2015 which resembles a rapid growth of capitalization of IT corporations in the 1990s, the innovation process is slowing down. Many observers note that the expenditures on the new drug development are reduced because corporations have to spend from 1.5 to 3 billion dollars for new drug development and the drug development together with testing takes from 10 to 17 years. Therefore, the number of principally new drugs is not only increasing but on the contrary, decreasing, there are no breakthrough inventions (*e.g.*, Saigitov 2015; Martyushev-Poklad 2015*).* One of the important reasons of reducing production of biostimulators is strengthening control over their production. And most likely the problem of accelerated production of safe drugs will aggravate in the nearest decades; the solution of this problem can become an impetus for a breakthrough.

*It is obvious that mass-market drugs have an important disadvantage:* its efficiency is decreasing and really help only some part of patients (from 30 to 50 per cent). The growth of pharmaceutical production is connected with unification which leads to decreasing efficiency as even well-investigated diseases often proceed individually. *Prescribing faults also cause serious side effects. For example, according to some data (probably, overestimated), in the period from the late 1990s to early 2000s, prescribing faults annually* caused more than 100,000 deaths (Null *et al.* 2003: Table 1).

The theory of production revolutions can provide a general explanation of such innovation slowdown in pharmaceutics. The main vector of the modernization phase of the Cybernetic Revolution is a wide dissemination of innovations which have already emerged (in the first stage), their modification and synthesis. Therefore, there can be fewer basic innovations in this period in certain directions than in the previous period (yet they are much more widespread). Besides, the increasing scale of the production revolution causes an intensification of the struggle between 'conservatives' and 'innovators' with respect to the implementation of innovations, for example in the field of drug control (as well as in the field of distribution of GMO and other innovations such as cloning, *etc.*).[12] In such situations it is rather difficult to say who is right: 'conservatives' or 'innovators'. On the whole, such discussions contribute to the search for optimal paths towards progress. On the other hand, one can suppose that in the nearest decades there will be a new burst of innovations and creation of new age cures. At present we observe some attempts to find new directions in the field of pharmaceutics.

*Obviously, in the work of pharmaceutical firms lacks such an important characteristic of the Cybernetic Revolution as individualization. It is quite obvious since the considerable expenses for the development of new drugs require huge market for their distribution.*

However, there are some precursors of the strategy changing towards individualization. For example, let us consider Christopher Wasden and Brian Williams' model. Pointing to such difficulties as lower reimbursement rates, diminished pools of venture capital, the advent of personalized care and a growing demand for improved patient outcomes, they consider them as a precursor to a hurricane that will batter unprepared companies and fundamentally change how healthcare is delivered and evaluated (Wasden and Williams 2012: 2).

These representatives of innovative business offer a new model in pharmaceutical and medical business which is named as 'Owning the disease: A new transformational business model for healthcare'. Their suggestions are based on the experience of IT companies and they propose to turn to consumer-centric disease solutions rather than the traditional R&D department approaches) (*Ibid.*).

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[12] Here one can make an analogy with a situation in the $17^{th}$ – $18^{th}$ centuries when different craft restrictions stood in the way of technological progress (and the technological progress bypassed these restrictions). That is why one can suppose that a brand new breakthrough can follow a different pattern.

The basic idea of this model is to combine the opportunity to solve the tasks and problems related to diagnostics and treatment of a certain disease. In other words, the patient gets the full range of services to solve health problems connected with the real (or potential) disease.

> Medical technology companies are changing their focus in three important ways, shifting from selling features to providing solutions; from focusing on silos to a broader systems approach; and from generating profits by increasing volume to winning by delivering greater value. In turn, these strategies are transforming the fundamental business model of medical device manufacturers, resulting in them taking a more comprehensive approach to their business that compels them to seek to 'own' the diseases or conditions their products are intended to treat. Owning the disease should not be confused with disease management, the early iterations of which evolved during the heyday of managed care but which lacked the connectivity and incentives to effectively understand, monitor, influence, and change patient behavior, as well as support care coordination or overcome the cultural divide between payers and providers (*Ibid.*: 7).

This approach takes account of such important tendencies of the forthcoming Cybernetic Revolution (which have been mentioned above) as resources saving (according to the authors of the project, the systemic approach allows reducing expenses) and individualization. The clients of medical companies insist on a personalized approach and on the correlation between the payment for treatment and its results but not the number of manipulations. As the company will be paid for the results of the treatment and not for the treatment process, it will be interested in avoiding the treatment and searching for the prevention measures and optimal solutions.

The authors of this work believe that the company which will be able to create a platform for 'mastering the disease', will have many strategic advantages over the competitors.

However, the conservatism of the present pharmaceutical and medical institutions and huge financial interests of very influential forces behind them will certainly obstruct such a transition.

**The struggle against incurable diseases,** as it was said, is the most important direction of medicine. In general, mortality from cancer in developed countries reaches the same level of mortality as does coronary artery disease.

With the rapid ageing of population the potential danger of age-related diseases will increase. The present tendency is that with growing life expectancy cancer diseases take first place among diseases. Therefore, the most significant task of medicine will be the struggle against cancer and other age-related diseases. Nowadays incurable diseases are the challenge for humanity. It is not surprising that big awards are provided for solutions to these problems.

In the context of the struggle against cancer there are some positive changes connected with the possibility of early diagnosis and increasing percentage of cured people (see below) but the situation has not changed dramatically. It is possible that cancer will not be defeated by the 2030s. Apparently, cancer treatment requires considerable changes. If we defeat this disease, there will appear a strong impetus for a breakthrough in medicine and its transition to a completely new level.

**Movement towards self-regulating systems and minimization of interference.** We observe the growing controllability of systems in different branches of medicine. Some of them have already reached the stage of real self-regulation. For example, life support systems or artificial organs. Other systems are moving towards self-regulation and they are intrinsically linked to the minimization of traumatization of a patient. For example, in surgery a lot of flexible instruments are used allowing the doctor to be able to perform surgery on the most inaccessible parts of human body with minimal incision. These operations are conducted with the help of endoscopes and video cameras transmitting an enlarged image on the monitor. In order to solve the problem of hand tremor special robots are used to substitute for human hands. Operating such a device, a surgeon controls the smallest movements of the instrument (including the laser, or ultrasound). One can anticipate that in the nearest future a lot of operations will be conducted without human surgeon's participation.

**Robots in surgery.** Surgical robots is a rapidly developing sector. There were only 1000 surgical robots in 2000 around the world. In 2011 they already amounted to 360000, in 2012–450000 (Pinkerton 2013). Since 2000, about 1370 clinics of the USA ordered robots, which average price is about 2 million dollars for one robot (Beck 2013). Robots-surgeons are classified as: assistance functions robots, telesurgical instruments, navigation system, robots for precise positioning, robots for specific surgery tasks (Taylor 1997)

According to the research data conducted by the Columbia University from 2007 to 2010, in the clinics of the USA robots performed from 10 to 30 per cent of surgical operations (*Ibid.*). The surgical operations involving robots' participation have a lot of advantages. The surgical robot DaVinci is mostly widespread.

It is a big machine which is equipped with flexible ‘hands’ – manipulators with a set of surgical tools. A very small incision is made to the patient, therefore surgical operations are not so painful and demand the smaller period of recovery. Robots allow to use all the latest tele-video systems which help doctors to see clearly the operation process much enlarged and in color. The doctor watches the monitor and controls the robot, sitting in the other part of the surgery (in future he can also be in any other city or even country), the assistant watches the robot and the patient. For the purpose of watching the surgery process in full detail HD 3D screens are installed for the patients. Surgeries involving robots' participation are becoming very popular, for example, the medical companies in the USA use the billboards for attracting more clients to these painless fast procedures (Pinkerton 2013).

However, along with the advantages, surgical robots cause serious fears. The doctors from Rush University Medical Center, the University of Illinois and the Massachusetts Institute of Technology provided the data according to which the strong increase in the cases of injuries and fatalities after the operations performed by the robots is observed, from 13,3 cases per 100 000 surgical operations in 2004 to 50 cases in 2012 (*Ibid.*). FDA registered an increase of 34 per cent of the deaths from surgical operations involving robots in 2013, relative to the previous year (*Ibid.*). In 2013 Massachusetts health officials sent an advisory to the state's hospitals urging caution, 'As with any new technology, care should be taken that protocols are in place to ensure appropriate patient selection and the full explanation of risks and benefits for all surgical options' (*Ibid.*). The cost of surgical operations involving robots is higher as compared to the ordinary types of surgery and in the USA varies from US$ 30,000 to 50,000. The price of Da Vinci starts from one million dollars. However, in view of significant economy at a recovery stage, it is possible to predict that clinics will prefer to buy robots for the long-term economy and customer engagement (*Ibid.*). Substantial savings can be realized on the skilled work of surgeons. Many clinics may not have the leading surgeons, they will be able to use services of online surgical operations conducted by the leading experts hands.

### 2.2. The social-economic premises for a breakthrough

As we have mentioned, the field of some innovative branches of medicine will be the sector where the final phase of the Cybernetic Revolution will start and develop. The unfolding situation will arise by the 2030s in the growth of the economy, demography, culture, living standard, *etc.*, will contribute to this. And this will determine a tremendous need for a scientific and technological breakthrough. On the whole, these successful conditions will entail major investments in medicine: increase in the number of well-off and educated people and middle-aged and elderly people (who particularly are willing to actively spend money on medicine), strengthening of the need for extra labor force and interest of the state in improving the working capacity of elderly people. In other words, the conditions for activization of business, science and state in order to provide a breakthrough in the field of medicine can be unique and *the formation of such unique conditions is necessary for the beginning of a new phase of the Revolution!*

One more prerequisite for the beginning of the final phase of the Cybernetic Revolution in the 2030s will become remote medical care which will be well developed by this time and due to which there will also be a leveling of conditions for patients. It means that the quality of medical care services will not be so highly dependent on the qualifications of medical personnel in a particular medical care unit. Even now we are witnessing this process, thus we can say that it will be very strong in the nearest decades and in the beginning of the final phase of Cybernetic Revolution.

## 3. The Shifts during the Final Phase of the Cybernetic Revolution

### 3.1. The developing characteristics of the Cybernetic Revolution

**Preliminary ideas about the forthcoming changes in medicine.** As we have already mentioned the transition to the final phase of the Cybernetic Revolution will begin in some field of new medicine (which could be closely related to some other innovative technologies) and then step by step will affect other fields. In particular these revolutionary changes will be connected with the formation of systems for monitoring health, supporting the organism and treatment will be performed mainly by the autonomous systems which will be able to function regularly and constantly.

Medicine will also develop in the direction of: a) prevention and propedeutics of diseases; b) controlling the processes of life and elimination of irregularities; and c) maximal account of individual characteristics.

Self-regulation and controllability of systems is manifested in many branches of medicine, for example in the situation when treatment, operations and further rehabilitation will be under a fuller control of self-regulating systems. In the future it will be possible to provide certain treatments through special devices, systems, robots, *etc.* It is one of the most important directions which will be realized during the 2030–2050s.

Emergence of robots also shows the transition to self-regulating systems. The scientists from the Oslo University in Norway by means of 3D-printing invented the self-learning robots which also have 3D printers in their structure and are capable to print the necessary detail (Howell O'Neill 2014). The RoboEarth project is very interesting, *i.e.* it is the Internet for robots in which they record all their operations and can address it if the necessary operation is absent in the installed program. It is the beginning of the collective intelligence of robots (Waibel *et al.* 2011).

Another manifestation of self-regulation will consist in the technological control of processes of human organs (through necessary albuminous compounds, cells, antibodies, activization of immune system, *etc.*). In other words, treatment will become more targeted.[13] The drug delivery systems will change dramatically. Nanotechnology, particularly nanotubes, will probably play the key role in it.

[13] One of the contemporary optogenetic technologies provides a good example as well as a general idea of how this can work. The essence of the technology is that the DNA fragment which codes for special membrane proteins is integrated into the genome. These light-activated proteins (from the light-source implanted in the brain tissue or through transosseous luminescence) can create an ion flow inside the cell and thus, lead to its activation (Saigitov 2015).

The radical transformations in medicine will dramatically change the position of a doctor. Which technological innovations will cause such transformations?

At present the tests for important indices can be made without doctors by means of special devices and testers (see, *e.g.*, the chapter about the antibodies). On the basis of the test results one can define the norm and abnormalities. For example, in order to remotely control the patients, the company Applied Digital Solutions developed the device 'Digital Angel' equipped with the self-rechargeable energy. This tiny biochip measures the biological parameters of the body. It is unlikely that such devices will appear in the very near future. Nevertheless, the emergence of such forecasts is quite remarkable as they show the movement towards the development of self-regulating systems.

Due to such technologies a number of functions of a doctor can be performed by the patients. Perhaps, in the near future diagnostics will be transferred to mobile devices on the basis of biochips which do not require the specialists' participation. Already now the centers of the best practice (Centers of Excellence) are developing, *i.e.* the places from where the leading doctors will be performing the operations and consulting the colleagues online (Binder *et al.* 2004). Thus, the profession of a doctor in its current form can lose a number of its present attributes. At present such a metamorphosis occurs in service sector (such as photo service, type setting and page makeup, design, selection of interior, purchase of tourist vouchers, selection of routes, *etc.*). Of course, the profession of a doctor will exist but the number of doctors probably will not grow and in the end of the final phase of the Cybernetic Revolution its number will even decrease. Such systems as health monitoring system described below will also affect the positions of a doctor.

**Constant health monitoring as a self-regulating supersystem.** Nowadays the boundary between medical diagnosis and treatment already becomes more and more imperceptible. Diagnostics is a constant necessary measure for disease controlling and drug dosage. During the final phase of the Cybernetic Revolution there will start a breakthrough in all fields of medical care. Thus, very important direction of self-regulation can be associated with the development of the health monitoring system that will allow early diagnosis and preventing diseases. The key compounds of such devices are biosensors.[14]

One can easily imagine that in the future biosensors will be able to become an integral part of human life fulfilling the function of a constant scanner of the organism or of certain organs and even transmitting the information about it to medical centers in case of potential threats or serious deterioration in the state of health. Built-in sensors will allow for controlling and regulating all vital pro-

[14] Biosensors are electronic registering devices which use biological material such as enzymes, cells and antibodies (for more detail see in the paragraph about biotechnologies).

cesses, as well as prompting the time of drug intake and their dosage, time of physical activities and required exercises with the account of different circumstances, and recommending the most appropriate diet, *etc.* Thus, smart computer systems will be able to monitor significant fluctuations of indicators and give recommendations about short- and long-term living habits.

What will these innovations bring: will the consequences be good or bad? Of course, people's free agency will be restricted as well as it is possible that they will get used to obey machines and in some measure lose ability to decide by themselves. At the same time, certain imperatives with respect to health will be formed.

