EVOLUTION

COSMIC
BIOLOGICAL
SOCIAL

Edited by
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Andrey V. Korotayev
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‘Evolution’ Almanac

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This issue initiates a series of almanacs with *Evolution* as its general title; these almanacs are aimed at the consolidation of those researchers who study all the possible types of evolutionary processes. The interdisciplinary studies have demonstrated their effectiveness, whereas the study of evolution is one of the most fruitful areas of interdisciplinary knowledge where representatives of natural, mathematical, and social sciences, as well as the humanities can find a common field for their research. The Almanac is designed to present to its readers the widest possible spectrum of subjects and problems: from the approaches of the universal evolutionism to the analysis of particular evolutionary regularities in the development of biological, abiotic, and social systems, culture, cognition, language, etc.

The first section of the Almanac presents a general sketch of the universal evolution, its main phases, vectors, and trends. The second section is dedicated to the problems of comparisons of different types of macroevolution, as well as to the possibilities to use achievements of certain fields of evolutionary research in its other fields. The third section deals with major issues of social evolution. The topics of all the sections and articles intertwine rather tightly, that actually transforms the present issue of the Almanac into a collective monograph dedicated to the search for contours and instruments of evolutionary *mega*paradigm. The Almanac's articles present a wide panorama of the application of various approaches and concepts in the framework of this emergent general paradigm that will allow to detect in a much more effective way both fundamental similarities and essential differences between different types of evolutionary dynamics.

This Almanac will be useful both for those who study interdisciplinary macroproblems and for specialists working in focused directions, as well as for those who are interested up to a certain degree in the evolutionary issues of astrophysics, geology, biology, history, anthropology, linguistics, and so on.

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Introduction

Evolutionary Megaparadigms: Potential, Problems, Perspectives

Leonid E. Grinin, Andrey V. Korotayev,
Robert L. Carneiro, Fred Spier

The formulation of the first scientific theories of the evolution of nature began at least two centuries ago. However, the philosophical roots of evolutionary ideas are much older (see, *e.g.*, Vorontsov 1999; Asmus 2001; Chanyshev 1976, 2001; Barg 1987; Ilyushechkin 1996; Losev 1977; Nisbet 1980). An incipient understanding of the historical dimension of natural processes can already be found among the ancient Greeks (*e.g.*, Heraclitus, Anaximander, Empedocles, *etc.*). In the late Modern period these ideas strengthened in conjunction with the idea that historical changes in nature can be described with the aid of rigorous laws. This type of thinking created the evolutionary approach in science. However, these ideas penetrated rather slowly in various branches of science. Nevertheless, supported by a growing body of firm evidence, the evolutionary approach became gradually established during this period in geology, cosmology, biology and social sciences.

It is commonly believed that the concept of evolution was first formulated by Charles Darwin, but that was not the case. Although it is not generally known, Darwin did not even use the word 'evolution' in the first five editions of *The Origin of Species*. Not until the 6th edition, published in 1872, did he introduce the term into his text. Moreover, he used it only half a dozen times, and with no more of a definition than 'descent with modification'.

It was Herbert Spencer who, in *First Principles* – a book published ten years *before* the 6th edition of *The Origin* – introduced the term into scientific discourse. Stone by stone, over the seven chapters that make up the heart of that book, Spencer carefully built up the concept of evolution, culminating in his classic definition: 'Evolution is a change from an indefinite, incoherent homogeneity, to a definite, coherent heterogeneity, through continuous differentiations and integrations' (1862: 216).[1]

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[1] *First Principles* represented only the final, full-blown formulation of Spencer's concept of evolution. Previously, in a series of essays written during the 1850s, he had exhibited various aspects of the process as manifested in various domains of nature. Then in 1857, in the article entitled

And – that is especially important for our subject – whereas Darwin applied evolution exclusively to the world of life, Spencer saw it as a process of universal application, characterizing all domains of nature.[2]

There followed a series of works – *The Principles of Biology* (1864–1867), *The Principles of Psychology* (1870–1872), and *The Principles of Sociology* (1876–1896) in which Spencer showed, in great detail, how evolution had manifested itself in each of these fields. Already in the 19th century it was possible to see Darwinian and Spencerian evolution as two contrasting – and indeed competing – interpretations of the kinds of change phenomena had undergone.[3]

Thus, after works of Darwin and especially Spencer in the final decades of the 19th century the idea of evolution in nature and society, together with the notion of progress, became a major component of not only science and philosophy, but also of social consciousness in general,[4] leading to an overall picture of the world development. In the second half of the 20th century the related

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'Progress: Its Law and Cause', he wrote: 'The advance from the simple to the complex, through a process of successive differentiation, is seen alike in the earliest changes of the Universe to which we can reason our way back, and in the earliest changes which we can inductively establish; it is seen in the geologic and climatic evolution of the Earth; it is seen in the unfolding of every single organism on its surface, and in the multiplication of kinds of organisms; it is seen in the evolution of Humanity, whether contemplated in the civilized individual, or in the aggregate of races; it is seen in the evolution of Society in respect alike of its political, its religious, and its economical organization; and it is seen in the evolution of all those endless concrete and abstract products of human activity...' (Spencer 1857: 465). Despite his use of 'progress' in the title of this article, Spencer came to realize that the word had normative overtones, and that he needed a word free of that. In 'evolution', he found a word – not often used in scientific writing up to that time – that proved to be the answer to his search.

[2] It is worth to point that Spencer first hit upon the idea of evolution while reading a description of Karl von Baer's discussion of embryological development. Von Baer described it as essentially a process of successive differentiations, from very rudimentary beginnings. Starting out as a single fertilized egg, the embryo underwent a series of divisions and subdivisions, its parts becoming progressively more varied and more specialized. Spencer was struck by the fact that the process that marked the development of a single organism was also the process that characterized the development of all orders of phenomena.

[3] The contrast between them was not just that one concept was limited to the biological sphere while the other characterized change in the rest of nature as well. Rather, the contrast involved *different aspects* of the process itself. Both views saw natural selection providing the basic mechanism behind evolution, but while alike in this regard, the two conceptions of evolution differed in a number of respects. Darwinian evolution not only operated on a smaller scale, it also was more closely tied to individual events. It was more opportunistic, more contingent as to just what path it followed. In Darwinian evolution the form of an animal species could zigzag back and forth over the course of generations, seeking the most favorable adaptation to existing conditions. Only when it could be seen as having moved in the direction of increasing complexity could it be considered to have evolved in the Spencerian sense.

[4] Morris R. Cohen (1958) maintains that the idea of universal evolution, starting with Spencer, has produced a very strong influence over people and has excited their imagination to such a degree that is only similar to a very limited number of major intellectual achievements since the Copernican revolution.

ideas of historism and evolutionism had penetrated rather deeply into natural sciences such as physics and chemistry.

While this respectable scientific tradition has quite ancient roots, even today there is only a rather limited number of studies that analyze the evolution of abiotic, biological, and social systems as a single process. Even fewer studies seek to systematize the general characteristics, laws, and mechanisms of evolutionary dynamics in order to allow a comparative analysis of different evolving systems and evolutionary forms. Furthermore, the history of evolutionary approaches and methods is rarely represented in the literature. Encyclopedias, for instance, pay very little attention to the notion of evolution and the development of evolutionary approaches to history.[5] This is remarkable, given the fact that the application of the evolutionary approach (in the widest possible meaning of the term) to the history of nature and society has remained one of the most important and effective ways for conceptualizing and integrating our growing knowledge of the Universe, society and human thought. Moreover, we believe that without using mega-paradigmatic theoretical instruments such as the evolutionary approach scientists working in different fields may run the risk of losing sight of each other's contributions.

What could have caused the current insufficient attention to evolutionary studies? First of all, the crisis of evolutionism in the late 19th century and the first half of the 20th century in philosophy, biology, anthropology, sociology and some other fields (see, *e.g.,* Zavadsky 1973: 251–269; Zavadsky *et al.* 1983: 21–26; Cohen 1958; Carneiro 2003: 75–99) was caused by the fact that some classic evolutionists (but not all of them, including Darwin himself) based their ideas on a rather naïve belief in the idea of the unilinearity of development and the universality of general laws, as well as that nature and knowledge coincide entirely (see Bunzl 1997: 105). As a result, the positivistic philosophy of evolutionism could no longer accommodate the rapidly developing scientific knowledge and was rejected together with the idea of uninterrupted progress (Parsons 2000: 44).

However, the mistakes of the early evolutionists, who tried to encompass all the processes with a single and eternal evolutionary law, should not be regarded as the main cause for the current lack of attention to mega-evolutionary research. Such ‘excesses’ are rather common during the formative period of scientific schools. Since that time, the evolutionary approach has been purged from many of these excesses. This explains to a considerable extent why many scientists have returned to using evolutionary ideas at a new level of scientific understanding as well as why they are developing them actively, not only within boilogy, sociology, or anthropology, but also within physics, chemistry and astro-

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[5] We mean the approach to evolution as a general scientific interdisciplinary paradigm.

nomy. During the same period in the 20th century, the scientific understanding of timescales related to the evolution of the Universe, life and humanity improved dramatically. The better understanding of often enormously long periods of time during which certain systems and structures were formed stimulated (especially within natural sciences) studies into the emergence of everything. These studies proved to be more successful when they were based on evolutionary paradigms.

However, we believe that a major cause for the lack of attention to evolutionary paradigms is connected with the deepening contradiction between, on the one hand, the aspiration for levels of scientific precision and rigor that can only be achieved through narrow specialization, and, on the other hand, the limited human ability to absorb and process information. In addition, perhaps more than any other theory, macro-evolutionary theories have to deal with the acute contradiction between the world and its cognizing agents; this contradiction can be expressed in the following way: how can infinite reality be known with the aid of finite and imperfect means? The wider the scope of studied reality is within a given theoretical approach, the more acute this contradiction becomes.

In earlier eras of scientific studies one could hope to know reality interpreted as a ‘thing’ that is hidden from the human eyes by the armor of ‘phenomena’ (see Bachelard 1987: 17–18). The speculative philosophy dominant in the mid 19th century was based on the assumption that the search for universality implied the presence in the Universe of some form of essence that did not permit any relationships outside itself. It was the task of speculative philosophy to discover such an essence (Whitehead 1990: 273). Today, however, this type of approach has largely been abandoned.

If Popper (1974) and Rescher (1978) are right by maintaining that for any concrete scientific problem an infinite number of hypotheses is possible, and if it is correct that the number of scientific laws in any scientific field is an open system with an indefinite number of elements (see, *e.g.,* Grinin 1998: 35–37; Grinin and Korotayev 2009: 45), then what could be a possible total number of hypotheses in evolutionary theory? Furthermore, the need to master colossal amounts of information as well as complex scientific methods makes research into macroevolution rather difficult. However, if the human mind had always retreated while confronting problems of cognition that appeared overwhelming, we would have neither philosophy nor science today. The complexity of such tasks and the difficulties in reaching solutions both stimulate the search for new theoretical and experimental means (including bold hypotheses, theories, and methods). As we see it, evolutionism as an interface theory that analyzes historical changes in natural and social systems and as a method that is appropriate for the analysis of many directional large-scale processes will occupy a most important place in the struggle for human understanding of the outside world.

In the past, philosophers and thinkers could try to embrace the whole universe with a single idea. Today, it seems as if the epoch of great universalists and polymaths, who could make great discoveries in very diverse fields of knowledge, will never return. However, the need for conceptual organization and unification of knowledge still exists and is felt as such by many scientists. As Erwin Schrödinger (1944) noted, even though it has become almost impossible for a single mind to master more than one small specialized field of science, some scientists should still try to synthesize facts and theories into large-scale overviews.

The fact that the need for modern analyses of a great variety of large-scale processes remains rather strongly felt and is even increasing today is not surprising. The currently globalizing world needs global knowledge. That is why we see the emergence of forecasts of the future of the Universe, of our planet and our World System; the development of gigantic data bases; the study of trends and cycles with enormous lengths and with very diverse characteristics. The trend toward multi-disciplinary approaches is also becoming ever more evident today.

However, we still need to develop effective meta- and mega-theories that allow us to study the development of nature, society, and, indeed, the entire universe on suitable scales of time and space. We need effective theories that provide good ways for linking universal and local levels as well as relatively objective instruments for comparing various systems using a range of parameters. Only this will make it possible to detect common features and trends in the endless flow of change and diversity observed in reality. This may also allow us to identify hierarchies of causes that influence the course of change and development.

We need epistemological key terms in order to understand change in nature and society in its entirety. There are not that many scientific notions that could play the role of such key terms. We think that *evolution* is one of them. As we see it, the idea of evolution remains important for the unification of knowledge. Yet one should not overestimate the importance of evolution in the way of Pierre Teilhard de Chardin (1987), who believed that the evolutionary theory is more than scientific theory. To be sure, no scientific method can claim to be the only one. There will always be alternative points of view. Any method or approach has its limitations. Today, the evolutionary approach seems especially valuable. Evolutionary studies constitute one of the most fruitful fields of interdisciplinary synthesis, where representatives of the natural and social sciences as well as the humanities find common ground for research and analysis.

We are entirely ready to acknowledge that evolutionism (as any other paradigm) has its limitations. That is why we want to discuss them here with the aim to improve our understanding of it. This could raise evolutionary theories to a new qualitative level that is in agreement with current scientific knowledge. We believe that the present Almanac, which brings together scientists working in different areas of the vast evolutionary field, will hopefully make a contribution to this process.

* * *

One of the clearest manifestations of the evolutionary approach is the form of universal evolutionism (*Big History*) that considers the process of evolution as a continuous and integral process – from the Big Bang all the way down to the current state of human affairs and beyond. Universal evolutionism implies that cosmic, chemical, geological, biological, and social types of macroevolution exhibit forms of structural continuity (for examples of this approach see, *e.g.,* Chaisson 2001; Nazaretyan 2004; Panov 2008b; Fesenkova 1994; Christian 2004; Grinin *et al.* 2009; Jantsch 1983; Spier 2005, 2010).[6] The great importance of this approach (that has both the widest possible scope and a sound scientific basis) is evident. It strives to encompass within a single theoretical framework all the major phases of the universe, from the Big Bang down to forecasts for the entire foreseeable future, while showing that the present state of humankind is a result of the self-organization of matter. However, the conceptual efforts of a single scientist – even if he or she possesses exceptional erudition – have their limits. This situation does not change radically when a few such theorists become united in scientific schools. We now need a higher level of co-operation that can achieve a large-scale analysis of evolutionary processes through interdisciplinary approaches.

Which forms and directions could be especially promising in this respect? We believe that one of them could be *comparative evolutionary studies*, *i.e.* the approach followed in articles published in the second section of this Almanac.[7] The search for a 'common denominator' for different evolutionary levels is very important, as it could show common fundamental characteristics of all forms of matter.[8] Yet, there is some risk to exaggerate its potential for

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[6] Although the notions of *mega*evolution and *macro*evolution are very similar at the moment and can well be regarded as synonyms, it may still make sense to discriminate between them. For instance, the term *mega*evolution could be used for the whole process of evolution, all of its phases and qualitative levels from the Big Bang to the forecastable future, whereas *macro*evolution may be useful to characterize the full course of evolution within a particular realm – in such cases we would speak of cosmic, geological, chemical, biological, social macroevolution. In this book we will use those terms in this way.

[7] Examples of comparative evolutionary studies include Carneiro (2005 and this volume), Grinin, Markov and Korotayev (Markov and Korotayev 2007; Grinin, Markov, and Korotayev 2008 and this volume); see also a number of articles in the special issue of the *Social Evolution & History* (Barry 2009).

[8] Sometimes this is done using such 'common denominators' as energy or entropy (see, *e.g.*, Chaisson 2001, 2005, 2006; on the analysis of such an approach see Spier 2005, 2010; see also his contribution to this Almanac).

the understanding of specific features of each type of macroevolution and its driving forces. Hence, any theoretical approach aiming to unite the methodological arsenal for analyzing different types of macroevolution cannot be mechanical in its nature. Thus, we need to develop and refine our common terminology, methodology, and conceptual contents.

This implies the necessity to create a *common field* for the study of evolutionary processes (among other things, through interdisciplinary research), within which we could clarify and refine the common and peculiar features in evolutionary approaches, terminology, principles, as well as conduct cross-evolutionary research. The wider the field will be and the more diverse the form of its integration, the more significant advances we may expect. We believe that this may well provide new productive opportunities leading to a better understanding of the course, trends, mechanisms, and peculiarities of each type of evolution.