Respectively, such mini-systems can be integrated into a large system which monitors a large number of people, for example in medical centers, therapeutic facilities, hotels, *etc.* We have already mentioned the decreasing number of hospitals, and such monitoring and remote online access can significantly relieve hospitals. One can imagine that such systems will be able to detect potentially dangerous situations and quickly respond to critical situations. That is a good example of prognostics and prevention of problems. We suppose that it will take much time to create such systems. Besides, there are complicated ethical and legal problems as regards to such monitoring as there always exists the danger that a watching 'Big Brother' will take advantage of this.

**Economy and optimization of resource consumption.** The achievements in medicine will make a significant contribution to *the optimization of resource consumption*: first, it will increase life expectancy (which is the most valuable resource); and, second, it will increase human health and thus productivity. Optimization of resource consumption will be expressed, for example, in the drugs economy due to the targeted delivery and minimization of interference with the organism. Hospital treatment will be less used as the operations will be more targeted, and the rehabilitation period will be minimal. More people will be treated at home since the development of remote treatment is rather probable when doctors control the indices of a patient online and can make the necessary prescriptions remotely. It could sharply decrease a cost of medical treatment which now is exorbitant one for a great number of people. Saving money (as well as resources) is one of the most important directions for the economy.

Medicine develops in the direction of growing **miniaturization (as one of the economy).** We think that with respect to medicine we can use the term 'miniaturization' in two senses. One is the common one– as a trend of constantly decreasing size of instruments to micro and nano size (Peercy 2000). The second one is a trend of constantly decreasing the zone of medical intervention on human organism. For instance, during surgery contact is focused only on the target epidermis layers. For example, some eye operations with the use of laser are aimed at removing tissues only a few microns thick. Such operations require no subsequent rehabilitation.

### 3.2. The forecasts of the development of some medical technologies

**Artificial antibodies and the growth of opportunities to use the immune system.** There will never be any universal drug against all diseases. But strengthening the immune system is one of the universal directions which can transform this situation and help the struggle against different diseases. Everyone has his own protective system based on the 'history of diseases'. It is one of the most important directions of development of **individualization**.[15] Medicine is always connected with a patient's individuality. However, in the twentieth century there was a tendency towards mass medicine (connected with mass vaccination, preventive examinations, *etc.*). At present there are some signs of transition from mass medicine to individual medicine (in particular, in aesthetic medicine), which is related to the general tendency of the Cybernetic Revolution towards individualization. But individualization to an even greater extent will be manifested when based on the unique characteristics of the organism, one of which is the immune system.

One of the main ways to create an artificial immune system is to produce artificial antibodies. Antibodies are the molecules synthesized to fight against certain cells of foreign origin – antigens.

Scientists have repeatedly attempted to produce artificial antibodies. Various methods were used, the most widespread method was isolating antibodies from the blood of animals but the degree of purification remained low. In 1970, Cesar Milstein and Georges Köhler found the method of producing the antibodies of a certain type, that is of monoclonal antibodies. In 1984, they were awarded the Nobel Prize for this discovery. Nowadays a focus of much medical research is into the production of antibodies by other means (Schirhagl *et al.* 2012) and also the creation of chemoreceptors (Dickert *et al.* 2001). Antibodies have already become widely used in pregnancy tests, in the diagnostics of many diseases, in laboratory experiments.

*We suppose that during the final phase of the Cybernetic Revolution there will be considerable progress in the creation of artificial antibodies and their acceptance by the organism.* The formation of artificial antibodies will play an important role in the prevention and treatment of many serious diseases, they will prevent the rejection of transplanted organs, *etc.* This will help make controlling the course of a disease easier and will help in suppressing the disease and defeating the disease if it is possible. Progress towards the creation and acceptance level of artificial antibodies will mean a significant growth of *opportunities to control processes previously inaccessible for controllable interference and appearing of self-regulating systems for regulation of such interference.*

[15] Here the notion of individualization refers not to every antibody but to the artificial antibodies specifically created by each individual organism.

**Control of programmed cell death** (*apoptosis*) is one of the promising methods to defeat serious diseases including cancer. The researches into this field have been carried out from the 1960s. They show that some cells often die in strict compliance with the predetermined plan. Thus, the microscopic worm nematode's embryo consists of 1090 cells before hatching but later some of them die and there remain only 959 cells in the adult worm organism (Raff 1998; Ridley 1996). The mechanism of apoptosis is associated with the activity of signaling molecules and special receptors which receive the signal, launch the processes of morphological and biochemical changes, and as a result lead to the cell death.

An opportunity to trigger the self-destruction of the cells provoking the diseases can make the struggle against diseases controllable. Besides, it provides a rapid recovery without long period of rehabilitation which is necessary after surgical intervention, chemotherapy or radiation treatment (it is the example of economy of energy and time for a patient). Also switching off the mechanism of cell self-destruction will help to save an organism from some diseases and, probably, to control the process of ageing. We suppose that during the final phase of the Cybernetic Revolution medicine will be able to make progress in this direction and in the mature stages of the scientific-cybernetic principle of production to control it. In this case similar to the artificial antibodies and the systems of immune production (see about it below) the movement towards creation of self-regulating systems will occur on the basis of the influence on the key elements of these subsystems of the organism in order to select the optimal regime in the context of certain goals and tasks. So in some cases it will be possible to evoke the death of unwanted cells deliberately and in other cases to block the mechanism of death of necessary cells.

**Breakthroughs in the field of control of human body. Transplantation: on the way to biotechnical systems of the highest level.** Another important direction of medicine is connected with the regeneration and transplantation of organs and parts of the human body. At present such operations are already performed, for example, heart, lungs, liver, pancreas, and kidneys are now transplanted. However, human donor organs are scarce, and people who distribute donor organs without special agreement are brought to criminal responsibility all over the world. The solution to the problem of shortage of organs is carried out in different directions:

1. Use of a part of a donor organ and growing a new organ using stem cells.

2. The possibility of xenotransplantation (transplantation of animal organs into humans).

3. The development of different organ substitution technologies such as 3D printers (the most promising direction).

Besides, in medicine scientists already use or work to design different artificial organs: skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, lungs, pancreas, bladder, ovaries. Even combination of the above-mentioned opportunities is rather possible. There is already an opportunity of tissue engineering. In laboratories they cultivate healthy skin or cartilage cells to replace injured bone or cartilage.[16] The potential of this technology is the formation of cell therapy and methods to regenerate tissues.

A breakthrough in medicine has become the development of artificial cornea by the scientists of Stanford University (USA). Such a great achievement became possible due to joint researches in the field of chemistry, nanotechnologies, biology and medicine (which are typical of complex technologies of the Cybernetic Revolution).

We can forecast that the finding of the opportunity to 'deceive' the mechanism of immune suppression of foreign cells will be the breakthrough in the field of regenerating and transplanting organs and tissues (see above). Already some steps have been made in this direction. Here one can also point to the opportunity to control processes by affecting the key elements of initial subsystem of human organism, in this case switching off the most vigilant systems of immune protection (just like anesthesia during a surgical procedure). The important event was when Japanese scientists discovered a way to reprogram the functions of cells. For example, the skin cells were reprogrammed and substituted for the damaged cells of an eye. Such kind of cells are not rejected, so this direction is exceptionally promising (Kostina 2013).

**Neural interfaces.** The technologies creating the interaction between an individual's nervous system and external devices are called neural interfaces (Brain-Computer Interface). They implement the interaction between brain and computer systems that can be realized via electrode contact with head skin or via electrodes implanted into brain. The implementation of neural interfaces is already wide-spread. They have developed neural interfaces that allow prosthetic devices to be moved via brain signals. Today, there have been developed scanning techniques to study brain signals. This gives an opportunity to reproduce any brain response.

At present there already exist devices which allow paralyzed people to speak, write and even work at the computer as, for example, in the case of the famous astrophysicist, Stephen Hawking. The neurosurgeons from the University of Pittsburgh School of Medicine performed a miracle when they implanted a chip in Tim Hemmes's brain. Being paralyzed, he can move a bionic prosthesis with his mind. The prosthesis has a special computer which conducts the

[16] Having grown a sufficient number of cells, these cells are implanted in the developed materials on the basis of polysaccharides and special substrates which control this growth. The growth conditions of the cells in these structures are very similar to their natural environment.

neural impulses from the brain to the specified action (Pylyshyn 2003). Global media actively discussed the news about the attaching of the electrical prosthesis by Italian and Swedish surgeons to a 22-years old drummer Robin Ekestam who lost his arm as a result of cancer.

However, despite the fact that neural interfaces show impressive results, their implementation is connected with many difficulties. For instance, many nanostructures and nanotubes are quite toxic for cells (Kotov *et al.* 2009). Implanting external devices leads to the traumatizing an organism despite the availability of many methods of mitigating the traumatizing effect (Grill, Norman, and Bellamkonda 2009). Another problem is the different electrical conductivity of biological tissue and the technical device. Probably, new nanostructures from which nanofibers for neural interfaces are made, can solve this problem (Abidian and Martin 2009).

**Gene therapy is an advanced means of correction of an organism.** Gene therapy constitutes a separate direction in modern medicine. A significant contribution to its development has been made by the Human Genome Project, whose aim is to determine the sequence of human DNA (Brown 2000; Stein 2004). However, the path from defining the structure of the genome to understanding its functions is long and this scientific discipline is at the very beginning of its development. The leading countries spend billions of dollars on the researches in the field of gene therapy.

Gene therapy combines a whole range of characteristics of the Cybernetic Revolution including expanding opportunities for *choosing optimum regimes in the context of certain goals and tasks*. Historically gene therapy was aimed at treating hereditary genetic disorders. But at present gene therapy is already considered as a potentially universal approach to the treatment of a wide range of diseases from genetic to infectious ones.

There are two approaches to gene therapy: *fetal gene therapy* when foreign DNA is introduced into the zygote (fertilized egg) or a germ at the early stage of development; thus, it is expected that introduced material will be inherited. The second approach is *somatic gene therapy* when the genetic material is introduced only in somatic (that is non-germinal) cells and it is not transferred to sex cells.

There is another approach – activization of organism's own genes for the sake of full or partial overcoming the impact of the mutated gene. The striking example of such approach is the usage of hydroxyurea for the activation of the synthesis of fetal hemoglobin in patients with sickle-cell anemia and thalassemia.

Gene therapy can become the example of individualization of the technologies and targeted influence on the processes. On the basis of the genetic data the most appropriate treatment will be adapted for individual patients, and if it is necessary the defective genes will be corrected. Presumably, gene therapy will manifest itself first of all in sports medicine as, first, it can become a new tool in the attempts of the pharmaceutical companies to avoid the control of anti-doping committee and, second, inherent potentialities become insufficient for achieving the best results in big-time sports.

When choosing the appearance of a future child (color of eyes, skin, *etc.*) gene therapy can be used. In future it might be possible that babies will be born almost by order, these will be 'the perfect babies' (Fukuyama 2002 with cite McGee 1997).[17] In other words, that means that parents will choose desirable features of a child before his birth. So, the geneticists will probably find 'the genes' of such qualities as nobility, aggression or unselfishness and even intelligence and due to this there will be created an 'improved' baby. Such genetic improvement will remind the improvement of face and body by plastic surgery methods. In other words, it will be impossible to make a genius or a champion of any child but it is not excluded that it will be possible to improve his potentialities. Just like at present it is possible to improve the sports and intellectual potentialities via special methods.

Presumably, first gene therapy will manifest itself in sport medicine as enormous investments are made in it and the best minds are engaged in this field (*e.g.*, the average annual salary of a physician in sports medicine is about US$ 200,000). Second, it can become a new method in the struggle of pharmaceutical companies against anti-doping committee. Third, increasing of sportsmen abilities is in great demand in professional sport as innate potentialities are no longer enough to set the record.

**Changing human reproductive capabilities** is an especially important field of medicine. The number of incurable diseases causing infertility decreases. Nevertheless, the only opportunity for some patients is to use *in vitro* fertilization. Besides, due to the development of medicine there increases a number of women who want to have children after their reproductive age is over (*e.g.*, Annegret Raunigk, a 65-year-old woman from Germany gave birth to quadruplets [Q13Fox 2015]). One should mention the technologies of growing an embryo outside the woman's body. The transplantation of reproductive organs becomes possible.[18] The scientists are developing the artificial womb which can be transplanted to a woman with the damaged womb or even to a man that will radically change the concept of sex (McKie 2002) and will cause new ethical problems. Artificial womb experiments have been successfully conducted

[17] It is difficult to say how 'perfect' they will be and what kind of problems will appear as a result of these technologies. For example, the possibility to predict the baby's gender resulted in gender imbalance in China. As a result, there are a disproportionate number of boys. Thus, we agree with Francis Fukuyama, who believes that the future achievements of the 'biotechnology revolution' should be accepted with great prudence (Fukuyama 2002).

[18] See http://www.theguardian.com/science/2014/oct/04/woman-gives-birth-womb-transplant-medical-first.

in Italy where artificial womb was grown and transplanted to a woman. In our opinion as a result of the final phase of the Cybernetic Revolution the number of the experiments with artificial fertilization will increase and growing of embryo outside the woman's body will become the reality.

**The perspective direction in medicine is slowing down the ageing process.** It was very difficult to find the scientific foundation of this process but finally it probably became tangible after the invention of the genetic structure of special bodies of the cells which are necessary for division – telomeres. It appeared that every time after the duplication of chromosomes a number of telomeres at its ends decreases. That is one of the reasons why cells are getting old and die when an organism reaches certain age. Perhaps, that is why our bodies get older, though hot debates among the scientists about this issue still take place (Slagboom *et al.* 1994). In 2009, Elizabeth H. Blackburn, Carol W. Greider and Jack Szostak were awarded the Nobel Prize in Physiology or Medicine for the discovery of the way chromosomes are protected by telomeres and the enzyme telomerase from terminal underreplication.

It is probable that genetic methods can significantly increase life expectancy. At present we observe the dynamics of increasing life expectancy, when the average life expectancy in some countries is more than 80 years. In our opinion, it will increase. Fig. 5 shows the dynamics of growth rate of persons aged 80 years or over until 2070. It will be even in the case of inertial prognosis. In fact in the end of the final phase of the Cybernetic Revolution the number of people 80+ can increase.

In the modernization phase of the Cybernetic Revolution the increase of life expectancy will be the largest in developing and medium-developed countries where life expectancy is significantly lower than in developed countries. There will be no significant increase of life expectancy in developed countries. The breakthrough in the field of medical technologies will occur a little bit later, as we have already said, in the 2030–2050s. Then, probably, there will be a new breakthrough in increasing the life expectancy; perhaps, it will increase by 5–15 years. The increase of life expectancy and especially preserving the quality of life and the individuals' activity for as long as possible in the context of the abovementioned characteristics of the revolution of the controllable systems means a further development of controllable systems, individualization, selection of optimum regimes, huge energy saving (including emotional) and unique experience and world perception. Every person gains invaluable life experience during his lifetime. One can also mention that it is an opportunity to preserve the previous generations' experience (under the conditions of rapid technological development and as a result the inevitable rejection of experience and knowledge accumulated by previous generations) at the expense of the personal experience of long-livers and personal contact of their descendants with them.