In recent decades a number of researchers have tried to interconnect various forms of evolution. However, the study of evolutionary processes is mainly developing within each of its specific areas in rather isolated ways. In most cases, the scientists who study evolution often do not know that the problems they analyze may already have been solved in other fields of the evolutionary studies. The conclusions that they may have reached independently may be surprisingly similar for abiotic, biological and social systems. Some contributors to this volume experienced this firsthand when they discovered that solutions found in one field turned out to be applicable in another.[9] The fullest consideration of this question is presented in the contribution by Leonid Grinin, Alexander Markov, and Andrey Korotayev 'Biological and Social Aromorphoses: A Comparison between Two Forms of Macroevolution' (in this Almanac); this article demonstrates how the application of ideas developed through the study of biological macroevolution can be very productive in the study of social macroevolution and *vice versa*. The authors trace contours of general analytic instruments, regularities and laws that are common for both types of macroevolution. This confirms once again the point that both a common field and significant theoretical elements that can shape a general paradigm of evolutionism are already available. However, they need to be developed further.

Thus, we first of all need to unite our efforts in order to see better what has already been done in this field. Those who are working with evolutionary *mega*-paradigms need to be enabled to know more about each other, in order to see

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[9] It is well known that, while developing the theory of natural selection (and, especially, the idea of struggle for survival) Darwin explicitly or implicitly relied on concepts of demography, political economy, and macrosociology, most notably the ones developed by Thomas Malthus, Adam Smith, and Herbert Spencer (see, *e.g.*, Darwin 1991: 23; Mayr 1981: 18–19; Schweber 1977, 1980; Ingold 1986; see also Lekevičius' contribution to this Almanac, as well as the contribution by Grinin, Markov, and Korotayev). Note also that biologists have borrowed from economics such notions as 'invention' and 'innovation' (see, *e.g.*, Erwin and Krakauer 2004).

and understand what has been done (and by whom), so that they can enrich themselves with the experience of scientists specializing in different fields of evolutionary studies. The best way to initiate such a process has often been to start a scientific publication. This approach formed the basis of the idea to start a multidisciplinary almanac with *Evolution* as its general title. We plan to publish here those articles that study multifarious forms of evolution. We suggest the widest possible range of topics in terms of both the scope of fields and the broadness of research designs: from approaches of the universal evolutionism to the analysis of particular evolutionary regularities in abiotic, biological, and social systems, culture, cognition, language, psychological phenomena, *etc.*

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The comparison between different types of macroevolution is an extremely important but, unfortunately, rarely studied subject, the analysis of which has convinced us that there are both fundamental differences and similarities. However, one may wonder on which common principles and aspects such a unified field, dealing with everything from galaxies to human societies, could be based. We believe that there are several important aspects to such an approach.

First of all, there are established fundamental notions such as ‘matter’, ‘energy’, ‘entropy’, ‘complexity’, ‘information’, ‘space’, and ‘time’, that provide a general framework for comparisons. In this issue of the Almanac several contributions deal with these issues, including Chaisson's ideas concerning the correspondence between increasing levels of complexity and the amount of energy flowing through them. This is expressed in terms of the amount of free energy that passes through a system during a certain period of time (Chaisson 2001, 2005, 2006). On this basis Chaisson seeks to detect a general mechanism of cosmological, biological, social, and even cultural evolution. In Spier's contribution to this Almanac, some of the merits and contradictions of this approach are discussed (see also Spier 2005, 2010).

In the second place, matter has some very general properties, which were perhaps already predetermined during the initial super dense phase of the universe. During the subsequent phases of universal evolution, matter acquires very specific forms, while new properties emerged at every new stage of the universal evolution.

In the third place, a few general system-dependent structural properties of matter[10] appear to determine similarities between different types of macroevolution. Ashby (1958) noticed that while the range of systems is enormously wide, most systems consist of physical parts: atoms, stars, switches, springs,

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[10] If we take into account the concept of dark matter, it might be more appropriate to speak about ordinary matter as ‘matter that is capable of evolution’. Until now it has not been possible to say anything specific about ‘dark matter’, which supposedly forms the greatest portion of matter in the universe.

bones, neurons, muscles, gases, *etc*. (see also Hall and Fagen 1956). In many cases we are dealing with very complex systems that are found in many places (Haken 2005: 16). The emergence of forms of greater complexity results from the transition from one evolutionary level to another. The general principles related to the functioning and development of such objects can be described by general system theory. The concepts of self-organization and transition from equilibrium to a non-equilibrium state are also relevant in this respect. In addition, both biotic and abiotic systems show complex interactions with their environment that can be described in terms of general principles.

In the fourth place, mega-evolutionary trajectories can be considered as components of a single process, and their different phases can be regarded as different types of macroevolution that could be similar in terms of their main trends and directions as well as particular mechanisms. This will be discussed in more detail below.

In the fifth place, we can speak about common vectors of megaevolution as well as common causes and conditions during the transition from one level of organization to another.[11] There is a number of very important categories that are relevant for the analysis of all phases of megaevolution, most notably self-organization, stable and chaotic states, phase transition, bifurcation, *etc*.

Because of our rapidly growing knowledge of the universe, on the one hand, and, simultaneously, our lack of reliable information about many of its aspects, on the other hand, arguments regarding the issue of whether our world is ‘strange’, fortuitous (see, *e.g.,* Davies 1982, 1985, *etc*.), or ‘regular’ remain rather polarized (see, in particular, Kazyutinsky 1994). At present, we are dealing with conflicting paradigms that are hard to falsify, while even the very notion of what ‘regular’ means is not sufficiently rigorously defined (see Grinin and Korotayev 2009: ch. 1 for more detail). For this reason, modern cosmological theories and hypotheses sometimes exhibit directly opposing ideas. For example, according to Panov (2008a), the cosmological theory of ‘chaotic inflation’ implies that there is not just one universe, but in fact, an unlimited number of them, while all those universes can possess entirely different physics. As a result, life may be possible in some universes and impossible in others. Since we emerged in a universe where the life was possible, we observe the set of parameters that corresponds to the so-called ‘anthropic principle’.[12] However, it may be that the cosmologies of inflation, the multiverse, and string theory do not have any relevance for reality as we observe it. The fundamental constants may

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[11] The problem of evolutionary transitions from one level of megaevolution to another is discussed in a number of contributions to the present Almanac (Spier, Snooks, Grinin, Markov, Korotayev, Heylighen).

[12] The anthropic principle (that does not have any generally accepted wording yet) maintains the presence of a link between the large-scale properties of the expanding universe and the emergence of life, intelligence, and civilizations within it (see, *e.g.*, Kazyutinsky 1994).

simply have the observed values just because they cannot have any other values due to some yet unknown fundamental physical laws (Panov 2008a: 54–55).

At least five basic aspects can be identified that help us to recognize substantial similarities between different evolutionary forms and processes:[13]

1) the ‘starting’ level/aspect, consisting of a minimum number of general characteristics of matter and energy that are, apparently, determined at the very beginning of space and time. These fundamental characteristics allow us to identify the most basic common denominator for different evolutionary levels in terms of entropy/energy, self-organization potential, *etc.*;

2) ‘genetic-hierarchical’ levels/aspects, because any new form of evolution must be connected with the previous ones;

3) ‘interaction and adaptation’: emerging levels of organization may ‘tune up’ their parameters compared to preceding evolutionary forms, while at the same time all forms of evolution depend on each other; hence, there is a certain kind of ‘accommodation’ between them;

4) ‘behavioral’ aspects: different forms of matter can sometimes behave rather similarly in certain conditions. They can acquire similar structures, while it may also be possible to detect similar phases, cycles, rhythms and patterns. As a result, by concentrating on similarities instead of differences in details we may be able to formulate certain general principles concerning the ‘behavior’ of objects at various levels of evolution;

5) trends in, and possible direction of, evolution: this aspect has attracted the attention of especially those evolutionists who seek to define evolution in terms of transitions from less complex/developed systems to more complex/developed ones. Major issues include the following questions: Are these trends large-scale (for example of intergalactic level) or more localized, such as of the planetary scale and below? Is this dynamics cyclical or linear, like, for example, the rise and demise of certain societies? Do we need the anthropic principle to explain this? Currently, no consensus exists on these and many other issues of this kind. However, there can be no doubt that a great number of trends can be observed in megaevolution, which needs to be explained.

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We can now provide a fuller, yet still preliminary, characterization of evolutionary *mega*paradigms. First of all, this involves general evolutionary laws, characteristics, and principles; vectors, levels, and rhythms of mega- and macroevolution as well as similarities of ‘behavior’ of different forms of matter in

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[13] In particular, many processes that take place at different evolutionary levels are described by similar basic models; their phase portraits are also often very similar, which makes it possible to detect a number of important common traits in many different evolutionary processes (Chernavsky 2004: 83).

certain conditions.[14] While discussing these aspects we need to answer the following questions: 1) What are the specific subjects of evolutionary studies? 2) Can we detect a certain unity in evolutionary *mega*paradigms? Tentative answers to those questions may include the following: within this approach we are dealing with specific processes of qualitative transformations of objects and structures, resulting in the emergence of new levels of organization of matter with new qualities, possibilities, and perspectives.[15] We can identify at least three types of qualitative changes: a) changes leading to relatively small and localized qualitative changes; b) changes leading to more significant qualitative changes (for example, the emergence of a new level of integration); c) especially significant qualitative changes, whose emergence creates possibilities for evolutionary breakthroughs.[16] In the words of Henri Claessen: 'Evolutionism then becomes the scientific activity of finding nomothetic explanations for the occurrence of such structural changes' (2000a: 2). Such qualitative transformations are described by a number of general evolutionary principles, laws, and rules, some of which are mentioned below.

In the second place, *mega*paradigms may include *mega*-laws that should be regarded as certain principles rather than as rigid and fixed relationships. However, the significance of each of those principles can be rather different, depending on the nature of the evolving systems (cosmic, biological, or social). It is not sufficient to formulate only very general principles and laws. It is also necessary to translate these more abstract principles into methodological models for specific case studies. The present issue of the Almanac considers such laws, rules, and regularities. We hope that this will lead to more detailed discussions in subsequent issues.

In the third place, the notion of *mega*paradigms implies the possibility to detect not only large-scale regularities and rules but it also opens up the possibility to analyze the degree of applicability of particular rules to the various types of macroevolution. Indeed, the appearance of certain similar traits, principles, and regularities in different types of macroevolution does not necessarily prove that they are the same type of process. Large underlying differences may convey the impression of similarities. Such a discovery can lead to a better understanding of such differences.[17]

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[14] These include, for example, patterns of evolutionary expansion and differentiation of forms, developmental crises, fluctuations around certain 'attractors', phase transitions, certain forms of self-organization, relationships of components as parts of internal structures, relations between the whole system and its environment, *etc*.

[15] We generally follow the definition of Voget – Claessen who define evolution as 'the process by which structural reorganization is affected through time, eventually producing a form or structure which is qualitatively different from the ancestral form' (Voget 1975: 862; Claessen 1989: 234; 2000a, 2000b).

[16] See Grinin and Korotayev 2007; 2009: ch. 1; Grinin, Markov, and Korotayev 2008 for more detail.

[17] For example, the genomes of chimpanzees and of humans are very similar; the differences constitute only a few per cent (see, *e.g.*, Cohen 2007); however, there are enormous intellectual and so-

In the fourth place, we need to develop a common terminology. We have already mentioned a few such terms, *e.g.,* 'energy', 'matter', 'information', 'system', *etc.*

However, are there any terms that are specific for evolutionary studies? We think these terms should include, obviously, evolution and coevolution as well as micro-, macro-, and megaevolution; numerous notions labeled with the adjective *evolutionary*; various terms characterizing evolution, such as speed, directionality, levels, forms, types; terms that characterize spheres of evolution, most notably, perhaps, the biosphere, the noosphere, the technosphere, *etc.*; possibly, perhaps, notions of progress or the lack of it; processes of selection and resulting variation. However, for a further development of evolutionary *mega*paradigms these terms may not be sufficient, and examples of the use of new terms can be found in some contributions to this Almanac. It is noteworthy that all the existing mega-evolutionary terminology is interdisciplinary by nature. More likely than not, therefore, new terms will also have an interdisciplinary character.

In the fifth place, there is a potential for the development of cross-disciplinary and comparative research that can establish similarities as well as detect differences of both methodological and practical nature; this may allow us to find new heuristic evolutionary theories. While the issues studied within different branches of sciences may be very specific, through the prism of the evolutionary approach it is often possible to find opportunities for interdisciplinary comparisons, the creative borrowing of methodology, the identification of common mechanisms, of 'vectors' as well as systemic properties that are characteristic of different forms of organization of matter, energy, and information in abiotic, biological, and social systems (cf. Carneiro, Spier, Snooks, Grinchenko, Grinin, Markov, Korotayev, Reznikova, Lekevičius, Heylighen in this Almanac). In forthcoming issues of the Almanac we hope to present more discussions about these aspects.

In the sixth place, research in terms of evolutionary *mega*paradigms frequently requires considering issues such as directionality (vectors or trends), speed, reversibility, *etc.*[18] In sum, the general nature of evolution requires attention to a great many fundamental aspects: ontological, epistemological, terminological and methodological.

In the seventh place, any serious scientific paradigm requires a study of its own history. We are planning to publish such overviews and discussions in future issues of the Almanac.[19]

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cial differences between chimpanzees and humans that arise from the at first sight 'insignificant' difference between the two genomes.

[18] In particular the speed of evolution has received considerable attention from a number of contributors to the Russian version of the Almanac (Tsirel 2009; Nazaretyan 2009; Iordansky 2009; Grinin, Markov, and Korotayev 2009a).

[19] See also the issues of the Almanac in Russian: Grinin, Markov, and Korotayev 2009a, 2009b; Grinin, Ilyin *et al.* 2010; Grinin, Markov, and Korotayev 2010.

In the eighth place, we believe that there are common methodological principles and approaches to evolutionary studies, even though we are dealing with processes that never fully repeat themselves.

In contrast to the system approach that considers systems and structures as essentially static (or concentrates on their functioning), evolutionary approaches focus on those special conditions and factors that determine qualitative evolutionary transformations and reorganizations of such systems. These factors themselves become the subject of theoretical analysis. This may lead to the development of analytical instruments which are common for different branches of the evolutionary studies.

In evolutionary studies, the attention is usually focused on what is considered to be the most important, on qualitative changes and transformations (reorganizations). Leading questions include the direction of such changes: for example, if they lead to a decrease, or increase, in complexity; whether they constitute a transition to a new evolutionary level; or whether they are similar to, for instance, the mechanism of adaptive radiation in biology; whether it is possible to trace some genetic links.

The 'historical method' employed in evolutionary studies differs from the 'logical method' of traditional philosophy. Within such philosophical approaches 'the logical' was supposed to clean 'the historical' from various contingencies in order to detect its essence. However, in this 'cleansing' process the resulting logical constructions tended to lose their connection with reality entirely, which is unacceptable within evolutionary studies. This will be elaborated below.

Finally, a few epistemological aspects and principles are common to all evolutionary studies, because they stem from the peculiarities of self-organizing processes (see Grinin and Korotayev 2009: ch. 1 for more detail). As direct observations of complex large-scale objects and processes are impossible, our reflection about these things constitutes a multi-layered indirect process of cognition that is complicated greatly by linguistic ambiguities and other semiotic problems.

In conclusion, evolutionary *mega*paradigms must be based on empirical observations and plausible hypotheses, which allow the application of the standard scientific procedures of verification and falsification.[20] They must be able to accommodate most, if not all, of the existing evidence. We want to encourage as much open discussion as possible about evolutionary studies, in hope that from a new diversity of approaches a new unifying approach may emerge sometime in the future.

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[20] For example, according to Popper (1974, 1984), Campbell (1974), and some other researchers.

The Almanac's Structure

The contributions to this volume are subdivided into three sections: Section I ('Universal Evolution', 2 articles); Section II ('Biological and Social Forms of Evolution: Connections and Comparisons', 4 articles); and Section III ('Aspects of Social Evolution', 3 articles).

Subjects and issues of the contributions to all three sections have a great deal in common and significantly supplement each other. As a result, the present issue may be regarded as a collective effort dedicated to the search for the contours and specifics of evolutionary *mega*paradigms. In addition, in this issue we have tried to present articles that study problems on various scales. Yet in general this issue deal with studies at very large temporal and spatial scales, in other words, the issues of mega- and macroevolution.

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The First Section of the Almanac (**Universal Evolution**) starts with *Fred Spier's* article 'How Big History Works: Energy Flows and the Rise and Demise of Complexity'. This article is written within the tradition of universal evolutionism, also known as the Big History. This research project aims at integrating the natural sciences and the humanities. In doing so it has become possible to detect a number of general vectors and trends in evolution as well as mechanisms and regularities, including their specific qualitative features at various evolutionary phases. The Big History emerged as a scientific discipline in the late 20th century. It offers an integrated model of the evolution of the Universe that connects the development of social, biological, and abiotic systems into a single consecutive process.[21] Such Big History models lead to the following question: is the information component within the triad 'matter – energy – information' a significant factor of evolutionary processes, or are two basic categories (energy and matter) sufficient for their description? The changes in the Universe during 13.7 billion years reveal certain simple trends.