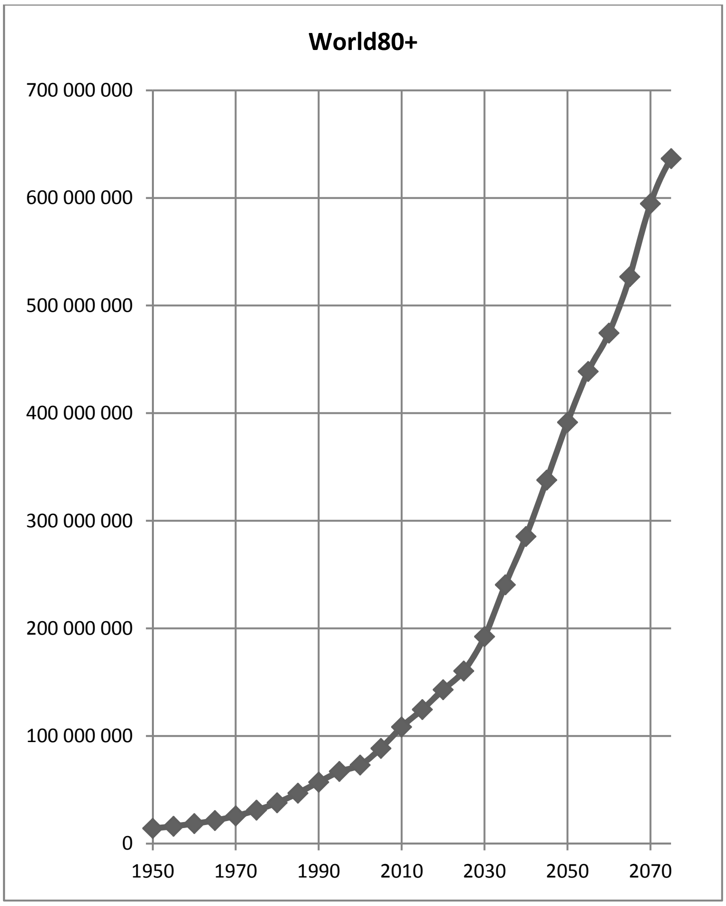


**Fig. 5.** Predictable increase in the number of people aged 80+, estimated for 1950–2015 and projected to 2075.

*Source:* UN Population Division 2015 (Grinin and Korotayev 2015b).

### 3.3. Will the development of the Cybernetic Revolution proceed in the direction of cyborgization?

A very popular word 'cyborg' (short for 'cybernetic organism') derives from the word 'cybernetic'. Cyborg is defined as a theoretical or fictional being with both organic and biomechatronic parts.[19] The term 'cyborg' often applied to an organism that has restored function or enhanced abilities due to

[19] The term was coined in 1960 by Manfred Clynes and Nathan S. Kline (Halacy 1965).

the integration of some artificial component or technology that relies on some sort of feedback.[20]

It is obviously that many achievements in medicine will impell our civilization to the state in which more and more humans can become partial cyborgs. Thus, we are following the path of development of self-regulating systems of a new type which will be constituted by the elements of different origin: biological and artificial. All that we have written about artificial organs and tissues will contribute to the breakthrough in the field of both production of absolutely new materials which will expand the implementation of non-biological elements in the human body. Thus, the Cybernetic Revolution is closely connected with the process that can be designated as cyborgization. We should be aware of the fact that this actually means not only the formation of a new direction in medicine, but also the moving towards the **cyborgization** of a human being.

Of course, this can cause a certain and quite reasonable anxiety. On the other hand, expanding the opportunities for not just a long but also an active life is hardly possible without significant support for the sensory organs and other parts of the body which weaken as a result of ageing and other reasons. Finally, glasses or contact lenses, artificial teeth, tooth fillings, bones, aerophones, artificial blood vessels, mitral valves, *etc.* allow hundreds of millions of people to live and work and these people still remain humans. The same is true with respect to more complex systems and functions. Thus, people with disabilities can benefit from the development of medicine and cyborgization as they will be able to significantly compensate their drawbacks.

However, we suppose that the idea that some day the human body will be fully replaced by non-biological material and only the brain or the organs which support the senses will remain are just fantasy. This will never come true (the well-known ideas about such future for humankind are presented by Kurzweil [1999]; see about such fantasies also in Rybalkina 2005: 333). People who propose such solutions, for example, to replace supposedly less lasting and comfortable biological material by the technological inventions (such as replacement of haematocytes by billions of nanorobots, *etc.*) in their forecasts try to use the outdated logic that was widespread several decades ago in science fiction or scary stories: the replacement of biological organisms with technical ones. The modern logic of scientific and technological progress including the latest achievements in bioengineering shows the movement towards the synthesis of biological forms and technical solutions into a unified system. Technical achievements can hardly replace the biological mechanisms which have been selected for many millions of years. On the contrary, we should follow the path of 'repair', improvement, the development of self-regulation and support of biological mechanisms via some technical solutions.

[20] URL: https://en.wikipedia.org/wiki/Cyborg.

The human brain is very tightly connected with the body and sensory organs, most of its functions are based on the control of the body that does not imply its full-fledged work outside its biological foundation. The opportunities of science and medicine to replace worn organs will increase but the biological foundations of a human will always exist and must prevail. If one can help the human body by different means including methods of activization of immune system, opportunities of genetics, the methods of blocking or decelerating the process of ageing, *etc.*, it is much more reasonable to preserve the human biological foundation. In any case, in the nearest decades in the process of cyborgization quite radical breakthroughs are possible, but nevertheless the process of cyborgization will not go too far.

**Improvement of individuals' natural abilities.** It is important to note that at present all these technologies aim at restoring individual's lost functions. It does not exclude the future possibility that this direction will provide opportunity to move towards improvement of natural and intellectual abilities beyond the natural bounds. However, in fact this can hardly happen by the end of the 21st century. Probably, the process will be similar to the process in the field of plastic surgery which was first created for the repair of damaged tissues but then it became the beauty industry.

## Section 3. FORECASTS: BIOTECHNOLOGIES IN CYBERNETIC REVOLUTION

**Definition.** Biotechnology is a broad and multifaceted notion. Until the 1970s the term 'biotechnology' was used mainly for the description of some technological processes in food industry and agriculture. After in laboratories they started using recombinant DNA and cell cultures grown up in vitro, biotechnology began to be associated with genetic engineering, and at present these two concepts are even often used as synonyms. At present, there are known several dozens of definitions of biotechnology (see, e.g., Blinov 2003). There are also official international definitions, for example: 'Biotechnology represents a complex sphere of activity in which new methods of modern biotechnology are connected with the established practice of traditional biotechnical procedures. The basis of this growing knowledge-intensive industry is made by the complex of methods giving a chance to the person to change purposefully the structure of deoxyribonucleic acid (DNA), or genetic material, plants, animals and microorganisms as a result of receiving useful products and technologies' (the UN 1992: ch. 16). We understand *biotechnology as a set of scientific and industrial methods of production of various products through using live organisms and biological processes.*

The main directions of modern biotechnology are the biotechnology of food, agriculture, means and products for industrial and household use, pharmaceuticals and other medical preparations, environment protection against pollution, *etc*.

## 1. History of Biotechnology before the Start of the Cybernetic Revolution

In spite of the fact that biotechnology is a rather new branch, the period of 'traditional' microbiological production goes back to the Stone Age: yeast bread, yoghurt, beer, wine, vinegar are used since ancient times. The first scientific foundations of biotechnology were set by Louis Pasteur who discovered the fermentation nature. At the end of the 19th and the beginning of the 20th century the knowledge in microbiology which found increasing practical application was actively accumulated. In 1917, the Hungarian engineer Károly Ereky introduced the term 'biotechnology'.

Some scholars (Glick and Pasternak 2002) mark the following periods of development of biotechnology: 1) until 1917 it was the period of 'conventional' microbiological production; 2) from 1917 to 1973 – the period of invention of laying scientific foundations for modern biotechnology. In addition, this period is subdivided into two intervals: from 1917 to 1940 is in a way an 'incubatory' subperiod when biotechnologies were already actively used, but generally played no significant role in industry and economy; and from 1940 to 1970 when biotechnology already became a noticeable branch of industry; 3) from 1970 to the present is the period of the modern biotechnology, implementation of scientific research results in biotechnological production.

Such a periodization fits well our concept of the Cybernetic Revolution. Actually, starting from the 1940s and until the 1970s it is possible to speak about a rapid development of biotechnologies as a part of the scientific and information phase of the Cybernetic Revolution. They started to most powerfully develop from the 1970s on the basis of the Cybernetic Revolution.

Biotechnology appeared at the last stages of the industrial production principle alongside many other innovative branches. In the late 19th and early 20th centuries there appeared biofertilizers and biological preparations for pest control and combatting plant diseases, production experiments in bioconversion (Volova 1999). There was established the production of acetone, butanol, antibiotics, organic acids, vitamins, feed proteins, *etc.* with the help of microorganisms (Yegorova and Samuilova 1987).

*The 1930–1940s were marked by the formation of a background for the transition to the Cybernetic Revolution*. At that time there started industrial production of some vitamins, for example, vitamin C. The production of preparations by means of biotechnological methods increased. The first mass biotechnological production was the production of penicillin which started in 1943. The World War revealed an urgent necessity to organize mass production of cheap drugs, provision and vitamins.

## 2. The Initial Phase of the Cybernetic Revolution

### 2.1. Biotechnology becomes an essential branch of industry

According to our concept, the 1950s appear to be the beginning of the Cybernetic Revolution (of its scientific and information phase) when *a number of trends which used to be non-systemic in relation to the previous production principle obtained a systemic character*. During this period, biotechnology finally became a rapidly growing industrial sector which affects the whole economy. The biotechnological products were applied very widely. In the first decades after World War II there was organized large-scale production of amino acids, unicellular feed proteins (from oil and paper-pulp industry waste), steroids, and also cell culture of animals and plants was mastered. Already from the late 1940s there started organizing mass production of antibiotics. They found extensive use not only in medical industry, but also in agriculture for treatment of animals and plants, as bioadditives in fodders. Some highly effective forms of antibiotics were created with the help of mutations. The intact cells of microorganisms began to be widely used for receiving medical substances of the steroid type, large-scale production of vaccines was organized (Volova 1999). The production of pharmaceuticals became successful, and also a very profitable business; therefore, capitals and scientific forces flowed there. The quantity of medical supplies received via biotechnological method or the so-called 'red biotechnology' began to increase steadily. Let us emphasize that biotechnology became a powerful support for agriculture, as it provides the production of feed, additives, vitamins, and fertilizers, as well as the protection against pests. By means of biotechnology people also receive biofertilizers, amino acids, organic acids, alternative energy sources, and utilize biological waste. The industrial biotechnological production became possible also due to a wide implementation of automated processes. The automation, as noted above, is one of the main characteristics of the initial and middle phases of the Cybernetic Revolution.

### 2.2. Fundamental breakthroughs in biotechnologies

The breakthroughs in biotechnologies are connected, first of all, with the achievements in the study of the mechanism of transferring hereditary information. In 1953, James Watson and Francis Crick defined the structure of the DNA molecule. It laid the foundation for understanding the role of genetic information and basic opportunities of the purposeful transfer of genes from one organism to another. It opened enormous prospects, perhaps, surpassing the most courageous fantasies, like the ones presented by Herbert Wells in his novel 'The Island of Doctor Moreau'. The further discoveries connected with the genome were abundant. But, naturally, it took decades for the discoveries to their industrial implementation.

The 1970–1990s (the end of the initial and the transition to the middle phase of the Cybernetic revolution) were also marked by a tidal wave of advances in understanding of molecular biology.

We will enumerate some of them:

– 1973 – Herbert Boyer and Stanley Cohen laid the foundation of the recombinant DNA technology;

– 1975 – George Köhler and Cesar Milstein developed the technology of getting monoclonal antibodies;

– 1978 – the Genentech Company produced human insulin received by means of E. coli (colibacillus);

– 1981 – the first automatic synthesizers of DNA hit the market;

– 1982 – the first vaccine for animals received by the recombinant DNA technology is allowed for use in Europe;

– 1983 – hybrid Ti-plasmids are applied for the transformation of plants;

– 1988 – the method of the polymerase chain reaction (PCR) is invented.

As a result of the mentioned and not mentioned findings the genetic engineering becomes a powerful direction in biotechnology. The qualitatively new level of development of biotechnologies from the 1970s meant that within the frame of the Cybernetic revolution they already outgrew the potentialities founded yet by the industrial production principle and started developing on the new basis. During the last decades of the initial phase of the Cybernetic Revolution (the 1970s – the early 1990s) biotechnology became already quite a significant industrial branch which significantly contributes to agriculture (both plant growing, and cattle breeding, including also veterinary science), food and chemical industry, pharmaceuticals and medicine.

## 3. Biotechnology in the Modernization Phase of the Cybernetic Revolution

The 1990–2000s were marked by a powerful advance in biotechnology as a branch of industry.

Biotechnologies become a rapidly growing sector in which many countries started to invest significant amounts of money. The company Ernst&Young (EY) which over 30 years has been analyzing the biotechnological market recorded the sharp rise of the biotechnological industry in 2000. In the period from 2000 till 2005 the global revenue in the field of biotechnologies doubled and grew to US$ 50 billion. And in 2013 in the USA, Europe, Canada and Australia the revenue in the field of biotechnologies was about US$ 100 billion (Glen *et al.* 2013). From 2008 most investments in biotechnologies were made in R&D, *i.e.* innovations.

During this period the directions connected with genetic modification that developed in the previous phase became stronger. Organisms are cloned, a number of diseases are treated by means of genetic modifications. Along with production of medicine, bioadditives to feeding-stuffs, *etc*., the production of GMO became already a very significant segment of agriculture, the price increase for energy products led to a rapid growth of the production of biofuel (which includes GM foods).

No wonder that biotechnologies are considered as the most promising branch which can become the engine of a new innovative breakthrough.

The significance of biotechnologies is proved by a wide use of their achievements in different fields. Thus, in food industry there are practically no directions in which it could not be applied. Chemical production (in particular, polysaccharides, biodegradable polymers, biocatalysis, and also creation of new materials, for example, bioplastics), energetics, agriculture, municipal service (*e.g.*, in waste recycling), the branches connected with long storage of production; medicine and pharmacology; nanotechnologies; cosmetology; military branch are connected with biotechnology. At last, biotechnologies actively become common for people who use bioadditives and vitamins, special products in a diet, use certain type of cosmetic products, *etc*.

**Biotechnologies contribute to the development of biosensors.** A biosensor can be generally defined as a device that consists of a biological recognition system, often called a bioreceptor, and a transducer (Ferrari and Mauro 2006). Different biological materials such as enzymes, cells and antibodies are used in biosensors (Vo-Dinh *et al.* 2001), (Rusmini *et al.* 2007). Biosensors are able to transform biological energy into electric one. Thus, biosensor technology combines the achievements in biology and modern microelectronics. That is one of the most important ways to combine the technical and biological elements of the future self-regulating systems into a single system. There are different types of biosensors. Some of them are the devices which measure a limited number of the parameters (*e.g.*, blood glucose level), another measure a lot of parameters. At present they are used in many fields including for measuring the environmental pollutants. They are especially useful for different analyses in medicine, for example determination of metabolites or hormone levels (see also above about health monitoring in the future). Biosensors allow to control different changes in organism during surgery. An example of biosensors used at home is the glucometer, which helps to define the glucose concentration in blood. Biosensors are also used in measuring physical activity. For sportsmen biosensors are already the instruments of control of their physiological parameters. Hundreds and even thousands of biosensors combine the biochips. Biochip is a miniature device, essentially the entire laboratory which can perform thousands of simultaneous biochemical reactions. Biochips help to carry out quick analysis of a large number of biological parameters for different purposes, including diagnosis of a cancer, infections, and intoxications (Fung *et al.* 2001). Promising direction is the combination of biochips and nanorobots which, for example, can monitor the spread of viruses in the blood online (Cavalcanti *et al.* 2008).

The prospects of biotechnology are great. So far they are closely connected with microbiology, and microorganisms are present everywhere, even in this regard the sphere of application of biotechnologies will be boundless (from space needs to production and processing of mineral resources). At last, biotechnologies will become one of the main areas where the final phase of the Cybernetic revolution and the consecutive epochs (the 2030–2070s) will unfold.

## 4. The Characteristics of the Cybernetic Revolution in the Development and Application of Biotechnologies

**The progress on the way to self-regulating systems**. Already in the 1970s, computers were applied for the automation of biotechnological production. Computers rather quickly ceased to play a secondary role and have become the basis of automation ( Zudin *et al.* 1987); one should point out that such journal as *Computers and Automation*, the editor of which was Edmund C. Berkeley, appeared not by chance in 1961. Dozens of devices for biotechnology were designed with the help of microprocessors, especially for work with DNA. In the modernization phase of the Cybernetic Revolution, the powerful development of ICT and software has raised the automation in biotechnological production and scientific researches to a new level.

In particular, in course of time factories producing biotechnological products demanded a lesser human participation. This substantially cheapens mass production of medicine and agricultural goods making them more available.

The software for the needs of genetic engineering is rapidly improving which appears to be the one of many examples of convergence of the directions of the Cybernetic Revolution. Today experts, without leaving the computer, select the necessary gene, model its embedding and behavior at transformation. The devices for automatic purification, cleaning of DNA and division into necessary fragments, transfer of a gene, *etc.* emerge. The sequenators (the devices for division of a chain of nucleic acids into nucleotides composing them) which used to occupy an impressive part of laboratories today are produced in the form of USB flash drivers and serve an example of miniaturization as well.[21]

It is extremely important that at present we can already speak about realization of the principles of self-regulation at the genome level. In particular,

[21] See about Oxford Nanopore Technologies. URL: https://www.nanoporetech.com/products-services/minion-mki

together with a useful gene, for example, of salt-tolerance in plants (Grinin *et al.* 2010), built in the special genes-controllers – the pro-motors which launch the necessary gene only under certain conditions (a high concentration of salt in the soil). Thus, there appears a self-regulating biological system (without human participation in the process, but controlled by people), which has not existed before and which, however, works in a proper way. In brief, we observe a prototype of autonomous and self-regulating biological systems which thanks to biotechnologies will be widely and actively used in the future in almost all spheres of life.

In biotechnologies self-regulation is widely applied also at the level of a cell. For example, the feedback strategies of a substratum and enzyme are used, known as the operon model for which in 1965 François Jacob and Jacques Monod got the Nobel Prize.

The achievements of contemporary genetic science and technology demonstrate the opportunities of creation of self-regulating biological (and ecological) systems of a rather high level in the future. Already today a genetic modification can change a whole population. Thus, the method of distributing genes via 'decoy' individuals is widely spread. For example, infertile mosquitoes had been massively introduced into the wild population, such ineffective crossing led to the reduction in a number of insects (Tkachuk 2011; Benedict and Robinson 2003).

**Creation of new materials**. In the 1940–1970s, one of the main directions was the development of industrial production of already known substances (*e.g.*, vitamins) or their analogues; however, during the same period there appeared the elements which did not exist in natural environment (*e.g.*, Humalog, which is a widely applied synthetic analogue of human insulin [Woollett 2012]). This sequence reminds the history of development of chemistry: at first people learned to produce the known substances, and then the artificial materials.

Due to biotechnologies many new materials are produced, for example, bioplastics. The main advantage of this material is that unlike ordinary plastic it can biodegrade. Thus, the main goal of bioplastics production is preserving environment, reducing the production of goods from non-renewable resources and cutting the discharging of carbon dioxide into the atmosphere. This is an important step to the creation of self-cleaning ecological systems in the future and also to the preservation of the environment. The range of bioplastic products is already very wide. From 2000 to 2008, the world consumption of compostable plastics made of starch, sugar and cellulose increased by 600 per cent (Ceresana Research 2011). However, the production of oil-free plastic amounts only one per cent so far. The experts consider that by 2020, the production of bioplastics will make 3.5–5 million tons, but, unfortunately, it will be only about 2 per cent of total production of plastics (Leshina 2012). Despite difficulties, biotechnology brings hope for more nonpolluting and renewable production which in the long-term perspective will allow saving resources.

**Individualization in biotechnologies**. Genetic engineering appears to be an especially bright example of individualization which is one of the main characteristics of the Cybernetic Revolution. Individualization in biotechnologies is connected, first of all, with the emerging opportunity to change the genome and to get new properties of an organism. According to this, in future the identity of each human body in the context of the formation of its life style, control over health, improvement of work of an organism, *etc.* will be taken into consideration. (Perhaps, individualization in biotechnologies will be applied not only to the human organism, but for example, to pets – dogs, cats, *etc.*).

Another example of individualization in biotechnology is cloning. Cloning by itself is a very widespread phenomenon in nature. One of the first experiments on cloning was performed by Georgy Lopashov in 1948. He proved that if the cell nucleus of other species is put into the ovule, the set of genes of an embryo will be the same as of an organism the cell nucleus of which is used. Numerous experiments showed that if the nucleus of adult cell is used, an embryo will be nonviable. The experiments on frogs proved that the cells which are not yet specialized can be used in cloning. Thus, the stem (immature) cells began to be used in cloning (Gurdon and Colman 1999). Since then the scientists have managed to clone pigs, sheep, cows, dogs and other animals. But these experiments were not so successful.

There is full and partial cloning of organisms. Of course, cloning of a whole organism is of greatest interest for public and also it provokes the largest disputes on the need and allowability of such kinds of researches. However, despite famous experiments, especially with the sheep Dolly, due to serious biological obstacles cloning will hardly develop much in the near future. It is necessary to point that the results of cloning are strongly exaggerated because of the aspiration for sensation. The sheep Dolly grew old twice quicker than the congeners. As a result, the animal was put down. Thousands of experiments were conducted with different animals, including more than a hundred anthropoids, but the positive result has not been achieved so far.

The therapeutic cloning provides much more ample opportunities for development and introduction at the level of commercial production. This type of cloning is described in more detail in the section about medicine.

**Resource and energy saving** is one of the main tasks and outcomes of introduction of biotechnology. The basic opportunities with respect to resources saving are connected with an opportunity to influence the genetic organization of living beings which at present serves the basis for the agricultural ('green') biotechnology which has already become a part of the initial phase of the Cybernetic Revolution. The breakthrough in this area is connected with *totipoten-*

*cy*, that is an ability of plants to form a full-fledged organism from a single cell. With the necessary gene transfer, one can make, for example, a variety of potato resistant to the Colorado beetle, or reduce the susceptibility to drought, cold and other stresses (Grinin *et al.* 2010). New agricultural technologies are of great importance for the developing countries. For example, genetically modified and pest resistant varieties of cotton plant and corn demand much smaller usage of insecticides which is more cost-effective and eco-friendly. The individualization is also noticeable in the animal genetic engineering which develops more slowly, but even now and in prospect it has an enormous value for agriculture and medicine (by means of genetic engineering it is possible to increase milk production, to improve quality of wool, *etc.*).

**The increase and cheapening of food production** is a global challenge for the humankind taking into account that the population number will continue to increase for several more decades (first of all in the poor and poorest countries, especially in Africa), perhaps, reaching nine or more billion people (see Population … 2012). Biotechnologies can make a huge contribution to the solution of the problem. Already today biotechnologies has made much with respect to the increase of the overall food production due to the increasing yield, resistance of plants to stresses, adaptation to local conditions through the creation of new and improvement of already existing genetically modified organisms (GMO), production of a significant amount of artificial nutrients, in particular, proteins.

The agricultural ('green') biotechnology which has already become the part of the initial phase of the Cybernetic Revolution is based on the technology of genetic modification (see, *e.g.*, Borlaug 2001).[22] GMOs allowed to significantly reduce the expenses, to increase crop capacity, to economize on the refusal from long selection. Due to genetic modification one can obtain the plants which are resistant to crop pests (*e.g.*, potatoes resistant to Colorado beetle), one can reduce susceptibility to drought, cold and other stress factors. One of the most widespread and widely discussed methods of genetic transformation is the transition of gene of resistance to chemical herbicide under the trade name Roundup (Williams *et al.* 2000; Richard *et al.* 2005). As a result when treated with Roundup, genetically modified plants remain intact but weeds are killed.

Despite various sanctions, the overall production of GMO is quickly growing in crop farming. Beginning from 2010, the GMO farming area in developing nations surpassed that in developed countries (Clive 2011). The analysis of the world economic effect of using biotechnological cultures shows the increase of profitability thanks to two sources. First, this is the reduction of production expenses (to 50 per cent) and the opportunity to get large crops on the same agricultural areas. Second, a considerable increase of harvest (in case of remov-

[22] About successes of Green Revolution in different countries see Wik *et al.* 2008; Pingali 2012.

al of restrictions on distribution of GMO World GDP could grow by US$ 200 billion [Kamionskaya 2011]).

The problems connected with GMO, real and imaginary, demand a special consideration. However, in comparison with the problem of hunger or malnutrition they seem less important. No doubt, that such production will increase (especially the production of biofuel) as it is the only way to solve food problems. The biotechnological production gives cheaper food-stuff, increases productivity in the places which used to be unsuitable for the cultivation of crops. New properties of farm animals and plants considerably save time and expenditures which are inevitable in case of long selection.

In general, as it was already told, achievements in genetic engineering will become one of the most breakthrough directions of the future revolution.

**Biofuel.** Biotechnology can help to produce rather cheap alternative energy sources. One can hardly say that biofuel is something new in the history of mankind as firewood, brushwood, *etc.* have been used from ancient times. But now it is extremely important to note that it is a renewable resource, whose overall production has become large notably thanks to biotechnologies. Now its global production amounts to more than 100 million tons (mainly, in the USA, Europe and Brazil). Today biofuel makes 10 per cent of all energy output; however, perhaps, its application will grow more than ten times by 2035. However, the majority (80 per cent) of biomass for biofuel is from forestry residues (Kopetz 2013). So the aspiration for maintenance of the ecological balance of the planet and to reduce wood use can strongly affect this source of alternative energy.

## 5. Forecasts of Development of Biotechnologies at the Final Phase of the Cybernetic Revolution

### 5.1. The introduction of new technologies in the modernization phase of production revolutions

The modernization phase of a production revolution is characterized by the two major tendencies: 1) the extensive distribution of new technologies with simultaneous improvements as a result; 2) the strengthening of social tensions and even struggle for necessary changes in some spheres of social life due to the introduction of these technologies. In order for the final phase of a production revolution to begin, the development of technologies during the modernization phase has to achieve both a rather large variety and 'density'. Taking into account that biotechnologies are innovative branches, any country which wants to be the leader in this field, will have to develop them anyway. On the one hand, we will observe a wide diffusion of biotechnologies into our lives: in nutrition, various nutritional supplements, influence on our body (through various branches of medicine, in particular cosmetic and one's own treatment of the body as, for example, body-builders do), *etc*. There must quickly develop both the branches which have already become a reality (*e.g*., the cultivation of genetically modified plants, affecting the productivity of domestic animals, production of biofuel), as well as the technologies which are less spread today, in particular in the development of biomaterials.

On the other hand, such a wide implementation of biotechnologies, undoubtedly, will intensify public, diplomatic and economic struggle against the change of traditions, national features, real or imaginary harm. Such a movement against cloning, GMO, computer selection, *etc.* has been already taking place in different countries. Such a reaction is quite natural, legitimate and in many respects useful though it may happen that conservatism will suppress progress. Just within the framework of this struggle and collisions, there may originate decisions which become important in the long term and will not only promote achieving of some balance, but also give an impetus to the development (let us remember that the ban on the importing of cotton fabrics in England served as a trigger for the development of its own cotton industry which became a cradle of the Industrial Revolution [Mantoux 1929; Allen 2009; Grinin and Korotayev 2015a]).

### 5.2. The beginning of the final phase of the Cybernetic Revolution and the development of the Scientific-Cybernetic production principle

Now, proceeding from current tendencies and a general sense of the development of the Cybernetic Revolution, it becomes possible to set out *the future developmental milestones in biotechnology* in the final phase of the Cybernetic Revolution (the 2030–2070s). As has already been mentioned, it can start in a rather narrow sphere, from which the innovations will start distributing and gradually penetrate the new areas.

Certainly, it is very difficult to anticipate the direction and moment of concrete discoveries. We suppose that at the very first stage biotechnology, as an independent direction, will play a less important role than medicine. It will be rather an important component of medical technologies, providing breakthroughs in the area of the treatment of diseases and the regulation or monitoring of organism functions.

**Forecasts of self-regulation development.** The level of controllability will increase considerably within a number of important systems connected with biotechnologies. Thus, probably, while transforming an organism, they will insert not a separate useful gene (Simon *et al.* 1983), but a whole set of necessary genes which will operate depending on environmental conditions. Such characteristics will be extremely important in the case of climate changes which are quite probable. It will become possible to choose the most optimal varieties of seeds and seedling for a unique combination of weather conditions and territory (the sort of imitation of evolutionary selection via automatic search in databases). Consequently, huge databases of such plant varieties and variations will be created. It is quite possible that in the future the whole process of getting a transgenic plant will take place without human participation, thus, it will become self-regulating.

It is possible to assume that by the end of the phase of self-regulating systems (and perhaps, even earlier, *e.g.*, by the 2050s) the agricultural biotechnologies will be already very developed. It may predict that the very adaptiveness of the modified products will allow for a response even to the smallest fluctuations of local conditions. In other words, it will be possible to order producers or collectors to create varieties of plants for individual greenhouses, hotbeds or plots. Farmers will be able to select individual fodder and drugs by means of programs and to order them via the Internet. Even an individual will be able to invent a houseplant hybrid suitable for the interior and to order its production and delivery. Thus, individualization will reach a new level.