Fred Spier advances an explanatory scheme for all of history from the beginning of the Universe until life on Earth today (Big History). His scheme is based on the ways in which energy levels as well as matter and energy flows have made possible both the rise and demise of complexity in all its forms.

According to Spier, the history of complexity in the Universe consists of a rather boring beginning, followed by a more exciting period of increasing local and regional complexity, which will subsequently peter out into total boredom. This is directly linked to the fact that, from the very beginning, the Big History has exhibited a trend towards lower energy levels as well as towards energy flows which first increased and then mostly began to decrease. As a re-

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[21] In 2005 the journal *Social Evolution & History* published a special issue (*Exploring the Horizons of Big History* [Snooks 2005]) dedicated to the problems of this direction of universal evolutionism; we have already made above some references to some contributions to that special issue.

sult, in most places the level of complexity has remained rather low. This is first of all due to the fact that most of the Universe is virtually empty. Wherever there was sufficient matter, complexity rose in the form of galaxies, which are made up of stars, planets, and clouds of gas and dust, possibly with black holes in their centers. The growing range of chemical elements needed for life was cooked by exploding stars. This signaled another rise in complexity.

In the beginning, the energy levels determined the level of complexity the Universe could attain. After about 400,000 years of expansion, however, the rise of complexity has come as a result of the interplay between energy levels and energy flows. The first level of material complexity would be reached as a result of the nuclear force. This complexity consisted of the smallest, subatomic and atomic particles. Electromagnetism would take care of the second, intermediate, stage, in which atoms, molecules and complexes of molecules would be formed. The effects of gravity would inaugurate the last stage and would bring about all the larger structures we know in the observable Universe.

Spier believes that greater forms of biological and cultural complexity are exceedingly rare in the Universe. During the past four billion years or so, the energy flows and levels on the surface of our home planet were suitable for the emergence of this type of complexity. The intricate energy flows on the Earth's surface first made possible forms of biological complexity. Life began to actively harness more and increasingly varied sources of matter and energy. A very similar process took place during the cultural evolution of humankind. This has led to the greatest levels of complexity known today.

Robert L. Carneiro ('Stellar Evolution and Social Evolution: A Study in Parallel Processes') suggests that the process of evolution can be seen at work in all domains of nature. Carneiro points out a number of parallels between the development of stars and the development of human societies. For example, the use of the comparative method has been prominent in the study of evolution in both fields. Also, there are parallels between the two, such as the use of stages to distinguish significant phases of the evolutionary process, the manifestation of both multilinear and unilinear evolution in both, and differential rates of evolution among stars and societies.

As has been already mentioned above, in his book *First Principles* (1862), published only three years after Darwin's *On the Origin of Species*, Herbert Spencer portrayed evolution as something far beyond 'descent with modification'. He saw it as a much broader process, which had manifested itself throughout the Universe, from the tiniest microorganisms to the largest galaxies. The evolution of the stars, then, was clearly within his purview.

As a field of astronomical research, stellar evolution has been pursued with increasing vigor and impressive results since Spencer's time. In fact, it may well be that the results astronomers and astrophysicists have been able to accomplish in reconstructing the process of cosmic evolution stand among the greatest intellectual triumphs of all time.

Carneiro points to some striking parallels between the evolution of stars and the evolution of human societies which anthropologists are barely aware of. And while recognition of these parallels may mean very little to the powerful and sophisticated science of astronomy, it just may be of some interest and value to the fragile and beleaguered field of cultural evolution.

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The Second Section of the Almanac **(Biological and Social Forms of Evolution: Connections and Comparisons)** considers a number of important macro-evolutionary problems of biology and sociology. However, it will not be an exaggeration to say that it is primarily devoted to what may be denoted as *comparative evolutionary studies*. All the contributions to this section deal with comparisons between mechanisms, factors, laws, and trends in various fields of evolutionary studies as well as with terminology developed and applied in those fields, while the authors also consider the possibilities of their use in other fields. These articles also deal with issues of the development of general evolutionary methodologies and terminologies. This section mainly deals with comparisons between biological and social macroevolution, mostly since social evolution is substantially closer to biological evolution rather than to the evolution of abiotic systems. However, we have no doubts about the intrinsic possibility of comparative research with respect to any types of evolution (such as, for instance, shown in Carneiro's contribution to the First Section). In addition, relatively close types of macroevolution (physical and chemical, chemical and biological, geological and biological, *etc.*) may share evolutionary processes to some extent. In many cases it may even be better to speak of co-evolution between them – for example, with respect to geological and biological macroevolution, or biological and social macroevolution. Especially during the 20th century new scientific approaches emerged and developed quickly based on the analysis of such mutual links and parallels, including cybernetics and biogeochemistry, which studies, among other things, the relationship between the evolution of life and of inorganic matter on the Earth.

Contributions to the Second Section of the Almanac cover a wide range of topics, ranging from specific issues in biological and social sciences to the application of general systems theory to biological and social systems, including behavioral strategies. One of the main issues covered in this section is the problem of progressive change and its criteria in biology and history (this subject is discussed in the contribution by Leonid Grinin, Alexander Markov, and Andrey Korotayev). The notion of progress (together with the one of evolution) came to the evolutionary biology from philosophy. However, this term remains highly controversial and is rejected by many biologists and sociologists. While discussing the possibility of the use of this term in evolutionary biology, Grant (1991: ch. 34) poses the following questions:

1) Is it possible to transfer satisfactorily the notion of progress from the sphere of human activities to evolutionary biology?

2) If so, would it be possible to formulate scientific criteria that allow us to define the notion of progress in organic evolution?

Different scientists suggest diametrically opposite answers to those questions. There are even more problems with the application of the notion of progress to the study of social macroevolution (see, *e.g.,* Korotayev *et al.* 2000; Korotayev 2004; Grinin 2006 for more detail).

In all these cases, it appears necessary to take into account the fact that both in social and biological macroevolution the point of view of an observer and her or his value system plays a major role in defining the notion of progress (Grant 1985). Furthermore, the application of the notion of progress to the study of social evolution introduces a number of ethical problems. Although a great many attempts have been undertaken to apply the notion of progress more objectively in such studies, it has turned out to be impossible to avoid ethically charged positive connotations with this notion. In fact, the claim to be able to define the social progress with the aid of 'objective criteria' may imply the claim by some groups to know 'objectively' better than other people what these other people really need.

In his article **'**Constructing a General Theory of Life: The Dynamics of Human and Non-Human Systems' *Graeme Donald Snooks* maintains that the ultimate objective of theorists studying living systems is to construct a general theory of life that can explain and predict the dynamics of both human and non-human systems. Yet little progress has been made in this endeavor. Why? The author suggests that this is because of the inappropriate methods adopted by complexity theorists. Snooks claims that by assuming that the *supply-side* physics model – in which local interactions are said to give rise to the emergence of order and complexity – could be transferred either entirely (social physics) or partially (agent-based models, or ABMs) from the physical to the life sciences, we have distorted reality and, thereby, delayed the construction of a general dynamic theory of living systems. According to Snooks, the solution can only be found if we abandon the deductive and analogical methods of complexity theorists and adopt the inductive method. With this approach it is possible to construct a *realist* and *demand-side* general dynamic theory, as in the case of the dynamic-strategy theory presented in this paper.

In his contribution 'Ecological Darwinism or Preliminary Answers to Some Crucial though Seldom Asked Questions' *Edmundas Lekevičius* asserts that evolutionary regularities might be deduced from basic principles describing how life functions, most notably part-whole relationships and control mechanisms. The author suggests adding the concept of functional hierarchy to the concept of the struggle for existence: no solitary individual or species is functionally autonomous. Life as we know it can exist only in the form of a nutrient cycle. Only two purely biotic forces – 'biotic attraction' and 'biotic repulsion' – act in the living world. The first one maintains and increases diversity and organizes solitary parts into systems integrated to a greater or lesser degree. The second one, in the form of competition, lessens biodiversity but at the same time provides life with necessary plasticity. On that ground, tentative answers to the following questions are given: (1) Why does life exhibit such a peculiar organization with strong integration at lower levels of organization and weak integration at higher ones? (2) Why did particular species and guilds appear on the evolutionary stage at that particular time and not at any other? (3) Why was the functional structure of ecosystems prone to convergence despite a multitude of stochastic factors?

In her article 'Evolutionary and Behavioral Aspects of Altruism in Animal Communities: Is There Room for Intelligence?' *Zhanna Reznikova* analyzes the phenomenon of the altruistic behavior by animals from an evolutionary perspective. The altruistic behavior of animals is still enigmatic for many evolutionary biologists, even though a great many data have been analyzed and several rational concepts have been developed, such as the theory of inclusive fitness and the theory of reciprocal altruism. Altruistic behavior in animal societies is based on the division of roles between individuals who are dependent on each other as a result of their behavioral, cognitive and social specialization. It is a challenging problem to explain intelligence within the framework of social specialization in such animal communities. In this review, the characteristics of different levels of sociality are considered and the role of flexibility of individual behavior within the functional structure of animal communities is analyzed. In some situations, behavioral, cognitive and social specialization can be congruent; maybe this is the formula for happiness in animal societies.

In their contribution 'Biological and Social Aromorphoses: A Comparison between Two Forms of Macroevolution' *Leonid Grinin, Alexander Markov,* and *Andrey Korotayev* emphasize the point that the comparison between biological and social macroevolution is a very important although insufficiently studied subject, whose analysis offers new significant possibilities to comprehend the processes, trends, mechanisms, and peculiarities of each of the two types of macroevolution. Even though there are a few important differences between them, it appears possible to identify a number of fundamental similarities. At least three fundamental sets of factors determining those similarities can be singled out. First of all, in both cases we are dealing with very complex non-equilibrium (but rather stable) systems whose principles of functioning and evolution are described by General Systems' Theory, as well as by a number of cybernetic principles and laws. Secondly, in both cases we do not deal with isolated systems but rather with complex interactions between both biological and societal organisms and their external environment. The reaction of such systems to external challenges can be described in terms of certain general principles that are expressed, however, rather differently within biological and social reality. Thirdly, there is a direct 'genetic' link between the two types of macroevolution and their mutual influences.

The similarity of the principles and regularities of these two types of macroevolution does not imply that they produce the same results. Remarkable similarities are frequently accompanied by enormous differences (see, for example, the above mentioned case of the impressive similarity between genomes of chimpanzees and of humans).

According to the authors it appears reasonable to consider biological and social macroevolution as one single macro-evolutionary process to at least some extent, even though their concrete biological or social manifestations may display significant variations, depending on the specific properties of the evolving entities. This implies the necessity to comprehend general laws and regularities that describe this general process. An important notion that may contribute to our understanding of the differences and similarities of these two types of macroevolution is the term **social aromorphosis.** This term was developed as a counterpart to the notion of biological aromorphosis, which is well established within Russian evolutionary biology. Grinin, Markov, and Korotayev regard social aromorphosis as a rare qualitative macro-change that increases in a very significant way complexity, adaptability, and mutual influence of social systems, and thus opens up new possibilities for social macro-development. In their contribution, they discuss a number of regularities that describe biological and social macroevolution by employing the notions of social and biological aromorphosis, including such regularities as rules of 'module evolution' (or the evolutionary 'block assemblage'), 'payment for arogenic progress', *etc.*

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The Third Section of the Almanac (**Aspects of Social Evolution**) starts with the contribution by *Dmitri Bondarenko, Leonid Grinin, and Andrey Korotayev* 'Social Evolution: Alternatives and Variations (Introduction)'. The article deals with important theoretical problems of social evolution. In the authors' opinion, a number of general evolutionary ideas, principles and conclusions formulated in the article may not only be significant for the study of social evolution but also for evolution as a whole. The authors' basic ideas and principles are as follows: Evolutionary alternatives can be found for any level of social complexity. Very often, different social and political forms have co-existed and competed with each other for a long time. Within specific ecological and social niches, some models and variants could be more competitive first, only to be taken over by other forms later. As a result, many statements about certain 'inevitable' outcomes of evolution can be considered correct only in the most general sense and within certain conditions. The underlying reasoning is that evolutionary outcomes are usually the result of long-lasting competition between different forms, sometimes resulting in their destruction, or in transformations, social selection, adaptation to various ecological milieus, *etc.* This means that evolutionary outcomes are not inevitable for each and every particular society.

These ideas are illustrated at different levels, including pre-state societies, most notably chiefdoms. The notions of homoarchy and heterarchy as labels for ideal models of rigid (invariable) and non-rigid (variable) social structures respectively, are also discussed. The authors argue that it may be possible to postulate heterarchic and homoarchic evolutionary trajectories that embrace all cultures throughout all of human history. Special attention is paid to the analysis of models of politogenesis, in the course of which alternative models of transition to complex societies were realized. This idea is suggested as a replacement for the outdated theory that represents the transition from non-state to state societies as direct and unilinear. The authors show that this transition was multilinear. They introduce the notion of early state analogues and propose a classification of various types of early state formation. Furthermore, some societies resembling early states can, in fact be regarded as complex non-state societies that are similar to early states in terms of size, socio-cultural and/or political complexity, functional differentiation level, *etc.*, while they did not share some salient features that are typical of early states.

Christopher Chase-Dunn in his paper 'Evolution of Nested Networks in the Prehistoric U.S. Southwest: A Comparative World-Systems Approach' uses a nested interaction networks approach to interpret patterns of social evolution in the late prehistoric U.S. Southwest within a comparative and world historical perspective. Place-centric interaction networks are arguably the best way to bound human systemic processes, because approaches that attempt to define regions or areas based on attributes necessarily assume homogenous characteristics, whereas interaction itself often produces differences rather than similarities. The culture area approach that has become institutionalized in the study of the evolution of pre-Columbian social systems is impossible to avoid, but the point needs to be made that important interactions occur across the boundaries of the designated regions and interaction within regions produces differences as well as similarities. Networks are the best way to bound systems, but since all actors interact with their neighbors, a place-centric (or object-centric) approach that estimates the fall-off of interactional significance is also required. The comparative world-systems approach has adapted the concepts used to study the modern system for the purpose of using world-systems as the unit of analysis in the explanation of human social evolution. Nested networks are used to bound systemic interaction because different kinds of interaction (exchange of bulk goods, fighting and allying, long-distance trade and information flows) have different spatial scales. Core/periphery relations are of great interest but the existence of core/periphery hierarchy is not presumed. Rather the question of exploitation and domination needs to be asked at each of the network levels. Some systems may be based primarily on equal interdependence or equal contests, while others will display hierarchy and power-dependence relations. It should not be assumed that earlier systems are similar to the modern global system in this regard. Rather it should be a question for research on each system.

This section ends with *Francis Heylighen's* article 'Conceptions of a Global Brain: An Historical Review'. The 'global brain' is a metaphor for the intelligent network formed by the people of this planet together with the knowledge and communication technologies that interconnect them. The different approaches leading up to this conception, by authors such as Spencer, Otlet, Wells, Teilhard de Chardin, Russell and Valentin Turchin, are reviewed in their historical order. The contributions are classified in three major approaches: organicism, which sees society or the planet as a living system; encyclopedism, which aims to develop a universal knowledge network; and emergentism, which anticipates the evolution of a suprahuman level of consciousness. The shortcomings of each perspective lead us to propose an integrated approach based on evolutionary cybernetics. Its selectionist logic allows us to analyze the process whereby initially selfish individuals self-organize into a synergetic system functioning at a higher level of intelligence, making use of an advanced version of the World Wide Web.

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I. UNIVERSAL EVOLUTION

1

How Big History Works: Energy Flows and the Rise and Demise of Complexity*

Fred Spier

Introduction[1]

Surely, any claim to explain all of history must sound preposterous. So let me be clear about my aims and claims. To begin with, I do not claim to have found exhaustive explanations for every little thing that has ever happened in history. To the contrary, explaining any part of the past always means striking a balance between chance and necessity. My explanatory scheme is about necessity. It consists of general trends that make possible and constrain certain forms of complexity. Yet within these bounds, there is ample room for chance. Although in this essay I do not systematically focus on chance, the reader should keep this in mind.[2]

The central concepts of my scheme are matter, energy and entropy (disorder). This will be elaborated below. Seen from the modern scientific point

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[1] I am most grateful to Mart Bax, Svetlana Borinskaya, Eric Chaisson, David Christian, Karel van Dam, André Gunder Frank, Gina Giandomenico, Teije de Jong, Gijs Kalsbeek, Arnold Labrie, Koen Martens, William H. McNeill, John R. McNeill, Akop Nazaretyan, Maarten Pieterson, Lucas Reijnders, Graeme Snooks, Jan Spier, Egbert Tellegen, John de Vos, Peter Westbroek, and Antonio Vélez for their insightful commentaries. Of course, they cannot be held responsible for my use of their critique.

[2] The views presented here came as a result of my academic career. I was first trained as a biochemist specializing in genetic engineering of plants. Subsequently, I was trained as a cultural anthropologist and social historian, specializing in religion and politics in Peru. Next came my ten-year experience with organizing a Big History course at the University of Amsterdam, which presents a comprehensive view of the past from the origin of the Universe up until life on Earth today. The Amsterdam course was set up following David Christian's pioneering initiative at Macquarie University, Sydney, Australia, in the 1980s. All the scholars teaching in the Amsterdam course have contributed to my better understanding of our all-embracing past. The breakthrough towards my current scheme took place in February of 2003 while the annual Amsterdam Big History course was running. Returning from a lecture, my wife Gina – while preparing dinner – asked me why Big History happened the way it did. Trying to be as clear and succinct as possible, I suddenly realized that this was a question no one had ever posed to me in such a way. I also saw in a flash that the answer might be both simple and elegant. This essay is my answer to Gina's question.

of view, everything that has existed has been composed of matter and energy of some sort. A major advantage of using such general terms is that they are applicable to all aspects of Big History. A second major advantage is that no new physics are needed in order to understand the course of Big History.

I see my explanatory scheme as a further elaboration of concepts explained in my book *The Structure of Big History* (1996). There, I proposed to employ the term *regimes* for all more or less structured processes that make up Big History. Now, it seems to me that regimes are not only very useful for describing Big History but also for explaining it.

In addition to the general insights into the workings of matter, energy and entropy that I gained during my career in chemistry, my understanding of energy flows has been strongly influenced chronologically by the writings of Marvin Harris (1975; 1980), Jeremy Rifkin (1981), I. G. Simmons (1993; 1994), David Christian (over the period 1991–2004), Ilya Prigogine and Isabelle Stengers (1984), Stuart Kauffman (1993; 1995), Eric Chaisson (over the period 1981–2005), Erich Jantsch (1980), Vaclav Smil (1994) and Leslie White (over the period 1943–1975).[3] My argument leans heavily on Eric Chaisson's scholarship, most notably his book *Cosmic Evolution: The Rise of Complexity in Nature* (2001), and also on David Christian's work: his article ‘The Case for “Big History”’ of 1991 and his book *Maps of Time: An Introduction to ‘Big History*’ published in 2004. Also the historian John R. McNeill wrote an overview pointing in the same direction (J. R. and W. H. McNeill 2003: 319–323). The synthesis presented here must, therefore, to a considerable extent be considered a communal product.

As a result of limited space, in this article I have stripped the argument down to its barest essentials. Many nuances, examples and elaborations needed to be scrapped. Those readers who are not satisfied by this approach can consult my new book *Big History and the Future of Humanity* (2010), in which these aspects are explained in more detail.

Complexity and Cosmic History

The history of the Universe is the history of emerging complexity. In the beginning there was no complexity at all. The further the Universe evolved

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[3] Leslie White's insights into the workings of energy, entropy and culture within the framework of Big History (1943, 1959, 1975) preceded the work of all big historians I know. J. R. McNeill's postscript: ‘Big Pictures and Long Prospects’ in J. R. McNeill and W. H. McNeill's recent book *The Human Web: A Bird's Eye View of World History* (2003: 319–323) are a restatement of Leslie White's agenda combined with Eric Chaisson's general views. After I had formulated my approach, I became aware of Graeme Snooks' theories (beginning in 1996 and most recently expressed in Social Evolution & History in 2002). Although I find some of his formulations not entirely convincing (especially I do not think that maximizing matter and energy flows has been the dominant strategy), I do think we are on similar tracks.

the more complex some portions could become. Right now, after about thirteen billion years of cosmic evolution, the human species is arguably the most complex organism in the entire known Universe.

Seen from the most general point of view, complexity is a result of interactions between matter and energy, resulting in more or less complex arrangements of matter (I will call them *matter regimes*). Cosmic history, therefore, primarily deals with the question of how these matter regimes have formed, flourished and foundered over time. Unfortunately, no generally accepted definition exists of how to determine the level of complexity of matter regimes. Yet there can be no doubt that it makes sense to call certain regimes more complex than others. Who, for instance, would be willing to argue that a bacterium is more complex than a human being, or a proton is more complex than a uranium nucleus? Apparently, the numbers of the building blocks of a certain matter regime, their variety, and their interactions jointly determine the level of complexity. I would therefore argue that a matter regime is more complex when more and more varied interactions take place among increasing numbers of the ever more varied building blocks of which the regime consists. In other words, a regime is more complex when the whole is more different than the sum of its parts (Chaisson 2001: 12–13).

From the perspective of Big History, the greatest complexity appears to exist on the surfaces of celestial bodies situated on the outer edges of galaxies. In other words, greater complexity is typically a marginal phenomenon, both in the sense that it can be found on the margins of larger regimes and in the sense that it is exceedingly rare. Most of the Universe consists of lesser forms of complexity. To be sure, as Eric Chaisson observed, this is not true for life itself. The greatest biological complexity, most notably DNA and brains, are to be found in, or near, the center of their regimes and not on their edges. Apparently, this type of greater complexity needs to be protected against matter and energy flows from outside that are too big, in which case it would be destroyed, or too small, in which case it would freeze. In other words, life has created a space suit for its own greatest complexity. In fact, terrestrial life may have well succeeded in turning the entire biosphere into a space suit. This is, in my view, the essence of James Lovelock's Gaia hypothesis, which states that terrestrial life has evolved feedback mechanisms that condition the biosphere in ways that are advantageous for life's continued existence on our planet.

Three Fundamental Types of Complexity

Three major types of complexity can be discerned: physical inanimate nature, life and culture. Let us start with physical nature. First of all, it is of great importance to see that most of nature is in fact lifeless. The following example may help to grasp the significance of its sheer size. For the sake of simplicity, let us assume that the Earth weighs as much as an average American car (about

1000 kg). The weight of all planetary life combined would then amount to no more than seventeen micrograms. This equals the weight of a very tiny sliver of paint falling off that car. Seen from this perspective, the total weight of our Solar System would be equivalent to the weight of an average supertanker. Since the mass of the Universe as a whole is not well known, I refrain from extending this comparison any further. But even if life were as abundant in the Universe as it is within our Solar System, its relative total weight would not amount to more than a tiny sliver of paint falling off a supertanker.

All this cosmic inanimate matter shows varying degrees of complexity, ranging from single atoms to entire galaxies, and it organizes itself entirely thanks to the fundamental laws of nature. Although the resulting structures can be exquisite, inanimate complexity does not make use of any information for its own formation or sustenance. In other words, there are no information centers dictating what the physical lifeless world looks like. It does not make any sense to wonder where the information is stored that helps to shape the Earth or our Solar System.

The next level of complexity is life. In terms of mass, as we just saw, life is a rather marginal phenomenon. Yet the complexity of life is far greater than anything attained by lifeless matter. In contrast to the inanimate Universe, life seeks to create and maintain the conditions suitable for its own existence by actively sucking in matter and energy flows with the aid of special mechanisms. As soon as living things stop doing this, they die and their matter and energy return to lower levels of complexity (unless they are consumed by other life forms). Life organizes itself with the aid of (mostly hereditary) information stored in molecules (mostly DNA). While investigating living species, it does make a great deal of sense to wonder where the information centers are, what the information looks like, and how the control mechanisms work that help to translate this information into biological shapes.

The third level of complexity was reached when some complex living beings began to organize themselves with the aid of cultural information stored as software in nerve and brain cells. The species that has developed this capacity the furthest is, of course, humankind. In terms of total body weight, our species currently makes up about 0.005 per cent of all planetary biomass. If all life combined were just a tiny sliver of paint falling off a car, all human beings today would jointly amount to no more than a tiny colony of bacteria sitting on that flake. Yet through our combined efforts we have learned to control a considerable portion of the terrestrial biomass, perhaps as much as 25 to 40 per cent. In other words, over the course of time this tiny colony of microorganisms residing on a sliver of paint has succeeded in gaining control over a considerable portion of that flake. We were able to do so with the aid of culture. In its barest essence, culture consists of accumulated learned experiences stored as software in our brains and nerve cells or in human records. In order to understand how human societies operate, it is therefore not sufficient to look only at their DNA and their molecular mechanisms. We need to study the information humans use to shape both their own lives and the rest of nature.

Energy Flows and Complexity

During the history of the Universe, all the major forms of physical, biological and cultural complexity apparently emerged all by themselves. In the scientific approach, the possible influence of supernatural forces bringing about complexity is not considered to be an acceptable explanation, since we have never observed such forces at work. The major question becomes therefore: how does the cosmos organize itself? This question becomes even more difficult by realizing that, in our daily lives, we often observe the opposite: the breakdown of complexity into chaos. Children's rooms, for instance, never clean themselves up all by themselves and, without a trash collecting system, cities would soon choke in their own refuse. This breakdown of complexity into chaos is known as the Second Law of Thermodynamics. This law states that over the course of time, the level of disorder (entropy) must increase. In other words, the history of the Universe must also be the history of increasing disorder. Any local rise in complexity must, therefore, inevitably have been accompanied by a larger rise of disorder elsewhere.

According to the modern view recently expressed by, among others, Ilya Prigonine, Isabelle Stengers, and Eric Chaisson, complexity emerges when energy flows through matter. Only in this way it is possible for more complex structures to arise. Yet what does the concept of energy flows mean? This is not as straightforward as it may seem. Eric Chaisson defines *free energy rate density* – indicated with the symbol Φm – as the amount of energy per second that flows through a certain mass (free energy is energy able to perform useful tasks; this means an energy differential exists that can be tapped). Chaisson next shows that there is a clear correlation between levels of complexity and his calculated *free energy rate densities*. This is the central argument of his book *Cosmic Evolution: The Rise of Complexity in Nature* (2001).[4] Although, compared to most other aspects of Big History, humans may seem vanishingly small, according to Chaisson we have generated by far the biggest *free energy rate densities* in the known Universe. Unfortunately, the term *free energy rate density* is rather cumbersome, while it is equivalent to the term *power density* used by other scientists. Because now Chaisson is also using the term *power density*, this will be our preferred term.

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[4] Although I greatly admire Eric Chaisson's approach, I see some problems with his term *free energy rate density*. I keep wondering whether in addition to mass, volume should also be included in this term. Surely, a star like our Sun is far denser than our galaxy as a whole, or the terrestrial atmosphere, or human society. Clearly, humans would be unable to function if they were packed very close together – they need some space. In Chaisson's approach, these differences are ignored. For future research, we might also want to define a slightly different term which I will tentatively call *adapted power density* in terms of energy per time per mass per volume. This correction for volume would perhaps lead to more realistic comparisons of the energy flows through matter.

Surprisingly little attention has been devoted to the demise of complexity.[5] Seen from the highest level of generality, complexity is destroyed when the energy flows and/or energy levels (temperatures and pressures) become either too high or too low. For instance, without a sufficient energy flow, no biological regime will survive. Yet if such an organism experiences energy flows that are too big, it will succumb to them, too. This is also the case for lifeless regimes, such as rocks, planets or stars. All matter regimes are, therefore, characterized by certain boundary conditions within which they can exist. In a reference to a popular children's story, I call this the Goldilocks Principle. My claim in this article is that the energy approach outlined above combined with the Goldilocks Principle equals the first outline of a historical theory of (almost) everything. This may be a grand claim, yet I think this is the case. This theory cannot, of course, explain all the details, yet it does provide some structure and explanations for the way Big History has gone. In the pages that follow I present the first version of this theory.

The Big Bang and the Radiation Era

According to our modern creation story, at the beginning of time and space there was a lot of undifferentiated energy/matter packed extremely close together. At the instant of creation, the Universe was infinitely dense and unimaginably hot. At that very moment, the Universe was entirely undifferentiated. In other words, the instant of the Big Bang was the most simple and basic regime imaginable.

The Radiation Era first witnessed the emergence of the three basic forces that organize matter: the nuclear force, electromagnetism and gravity. The first level of material complexity would later be reached as a result of the nuclear force – which acts by far the strongest on very short distances. This complexity consisted of the smallest, subatomic and atomic particles. Electromagnetism, the intermediate force, would take care of the second stage, in which atoms, molecules and complexes of molecules were formed. The effects of gravity, the weakest of the three forces but with the longest reach, would kick in the last and would bring about all the larger structures in the observable Universe.

During the first period of cosmic expansion, temperature differences were very small, if they existed at all. Yet as a result of the cosmic expansion, temperatures began to drop rapidly. Radiation dominated the early Universe, while any stable large-scale matter did not yet exist. Eric Chaisson calls, therefore, this early phase of cosmic history the *Radiation Era*. Yet during this period, as the Universe expanded while the temperature and the pressure dropped steeply, all the elementary particles emerged out of radiation, first the heavier hadrons,

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[5] Tainter's book *The Collapse of Complex Societies* (1988) offers a remarkably prescient exception. In this book Tainter discusses the collapse of complex societies in terms of energy flows.

mostly protons and neutrons (within a fraction of the first second), followed by the lighter leptons, such as electrons and neutrinos. Their emergence took about 100 seconds. Yet according to the standard cosmological view, most of these subatomic and atomic particles that were originally formed soon annihilated one another and were reconverted into radiation. Only a tiny fraction of ordinary matter survived. This left-over stuff constituted the building blocks for all the known material complexity that followed.

This period was followed by the nucleosynthesis of some lighter elements, most notably helium and deuterium as well as a few heavier elements. Yet the expansion went so fast that most matter remained in the form of protons, which are the nuclei of hydrogen. This led to a primordial composition of the Universe of about 70 per cent hydrogen and 27 per cent helium, while the rest was made up by a few heavier chemical elements. This whole process took about fifteen minutes. Apparently, the expansion of the early Universe created Goldilocks circumstances for this sequence of events.

It is not completely clear whether radiation was completely uniformly distributed during this period. At that time, as Eric Chaisson emphasizes, entropy was at a maximum. Current measurements of the cosmic background radiation, which dates back to about 400,000 years after the Big Bang show minor fluctuations. I wonder whether this may also provide an indication of emerging complexity of the energy regime of the very early Universe.

The Matter Era

After about 50,000 years of cosmic expansion, the Radiation Era came to an end. By that time, the temperature of the early Universe radiation had dropped to around 16,000 Kelvin.

Since the Universe kept expanding, the temperature of the radiation kept dropping. As a result, the importance of radiation decreased. Cosmic expansion had, however, no similar effect on matter. Although, seen on the scale of the Universe, matter became more diluted, the particles themselves did not change in nature. As a consequence, relatively speaking, matter became increasingly important. According to Eric Chaisson, the *Matter Era* had begun. This transition marked the first formation of stable material complexity. During the early phase of the Matter Era only a few types of small building blocks of matter existed, mostly protons, neutrons and electrons. No heavy chemical elements were formed yet. The expansion would have gone so very quickly that the conditions of high temperatures and pressures needed to cook heavier elements did not prevail for long enough. As a result, the possibilities for greater complexity in the early Universe were limited.

Here we see a critical factor for the formation of complexity in operation, namely time. It takes time, often a great deal of time, for complexity to emerge. In certain situations the energy flows and levels may be right for the emergence of greater levels of complexity. Yet if such conditions prevail for only a short period of time, no substantial amounts of such complexity can form. The destruction of greater levels of complexity, by contrast, can take place very quickly indeed.

After about 400,000 years of expansion the Universe had cooled down to about 3000 Kelvin, while the pressures had been dropping also. These lower energy levels allowed negatively and positively charged particles to combine for the first time and form matter regimes of greater complexity, first atoms and later molecules. This process had a marked effect on radiation, since it is far less affected by neutral particles than by charged ones. Radiation could now suddenly travel throughout the Universe virtually unimpeded. As a result, the Universe became transparent. The cosmic background radiation of 2.73 K that can be observed today dates back to this monumental change.

This ‘neutralization’ of the Universe also marked an important transition for the factors which determine the levels of material complexity that can be attained. Before that time, only the energy levels limited the levels of material complexity. Yet after about 400,000 years of cosmic expansion, the formation of complexity would come as a result of the interplay between energy levels and energy flows. Since that time, all subatomic complexity has been determined by the nuclear force (in some conjunction with the ‘weak force’, now thought to be part of electromagnetism). The intermediate scales of complexity, from atoms and molecules up to stars and planets have come as a result of the electromagnetic force and of gravity, while all the large-scale complexity, ranging from our solar system to galaxy clusters, has been shaped by gravity.

According to Eric Chaisson, cosmic expansion has been vital for the formation of complexity (2001: 126). Because in the early Universe entropy was at a maximum, for complexity to form, some sort of entropy trash can was needed, since the formation of local or regional order requires the formation of more disorder somewhere else. The continuing expansion of the Universe provided increasing room for entropy, and thus functioned as a huge entropy trash can, which can take up low level energy, most notably heat. And as long as the Universe keeps expanding, the cosmic entropy trash can will get bigger. As a result, it can store increasing amounts of low level energy. This – and this alone – allows energy levels to keep flowing and greater complexity to exist.