The same refers to domestic animals: it will be possible to breed animals with peculiar characteristics within separate breeds of animals (or even by the individual order). It is probable that the selection of animals on the basis of genetic engineering will also develop in the direction of decreasing human participation.

**The solution of urban and some environmental problems.** Undoubtedly, there will occur important changes in using biotechnologies for the solution of environmental problems. Here it is possible to assume that biotechnologies will be intruded first of all in the urban ecology. It is necessary to consider that in the coming decades the urban population will increase by 40–50 per cent (see, *e.g.*, NIC 2012). With the pace of development quickening in poor countries the problems of unsanitary conditions, incidences of disease, *etc*. will become very acute. And since different diseases can quickly spread worldwide, the problems of some countries will become problems for all countries. Among the problems which can be potentially solved by means of the development of biotechnologies, are those related to water cleaning, recycling of waste, liquidation of stray animals. Already today the micro-organisms for water cleaning are applied; with their help we also get bio-gas from waste recovery. But in the future these and similar problems will be solved by the development of self-regulating systems that will make it possible to solve a number of technical and scientific problems.

Thus, just as in the late 19$^{th}$ and early 20$^{th}$ centuries people coped with mass infections by means of biotechnologies, in the middle of the 21$^{st}$ century, the latest biotechnologies, perhaps, will help to solve the most vexing problems of cities where at least two thirds of the population will live. But the ecological problems, naturally, is not limited by the cities; it has to be extended to the cleaning of reservoirs and other ecosystems. The creation of ecological self-regulating systems will considerably reduce expenses and free huge territories occupied by waste deposits, as well as allow breeding fish in self-cleaning reservoirs.

One can assume that an important direction will be the creation of self-regulating ecological systems in resort and recreational territories which will provide the best conditions for rest and business.

**The breakthrough in the sphere of resource saving.** Biotechnology can help to solve many global issues, for example, to cheapen the production of medicines and foodstuffs including producing and making them in ecologically sound ways that can also keep or make the environment pristine, thereby considerably expanding their production. The solution to the food problem will come in the different ways, in particular due to the mass production of food protein whose shortage is sharply perceived in many societies (at present the feed protein for animals is generally produced in this way). Even now there are results based on the production of food proteins or, for example, imitation meat. But so far such a production is too expensive. Now a gram of laboratorial meat costs 1000 dollars (Zagorski 2012), but this is part of the usual process from the laboratory to mass cheap production.

**The creation of new materials.** The opportunities of creation of self-regulating and self-operating systems by means of biotechnologies, in particular genetic manipulations, opens an important direction in the field of new materials with desirable properties (*e.g.*, genetic material). At present genetic engineering is able to create not only the certain genes but also the entire genomes and even chromosomes. Artificial chromosomes can be added and consist of new genes which were not inserted into the organism (Dymond *et al.* 2011). It potentially allows for making substitutes for the natural process feedstock, for example, leather. The respective projects are already present now. For example, the Modern Meadow Company aims at making a revolution in the clothing industry by growing leather and other types of animal skin in the laboratories (Zagorski 2012).

The process of creation of biotechnological genuine leather will include several stages. At first scientists will select millions of cells from the donor animals. It can be both cattle and exotic animal species who are often killed only because of skin. Then these cells will be multiplied in bioreactors. At the following stage the cells will be mingled in one mass which will be formed in layers by means of the 3D bioprinter. The skin cells will create collagen fibers, and the 'meat' cells will form a real soft tissue. This process will take some weeks after which soft and fat tissues can be used in food production. Despite the exoticism and queerness of the above-described situation, in principle, it is very similar to the process of production of artificial furs which made it possible to solve the problem of warm clothes.

## Section 4. NANOTECHNOLOGIES

### 1. Definition and History of Development of the Field

**Definition and parameters.** The humankind has been using nanomaterials for a long time whereas the ideas of nanotechnologies have appeared quite recently. Now with the existence of nanoparticles one can explain the peculiar properties of the well-known materials created in ancient times such as various enamels, painting materials, damask steel, *etc*.

Nanotechnologies is a widely used concept which can be conventionally defined as *an interdisciplinary area of fundamental and applied science, proving and developing practical methods of research*, *the analysis and synthesis*, *and also technology and methods of production of nanomaterials by a controlled manipulation of separate atoms and molecules*. The large scale of the concept of nanotechnologies makes it a problem not only to define them, but also to classify nanoproducts for whose specification there was even created a special group within European Commission.

Now in Technical Committee ISO/TC 229 the nanotechnologies are defined as follows (ISO 2005):

– knowledge and control of processes, as a rule, on a nanometer scale, but not excluding the scale of less than 100 nm in one or more measurements;

– use of properties of the objects and materials in the nanometer scale which differ from the properties of free atoms or molecules, for the creation of more perfect materials, devices, and systems realizing these properties.

Thus, the main point in nanotechnologies is using of the particles of no more than a certain size (to 100 nanometers in one measurement; one nanometer is equal to one milliard share of the meter, or $10^{-9}$ m).

Why nanoparticles became so popular? At this level the fundamental property of matter is clearly shown, that is realization of antipodal properties in its various systems. For example, at the macrolevel gold is a conductor, but at the nanolevel it is an insulator. The particles of some materials sizing from 1 to 100 nanometers show very good catalytical and adsorptive properties, other materials show wonderful optical properties. At the nanolevel the relation between the surface and volume changes, and thus, the properties of matter change. In the nature there exist nanosystems capable to be organized in special structures, gaining new properties, for example, the biopolymers (proteins, nucleic acids).

The peculiarity of nanoscience consists in the fact that it deals with atoms − compound particles of matter (a nanometer equals to a conditional construction of ten atoms of hydrogen built in a row). Now scientists already learned to operate with separate atoms and to merge them in blocks. In other words, in prospect, to receive a toothpick, it will be unnecessary to saw a tree, theoretically, it will be possible to force atoms to ‘construct’ it. Such an approach opens fantastic opportunities to create new materials with desirable properties. The prospect of this field was announced by the Nobel laureate Richard Feynman in the report 'There's Plenty of Room at the Bottom', presented in 1959 at the California Institute of Technology at the annual meeting of the American Physical Society. The scientist assumed that it would become possible to mechanically move single atoms by means of a manipulator of a corresponding size; at least, such a process would not contradict the known physical laws. Feynman offered a way of atom-by-atom assembly of objects that would allow reducing expenses on the material and saving energy in the production process. This direction was actively supported by scientific community and the era of discovery of nanocomposite materials began. At present, various and very ingenious means and forces are applied as such nuclear manipulators, but the solution of the problem is still far from done.

## 2. Nanotechnologies as an Outcome of the Cybernetic Revolution. Origin of Discipline and Field of Research

As it has been already mentioned, the first practical steps in the creation of nanotechnologies, as well as the ideological interpretation of this field were made in the 1950s (and the term, according to some scholars, was introduced in 1974 by the Japanese physicist Norio Taniguchi). In other words, nanotechnologies became a product of the Cybernetic Revolution. However, for quite a long time they stayed in the background of other important results. A rapid growth of practical interest in nanotechnologies began at the end of the initial phase of the Cybernetic Revolution, in the 1980s, with the publication of Eric Drexler's books 'Engines of Creation: The Coming Era of Nanotechnology' and 'Nano-Systems: Molecular Machinery, and Computation' (1987; see also Drexler 1992). But the term got the greatest expansion when it was caught-up by mass media. With the beginning of 'the nanotechnological race', the word 'nano' was especially frequently heard from TV screens and it flashed on newspaper pages. It meant that nanotechnologies started to be considered as a strategic branch of the future hegemony (together with others: biotechnologies, green power industry, *etc.*). Its ultimate task is to win the market of industrial production of new, important and highly sought technologies. The country which has won it can ensure economic growth and development for many years.

The race of nanotechnologies began at the suggestion of the USA which launched the competition. During President Clinton governance there started the development of the first program of National Science Foundation of the USA for studying the problems of nanotechnology. Explaining interest in the development of nanotechnologies, Clinton, in particular, declared, 'I earmark 500 million dollars in the current financial year (2001. – *A.G.*, *L.G.*), on the state nanotechnological initiative which will allow us to create new materials in the future (exceeding the existing ones a hundred times in characteristics), to write all the information of Congressional Library on the tiny device, to diagnose cancer diseases at the emergence of several diseased cells and to achieve other amazing results. The offered initiative is calculated, at least, in 20 years and promises to lead to important practical results' (see also Lane and Kalil 2007).

Almost at the same time at the request of the government a similar program was launched in Japan. A series of projects directed at the development of devices of nanometer size was planned, and the Angstrom Technology Project with the amount of financing in 185 million dollars became the most significant among them. It was calculated for 10 years, 80 firms participated in its realization. The Western European countries also joined the race and started carrying out the work in the area of nanotechnologies within the appropriate national programs. In Germany, nanotechnological researches are generally supported by the Ministry of Education, sciences, researches and technologies. In Great Britain the management of this direction is realized by Engineering and Physical Science Research Council, and also National Physical Laboratory. The first specialized journals *Nanotechnology* and *Nanobiology* appeared. In France the strategy of development of nanotechnologies is defined by the National Center of Scientific Researches. Russian Corporation of Nanotechnologies or Rusnano has been founded in Russia, nanoproduction of which in 2014 amounted to US$ 1 billion. There appeared the club of nanotechnologists which has united the scientists and industrialists of various branches. More and more attention to nanotechnologies is paid in China, South Korea, many other states, including Russia the starting positions of which are supposed to be rather good in this area (Dementiev 2008).

Now nanotechnology is one of the most intensively growing branches of economy.

## 3. The Development of Nanotechnologies in the Course of the Cybernetic Revolution

The characteristics and opportunities of nanotechnologies correlate with the concept of the Cybernetic Revolution, which is not surprising, as they originated from this revolution. They will play more and more important role in the process of its development. The stages of development of nanotechnologies even better fit the periodization of the Cybernetic Revolution, than biotechnologies and medicine.

1. The initial phase of the Cybernetic Revolution (the 1950s – the beginning of the 1990s) – the period of formation of the direction. Conditionally speaking, concerning nanotechnologies this is the period after 1959 when Richard Feynman presented the idea about constructing new materials from nanoparticles, before Bill Clinton's initiative in 2000. This period is characterized by

quite numerous scientific discoveries, many of them, however, did not get a significant application at that time yet.

For example, in 1956 D. N. Garkunov and I. V. Kragelsky described the effect of wearlessness. They found the phenomenon of spontaneous formation of a thin membrane of copper in pairs of friction between bronze and steel in aircraft parts. This membrane reduced deterioration and frictional force by ten times or more. The thickness of the membrane does not exceed 100 nanometers (the similar system is functioning in the joints). It is an example of the fact that the friction is represented not only as a destructive process, but under certain conditions it can be self-regulating, thus opening new and unknown properties. In 1968, Alfred Cho and John Arthur, the researchers from the Bell Company (USA), developed the theoretical bases of nanoprocessing of surfaces (see Rybalkina 2005: 21).

At this stage the development of nanotechnology in many respects was defined by the creation of devices of probe microscopy and devices with appropriate size. These devices are a sort of eyes and hands for the nanotechnologists. In particular, in 1981 the German physicists created a microscope which made it is possible to see separate atoms, and in 1985 the American physicists created the technology allowing precise measuring particles of a nanometer diameter.

**The modernization phase** (the period of distribution of innovations) of the Cybernetic Revolution is the period of the formation of 'modern nanotechnology' (the 1990–2020/30s). Nanotechnologies became an area of industrial production, the nanotechnological race between countries has started, dozens of projects and whole institutes of nanotechnologies have been created. The number of goods produced with nanotechnologies is rapidly increasing. The investments into researches increase, and the nanomaterials penetrate into various spheres: engineering, medicine, transport, aerospace and electronic industry, *etc*. According to the data of analytics of BBC Research (2012), the sales volume of products of nanotechnologies in 2009 amounted 11.67 billion dollars.

**Euphoria from the opportunities provided by nanotechnologies.** The analytics connect the first stage of the development of nanotechnologies (in 2000–2005) with the so-called 'passive nanostructures' (incremental nanotechnologies), but generally it was characterized by the production and use of nanodisperse powders. They were added in order to modify the properties of basic construction materials: metals and alloys, polymers, ceramics, and also in cosmetics, pharmaceuticals, *etc*. Now this is a rather primitive generation of nanomaterials already widely used in production, and they can be found in many goods. However, only few nanoprojects are applied in high-tech branches of industry.

The wide prospects due to the opportunities provided by nanotechnologies, stirred up by certain interests and mass media, caused euphoria of forecasts the majority of which had proven wrong or will hardly come true.[23] The emergence of such forecasts is quite natural. People want the process of creation of innovations and their implementation to go faster; at the same time they do not see the obstacles and challenges and do not take into account the economic crises which may change plans. Thus, the volume of nanoproduction is continuously growing despite the fact that the growth rates are not so fast as it has been predicted earlier.

A number of analysts suppose that after 2020 the era of 'radical nanosystems' in the form of nanorobots will start. At this stage there will be the development of nanobiotechnological and nanomedical systems which will significantly change human life, first of all increasing life expectancy. However, the theory of production revolutions argues that though there will appear a lot of innovations in the modernization phase, they will not be generally breakthrough – rather developing and improving, and many of them will be of low demand at all. At the same time the discoveries which will become the basis for the breakthrough are being prepared. But the breakthrough itself will happen later. In the field of nanotechnologies it will most likely happen in the 2030–2050s. Thus, the achievements of nanotechnologies which, according to a number of researchers, will happen by the 2020s (but, of course, not all of them) will actually take place one or two decades later. Nevertheless, in the coming decades the achievements which are already tested today in different areas, will be developed.

## 4. What Characteristics of the Cybernetic Revolution does the Development of Nanotechnologies Manifest?

**The creation of new materials with desirable properties**. One of the major problems facing the nanotechnology is how to make molecules to be grouped in a certain way, to self-organize in order to receive new materials or devices. The supramolecular branch of chemistry deals with this problem. It explores the interactions that can order molecules in a certain way, creating new substances and materials. There are different processes of self-assembling, for example, one of which is electrochemical anodic oxidation (anodizing) of aluminum, namely the one that leads to the formation of porous anodic oxidic membranes. At present in the field of nanocomposite constructional materials there appeared different technologies with various properties, for example protective, self-cleaning, antibacterial, *etc*.