While the cosmic trash can was getting bigger, another major trend started: energy differences began to level out. Both these processes have made possible the rise of complexity. Since the energy supplies of the Universe as a whole are not being replenished, and assuming that the Universe will keep expanding for the foreseeable future, the long-term effect of all these effects will be the overall increase of entropy everywhere. In other words, in the very long run the Universe will become a rather dull place.

Galaxy Formation

The unrelenting expansion of the Universe led to a further decrease of the temperature levels. As a result, gravity began to shape the ways in which matter clung together. Since that time gravitational energy has driven the formation of larger structures, ranging from asteroid-sized clumps of matter to clusters of galaxies. Only during the first two billion years or so were the conditions right for galaxy formation. Even while they were being formed, most galaxies began to fly away from one another. This defines, in fact, the expansion of the Universe. In a number of cases, however, gravity kept galaxies close together, while some galaxies actually merged with others. Yet with the passage of time, these occurrences diminished in importance.

It is now thought that the rather mysterious ‘dark matter’ may well have played a major role in the process of galaxy formation. The existence of dark matter is inferred by its gravitational effects on galaxies, which cannot be sufficiently explained with the aid of the established theory of gravity. Today, astronomers think that there is a great deal more dark matter in the Universe than ordinary matter. Yet other than through gravity, dark matter would not, or only very weakly, interact with the matter and radiation we are familiar with. According to this model, large amounts of dark matter would have begun to clump well before the neutralization of the Universe, thus forming ever larger gravitational structures, which subsequently attracted the baryonic matter we are familiar with, which coalesced into galaxies. This would have been the major mechanisms causing galaxy formation.

While the Universe kept expanding, the galaxies appear to have retained their original sizes more or less. As a result, the Universe became more differentiated. Over the course of time within galaxies greater levels of complexity would arise. The expanding intergalactic space, by contrast, was mostly empty and would therefore never become very complex. Yet intergalactic space did provide a cosmic trash can for low level energy produced in galaxies. This made possible the rise of greater complexity within galaxies.

The cores of newly forming stars within galaxies began to produce circumstances that were similar to the early stages of the Matter Era. Temperatures rose to 10^7 Kelvin and above, while pressures would go up to 10^{11} atmospheres and higher. The major difference with the early Matter Era was that stars last far longer than the period in which the first elements were cooked. This means that there was far more time available to produce heavier chemical elements. As a result, stars would become the major furnaces for producing greater levels of nuclear complexity.

The mechanism which drove this process was nuclear fusion. After enough hydrogen nuclei had gathered under the influence of gravity, temperatures and pressures would rise to the extent that nuclear chain reactions could ignite, forging one helium nucleus out of four hydrogen nuclei. During this process some matter was converted into energy, which was subsequently radiated out into the Universe. Over the course of time, this radiation would drive the formation of most biological and cultural complexity.

All stars came into being by gathering matter and energy from their surroundings through the action of gravity. Yet after their initial formation, harnessing external matter was no longer needed for their continued existence. In fact, stars shine thanks to the generation of energy within themselves (under the pressure of gravity) and not through a continuous extraction of matter from their environment. In contrast to living beings, which continuously have to extract both matter and energy from their surroundings in order to maintain their complexity, stars do not need any new matter in order to shine.

During the early period of galaxy formation many huge stars formed that burned very quickly and subsequently exploded. This released gigantic energy flows, which would have destroyed most, if not all, nearby levels of intermediate complexity that might have formed, such as planets or perhaps even life. In other words, a great deal of energy ultimately derived from the Big Bang was spent without creating any such complexity. Yet these explosions did create the right circumstances for heavier chemical elements to form.

Increasing Complexity of the Elementary Building Blocks

During the early phase of galaxy development, stars consisted of only very few elements, mostly hydrogen and helium. This severely limited the level of complexity the early Universe could attain. Over the course of time, however, an increasing variety of building blocks came into being. This was the result of nucleosynthesis, the forging of new elements within stars. Stellar nuclear fusion processes gradually but inevitably lead to the depletion of the main fuel supply, hydrogen. In larger stars under the continuing impact of gravity the core then heats up to temperatures higher than 10^8 Kelvin. New nuclear fusion processes begin, in which helium is converted into ever heavier chemical elements, up to iron. Also, this situation is a relatively stable steady state. In contrast to the circumstances prevailing right after the Big Bang, when expansion went so very quickly that the formation of heavier chemical elements was not possible, in stars approaching the end of their lives there is sufficient time for more complex atomic nuclei to form. As a result, these chemical elements are comparatively abundant.

After these processes are completed and no further nuclear fusion is possible within stellar cores, a star may first implode under the action of gravity and then explode as a result of sudden further nucleosynthesis. During these short-lived yet very violent circumstances even heavier chemical elements are formed, up to uranium. Since these circumstances last only a very short time, heavy chemical elements such as gold and uranium are rare. Over the course of time, these so-called nova and supernova events began seeding the surrounding space with these new forms of complexity. In other words, they enriched nature's construction kit with an increasingly large assortment of building blocks. As a result, more complex toys could be built. These chemical elements were sometimes dispersed to areas where the circumstances were favorable for the rise of further complexity. When close to the outer edges of galaxies new stars and planets formed from galactic dust clouds and assimilated these new chemical elements, new levels of complexity could emerge. On the surface of one such well-positioned planet, these chemical elements would become the essential building blocks for biological and, much later, for cultural complexity.

Stars and Planets

Most complexity within stars exists thanks to the fact that there is a continuous supply of energy released inside by fusing nuclei that are tightly packed under the action of gravity. This energy then flows down the energy gradient towards the surface. The complexity of stars is, therefore, the result of a balance between gravity and nuclear fusion. The situation for planets is more complicated. Their complexity is caused by gravity, by energy released inside – mostly through nuclear fission under the effect of gravity – as well as by external energy received in the form of radiation from their central stars. This radiation mostly influences the planetary surfaces. Like stars, planets do not need to continuously extract new matter from their environment in order to exhibit certain levels of complexity.

Because of this comparatively simple situation, most stellar and planetary complexity is rather basic. In the words of Philip and Phylis Morrison: ‘Astronomy is thus the regime of the sphere; no such thing as a teacup the diameter of Jupiter is possible in our world’ (Morrison and Eames 1994: 7). In other words, in the physical Universe, spheres, and clusters of spheres, rule. Since most matter in the Universe rotates, the resulting centrifugal force causes these spheres to flatten. This explains why the sky is dominated by more or less flattened spheres or by constellations of such spheres in various shapes. Only comparatively small objects such as asteroids can attain more complex forms. Teacups were, however, the invention of culturally endowed life forms.

Since stars and planets mostly rely on energy sources from within that ignite spontaneously and maintain themselves without any form of active control, the possibilities for complexity within such bodies are rather limited. Especially deep inside big spheres and at the centers of galaxies, the *power densities* may be small, but the temperatures and pressures are elevated. These circumstances do not allow for the rise of more complex matter regimes.

The Formation of Complexity at the Edges

Near the edges of galaxies, or on the surfaces of stars and planets, greater levels of complexity can emerge. This is because the energy differentials between the surfaces of stars and planets and the surrounding space are large, while the energy levels may be more moderate. On the surfaces of stars, of course, the energy levels are still way too high for any great molecular complexity to exist. On the surfaces of small planets, by contrast, the energy levels may be more moderate. As a result, mountains and oceans can form, while chemical evolution might take place. In addition, the comparatively mild energy flow from a central star may significantly contribute to the rise of planetary complexity. Below the surfaces of planets towards the center, however, the chances for greater complexity are dimmer. Very soon the energy levels become too high and the energy differentials too small. On planets, therefore, only the surfaces and atmospheres can exhibit significant complexity.

As a result, biological and cultural complexity are marginal phenomena. They can only exist on the outer edges of planets circling stars which, more likely than not, find themselves on the outer edges of galaxies. Only in such places are the conditions right. The energy flows and levels are neither too big, which would destroy the greater forms of complexity, nor too small, which would not allow their formation.

Why is the Earth Such a Good Place for Greater Complexity?

First of all, the Earth has more or less the right size. If the Earth were smaller, its weak gravity could not retain its atmosphere or liquid surface water; if the Earth were bigger, its resulting gravity would crush most living things, especially on land or in the air. Also, as a result of its size, the Earth's interior is still hot. This provides energy for the process of plate tectonics, which recycles most of the Earth's surface, including waste produced by life (Westbroek 1992).

In the second place, our home planet orbits the Sun at more or less the right distance. This means that solar radiation is neither too weak, in which case that it would not provide enough energy for life to flourish, nor too strong, in which case that it would destroy life. In the third place, the Earth is endowed with a large moon which stabilizes the rotation of the Earth's axis. Without this moon the obliquity of the Earth's axis would change erratically. This would have produced huge changes in solar radiation on the Earth's surface, which, in its turn, would have made it far more difficult, if not impossible, for complex life to develop (McSween 1997: 119). Also, the orbits and sizes of the other planets, most notably Jupiter, would have contributed to keeping the terrestrial conditions right for the emergence of ourselves and of other forms of complex life.

Today all terrestrial life flourishes within a rather small bandwidth of Goldilocks circumstances. Temperatures range between zero to ninety degrees Celsius, while pressures vary from 1070 atmospheres (Marianas Trench) to about 0.6 atmospheres in high mountains or in the air itself. To be sure, bacterial spores may be able to survive lower temperatures, yet they cannot multiply in such circumstances. From the terrestrial point of view, this may appear to be a rather wide bandwidth. Yet seen from the perspective of Big History, this is a rather special situation. Only on the surfaces of planets, or of moons circling large planets, we may find such conditions. On our home planet this delicate equilibrium of energy flows and levels consists of solar radiation falling onto the surface of our planet, heat released from the Earth's interior, and the loss of heat through infrared radiation back into the cosmic trash can. Thanks to this finely tuned balance of energy levels and flows, life could emerge.

Life and Energy

Although life is very small compared to planets, stars or galaxies, surprisingly, perhaps, it has succeeded in generating far greater *power densities* (Chaisson 2001: 139). The average Φm of our galaxy would be only 0.5×10^{-4} watt/kg, while our Sun's Φm amounts to about 2×10^{-4} watt/kg. The Earth's Φm is considerably greater, namely 7.5×10^{-3} watt/kg. Yet modern plants manage to handle about 9×10^{-2} watt/kg, while animals do even better (2 watt/kg). How is it possible that the huge amounts of energy released in stars lead to such low Φm values? There are two reasons for this: first, stars are very heavy, and, second, the energy flows are not that large. In absolute terms, the energy flows harvested by life are, of course, minute. But, because life is very small and the energy flows it harvests are large by comparison, its resulting *power densities* are far greater. The same is true for the entropy produced by life, especially the low level radiation, which can easily be discharged in the cosmic trash can.

The emergence of life implied the rise of a fundamentally new mechanism for achieving complexity. Unlike stars and galaxies, biological regimes do not thrive because they convert matter into energy within themselves from existing supplies. Life needs to continuously tap matter and energy flows from its surroundings in order to maintain itself and, if possible, reproduce (Lehninger 1975: 3–4). If living creatures were not to do so, they would very soon die and disintegrate. This is not a new insight. Already in 1895, the Austrian physicist Ludwig Boltzmann stated that all life is a struggle for free energy (quoted in White 1959: 34). Many academics have followed in Boltzmann's footsteps (for an overview, see White 1959: 34 ff.).

Unlike stars, living cells extract matter and energy from their environment and rework them at very moderate temperatures and pressures, while utilizing very complex molecular machinery. In addition, all the biochemical compounds produced by cells can be said to fulfil functions for either their own survival and/or for the survival of the entire organism. These are major differences between physical and biological complexity. All living organisms survive by using hereditary information, with the aid of which they program themselves. I therefore propose to define life as 'a regime that contains a hereditary program for defining and directing molecular mechanisms that actively extract matter and energy from the environment, which matter and energy is converted into building blocks for its own maintenance and, if possible, reproduction'.

The Emergence of Life

We do not know how and when life first formed. Claims for the earliest evidence for life dating back to about 3.8 billion years have recently been challenged. Firm evidence for terrestrial life is about 3 billion years old. Given the fact that the Earth was formed some 4.8 billion years ago, there may, or may not, have been a long period of physical and chemical evolution leading to the rise of early life. Neither do we know whether life actually formed spontaneously on the Earth, or whether it was transported to us from elsewhere by whatever celestial object happened to dive into our atmosphere. If life did originate elsewhere in the Universe, we do not know where, when and how this happened.

If life originated on our home planet, more likely than not it was preceded by a long process of increasing physical complexity on the Earth's surface. This process is usually called chemical evolution. Under the influence of energy flows such as sunlight, volcanic activity, lightning and perhaps radioactive decay, increasingly complex molecules would have formed. At a certain point in time, a spontaneous process of self-organization leading to life would have kicked in. Next, Darwin's mechanism of natural selection would have started acting as a filter, allowing fitter organisms to produce more, and/or more efficient, offspring than others. This produced a selection for organisms that became both increasingly better at tapping matter and energy flows from their environment and at preventing themselves from becoming sources of matter and energy for others.

Early life may well have fed on the products resulting from chemical evolution. For a while, this would have provided enough matter and energy to survive and, if possible, reproduce. Yet after a certain period of time, life would have consumed more chemical soup than was formed anew. In the long run, therefore, chemical evolution could not possibly have sustained life. The earliest living blobs may also have extracted matter and energy from underwater volcanoes, the so-called black smokers. Such situations can be found today and may well have existed throughout the history of life on the Earth. And, as long as black smokers kept smoking and as long as no major mishaps took place, the continuity of life in such locations was assured.

Ever since the origin of life, the presence of sufficient water has been an absolute requirement for its continued existence. Without it, the matter and energy flows needed for life's sustenance could not have existed. Up until today, the distribution of water on our planet has set the boundary conditions for the areas where life and culture can develop. This suggests that life originated in the oceans, especially since the overall salt concentration within cells is very similar to that of the modern oceans (and, more likely than not, that of the ancient oceans also). In those early circumstances, the salt concentration of the pioneer cells could not have been very different, for that would have generated elevated energy differentials which would have destroyed those early cells almost immediately. Over the course of time, especially after life moved out of the seas onto land, such energy differentials did develop. As a result, mechanisms had to be evolved to protect cells against this new and hostile environment.

Early life forms were comparatively simple and could, therefore, handle only comparatively gentle energy flows. Yet these organisms must also have been pretty robust, because they were able to live under conditions of far higher external energy levels and flows than the ones which prevail in most places where life thrives today. Temperatures were higher; radioactivity and volcanism were far more prevalent than nowadays. Moreover, the Earth was bombarded by meteorites of many different sizes. Clearly, early life must have been adapted to these circumstances from the very beginning.

Increasing Complexity

Living organisms are regimes which maintain a relatively stable steady state. This comparative stability over billions of years allowed sufficient time for many types of greater complexity to form both within and among cells. Not unlike the building blocks of most physical regimes, the basic construction kit of life consists mostly of spheres, the cells. This is not the result of gravity but of the fact that the molecules which make up the skins of cells attract one another and as a result cause surface tension. Since gravity does not play a major role in the formation and sustenance of cells, their interiors could become very complex.

At a certain point in evolution, some cells began to cooperate in harnessing matter and energy. Some of these cells may have adapted to others to the extent that they became mutually dependent yet remained biologically separate. This inter-species division of labour is perhaps the most common form. Other cells may have fused into larger complexes, which led to forms of intra-cellular division of labour. Such cells may have emerged about two billion years ago. Over the course of time, this led to the emergence of even more complex eukaryotic cells, which could handle far greater matter and energy flows than their more humble cousins, the prokaryotic organisms.

In eukaryotic cells, the nucleus serves as the hereditary storehouse. Organelles such as mitochondria specialize in energy metabolism, while chloroplasts devote themselves to capturing sunlight and converting it into energy. Because eukaryotic cells became more versatile as a result of this intra-cellular division of labour, they became the building blocks for all greater biological complexity. Yet many organisms remained small and comparatively simple. These are micro-organisms we know today. As a result, the tree of life differentiated into increasing numbers and shapes.

Another way of achieving greater complexity consisted in increasing the cooperation among cells with the same genetic make-up. At a certain point in time, such cells began to hang together. Both prokaryotic and eukaryotic cells were able to do this. But over the course of time, only eukaryotic cells learned how to cooperate and divide tasks. I call this latter process the inter-cellular division of labour. As a result of the inter-cellular division of labour, cells within one single organism began to differentiate. This allowed for greater levels of complexity. The selective force that drove such processes consisted of the new opportunities this division of labor offered to improve the extraction, and use, of matter and energy. As a consequence, ever more new life forms began to emerge with increasingly intricate shapes. Gravity, however, still sets the upper limits on the size and shape of life forms. It is no coincidence that the biggest living bodies developed in the oceans, where buoyancy and gravity balanced one another to a considerable extent.