**The growth of systems' self-regulation properties. Self-organization of nanoparticles and self-organizing processes**. A close connection between

[23] For example, according to the forecasts of the British Trade Department, by 2015, the demand for nanotechnologies would make not less than one trillion dollars a year, and the number of experts engaged in this branch would increase to two million people.

nanotechnologies and growing self-regulation within systems is based on the opportunity to make the processes of self-organization of matter to serve humans, forcing molecules and atoms to be ordered in a certain spatial and structural way. And creation of new materials with desirable properties is a direct way to make systems work in predetermined conditions. No wonder that nanotechnologies show striking examples of different self-regulating systems. One of such examples are self-cleaning nanocoatings. For example, self-cleaning of vessels from bacteria or the mechanism of self-cleaning of car glass nanopolish products. The nanopolishes modify the surface in such a way that a drop of water slides on it, collecting all the dirt whereas on a smooth surface, on the contrary, a water drop, while slipping, leaves dirt on the surface. It is called the 'lotus effect'. The idea is borrowed from nature: the leaves of lotus are covered with the smallest wax bulges and cavities, and thus, water flows down from them, completely washing away the dirt.

**Miniaturization** is the phenomenon which is characteristic of the modern technological progress. We can see that the majority of devices, gadgets, and professional tools become more convenient and of a more compact size. Miniaturization is most visible in nanotechnologies. Modern processors consist of more than a billion of transistors, but nanodevices will allow increasing this number by an order of magnitude. Now there is a race to reduce the manufacturing processes for semiconductors and chips to nanometers. Some companies have already passed to 45, 32, 28 nanometer process. The Intel Company uses 32 nanometer process for tablet computers and smartphones, and the Qualcomm Company uses 28 nanometer process for manufacturing chips. The Intel Company already starts mastering 14 nanometer process. In the last decade the process diminished in size approximately by three times (from 90 nanometers to 32 nanometers). In the near future they are eager to achieve the size of 7 or even 5 nanometers. Whether it will be successful and possible to achieve the invention of a principally new generation of computers due to such a decrease in size is not clear yet.

**Nanotechnologies, energy efficiency and economy.** Many nanotechnologies aim at energy saving, and also at the invention of alternative energy sources. So, the decreasing size of process technology not only increases operating speed of electronic devices and packing density on the chip, but also reduces their energy consumption. And, for example, 'smart glass' for rooms is capable to react to change in illumination and environmental temperature by corresponding change in transparency and heat conduction. There are many various projects of such saving. Thus, a wide use of electronic paper could reduce deforestation. Nanotechnology also can help to solve the problems of sewage treatment.[24]

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[24] The Chinese scientists created a system which can produce electricity by decomposition of organic substances, alongside removing organic compounds from waste water. Yanbiao Liu with

Nanotechnologies are already actively applied in agriculture, in particular, in the production of fodders which allows a considerable cutting their consumption and providing the best accessibility. In crop farming the use of nanopowders combined with antibacterial components provides increasing resistance to poor weather conditions and increases productivity of many food crops, for example potatoes, crops, vegetable and fruit and berry crops.

## 5. Forecasts

### 5.1. Nanotechnologies as a breakthrough component in the final phase of the Cybernetic Revolution (the 2030–2070s)

One can trace all the characteristics of the Cybernetic Revolution in the future development of nanotechnologies: bionanotechnology and nanomedicine will start a vigorous development, the invention of technologies of regulating systems (in which nanorobots independently or as a part of more complex technology will play an important role), the production of new materials, saving of materials and energy (*e.g.*, in house due to nanomaterial for window glass; developing of targeted drug delivery system to minimize portion of medicine directly to the damaged area or even to separate cells, *etc*.).

**Connection with medicine: large opportunities**. Despite serious progress of nanotechnologies in electronics and other branches, the real nanotechnological revolution will most likely happen at first in medicine that will give an additional impulse to the development in other areas. As a result, the breakthrough in the final phase of the Cybernetic Revolution will be provided by deep integration of medicine with biotechnologies and nanotechnologies which will bring the emergence of various technologies of self-regulating systems. We have already mentioned some directions of integration of these branches in the previous sections. In general the prospects of such an integration are already evident. So, according to some forecasts, nanobiostructures capable of transposing medical nanosensors, medicines and even reconstructing cells of an organism will be created in a decade or so and in 15 years they will become everyday practice. Of course, their active use in diagnostics and developing means to acquire immunity will become an important direction in nanotechnologies. We already have examples of this process now. At the Engelhardt Institute of Molecular Biology (part of the Russian Academy of Sciences) they applied nanotechnologies to create a biochip (biosensor) allowing quick diagnosing of a number of dangerous diseases, including tuberculosis. The development of nanotechnologies seems quite promising in respect of creation materials imitating properties of, for example, bone tissue. Nanotechnologies are already implemented in such surgeries as nano neuro knitting for repair of severed optic

colleagues developed a photocatalytic fuel cell on the basis of nanotubes which uses solar energy to destroy organic compounds in waste water and converts chemical energy into the electric one.

tract, implantation of artificial limbs with high precision, cardiological surgery, *etc*.

The struggle with the cancer is one of the directions in which huge efforts of nanotechnology are concentrated is the struggle with cancer.

One can suppose that cancer treatment will become possible as soon as there is found a method to better target a certain layer of cells in a necessary part of the organism. However, it is possible that cancer will be defeated without destroying cancer cells, but by means of the method to fight metastases. The work is conducted in various directions here. Perhaps, the organism will give a clue. For example, it is known that metastases do not appear in heart tissues: obviously, there are some defense mechanisms which should be discovered (Marx 2013).

There are some examples of new directions of the cancer control based on nanotechnologies. For example, the system of carcinoma treatment is being developed based on heating of nanoparticles of iron oxide which are put into the infected tissue and influenced with a magnetic field as a result of which particles heat up and destroy cells.

At the Laboratory of Nanophotonics at Rice University in Houston, Professors Naomi Halas and Peter Nordlander, invented a new class of nanoparticles with unique optical properties – nanoshells. With a diameter 20 times smaller than red blood cells, they can freely move in the blood system. Special proteins, that is antibodies attacking cancer cells are specifically attached to the surface of cartridges. Some hours later after their injection the organism is beamed with infrared light which nanoshells transform into the thermal energy. This energy destroys cancer cells, and that the neighbouring healthy cells are almost not injured.

The important direction of research in the area of oncotherapy consists in automatic 'smart' hitting of the malignant cells by nanoparticles. The thing is that, only one-millionth part of the revolutionary new substance Herceptin, used to treat a considerable number of patients with breast cancer, would target the diseased cell. To make the transportation of Herceptin more effective, a group of American scientists invented a special model of a capsule from porous silicon into which the medicine is injected and is directly delivered just to the damaged cell. Now this technology is being clinically tested. The American scientist Mark Davis discovered a special capsule which has a structure similar to sugar and therefore, is not rejected and not excreted by the organism. A preparation is put into this capsule and can be stored in the organism for weeks. It is searching for a tumor moving within the blood-vascular system. Cancer cells are more acidic, than the usual, healthy cells, and, when finding such cells, the capsule opens and discharges the strong medicine. A patient with a pancreas terminal cancer, at the stage of metastasis was subjected to such cure and is still alive and even did not lose his hair after chemotherapy.

A future direction of medicine is the development of diagnostic methods that are also cost-cutting. We have already spoken about nanochips which can play an important role in medicine. The nanorobots which will be able not only to perform medical functions, but also to control individual cellular nourishing and excrete waste products will be put into practice. Nanorobots can be used for the solution of a wide range of problems, including diagnostics and the treatment of diseases, fighting ageing, reconstruction of some parts of human body, production of various heavy-duty constructions (Mallouk and Sen 2009).

It is clear that some promising technologies which are forecasted today, will fail to become successful in the future. But there is no doubt that the use of nanomaterials, nanorobots suitable for research, and other nanotechnologies will create important backgrounds for the future era of self-regulating systems in the area of medicine.

**The connection with biotechnologies and agriculture**. Other important directions are researches in the field of nanobiotechnologies. One can mention here the development of controlled protein synthesis technologies for receiving peptides with desirable immunogenic properties. Vector systems for the cloning of immunologically significant proteins of the causative agents of the diseases and vaccines of the new generation possessing a high activity and safety are created. Research is being conducted on creating nanoparticles for making genetically engineered proteins, the development of biochips and test systems for biological screening (Persidis 1998), immune monitoring and forecasting of dangerous and economically significant contagions of animals. Biochip technology is constantly improving and their manufacturing is cheapening (Rusmini *et al.* 2007).

It is expected that by means of nanotechnologies and use of robots the development and application of biotechnologies will significantly advance in the direction of creating self-regulating systems of farming, where agricultural operations will be for the most part performed in an autonomous mode. Many technologies will appear to promote this process. Thus, the implementation of membrane systems for cleaning, and also special biocidal coverings and silver-based materials will facilitate and increase the level of managing the farm livestock and providing them with high quality water. It is assumed that the use of nanotechnologies will allow changing technology of cultivation of lands due to the use of nanosensors, nanopesticides and a system for decentralized water purification. Nanotechnologies will make it possible to treat plants at the genetic level and allow creating high-yielding plant varieties especially resistant to the unfavorable conditions (Balabanov 2010). Today there are some innovative ideas which can be further elaborated in the agriculture. In particular, there appear microbial preparations based on associative, endophytic and symbiotic bacteria. These preparations are intended to produce and convey various enzymes and low-molecular biological active agents (nanoobjects) in plants.

These can improve adaptation of plants to unfavorable environmental conditions: pollution by toxic metals, salinization, superacidity, *etc*. A fundamental approach to getting high quality seed material is essentially developed. This approach is as follows. Biologically active and phytosanitary components which can increase the adaptation of seeds and plants to real negative environmental conditions are constructed in the form of multifunctional nanochips.

**Various prospects of using nanotechnologies in the Cybernetic Revolution and at the mature stages of Scientific-Cybernetic production principle.** Nanotechnologies have considerable prospects. The components of nanoelectronics, photonics, neuroelectronic interfaces and nanoelectromechanical systems will be developed. Then on the basis of the achieved results it is expected to advance to a regulated self-assembly of nanosystems, the creation of three-dimensional networks, nanorobots *etc*. One can also speak about the use of molecular devices, nuclear design, *etc*. Especially alluring prospects are observed in the development of nanomechanics, nanomechanical engineering and nanorobotics.

Quite long ago there appeared an idea where data creation and storage is performed not by means of a special condition of the environment (*e.g*., magnetic, electric, and optical), but through the use of nanotechnologies, for example, the replacement of silicon, the basic material in the production of semiconductor devices, by carbon nanotubes. In this case a bit of information can be stored in the form of numerous atoms, for example, of 100 atoms. It would reduce the sizes of processors by an order of magnitude or would essentially increase their operation speed. Now the number of transistors in the processor reached a billion and more. However, a few years ago the goal was set to create a processor with more than one trillion transistors by the 2010s (that would lead to radical increase of the ICT opportunities). Most likely, this is an unreal task to solve even by the 2020s, before the beginning of the final phase of the Cybernetic Revolution. It is supposed that this level will be achieved later, as we are already in the process of developing this phase (this would also open new horizons of full replacement of the information computer equipment due to a transition from using silicon to nanomaterials).

However, it is possible that the smallest computers will have an essentially new basis. According to Eric Drexler, nanomechanics and not nanoelectronics can become such a base. He has developed mechanical constructions for the main components of the nanocomputer – memory cells, logical bytes.

From special structures, such as fullerenes, nanotubes, nanocones and others, molecules can be gathered in the shape of various nanodetails – tooth wheels, rods, bearing details, rotors of molecular turbines, moving parts of manipulators, *etc*. The assembly of the finished parts into a mechanical design can be realized by using the assemblers (self-assemblers) with the biological macromolecules attached to the details capable of selective connection with each other. This idea was realized by Professor James Tour and his colleagues from Texas Rice University who in 2005 created a molecular mechanical design – the all-molecular four-wheel nanocar about 2 nanometers wide consuming light energy. It consisted of about 300 atoms and had a frame and axes. The development and creation of the nanocar took eight years. The scientists plan to create nanotransport devices, the nanotrucks, to transport molecules to conveyors in nanofactories (Balabanov 2010).

Certainly, this is more like toys, than research for practical use. They remind us of the steam toys like the mechanisms created by the Greek mechanic Heronus Alexandrinus, who amazed the audience in the 1st century AD. They hardly had any similarity with a steam-engine. But unlike Heronus who even did not think of a practical use of steam, the current nanotechnologists are absorbed with practical application. Therefore, the creation of nanomechanical engineering is quite real, though a long-term perspective. It will most likely happen close to the end of the current century. The same refers to nanorobotics. At the present, the expected designs of nanorobots and their use exist only in forecasts.

There is an opinion that in the 2030s some nanodevices will be implanted into human brain and will be able to perform the input and output of necessary signals from the brain cells and this can even make learning and getting education become unnecessary. But it causes great doubts. Even if such a cyborgization is realizable in principle, it will occur essentially later.

*Anyway it is obvious that both nanomechanical engineering and nanorobotics will propel the development of self-regulating systems to a new level towards the formation of an industry that will design such systems (similar the use of engines promoted their industrial manufacturing – mechanical engineering).*

## Conclusion

The described processes must prove the idea that the final phase of the Cybernetic Revolution will be the era of a rapid development of self-regulating systems. Actually, already now we use some systems of the kind, but do not take them as such. Other self-regulating systems have not found a broad application yet, but soon enough they can become a part of our everyday practice. With the emergence of machines in the preceding centuries there appeared dozens of bright insights about their future application, and at the same time numerous ideas which failed to come true. And today it is difficult to define what will become a reality and what will not. But there is no doubt that the development proceeds towards the invention and wide distribution of self-regulating systems. We expect the development of such systems which will work almost independently and control important aspects of human life like today computer programs of spelling start checking your style or spelling. All this demands a deep understanding of the field of minimization as a solution to important present day and emerging problems. As already mentioned, the Cybernetic Revolution (like any production revolution) brings changes in all spheres of production and areas of life. However, these changes being part of a single large process will happen not simultaneously.

Now it makes sense to say a few words about changes in other spheres.

**Demography.** Each phase of production revolution is inevitably connected with demographic changes. In general the production revolution changes the type of demographic model of population reproduction. It is expressed in a radical increase of population number, its growth rates and changes of demographic structure of society. During the Agrarian Revolution the population and its density grew tenfold (from several to hundreds million people). In the course of the Industrial Revolution it became possible to reduce drastically mortality and to extend life expectancy. Population generally increased very significantly (*e.g.*, the population of Great Britain increased five times in the interval from the mid-18$^{th}$ to the mid-19$^{th}$ century). The structure of population was also changed: the urban population was increasing at the expense of the rural.

As a result, the global population of the Earth is increasing. This growth applied, first of all to the developing countries and actually continued the trends of demographic revolution of the industrial era. But on the other hand, demographic revolution was completed in the developed countries in the form of a so-called demographic transition which consisted in reducing fertility. At the same time life expectancy and its quality considerably increased. The demographic transition is actually the result of the initial phase of the Cybernetic revolution. Today fertility rates fall in the increasing number of developing countries. In the developed countries as well as in some developing countries one can observe the increase in the proportion of aged population.