Here we see a major difference between the differentiation of biological regimes and of physical regimes. All more complex life forms exhibit a clear differentiation of both forms and functions within their own regimes. Physical regimes, by contrast, do show a differentiation of forms but not of functions. Galaxies, for instance, consist of a great many different objects. But to say that all the stars and whatever objects galaxies consist of actively fulfil functions for one another in order for the galaxy to exist and thrive does not make any sense to me.

We do not know how stable micro-organisms are in an evolutionary sense. There are some hints of great stability. In the shallow waters off the Western Australian coast, for instance, the so-called stromatolites may have existed for about three billion years. Stromatolites are basically mounds of micro-organisms that cluster together. Single cells living in the oceans may well have been rather resistant to change also, because their environment would have not have altered a great deal during the past three billion years or so. In other words: comparatively stable matter and energy flows in the environment may well have caused comparatively little evolutionary change.

Yet evolution by chance, caused by random variations in the genetic program which proved to be advantageous in terms of survival – or at least not disadvantageous – has led to an ever-growing range of organisms, especially when the environment changed. In actual fact, the process of evolution itself has also changed the environment which, in its turn, would have stimulated the emergence of new species. This led to feedback loops that might well have speeded up evolution. As a rule, the more energy a species could extract from the environment, the more complex it became, and *vice versa*.

Tapping New Energy Flows

Over the course of time, life has succeeded in maintaining itself and spreading all over the world, including too many places that did not offer a free chemical lunch. This could happen because micro-organisms and later plants evolved that were able to exploit sunlight. This energy was used for combining the atoms of carbon dioxide and water into a great many organic substances, which became the building blocks of life. We do not know how life learned to exploit sunlight for its own purposes. But, surely, mastering this art laid the foundation for all further biological complexity.

In this process called photosynthesis, free oxygen is released. It may have taken two billion years, but eventually this led to an oxygen-rich atmosphere. Subsequently, through respiration the internal combustion of organic matter with the aid of atmospheric oxygen became the major energy source for animals. Over the course of time, photosynthesis would, therefore, provide most of the energy that drove biological evolution. The oxygen-rich atmosphere allowed for the formation of the stratospheric ozone layer, which started to protect life against ultraviolet radiation. Up until that time, the energy flow of sunlight had suppressed the rise of biological complexity on land. Now, for the first time, life could leave the cradle of its protective watery surroundings and begin to colonize the entire planet.

The rise of an oxygen-rich atmosphere created another new type of energy differential. First of all, it provided energy for organisms that did not participate in the process of photosynthesis, both in the water and on land. But, perhaps even more importantly, it made possible the emergence of ever larger and more complex multi-cellular complexes. This was the case because oxygen could be transported to cells that were not in direct contact with the outside world. They could thus share in the exploitation of energy differentials. All the organisms that could not cope with the rise of the oxygen-rich atmosphere and the associated rise of energy differentials had two options. The first one was to limit themselves to places where the oxygen concentration remained low enough to handle. The second option was to become extinct.

The general trend seems clear: the more intricate biological regimes became, the greater the matter and energy flows were that they could tap. Apparently, over the course of time, biological evolution has created structures so intricate that they can handle increasingly larger matter and energy flows, at least for a time, without being destroyed by them (Christian, pers. com., 2003). The price to be paid for greater complexity was a growing vulnerability when the conditions changed. The huge matter and energy flows caused by volcanic eruptions and the impacts of extraterrestrial objects especially could spell the end of more complex organisms. In such circumstances, their less complex fellows appear to have had better survival chances. As a consequence, the life span of the more complex species as a whole decreased. In other words, the more complex species became, the quicker they became extinct. The overall result was the emergence of growing numbers of short-lived species exhibiting ever greater levels of complexity.

The Cambrian Explosion of Life

About 540 million years ago, the above developments led to the so-called Cambrian explosion of complex life forms. A great variety of multi-cellular complexes suddenly emerged, endowed with an ever greater variety of organs, all of which began to fulfil functions for one another to make it easier for the whole to survive and thrive. This led to the types of complex living organisms we are familiar with today.

The Cambrian explosion of life may have been caused by sudden changes of energy flows and levels on the Earth's surface. It seems that right before the Cambrian era, the Earth's surface had frozen over almost completely. This would have severely restricted the room for terrestrial life and may have wiped out many individuals and perhaps entire species. When for reasons yet unknown the big thaw began, suddenly a huge new niche opened up for the lucky survivors and their offspring (Walker 2003).

During the Cambrian explosion of life, two general types of complex organisms came into being that have continued to exist up until today. On the one hand, there are the ancestors of modern plants. They extract their energy from sunlight and their chemical elements from soil or water. With some exceptions, such organisms do not eat other organisms. Since they do not need to move and catch prey, they lack brains. Some parts of plants are actively involved in extracting energy. They tend to position themselves in ways that are the most favorable for capturing the right amount of sunlight. For the same goal, their photosynthetic mechanisms as well as their production of pigments are continuously fine tuned. According to Eric Chaisson, modern plants handle *power densities* of about 0.09 watt/kg (2001: 139).

On the other hand, there are animals. These are basically species feeding on other organisms. For the lucky ones, this implies the appropriation for their own purposes of supplies of energy and matter gathered by other creatures. The eaters use this energy constructively for themselves. Yet they became increasingly destructive for the unlucky ones that were eaten. During the process of evolution, therefore, living species became both increasingly constructive and destructive.

Since animals need to eat plants and/or other animals, they developed ways of purposefully moving around, including brains. They needed weapons to defeat their prey and suitable digestive tracts in order to eat them. As part of this process, animals became better at extracting both matter and energy. This meant that their *power densities* should be much greater. And, sure enough, according to Eric Chaisson, the *power densities* of modern animals would be in the order of 2 watt/kg (2001: 139). As a result, animals also became greater potential sources of matter and energy for others. In order to survive, they needed to develop ever better ways of defending themselves. Plants also began to defend themselves against predators, for instance, by producing toxins. The overall result was an increasingly complex biological regime consisting of ever more and more different species. Within this constantly changing regime, an increasing variety of matter and energy flows was exploited. This constant search for sufficient matter and energy in order to survive and thrive has been the major factor that has driven biological evolution up until today.

The development of a biological waste disposal regime must have been an absolute precondition for the continued existence of life on this planet. Without it, life would have choked in its own dirt a long time ago. One may wonder whether the rise of a biological waste disposal regime was an almost inevitable component of the successful evolution of life on our planet. It is not inconceivable that elsewhere in the Universe, life got kick started only to find itself being drowned by its own waste. Here we see another great difference with physical regimes. Although the Universe as a whole does function as a huge entropy trash can, galaxies, stars or planets have never evolved such garbage solutions of their own.

Brainy Animals

It is no coincidence that animals which possessed the characteristics of both plant eaters and predators developed the biggest and most complex brains so far and came to dominate the world. For humans could exploit the matter and energy flows provided by both plants and animals. The secret of human success has been a brain that could facilitate communication, coordination and adaptation of their behaviour, including the use of tools, to an unprecedented extent. The specific development of the human brain may have been the result of many, perhaps unrelated, geological and biological changes, yet the evolutionary trend is clear – towards species with bigger and more complex brains which allowed them to better tap matter and energy flows.

In the animal kingdom, the human brain is the most complex of all, and it uses a great deal of energy. Magistretti *et al.* (2000) calculated that 'although the brain represents only 2 % of the body weight, it receives 15 % of the cardiac output, 20 % of total body oxygen consumption, and 25 % of total body glucose utilization'. According to Eric Chaisson (2001: 139), while the average *power density* of human bodies is about 2 watt/kg, the *power density* of the human brain amounts to a whopping 15 watt/kg. This rather prodigious consumption must have had an upside. Natural selection would only have allowed the human brain to develop if it had made it easier for our ancestors to extract sufficient matter and energy to survive and, if possible, reproduce. And multiply they did, notwithstanding the fact that humans did not possess any other major biological weapons such as horns, hooves or venom. So far, the energy harnessed by using bigger and more complex brains has clearly outweighed the greater consumption of energy needed to keep the brains going.

Brains run complex software that can, at least in principle, be adapted according to the circumstances. This makes brainy animals far more adaptable, and therefore more effective, than living species which are not so well endowed. In the social sciences, this software is called *culture*. By using their cultural software, enhanced by ever more intricate forms of communication, humans have increasingly both adapted themselves to their environment and the environment to themselves. The sociologist Norbert Elias (1978) and the world historian William H. McNeill (1991; 1992: VII–XIII), among others, have made this point. More recently, David Christian characterized this process with the term *collective learning*. In Christian's view, collective learning operates for humans in ways similar to how natural selection works for the rest of nature (2003, 2004).

Culture and Energy

According to the view pursued here, cultural regimes are collective responses to the problems that people face. Yet one may wonder whether there is a bottom line to this problem-solving. Based on Leslie White's approach to culture as a way of capturing more energy, the Canadian ecologist Vaclav Smil summarized culture as follows:

> From the perspective of natural science, both prehistoric human evolution and the course of history may be seen fundamentally as the quest for controlling greater energy stores and flows (Smil 1994: 1).

This approach may not be popular among social scientists. Surely, human behaviour is far more complex and varied than just harnessing energy. I would not deny that. But, following Leslie White, Marvin Harris, Jeremy Rifkin, Vaclav Smil and David Christian, among others, I argue that for most, if not all of human history, the quest for sufficient matter and energy to survive and, if possible, reproduce has been the overriding theme. And the reason that humans have been able to harness ever larger matter and energy flows is to be found in their culturally learned behaviour. The matter and energy flows that our species has sought to master had to be neither too large, because humans would have succumbed to their effects, nor too small, because they would not have supported human life sufficiently. As I have argued, this is not only true for human history but also for Big History as a whole.

All human efforts to capture matter and energy flows have inevitably generated entropy. While the low level radiation produced by human activities could comparatively easily be radiated out into the cosmic trash can, for matter flows this was not the case. As a result of the ongoing human activities, therefore, material entropy on the surface of the Earth has relentlessly increased.

The Emergence of Early Humans

Around three to four million years ago, the first early humans emerged in a landscape in which the energy levels were characterized by a rather narrow bandwidth. The East African savannas have a rather mild climate. All year round temperatures would have ranged between twenty and thirty degrees Celsius. This does not differ a great deal from the average human body temperature. As a result, the early humans did not need extensive protection against high or low temperatures. Also, the air pressure on the East African savannas is rather mild, on average about 0.9 atmospheres. In this situation, the early humans would have been able to keep a *power density* of about 2 watt/kg going (Cook 1971: 136).[6]

The oldest utensils made by human hands that can be clearly recognized as such date back to around 2.5 million years ago. Apparently, by that time early humans had found ways to increase their matter and energy flows with the possibilities their hands offered, including the development of an opposable thumb, which allowed far greater dexterity than before. Subsequently, natural selection for traits stepping up the harvesting of matter and energy (including defence and offence) may have led to the emergence of all-round hands suited for performing a great many different tasks, including the making and use of tools.

According to the late Dutch astronomer Anton Pannekoek (1953), tool-making and tool-use may well have led to the simultaneous development of language and thought. This would have favoured selection for bigger and more complex brains, which, in their turn, would have facilitated better tool-making and tool-use. Over the course of time, this feedback process would have allowed the early humans to harness increasing amounts of matter and energy. It may, therefore, not be coincidental that about only 500,000 years after the earliest known tools were made, two new human species with far bigger, and presumably also more complex, brains emerged in Africa, first *Homo habilis* (handy man), and a little later also *Homo erectus* (upright man).

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[6] Cook provided his data in kcal/day/capita. In order to compare them with the data provided by Eric Chaisson in 10^{-4} watt/kg, a conversion factor was needed. Assuming for the sake of simplicity that average body weight throughout human history has been about 40 kilograms (adults and children combined), I calculated that Cook's data needed to be multiplied by a factor of approximately 10^4 in order to convert them to 10^{-4} watt/kg. This leads to the number of 2 watt/kg for early humans, which corresponds surprisingly well to Eric Chaisson's (average) *power density* for animals (2 watt/kg).

Fire Control

While both these new human species used tools, *Homo erectus* also began to use fire. *Homo erectus* was also the first human species to leave Africa and spread to many places on the Eurasian continent. They learned to adapt to many different climatic zones, with temperatures ranging from minus 20 degrees Celsius to plus 50 degrees Celsius. In all these circumstances they managed to extract sufficient matter and energy flows to survive and reproduce for at least 1.5 million years. Early fire control allowed humans to intentionally burn the landscape in order to favour certain plant species and diminish the survival chances of others. Predators could be kept at greater distances. Fire control also facilitated big game hunting and the clearing of woods in order to provide pasture for game animals. Thus, through fire control humans may have changed the face of the Earth for a long time. In doing so, they may have influenced the biological and inanimate planetary regimes for an unknown period and to an unfathomable extent. Slowly but surely, as the hunted became hunters, a growing power difference between the early humans and other higher animals developed to the advantage of the ancient folk (Gamble 1995: 66–70; Goudsblom 1992; Pyne 2001). Instead of being mostly scavengers, humans became hunters. Through cooking, roasting and other comparable types of food preparation, humans gained access to a greater range of foodstuffs, and thus to new sources of matter and energy.

Just as life forms and Gaia had done before, the early humans began to create their own micro-climates that were favourable to the protection of their own complexity (and, unintentionally, also the complexity of some unwanted other species) more so than any other species before. All this signalled the beginning of a long process in which humans began to adapt the planetary environment according to their own desires and designs. In particular, modern humans, *Homo sapiens*, who may have emerged around 200,000 years ago, began to migrate to virtually all parts of the globe (the poles excepted). This was an unprecedented achievement, if one thinks of humans as animals, partly because of the range of environments in which humans learned to live, and partly in terms of the speed of the process. It meant that humans began to harness matter and energy in almost the entire inhabitable world, including the high mountains, where the air pressure was no greater than only 0.6 atmospheres. According to recalculated data from Cook (1971: 136), more recent gatherer-hunters would have handled *power densities* of about 5 watt/kg. This would have been mainly due to fire control. And as a result of human population growth, the total human use of matter and energy flows went up accordingly.

It is not clear to what extent this increase in *power density* would have led to any more food intake. It may well be that most of it was used for creating, or destroying, complexity beyond the human body. This was the beginning of a new trend, namely humans using ever larger energy flows to create or destroy external complexity. Ever since that time, this trend has continued to exist. This makes the use of *power densities* for human history more problematic, since Φm only refers to human bodily weight and not to the external mass that underwent the energy flows handled by humans. Obviously, humans have never managed to live for a long time with daily energy intakes greater than 4000 to 5000 kcal, which corresponds to about 4 to 5 watt/kg. Any substantially greater levels of energy consumed by humans could not possibly have flown through their bodies without destroying them. As a result, all the further increases in energy flows handled by humans must have flowed through external matter. Since I do not have estimates at my disposal of how large such external masses would have been, reliable corrections are not yet feasible. All the *power densities* for human history presented below must, therefore, be viewed with due caution. I view them first of all as indicating major trends and not as the last word on energy flows.

It is not very clear to what extent the matter and energy flows harnessed by early humans were sometimes too big or too small. It may well have happened that early humans occasionally started fires that went out of control and killed them. They may also have settled in places where, as a result of human exploitation or because of climate change or natural disasters, the extractable resources became too scarce for the early folk to survive. This may be very hard, if not impossible, to glean from the fossil record, which is very limited anyway.

The rise of modern humans may have led to the decrease in ecological complexity. First of all, the sustained burning of savannas and forests must have changed their biological composition. As a result, some species may have become extinct, while other species profited. It is unknown to me whether human fire control led to the emergence of any new species. Modern humans may well have exterminated a number of large animals, especially in those areas that had never been visited before, such as Australia and the Americas. Right now, it is not very clear whether climate change and/or diseases were also among the root causes of such extinctions. Yet it remains striking that only a few thousand years after humans moved into such new territories, most of these big beasts disappeared from the surface of the Earth. If true, this would represent an example of the decline of ecological complexity as a result of human action.

Up until 10,000 years ago, it does not seem as if humans brought about any great increase of material entropy. They were operating within the ecological web of the biosphere, and they did not accumulate any significant long-lasting material culture nor produce a great deal of long-lasting waste.

The Domestication of Plants and Animals

Curiously, the growing dexterity of human, as well as their capacity for communication, learning and remembering things, did not immediately produce any major changes in the ways *Homo sapiens* harvested its matter and energy flows. To be sure, between 200,000 BP and 10,000 BP, modern humans intensified production, yet they did not revolutionize it. Apparently, the capacity for culture, or collective learning, was a most important precondition for the domestication of plants and animals, but it was not its direct root cause. Around 10,000 years ago, however, our ancestors discovered new ways of extracting matter and energy from the environment. Slowly but surely, they began to gain control over the reproduction of plants and animals considered useful. As a result, humans could increasingly harness and manipulate the energy and matter flowing through the biological food chains. This signalled the beginning of the second great ecological regime transformation: agrarianization.

As we saw earlier, according to recalculated data from Cook (1971: 136) gatherer-hunters mobilized *power densities* of around 5 watt/kg. Early agriculturists, by contrast, would handle around 16 watt/kg. More advanced farmers and herders would do even better. They employed more than 26 watt/kg. This was a fivefold increase. This does not mean that agriculturists ate more, or better, than gatherers and hunters. Over the course of time, quite often the opposite appears to have happened. The increasing *power densities* of agriculturists point to the fact that these people handled larger energy flows in order to produce sufficient food and other material means they needed.

The circumstances in which agriculture could thrive were more circumscribed than those in which gatherers and hunters operated. Although the pressure and temperature ranges were probably rather similar, a sufficient water supply was far more critical. As a result, even today agriculture has not spread across the globe's landmass as far and wide as gathering and hunting had done before. Also, the cultivation of fish in the seas and oceans has been taking off only very recently. This is mostly due to the problem of how to control fish stocks, while, until recently, catches were often bountiful.

There has been an extensive academic discussion over where and how the agrarian revolution took place.[7] Yet even today, the causes behind this great transition are not well understood. Both climate change – the end of the last ice age – and growing population pressure appear to have contributed to the emergence of the agrarian way of life. But, whatever the precise causes may have been, the effects are clear. The more efficient food production allowed increasing numbers of people to survive and, if possible, reproduce. And so they did, in all places where the agrarian regime took root. In other words, most new matter and energy were converted into growing numbers of people. As a result, a self-generated dynamics evolved, which led to a steady expansion of the agrarian regime to all suitable places (White 1959: 45–57).

Over the course of time, this led to a decrease in the matter and energy the remaining wild plants and animals could harness. They were increasingly marginalized or even became extinct. And since agrarian societies harnessed

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[7] For recent overviews, see Mears 2001, Christian 2004.

more intensive matter and energy flows, they proved dominant over the ancient gatherer-hunter regime. Just like the undomesticated plants and animals, this earlier human regime was also pushed back to places where farmers and herders could not, or would not, go. Today, all true gatherer-hunter regimes have completely disappeared.

Although agrarian societies became far more efficient in harvesting matter and energy flows than gatherers and hunters, this did not necessarily mean that all members of the band were better off. As a result, it may well be that, over the course of time, the average peasant had access to fewer calories than his ancestors during the age of gathering and hunting. As part of agrarian regime, people began to make an increasing variety of things, including better houses, storage areas, ceramics, forms of art, and monumental graves, with shapes that had not existed before during the known history of the Universe. In other words, the age of the teacup had begun. Many, if not all of these new shapes had the same general aim: the preservation of forms of complexity humans deemed desirable. As a result, the early folk began to produce more entropy also.

There are some striking parallels between the rise of complex animals in biological evolution and this phase of human history. The increasing interdependence of the cells of which multi-cellular organisms are constructed, as well as their inter-cellular division of labour, was parallelled by the growing human interdependencies and human social division of labour. In both cases, the resulting increased harnessing of matter and energy flows made those involved both more constructive and more destructive. The other parallel is that, while the speed of both biological and human innovations increased, the life spans of both the living species and the human cultural regimes involved decreased.

Early State Formation

The transformation into an agrarian regime led to social change. Because people became more tied to the land they worked, they began to live closer together and in greater numbers than ever before. This led to an increasing social division of labour. Yet these societies, which were largely based on kinship, remained comparatively egalitarian. To be sure, over the course of time agrarian societies became more hierarchical. Yet as long as there was enough room to move, no powerful group could impose itself upon others for long.

After about five thousand years, however, the agrarian revolution led to a most important social regime transformation: the emergence of states. In its barest essence, states are social regimes the elite of which has succeeded in monopolizing the important means of violence, at least to the extent that they are able to dominate the state. In the final analysis, this meant harnessing important matter and energy flows and denying them to others. This inevitably involved taxation: the channelling of matter and energy flows produced by others. Early state formation meant that for the first time in history, humans began to systematically exploit other humans as matter and energy sources.

In the centers of early states this led to increasing cultural complexity, while independent local forms of complexity declined.

Robert Carneiro (1970) pointed out that all early states emerged in ecologically circumscribed geographic situations: usually fertile river valleys surrounded by dry areas, mostly deserts. In other words, these were regions where the harvesting of matter and energy flows was comparatively easy, while they were flanked by areas with only very limited opportunities for doing so. This situation allowed the people who succeeded in manipulating larger matter and energy flows to dominate their weaker fellows. As a result of the growing inequality and the concomitant social division of labour, the matter and energy flows within and among societies became increasingly complex. This is not the place to go into any detail, but, in general terms, it seems clear that the new social regimes were first and foremost dealing with the questions of who would perform the tasks of matter and energy extraction; its elaboration and preservation; and, last but not least, who would have access to the results of all this labour. As was the case with biological evolution, there were a few basic strategies for doing this: using disinformation, stealing, and using force. In all likelihood, all these things would have happened during all stages of human history. Yet during the period of state formation this became more apparent and organized. Since that time, humanity has expended a great deal of energy on pursuing these strategies and on countering them.

All this required new ways of safeguarding information. Up until that time, most cultural information had been stored in individual brains. With the rise of the early states, however, humans invented systematic regimes for recording information by material means, ranging from clay tablets to woollen cords. This allowed them to increasingly harness matter and energy flows. The art of writing allowed, in fact, a more efficient use of both information and disinformation. Since, for the powerful strata, control over the information flows became increasingly important, huge efforts were expended to make sure that they were used in their own interests, while access was denied to others. This included limiting such information flows to privileged and often tightly controlled professional groups, the use of secret codes, and public displays of propaganda. Although it took a long time, the dissemination of the art of writing worldwide was inevitable. In our time, mostly as a result of the rise of worldwide electronic communication, we have witnessed a new explosion in the importance of externalized information and its associated uses for both information and disinformation.

Since states were getting bigger and more complex, their inhabitants did not know all the others face to face any longer. In order to keep the state together, the rulers had to expend a great deal of energy on forging overarching identities, first with the aid of the emerging state religions, and later by using state bureaucracies including schools. Benedict Anderson calls the results of such efforts ‘imagined communities’ (1991). In most early states, such overarching identities were usually expressed in terms of symbolic kinship, with gods, kings and queens often portrayed as the ‘fathers and mothers’ of their people.

Some new matter and energy flows were used for constructing the first large buildings, essentially huge artificial hills, most notably pyramids. In order to build them, human and perhaps animal muscle power was used to defy gravity and produce the first architecture of power. Since that time, humans have continued to make such things. While the more recent constructions have perhaps become more intricate, for a long time they did not become much taller. Only during the industrial period did it become possible to construct buildings that grew in height once again. Yet the biggest gains were made during early state formation and not in recent times. This was the result of the limits gravity poses for such human endeavours. The shapes of smaller artificial objects (such as teacups) were, of course, less constrained by gravity. As a result, they could exhibit a far greater variation.

State formation was not an ecological regime transformation. No new techniques were pioneered that would revolutionize the extraction of matter and energy from the surrounding environment. Certainly, inventions were made, some more important than others, most notably the increasing exploitation of energy flows from wind and water – both derived from solar energy. In some areas, people began mining coal and other combustible substances. Yet up until the Industrial Revolution, the ways in which people extracted matter and energy from the environment and used it for productive purposes in fact changed little.

The techniques that facilitated the extraction of matter and energy from other people, by contrast, most notably arms and armies, underwent revolutionary change. A new dynamics of growing social competition had begun, which led to the growth and expansion of states at the expense of independent farmers, herders and gatherer-hunters. It took about five thousand years before the process would be (almost) completed, yet this was the way states began to spread all across the world. To be sure, for a long time, tribal societies with sufficient destructive power – the Mongols offer probably the clearest example – could still overpower some states. But, in order to stay in power, the invaders could not maintain both their tribal status and their dominance over state societies for long. If the conquerors wished to consolidate their power, they had to adopt the lifestyles of the complex societies they had conquered.

Globalization

In my view, globalization is the emergence of a worldwide division of labour. Globalization is therefore a social regime transformation. This global division of labour was created by people who could be described as belonging to the middle classes. In contrast to traditional elites and peasants, these emerging middle classes were not tied to the land. As a result, they could only increase their matter and energy flows through trade, production and conquest. About five hundred years ago, some emerging middle classes succeeded in escaping from the control of their traditional rulers. Over the course of time, they were able to take over state control, first in the Seven United Provinces, next in parts of the British North American colonies, and subsequently elsewhere in the Americas and Europe. Especially since the beginning of the nineteenth century, because of the Industrial Revolution and the resulting emergence of middle classes worldwide, this process has gained momentum all around the globe.

The first wave of globalization began after Europeans had learned to exploit the energy stored in winds and ocean currents to transport themselves and their cargo all around the world. For the first time in human history, people began circling the globe within their own lifetime. Europeans began to sail the Seven Seas on ships armed with heavy guns looking for profit wherever it could be found. Soon, this led to a struggle for dominance between Spain, Portugal, Great Britain and the Seven United Provinces in the Americas, Asia and the Pacific area. As a consequence, these three great world zones merged into one single global entity increasingly dominated by Western Europe.

Especially after large portions of the Americas had been forcibly integrated into the growing world economy and direct trade links all over the world had been established by both peaceful and military means, a global social division of labour began to take shape. This led to a further intensification of the matter and energy flows. As a result, global cultural complexity began to rise. Local forms of complexity, by contrast, were often overwhelmed by these new matter and energy flows and succumbed or became marginalized.

After Europeans had become firmly established along the Atlantic seaboard of North America and were no longer dependent on matter or energy flows from Europe, a considerable number of them succeeded in getting rid of their colonial masters. They declared themselves independent from Britain and formed the United States of America. This new state was controlled by the wealthier members of society, both landlords and people belonging to the middle classes. The French revolution, in its turn, found great inspiration in this liberation movement on the other side of the Atlantic Ocean. This set the tone for societal shifts all over Europe. Yet arguably, the greatest shift took place in the Spanish and Portuguese Americas. The French occupation of the Iberian Peninsula had weakened Spanish and Portuguese control to such an extent that the emerging Central and South American middle classes could get rid of their colonial masters. Unfortunately for them, however, they soon found themselves in the grip of the local landholding elites. As a result, even today the Latin American middle classes are still struggling to get free from that grip.

Industrialization

The third great ecological transformation, industrialization, greatly reinforced these trends, owing to the fact that it was based on fundamentally new ways of tapping energy sources for productive uses. Until that time, all machines had been driven either by human and animal muscle power or by wind and water energy. These were all renewable energy sources. The harnessing of fossil fuels for productive purposes, however, first coal and later oil and gas, implied fundamentally new ways of handling matter and energy flows. Industrialization was, therefore, a major ecological regime transformation. As a result, huge power differences within and among societies developed. In industrializing societies, nationwide cultural complexity rose once again, while many forms of local complexity declined. In the rest of the world, cultural change as a result of industrialization proved inevitable also.

According to recalculated data from Cook (1971: 136), the early industrial societies would have handled on average *a power density* of about 77 watt/kg. Today, by contrast, more advanced technological societies may command about 200 watt/kg or more. Again, this means that, although such people may eat more than ever before, most of the increase is due to external energy flows. Industrial societies emerged in temperate zones with temperatures ranging between minus 20 to plus 30 degrees Celsius. The air pressure was close to one atmosphere, while there were always abundant water supplies. Although since that time many industrial production processes have moved to places where temperatures can be higher, interestingly the other conditions have not changed a great deal yet. Today, there are very few industries in high mountainous areas or in regions lacking sufficient water. In other words, the spread of industrial life across the globe has been even more limited than the spread of agriculture (which, in its turn, had been more limited than gathering and hunting). And, while risking to state the obvious, in contrast to gathering-hunting and domestication of plants and animals, industry has not yet taken off in seas or oceans.

Let us return to the early rise of industrialization. Control over the new production processes allowed the middle classes to become the most wealthy and powerful stratum of society. This was, in fact, Marx's observation of the bourgeoisie taking over the state. In order to gain state control, the middle classes began to campaign for voting rights for the wealthier portion of society. Later, the emerging working classes succeeded in organizing themselves to the extent that they could also gain access to democracy. These societal shifts led to the emergence of democracies we are now familiar with. This process is now spreading around the world for exactly the same reason, the rise of middle classes worldwide.

Since access to the new matter and energy flows was initially very unequally divided, huge worldwide power differences evolved. As part of this process, the industrializing nations began colonizing large parts of the world. After almost all the conquerable world had been subjugated, the newly industrialized nations battled it out among themselves. This led to two world wars. Yet over the course of time, all the areas which successfully industrialized became wealthy to an extent unparalleled in human history, first the elites and later also sizable portions of the general populace. Apparently, the elites found it impossible to keep the new matter and energy flows to themselves. This was partially the result of the fact that more and more people began to live in cities, where they could pose a direct threat to the elites. And after the industrialization of agriculture and of transport had made sure that urban populations could be fed, increasing numbers of people could move to the cities. As a result, the first huge (and rather complex) metropolitan areas emerged, housing many millions of people.

The spread of industry based on fossil fuels all around the world has led to unprecedented levels of the global social division of labour, and thus to a growing global complexity at the expense of local and regional forms of complexity. While the first industrialized nations have succeeded in remaining rather powerful, newcomers are increasingly challenging their positions. Especially since the 1960s, many energy- and labour-intensive industries have moved to areas where the production costs are lower.

Most notably during the twentieth century, people began to create an ever expanding set of microclimates. Not only houses for people were heated during the cold seasons, but also houses for cultivating plants (greenhouses). The next step was to create cold microclimates during the hot seasons. This included refrigerators, specialized railroad cars, freight trucks and ships, which made possible the production and transportation of meat and other perishable foodstuffs on a large scale. Cooled or heated microclimates for comfort and pleasure were the next step. They include climate controlled houses and cars; artificial ice skating rinks and skiing slopes; tropical swimming pools (not very surprising, since we are still a tropical animal). The exploration of space and of the deep seas led to the development of microclimates in the form of space ships and suits, submarines and diving suits. Never before during the history of the Earth has a species created such a diversity of artificial microclimates.

Industrialization has made possible to feed entire populations with unprecedented amounts and varieties of foodstuffs. Especially in societies where the service sector has become dominant, most people perform less manual labour than ever before. As a result, on average they are becoming heavier than ever before in human history. It is not yet clear what the upper limits of the digestible matter and energy flows are, but in affluent societies at least some people appear to be making determined attempts to reach them. In other places, by contrast, great numbers of people still struggle with the opposite problem.

Industrialized societies have become more powerful yet also more vulnerable. Right now, all industrial societies are very dependent on the dwindling stocks of fossil energy. Seen from a long-term perspective, the exploitation of the limited supply of fossil fuels can only be temporary. But, whatever the future may bring, up until today the large scale use of fossil fuels has made possible levels of global cultural complexity that were hitherto unimaginable, although at the cost of the decline of older forms of local and regional complexity. Today, people, matter, energy and information circle the globe in way unprecedented during any period of the Earth's history.

All the matter and energy flows harnessed by humans have resulted in increasing material entropy on the surface of the Earth in the forms of waste products. Even allowing for a possible enhanced greenhouse effect, the generated heat can still be comparatively easily radiated out into the cosmic entropy trash can. But virtually all the material results of human action will remain on this planet. For most of its history, humans have relied on the existing biological waste disposal regime in order to get rid of their trash. Especially since the Industrial Revolution, however, more and more materials have been made that cannot not be easily recycled by terrestrial biology. In addition, more matter has been dispersed across the face of the Earth than ever before. One may wonder whether humans will be able to invent an efficient trash recycling regime and, if not, what the consequences will be.

In the 1940s, scientists in different parts of the world began to explore possible new forms of energy, because they suspected that new and hitherto unimaginably large energy flows could be tapped. The use of nuclear bombs and later the more peaceful uses of nuclear energy demonstrated that they were right. In terms of energy flows, the energy liberated by nuclear fission is part of a rather limited piggy bank of energy on the Earth which originated from supernova events. The energy from hydrogen fusion, by contrast, is stored in a similar piggy bank, but this time originating from the Big Bang. If people find ways of harnessing the energy flows resulting from nuclear fusion in constructive ways, there may be a great deal of energy available in the future. For the time being, however, most of the energy liberated by both nuclear fission and fusion has been used destructively.