**Deduction.** Hence one may say that the final phase of the Cybernetic Revolution will change the quality and life expectancy (see Figs. 4–5) and will change the law of population replacement. In some developed countries life expectancy can increase to 95–100 years and in other countries it will reach the level of today's the most successful countries (like Japan) – 80–84 years but possibly it will be even higher. The process of population ageing will be visible in most countries of the world (probably, except for African countries). At the same time fertility decline and the exhaust of demographic dividend in most countries of the third world will lead to the great changes of the demographic structure, for example there will be the strong decline in the proportion of children and young people and the number of aged people will increase. Of course, it is possible that the countries will try to solve the problem of shortage of children developing the methods of artificial growing of children out of maternal placenta. Successful attempts will affect the family institution which is already weak.

**Power industry.** During the previous production revolutions the energy source would also change. The Agrarian Revolution brought biological energy into use, that was strength of animals; the Industrial one used at first water power, then it was replaced by steam power and then electricity and fuels.

To start the Cybernetic Revolution there has already existed an adequate energy source, namely, electricity. The idea that a new leading energy source will become thermonuclear, hydrogen or some other new type of power, has not been realized yet. There is a question: whether an adequate energy source for the final phase of Cybernetic Revolution has to appear? The experience from previous revolutions shows that it is not necessary at all. The transition to the irrigational intensive agriculture did not demand the obligatory use of animal draught power (for plowing) as well as the first sectors of the machine industry quite managed with the known water energy source. However later, in the end of the final phase of every production revolution and during the transition to mature stages of every production principle, new sources of energy were already appearing (so, the completion of the Agrarian Revolution in the rain fed zones was connected with agriculture with the use of bulls and oxen; and the completion of the Industrial Revolution – with the use of steam energy). It should be noted that in both cases it was not totally unknown energy. Steam energy was occasionally used since the 17$^{th}$ century.

**Deduction.** Essentially new power source will not be required to start the final phase of the Cybernetic Revolution therefore the development of alternative (low carbon) power engineering will not play a decisive role here. However, a new energy source has to appear either during the final stage of revolution, or a bit later. Also, most likely, it will not be absolutely new and not previously used. Most probably, thanks to technical innovations, it will become possible 'to tame' and to make sufficiently available this or that type of alternative energy (hydrogen, thermonuclear, solar; or it will be the invention of easily stored electric power which will also solve the problem with a power source for eco-friendly transport). At the mature stages of production principle changes in the energy area are also taking place which create the base for the new production revolution (so during the period of maturity of the craft-agrarian production principle the power of water acquired those properties, used for driving mechanisms, and during the period of maturity of the trade-industrial production principle – the electric power became such a source). But what energy will appear at the final stage of the scientific-cybernetic production principle is difficult to imagine so far.

**Communications.** The production revolution surely changes the ways of communication. In the beginning of the Industrial Revolution there was invented a new type of information technology which created one of the impulsive forces of communication. We mean the invention of printing. The role of the new types of communication and connection (TV and computer) became even more essential at the beginning of the Cybernetic Revolution. Thus, the initial phases of the production revolution can be caused by the emergence of the new types of communication. However, it is not a prerequisite for the beginning of the final phase of production revolution (though writing appeared on the eve of the final phase of the Agrarian Revolution, its role was not essential). New forms of communication could appear at the end of the final phase of revolution or after it. For example, electric coupling (telegraph, telephone) was introduced after the termination of Industrial Revolution.

**Deduction.** In the next decades the emergence of essentially new types of communication is hardly possible. The development of communication has made great progress during the last decades and in general even surpassed the overall level of the development. Most likely, the revolutionary new types of mass communication can appear only toward the end of the 21$^{st}$ century. However the powerful progress in existing ICT as we mentioned above, is quite possible within the next three-four decades.

**Transportation.** It is not so easy to mark out any distinct regularities in transportation. At the beginning of the only one (Industrial) revolution the development of transport became one of its driving forces: the long-distance sailing ships played a crucial role in the organization of the oceanic trade. However, during the final phase or/and after it new forms of transportation appeared.

The final phase of the Agrarian Revolution (in its irrigation version form) was not substantially connected with large changes in transportation. However, the transition to the riding and development of sea communication occurred already during the final stage of the Agrarian revolution in its version with using plow and oxen or other draught form on the periphery and during the later period. At its initial phase the Industrial Revolution was connected with already tested oceanic water crafts capable of moving in any wind (not only the fair wind). Such crafts were widely developed during this revolution. Great Geographical discoveries without which the Industrial Revolution would have collapsed were also connected with this innovation. But the emergence of the steamship and further the engine happened already toward the end of the final phase of the Industrial Revolution. The emergence of a new means of transport gave it an unprecedented scope. New means of transport appeared much later (a car, a plane), and it was quite enough to start the Cybernetic Revolution. It, certainly, brought very fundamental changes to all means of transport, but created nothing essentially new so far (space transport is no object) though one may note the development of high-speed railways (but they play a secondary role).

**Deduction.** In the middle or the end of the final phase of the Cybernetic Revolution (approximately in the 2050–2060s) there can be expected the emergence of some new means of transport. An electric car with a large power capacity and speed could be a possible example. But taking into account 'the sense' of the Cybernetic Revolution (as the revolution of self-regulating systems) the breakthrough most likely will happen in the direction of self-driving vehicles and its control. That is the means of transport and systems will become self-regulating. Even today there exist some ideas concerning the realization of this opportunity and there are some projects (*e.g.*, Mercedes-Benz or Google) which they will try to realize in the nearest decades.

**Specialist area.** The production revolution radically changes the specialist area of people, their professional skills (competencies) and creates a need for new professionals. The farmer and the craftsman replaced the competences of the hunter and gatherer during the Agrarian Revolution. With the emergence of metals specialists, stone working disappeared. But nevertheless, during the era of the Agrarian Revolution, changes were happening rather slowly.

Almost the whole period of the industrial revolution, since the sixteenth century and, at least, till the last third of the nineteenth century, passed under the banner of battles pitting the skilled craftsmen against the Leviathan of technological progress. This period is full of episodes of prohibitions on inventions, the acceptance by the representatives of factories of various constraining laws, and a history of destroyers of machines, *etc*. Thus, the grounds for such bans and constraints were the most serious: product degeneration, falling of earnings, competition between the people who do not have the necessary professional skills. However, as a result, machinery replaced manual operation, waves of technological innovations wiped out the groups of experts. The initial phase (and even the middle one) of the Cybernetic Revolution, especially during the extensive use of computers, led, in a great number of cases, to the replacement of professional skills, including in the area of intellectual functioning: books proofreading, magazines and newspapers, translation from one language into another (though of poor quality but still helpful), collection of information, library and archiving, design, advertizing, photography, cinematography, *etc*. No wonder that the time when books in the standard form will be treated as a rarity is around the corner. The emergence of the opportunity 'to be your own' (the cameraman, the publisher, the artist, the photographer, bank and ticket cashier, *etc*.) became the sign of the times.

**Deduction.** Not least, further development will undermine the grounds of very many professions – from a doctor (as we mentioned above) and a teacher to the nurse and taxman and even pilots (the two last due to the creation of self-regulating cars and airplanes in the future).

As a whole the general course of development has to move towards the reduction of the number of people employed in the service sectors (both simple types and more difficult), but a lot of new professions will be required at the same time. Reduction of the people employed in the service sector happens at least in part as a result of development in the field of robotics. In fact, everybody will have his own electronic nurse (just like the children of ancient Greek prosperous citizens had teachers from among the slaves, and the children of nobility of landowners had the teacher from among the servants). By the way, it can be especially important for controlling children and nursing sick people who stay at home. If there emerge some relatively cheap multifunctional robots able to flexibly react to changes, then the life of people will become much more comfortable (but in that case their independence will decrease).

**Robotics**. The principles of functioning of robots and possibilities of their use support the idea of the development of self-regulating systems very well. Besides, only such devices could solve a problem of service of the increasingly numerous elderly generation and solve a problem of the lack of labor to some extent. Therefore, there is no doubt that this direction sooner or later is awaiting for bright future though now the volume of the world production of robots is very small – only some billion dollars. But its increase, most likely, will happen during the Cybernetic Revolution on the basis of creation of the future technologies. In 2007 Bill Gates argued that the robotics was in a similar state as Computers were in the 1970s when they with Paul Allen founded the Microsoft Company, supposing, apparently, that in the 2030s the robotics will become so important, as ICT today. However, it appears that robots will become very widespread some later, approximately in the 2050s. After all even according to the optimistic forecasts of Japanese association concerning robotics, by 2025 the turnover of the robotic branch will make only 50 billion dollars (Gates 2007), that is the volume absolutely insufficient for the takeover in the economy. The ideas about clever robots are valuable for us precisely because they clearly represent the most important characteristic of the Cybernetic Revolution – the increase of a number and variety of self-regulating systems. However, the forecasts concerning the forthcoming emergence of such robots will not come true (just as the predictions of the scholars such as Moravec failed).[25]

Some authors go further and consider that robots in the 21st century will have all characteristics of human mental and physical abilities. In their opinion, the 21st century will become a century of the post-biological world when as a result of the natural selection robots will force the person out of the pedestal of evolution and will develop under the influence of the new – post-biological evolution which can exceed the rates of the biological evolution millions of times (Wadhawan 2007).

[25] In the book *Mind Children: The Future of Robot and Human Intelligence* H. Moravec (1988), speaking about the influence of the Moore's law on the development of civilization, predicted the future of the robotics. He claimed that in the 2010 there will appear the models of robots, whose mental abilities will be identical to the brain of a lizard. They will be used for cleaning of rooms without intervention of people and some other purposes. Moravec claims that in another two decades models with mental capacities of a monkey will be created. Such robots will be able to define the elementary technical and domestic problems and objects and to solve them independently without instructions of the person.

Approaching of the robot mind to the human one would be, really, a significant step towards the creation of self-regulating systems of a new type. However, in our opinion, most likely, the process of creation of such robots will take essentially much time. Thus, like during any development, many (the majority) of the researches in the area of robotics does not give the expected results. According to the pen-picture of *The Wall Street Journal* journalist, the writer Lee Gutkind, who got inside of the top institute of invention of robots observed only the sad faces, damning the regular failed experiment instead of the triumph in the laboratories (Anders 2007).

Quite often during the period of rapid development the branch which seemed earlier to have no chances for success gets the first place. Most service robots are created for military. Some researchers, for example, suppose that one of the most perspective directions in the development of robots can become intimate services. In this sphere robots are already showing substantive results and prospects (Yeoman and Mars 2012).

But we believe that the development of robots (and not only surgical robots) in medical science will become a priority for the future. Linkage to medical science, as we already noted, can become the engine for the development of the branch.

**Legal, ethical, pedagogical and ideological problems in the development of medicine.** The faster the pace of scientific and technological progress, the more difficult it is for society to keep pace with those changes, the more flexible become morals, more sophisticated the right, different minorities are emerging, defending their, not always clear rights, the society becomes more tolerant. But at the same time traditions are subverted more easily and quicker and it becomes more difficult to distinguish good from bad (criteria for these concepts are disappearing), it is more difficult for parents to pass on their experience to children, *etc*. We have already discussed these changes (Grinin 2006b; Grinin and Korotayev 2009; Grinin L. E. and Grinin A. L. 2013). The well-known book by A. Toffler 'Future Shock' (Toffler 1970) did not lose its topicality at all (see also Fukuyama 2002). These problems surely demand much attention. In particular, it should be noted that very complicated ethical problems can appear and a potential risk of violation of the social and biological basis of human existence can emerge. It is difficult to imagine, what will be the outcome of all of these changes. Radical changes in the human body are able to affect seriously such basic things as understanding of the family, gender, already strong transformed, and to attitude to life. Just for this reason forecasting of the development of the Cybernetic Revolution is useful. It can help us become aware of the creation of the optimal social, legal and other instruments in advance, so that such changes would not take us completely unaware and so that it would be possible to minimize negative consequences. Eventually, the Cybernetic Revolution also will influence many social systems in order to make them more controllable by means new technologies. It means that there will be large or even radical changes in human behavior. Thus, now it is a high time to consider the positive and negative influence of the forthcoming transformations. Therefore, the technologies based on social insight and elimination of social problems have to be developed; importantly these technologies must be tested before the mass distribution of innovations leads to serious misgivings.

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# IN MEMORIAM

## George Modelski (1926–2014)*

*William R. Thompson, Barry K. Gills,*
*Robert A. Denemark,*
*and Christopher K. Chase-Dunn*

George Modelski, born in Poland in 1926, passed away on February 21, 2014 in Washington, D.C. at the age of 88. He is survived by his wife of many years, Sylvia Modelski. Trained at the London School of Economics (BSc. in Economics) and the University of London (PhD in International Relations), he was Professor Emeritus at the University of Washington and had been a professor of political science there between 1967 and 1995. His main earlier appointment had been as a Senior Research Associate at the Institute of Advanced Studies, Australian National University. Visiting appointments at various points were held at the University of Chicago, Princeton University, Harvard University, the Netherlands Institute for Advanced Study, the University of Stockholm, and the University of Catania.

Throughout his career, George contributed to an impressive number of different research questions. His dissertation, completed in 1954 and published in 1962 as *a Theory of Foreign Policy*, was a very early attempt to treat foreign policy issues theoretically, as opposed to the then standard reliance on descriptive accounts. No doubt reflecting in part his Canberra position at the time, Modelski wrote several monographs in the early 1960s on Southeast Asian international relations. But he also wrote around this time early analyses of the international relations of internal war, Kautilya's international relations, the differences between agrarian and industrial systems, and the communist international system that were conspicuous in their attempt to treat these questions in a theoretical fashion. They also underlined his very early interest in comparing the types of international systems.

His main contribution to the study of international relations, nonetheless, has to be founding a research program on leadership long cycles. Modelski began developing this original perspective around 1974 (the first conference paper) and published the first article in 1978, following a slightly earlier effort to

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begin developing a systemic interpretation of world politics (*Principles of World Politics*, 1972). Responding to the destabilized international system of the 1970s, George constructed an interpretation of world politics that was based on the emergence of lead economies, their rise and fall, and implications for global war and order. His core writings on these processes, some co-authored, came out at about the same time (*Exploring Long Cycles*, 1987; *Long Cycles in World Politics*, 1987; *Sea Power in Global Politics*, 1494–1993, 1988; *Documenting Global Leadership*, 1988; and *Leading Sectors and World Power*, 1996). It is fair to say that the perspective that emerged over time came to be one of the leading schools of thought in world systems analysis.

Some of George's other work were highly complementary to the long cycle interpretation. *Transnational Corporations and World Order* (1979) focused on MNCs while *North/South Relations* (1983) examined dependency reversal processes in international political economy. The co-edited *World System History: The Social Science of Long-term Change* (2000) reflected the interest he and others had developed in the 1990s to push the study of world politics back to its origins. In addition to an edited special issue of *International Studies Quarterly* (1996), *Globalization as Evolutionary Process* (2008), also a co-edited work, highlighted his commitment to harnessing evolutionary perspectives to the study of long-term international processes. Another major venture in this vein was his effort to develop a better empirical and theoretical understanding of historical urbanization processes, as reflected in *World Cities, –3000 to 2000* (2003). Written after he had retired, this book represents a major contribution to the data base on city sizes in the ancient world, which he viewed as indicators of an evolving city network that undergirded world economic growth. The long-term trend towards democratization was another special interest, culminating in several articles on the subject.

George Modelski contributed to the International Studies Association in various ways. He was President of the ISA-West in 1982, a long-time member of the IPE Section's World Historical Systems group, and winner of the Susan Strange Award in 2006. He also chaired the University of Washington's Pacific Northwest Colloquium on International Security from 1982 to 1991. In 2012, he was awarded a bronze medal by the International Kondratieff Foundation and Russian Academy of Sciences for his contribution to social sciences. Throughout a long and distinguished career, George Modelski emphasized the need to bring together theory, evidence, and history in the unraveling of world political processes. Although never widely cited or known in IR circles, his contributions were always distinctively different and original.

# Contributors

**David Baker** studied his PhD in Big History at Macquarie University in Sydney under David Christian. He now teaches Big History at the universities of Amsterdam, Eindhoven, and Rotterdam alongside Fred Spier and Esther Quaedackers. His research interests include Universal Darwinism, collective learning, the rise of complexity, and demographic-structural theory. He is also engaged with the IBHA Publications Committee in setting up a Big History academic journal. In 2014 he released a Big History series on Youtube in partnership with Crashcourse and Bill Gates' bgC3.

**Craig G. Benjamin** is an Associate Professor of History in the Frederik J. Meijer Honors College at Grand Valley State University in Michigan, USA. At GVSU Craig teaches Big History, World History, and East Asian history, to students at all levels, from first-year to post-graduate. Craig is a frequent guest presenter at conferences worldwide, and the author of numerous published books, chapters and essays on ancient Central Asian history, Big History, and World History. He is the co-author (with David Christian and Cynthia Brown) of a Big History textbook – *Big History: Between Nothing and Everything* – published by McGraw-Hill in August 2013. Craig is also editor of Volume 4 of *Cambridge History of the World*. In addition to his many publications, Craig has recorded several programs and lecture series for the History Channel, The Teaching Company and *Scientific American Magazine*. Craig is a member of the College Board Test Development Committees for both the AP and SAT World History exams; Treasurer of the International Big History Association; and current President (2014/15) of the World History Association.

**Valentina M. Bondarenko,** PhD in Economics, is a Leading Research Professor at the Center for Real Economy Studies in the Institute of Economics, the Russian Academy of Sciences, and the Director of the International Kondratieff Foundation. In 1991, she defended her Ph.D. thesis on 'Political Economy' at the Institute of Economics of the USSR Academy of Sciences. Her academic activity is connected with cross-disciplinary studies, in terms of political economy and world view positions, as well as the agenda connected with formation and functioning of the mechanism of interconnection among production, distribution, exchange and consumption within various forms of production relations. Her current research interests are in the areas of search and substantiation of new production relations and relevant production forces, formation of Russia's development strategy and new life-organization model. She is the author of the monographs *Forecasting the Future: A New Paradigm* (2008) and *Crisis-Free Development – A Myth or the Reality?* (2012, 1st edition; 2014, 2nd edition). She has published more than 220 articles in Russia and abroad, and wrote a number of chapters for various monographs, published in Russian and English, which address fundamental theoretical problems, pertaining to formation of transition strategies that Russia and other countries can follow on the way to crisis-free development.

**Rendt Gorter** is a social scientist who obtained his PhD studying environmental democracy at the University of Auckland in New Zealand, where he continues to live and work.

**Anton L. Grinin,** PhD in Biological Sciences, is Leading Research Fellow of Volgograd Centre for Social Research. His main research interests include biotechnologies, global technological transformations and forecasts. He is the co-author of the monograph *From Chipper to Nanorobots: The World on the Way to the Epoch of Self-regulating Systems* (2015; Uchitel Publishing House; in Russian) and a number of articles including 'Macroevolution of Technology' and 'Global Technological Transformations'.

**Leonid E. Grinin** is Research Professor and the Director of the Volgograd Center for Social Research, as well as the Deputy Director of the Eurasian Center for Big History & System Forecasting, Senior Research Professor at the Institute for Oriental Studies of the Russian Academy of Sciences and Leading Research Fellow of the Laboratory for Destabilization Risk Monitoring of the National Research University Higher School of Economics. He is the Editor-in-Chief of the journal *Age of Globalization* (in Russian), as well as a co-editor of international journals *Social Evolution & History* and *Journal of Globalization Studies*. Dr. Grinin is the author of more than 450 scholarly publications in Russian, English, and Chinese including 26 monographs. These monographs include *Philosophy, Sociology, and the Theory of History* (2007, in Russian); *Productive Forces and Historical Process* (2006, in Russian); *State and Historical Process* (3 vols, 2009–2010, in Russian); *Social Macroevolution: World System Transformations* (2009, in Russian; with A. Korotayev); *Macroevolution in Biological and Social Systems* (2008, in Russian;

with A. Markov and A. Korotayev); *Global Crisis in Retrospective: A Brief History of Upswings and Crises* (2010, in Russian; with A. Korotayev); *The Evolution of Statehood: From Early State to Global Society* (2011); *The Cycles of Development of Modern World System* (2011, in Russian; with A. Korotayev and S. Tsirel); *From Confucius to Comte: The Formation of the Theory, Methodology and Philosophy of History* (2012, in Russian); *Macrohistory and Globalization* (2012); *Cycles, Crises, and Traps of the Modern World-System* (2012, in Russian; with A. Korotayev), as well as *Great Divergence and Great Convergence* (2015, in English; with Andrey Korotayev).

**Andrey V. Korotayev** heads the Laboratory of Monitoring of the Risks of Sociopolitical Destabilization at the National Research University, Higher School of Economics. He is also Senior Research Professor of the Oriental Institute and Institute for African Studies, Russian Academy of Sciences. In addition, he works as a Senior Research Professor at the Laboratory of Political Demography and Macrosocial Dynamics of the Russian Academy of National Economy and Public Administration and as a Professor of the Faculty of Global Studies of the Moscow State University and as Professor and the Head of the Department of Modern Asian and African Studies, Russian State University for the Humanities. He is the author of over 300 scholarly publications, including such monographs as *Ancient Yemen* (1995), *World Religions and Social Evolution of the Old World Oikumene Civilizations: A Cross-Cultural Perspective* (2004), *Introduction to Social Macrodynamics: Compact Macromodels of the World System Growth* (2006), *Introduction to Social Macrodynamics: Secular Cycles and Millennial Trends* (2006), *Macroevolution in Biological and Social Systems* (2008, in Russian; with Alexander Markov and Leonid Grinin); *Global Crisis in Retrospective: A Brief History of Upswings and Crises* (2010, in Russian; with Leonid Grinin), and *Cycles, Crises, and Traps of the Modern World-System* (2012, in Russian; with Leonid Grinin), and *Great Divergence and Great Convergence* (2015, in English; with Leonid Grinin). At present, together with Askar Akaev and Georgy Malinetsky, he 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 in 'The Best Economists of the Russian Academy of Sciences' Nomination (2006).

**David LePoire** has a PhD in Computer Science from DePaul University and BS in physics from CalTech. He has worked in environmental and energy areas for many governmental agencies over the past 25 years. Topics include uncertainty techniques, pathway analysis, particle detection tools, and physics-based modeling. He has also explored historical trends in energy, science, and environmental transitions. His research interests include complex adaptive systems, logistical transitions, the role of energy and environment in history, and the application of new technologies to solve current energy and environmental issues.

**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), *Human Evolution* (two volumes, 2011). 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).

**Jane Gray Morrison** is an ecologist, author and filmmaker whose work has taken her to over 30 countries. As a filmmaker, Ms. Morrison has produced numerous films for such networks as Discovery, PBS (for which she also co-directed 'A Day in the Life of Ireland' for Irish Television and WNET) and Turner Broadcasting for which she served as Senior Producer for the 10-hour series, 'Voice of the Planet'. Ms. Morrison recently completed a feature film documentary trilogy: 'Mad Cowboy', 'No Vacancy' and 'Hotspots' – all of which have aired on Public Broadcasting. In addition to numerous articles and essays, Ms. Morrison's books include *A Parliament of Souls: In Search of Global Spirituality* (co-editor); *No Vacancy: Global Responses to the Human Population Explosion* (co-editor); *Donkey: The Mystique of Equus Asinus* (co-author with Michael Tobias); and, *Sanctuary: Global Oases of Innocence* (co-author with Michael Tobias). For many years, Ms. Morrison has worked for the nonprofit Dancing Star Foundation.

**Alexander D. Panov** graduated from Moscow State University, Department of Physics. He is a senior researcher at the Skobeltsyn Institute of Nuclear Physics of Moscow State University (MSU SINP), and is DSc (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 and Big History. He is the author of about 140 articles in Russian and international academic journals, as well as the author of the monograph *Universal Evolution and Problems of the Search for Extraterrestrial Intelligence* (SETI).

**Ilya V. Ponomariov** graduated from Moscow State University. He defended his PhD dissertation in social anthropology at the Institute of Ethnology and Anthropology of the Russian Academy of Science (RAS). He is a senior research fellow at the Institute for African Studies of the Russian Academy of Sciences. He is an author of two books and a number of articles in Psychology and Anthropology.

**Olga A. Sorokina** studied the Deap-Sea Lilies Crinoidea, Millecinida for her PhD in marine zoology and ecology at the Institute of Oceanology of the Russian Academy of Sciences, Moscow. The work was dedicated to their systematic ways of evolution and dissemination of the taxa over the World Ocean.

**Michael Charles Tobias** is an ecologist, author, filmmaker, historian, explorer, anthropologist, educator and non-violence activist. His work encompasses ecological anthropology and aesthetics, the history of ideas, environmental psychology, comparative literature, philosophy and ethics, global biodiversity field research, systematics, deep demography, animal rights and animal liberation. In addition, he focuses on aspects of zoosemiotics and ethology, and the critical links between human demographic pressure (various population issues) and the genetic corridors and diverse, remaining habitats on Earth. He has received The Courage of Conscience Award, the Parabola Focus Award, in addition to countless film awards, nominations, and accolades. Tobias did his PhD in the History of Consciousness at the University of California-Santa Cruz focusing upon comparative literature, and the psychology, ethnography and history of ideas and aesthetic orientations pertaining to human views toward Nature. Tobias has lectured worldwide and has held teaching positions at several universities, including Dartmouth, the University of New Mexico (where he once held the Garrey Carruthers Chair of Honors), and the University of California-Santa Barbara (where he was a Distinguished Visiting Professor of Environmental Studies, as well as a Regents Lecturer). Tobias is the author of over 45 published books and the writer, director, producer and/or executive producer of well over 125 films, focusing primarily on ecological and humanitarian issues, both documentary and some drama and docu-drama, including the award-winning ten-hour dramatic miniseries, 'Voice of the Planet', starring William Shatner and Faye Dunaway, for Turner Broadcasting, and based upon Tobias' best-selling novel (Bantam Books, 1990) by the same title; and Tobias' hard-hitting 600 page book, and PBS documentary, *World War III: Population and the Biosphere at the End of the Millennium* (1994).

**Vasily N. Vasilenko** is a Doctor of Philosophy, author, editor-in-chief of the e-almanac 'Noosphere of the XXI century' (URL: http://noos.vgi.volsu.ru; http://www.socionauki.ru); senior staff scientist at Volzhsky Institute of Humanities, affiliate of Volgograd State University and Volgograd Centre for Social Studies; Full Member of the International Academy of Noosphere (sustainable development), Noospheric Public Academy of Sciences, International Academy of Innovation and Social Technology, European Academy of Natural Sciences; member of coordinating board at Noospheric Spiritual and Ecological Assembly of Peace. He is the author of over 200 scholarly publications, including several monographs. These monographs include *On the Way to Noosphere* (1997), *Sustainable Russia* (2003); *Globalization and Forced Migration of People* (2007; co-author R. Ulmasov); textbook *Noospheric Futurology* (2010; co-author G. M. Imanov); *Russia and Earthmen: Before Making a Choice* (2011; co-authors L. S. Gordina, G. M. Imanov, G. N. Bichev). He is a scientific editor of collective monographs such as *Man and Society: Noospheric Development* (2010); *The Noospheric Strategy of Russian Citizens' Health Protection* (O. A. Ragimova, 2010); *Noospheric Philosophy of Global Modernization* (G. M. Imanov, 2011); *Noospheric Foundations of the Philosophy of Creativity of Generations* (A. I. Dzura, 2012).

# EVOLUTION
# Interdisciplinary Almanac

## *Guidelines for Contributors*

The almanac 'Evolution' invites authors to submit papers addressing all the possible types of evolutionary processes.

The maximum size of the articles is 100,000 symbols. The paper's abstract should be no longer than 150 words. A separate sheet should give the author's brief CV (up to 250 words). A list of keywords should be supplied. Figures of good quality should be submitted as separate files.

*Bibliographical references* should be given in parentheses in standard author-date form in the body of the text: (Duffy, Morrison, and Macdonald 2002; Crumley 1987: 164–165; 1995: 4; 2001; Claessen 1985: 196–198, 201, 207; 2000, 2002; Chu *et al*. 2003: 29).

*Examples of references in text:*

'In a larger population there will be proportionally more people lucky or smart enough to come up with new ideas' (Kremer 1993: 685); according to Rothmaler (1976: 127–129).

A complete list of references cited, arranged alphabetically by author's surname, should be typed at the end of the article along the following:

A) Journal articles:

**Schaffer W. M. 1985.** Order and Chaos in Ecological Systems. *Ecology* 11(1): 103–109.

B) Edited volumes:

**Frank A. G., and Gills B. K. (Eds.) 1993.** *The World System: Five Hundred Years of Five Thousand?* London: Routledge.

C) Contributions to edited volumes:

**Humphrey N. K. 1976.** The Social Function of Intellect. *Growing Points in Ethology* / Ed. by P. P. G. Bateson, and R. A. Hinde, pp. 303–317. Cambridge: Cambridge University Press.

D) Monographs:

**Berryman A. A. 1981.** *Population Systems: A General Introduction*. New York, NY: Plenum Press.

E) Internet resource:

a) If the site does not mention the publication date:

**Chase-Dunn C., and Hall T. D. 1999.** *The Chesapeake World-System.* URL: http://www.wsarch.ucr.edu/archive/papers/c-d&hall/asa99b/asa99b.htm.

b) If possible, put the publication date:

**U.S. Bureau of the Census. 2008.** *World Population Information.* URL: http://www.census.gov/ipc/www/world.html. Date accessed: 24.02.2008.

*Quotations*. Single inverted commas should be used except for quotations within quotations, which should have double inverted commas. Quotations of more than 60 words should be set off from the text with an extra line of space above and below, and typed without inverted commas.

The articles are to be sent to the following email addresses:

Leonid Grinin lgrinin@mail.ru

Andrey Korotayev akorotayev@gmail.com

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