The Increase in Energy Used by Humans

If the numbers presented earlier are correct, there has been a rise in *power density* from the 2 watt/kg handled by early humans to about 50 watt/kg for contemporary human society as a whole (Chaisson 2001: 139). If true, the *power densities* during human history would have multiplied by about sixty times. Yet the total energy flow handled by humans has risen considerably more, since the human population as a whole has risen from a few thousands to over six billion today. This represents an increase by a factor of one million. All the energy flows harvested by humans during their history combined must, therefore, have increased by a factor of about sixty million.

Although a reliable breakdown of these energy flows is difficult to achieve right now, a good portion of it is the result of the harvesting of domesticated plants and animals, while most of the rest can be attributed to the exploitation of fossil fuels and nuclear energy. In both cases, we may be reaching the upper limits of the available energy flows that can profitably be exploited. Moreover, it is not clear whether these limits will be sustainable in the long run.

Conclusions

To sum up, the history of complexity in the Universe consists of a rather boring beginning, followed by a more exciting period of increasing local and regional complexity, which will subsequently peter out into total boredom. This is directly linked to the fact that, from the very beginning, Big History has exhibited a trend towards lower energy levels as well as towards energy flows which first increased and then mostly began to decrease. As a result, in most places the level of complexity has remained rather low. This is first of all due to the fact that most of the Universe is virtually empty. Wherever there was sufficient matter, complexity rose in the form of galaxies, which are made up of stars, planets, and clouds of gas and dust, possibly with black holes in their centers. The formation of a growing range of chemical elements needed for life was cooked by exploding stars. This signalled another rise in complexity.

In the beginning, the energy levels determined the level of complexity the Universe could attain. After about 400,000 years of expansion, the rise of complexity has come as a result of the interplay between energy levels and energy flows. The first level of material complexity would be reached as a result of the nuclear force. This complexity consisted of the smallest, subatomic and atomic particles. Electromagnetism would take care of the second, intermediate, stage, in which atoms, molecules and complexes of molecules would be formed. The effects of gravity would inaugurate the last stage and would bring about all the larger structures we know in the observable Universe.

Greater forms of biological and cultural complexity are probably exceedingly rare in the Universe. During the past four billion years or so, the energy flows and levels on the surface of our home planet have been suitable for the emergence of this type of complexity. The intricate energy flows on the Earth's surface first made possible forms of biological complexity. Life began to actively harness more and increasingly varied sources of matter and energy. A very similar process took place during the cultural evolution of humankind. This has led to the greatest levels of complexity known today.

There have been specific Goldilocks boundaries which have conditioned the rise and demise of specific types of complexity. The formation of chemical elements, for instance, requires rather high temperatures and pressures, but perhaps not very elevated energy flows. Life, by contrast, requires rather moderate energy levels but rather large energy flows.

Table 1: Energy levels and flows[8]

	Energy levels (temperature, in: K or C)	**Energy levels (pressure, in: Atmosphere)**	**Power Density Φm in: watt/kg**
Our Galaxy	Almost 0 K (interstellar space) up to 3×10^9 K (supernovae)	Almost 0 atm. (interstellar space) up to ?? (supernovae)	.00005*
Sun	15×10^6 K (core) up to 6000 K (surface)	340×10^9 atm. (core) to almost 0 atm. (edge of outer space)	.0002*
Earth	150 K (upper atmosphere) up to 7000 K (core)	Almost 0 atm. (upper atmosphere) up to 5×10^6 atm. (core)	.0075*
Life	0 C up to 90 C	1070 atm (Marianas trench) up to 0.6 atm. (high mountains – air)	.05 (plants)*
			2 (animals)*
			15 (human brains)*
Humanity	20 C up to 30 C (African savanna)	0.9 atm (African savanna)	2 (proto-humans)*
	–20 C up to +50 C	1 atm. down to 0.6 atm. (high mountains)	5 (advanced gatherer-hunters)**
			16 (early agriculturists)**
			26 (advanced agriculturists)**
		1 atm. down to 0.8 atm. (mountains)	77 (industrial society)
			230 (technological society c.1970)**
		1 atm. down to 0.6 atm. (high mountains)	50 (all humankind on average)*

This table summarizes the data mentioned before. Please note that sweet water resources, although extremely important for human survival, are not mentioned here.

In order to achieve a more precise picture of the matter and energy flows as well as the energy levels during Big History, it will be essential to further quan-

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[8] This table was constructed by combining data marked * from Eric Chaisson's Table 2: *Some Estimated Free Energy Rate Densities* from his book *Cosmic Evolution* (2001: 139) and data marked ** from Earl Cook's table *Daily Per Capita Consumption* in his article 'The Flow of Energy in an Industrial Society' (*Scientific American*, September 1971, Vol. 224, p. 136). For the sake of simplicity I assumed an average body weight of 40 kg for humans through human history (average of adults and children).

tify them. I am planning to do this in the form of a research program. I therefore invite all interested readers to participate in this exciting adventure.

The growing complexity of living species has exacted a price in the form of shorter life spans. This raises the question of whether we ourselves will become so complex as to drive ourselves to extinction. But whether we will survive or not, today, under pressure from the increasing energy flows tapped by humans, many other living organisms find it increasingly harder to harness sufficient energy in order to survive and, if possible, reproduce. For how long the current processes will last, we do not know. It will depend directly on the ways humans will handle the available matter and energy flows, both in a biological and cultural sense, while preserving complexity on the Earth to the extent that it will provide sufficient room for us to survive and, if possible, reproduce.

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Abstract

In this article, I advance an explanatory scheme for all of history from the beginning of the Universe until life on Earth today (Big History). My scheme is based on the ways in which energy levels as well as matter and energy flows have made possible both the rise and demise of complexity in all its forms.

2

Stellar Evolution and Social Evolution: A Study in Parallel Processes[*]

Robert L. Carneiro

The Comparative Method in Astronomy

To begin with, the parallels between stellar and social evolution are not be found simply in the *outcome* of the two processes. They also exist in the *methods* used by both astronomy and anthropology in arriving at them. Indeed, the principal tool used by astronomers in studying stellar evolution is the very one first employed by nineteenth-century anthropologists in studying the development of societies, namely, the *comparative method*. While astronomers never seem to call it by this term, that is precisely what it is.

Consider the problem astronomers face in trying to understand how the stars have evolved. The period of observation of any astronomer – or even all of them put together – is so infinitesimally small compared to the life history of a star that, except for a few dramatic events like a supernova, during an astronomer's lifetime no appreciable change can be detected in the vast majority of the stars he studies. How, then, is he to proceed in ascertaining just how stars have evolved?

As early as the eighteenth century, the distinguished astronomer Sir John Herschel, whose study of the heavens suggested to him that stars might be born out of the condensation of gaseous matter, argued for the utility of comparing many different stars when no single one could be observed for very long:

> ...to continue the simile I have borrowed from the vegetable kingdom, is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view? (quoted in Pagels 1985: 7)

Herschel could hardly have put the matter more precisely: where a process cannot be observed over its entire course in any one individual, it is equivalent to

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I would like to thank Neil de Grasse Tyson and Michael Shara, astrophysicists and colleagues at the American Museum of Natural History, for reading an earlier version of this paper and offering their incisive and informed comments. However, for any errors that may remain in the paper, the author is alone responsible.

observe it as manifested by a number of individuals, each representing a different stage of that process. In effect, then, what Herschel was saying was that from the comparison of *synchronic* data one could draw *diachronic* conclusions. This is the very heart of the comparative method, in astronomy or ethnology.

The Comparative Method in Anthropology

As we shall soon see, the type of comparison advocated by Herschel has borne rich fruit in astronomy. In ethnology, the method was widely used in the nineteenth century and yielded substantial and illuminating results. Today, however, the comparative method in ethnology is often decried or ignored, especially when it is used as an adjunct to the study of cultural evolution. For example, George P. Murdock (1966: 97), one of the few ethnologists who ever cited astronomy as a science which made extensive use of comparison, nevertheless failed to recognize the fact that the main reason astronomers compared individual stars was to draw inferences about their evolution.

Although writing thirty years before Murdock, the British anthropologist A. M. Hocart provided what stands as an answer to those who, like Murdock, are fearful of using ethnological comparisons to deduce the course of social evolution:

> Astronomy is universally acknowledged to be one of the most exact of sciences; yet it is not afraid to venture into those remote ages for which we cannot hope ever to find direct evidence. Whereas the historian is afraid to discuss the growth of society through a paltry ten thousand years except he has documents for each step, the astronomer coolly reconstructs the history of the solar system for millions of years from observation of the present only. He sees nebulae, suns, dead stars; he supposes that all these represent different stages through which our own solar system has passed or will pass. He imagines a course of development which will explain all the existing facts. Time may modify his scheme, but it does not modify his method (Hocart 1970: 12).

Hocart was writing during a period when anti-evolutionism was still in the ascendancy in anthropology. Astronomy too, it appears, had its own brief fling with anti-evolutionism. Nobel Prize winning astrophysicist Steven Weinberg recalls:

> ...the urge to trace the history of the universe back to its beginnings is irresistible. ... However, an aura of the disreputable always surrounded such research. I remember that during the time that I was a student and then began my own research... in the 1950s, the study of the early universe was widely regarded as not the sort of thing to which a respectable scientist would devote his time (Weinberg 1979: 1, 2).

With this much of a background, let us look now at how the comparative method was applied by astronomers and what results flowed from it.

The Hertzsprung–Russell Diagram

The story may be said to begin at Harvard College Observatory in the 1880s when E. C. Pickering and Annie Cannon began to analyse the emission spectra of the visible stars. The stars they examined were placed into several ‘spectral classes’, each class being designated by a letter of the alphabet. Eventually the number of spectral classes was reduced to seven, the letters designating them being O, B, A, F, G, K, and M. It was not known then just what these differences in the spectral classes represented. The observations had been made, but the interpretations had yet to follow. (Recently, the classes L and T have been added to include the newly discovered ‘brown dwarfs’.)

The first great step forward toward interpreting the significance of differences in the spectra of the visible stars was made independently by the Danish astronomer Ejnar Hertzsprung and the American astronomer Henry Norris Russell. Hertzsprung and Russell asked themselves if the luminosity of stars was correlated with their surface temperatures, and, for each star they had observed, they plotted one value against the other. This graphic plotting of the luminosity *versus* the surface temperature of stars has come to be known as a Hertzsprung–Russell diagram, or, simply, an H-R diagram.

Fig. 1 is an H-R diagram which shows that stars are not randomly distributed over the entire graph but are concentrated in certain areas, while being totally lacking in others. The greatest number of stars by far fall along a diagonal running from the lower right-hand corner of the diagram toward the upper left-hand corner. This slightly curved line is now known as the *main sequence.* (To make the H-R diagram a little more familiar, in Fig. 2 the position of several well-known stars has been plotted.)

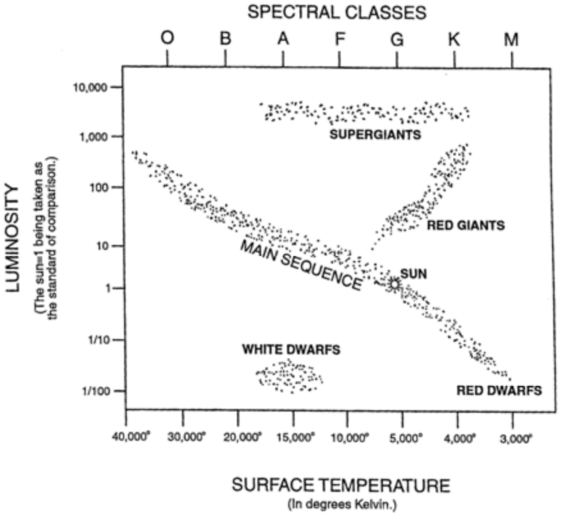

Fig. 1. Hertzsprung–Russell (H-R) Diagram

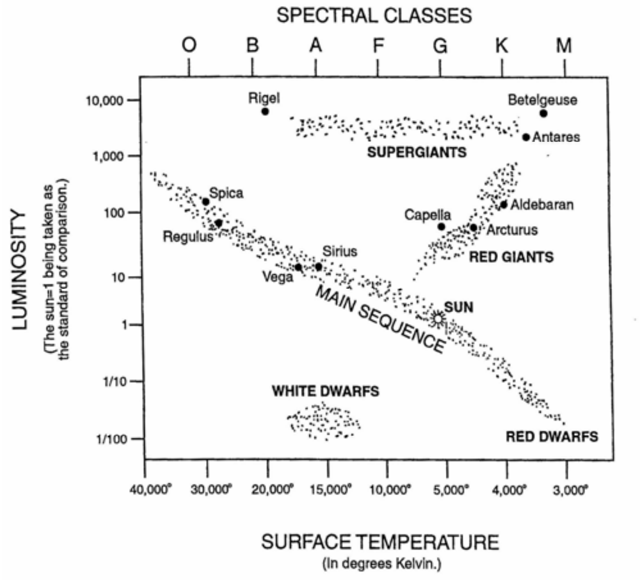

Fig. 2. H-R Diagram locating some well-known stars

The patterns made by the distribution of stars on an H-R diagram were certainly distinct, but what did they mean? Basically, the interpretation astronomers now make of these patterns is that they reveal sequences in stellar evolution. Stars occurring in different areas of an H-R diagram are at different *stages* of an overall evolutionary process. Thus, the comparison of certain values of a great many stars, observed at essentially a single point in time, led astronomers to acquire an understanding of how stars as a whole had evolved. The H-R diagram thus contributed mightily to the advancement of astronomical knowledge. And, as Marcia Bartusiak has observed, 'This famous graph remains the cornerstone of all astronomical research related to the evolution of stars' (Bartusiak 1993: 82).

The important point to keep in mind here is that by plotting stars on an H-R diagram *synchronic* data had led to a *diachronic* explanation. Of course, this understanding did not come all at once. Decades of hard work were required for astronomers and astrophysicists to achieve it. And, though the picture of stellar evolution is not absolutely complete, the basic processes are well understood.

Now, in a simplified way, I would like to trace the course of stellar evolution as astronomers have pieced it together. Moreover, along the way, I will try to point out parallels which I think exist between stellar evolution and social evolution.

Stage and Process in Stellar Evolution

The first discrete population of stars to be identified and labelled were those on the 'main sequence', and stars known as red giants and white dwarfs. Later, other categories were added, such as protostars, red dwarfs, brown dwarfs, black dwarfs, subgiants, and supergiants. Shortly, the evolutionary relationship among them will be examined.

First, though, we should note that these types of stars are more than just *types;* they are also *stages.* And this fact accounts for a large measure of the differences between them. The same is true of human societies. They differ not just because they are, somehow, different sorts of things, but because they are at different *stages* of the same general process. Thus, for example, the Powhatan differed from the Paiute for many reasons, but one of the major ones was that they had progressed farther along a specifiable evolutionary track.

The concept of *stages* is not at all incompatible with that of *process.* Astronomers recognize that stages in stellar evolution are convenient and useful labels for successive and distinct forms in a process through which all stars have passed. Now, it has become fashionable for some ethnologists and archaeologists who proclaim themselves friendly to evolution to assert that they are not interested in *stages*, but only in *process*, as if that were a sign of greater intellectual maturity. Wrong! Stages play the same role in anthropology that they do in astronomy. They designate important way stations along a path that many societies are following. The process of political evolution has passed through certain stages – band, autonomous village, chiefdom, and state, to name the major ones – which label significant contrasting forms of a unitary progression (see Carneiro 2000).

In order to lay the basis for additional parallels between stellar evolution and social evolution, let us take a typical star, one about the size of the sun, and follow its development as it would appear on an H-R diagram. Fig. 3 depicts this evolution.

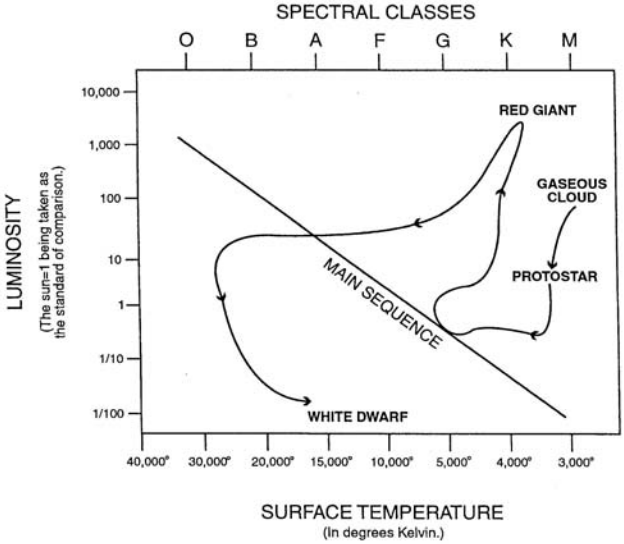

Fig. 3. Evolutionary track of a star with the same mass as the Sun

Early Stages in the Evolution of a Star

The first thing to note is that the main sequence on an H-R diagram, which appears as a long belt running diagonally from lower right to upper left, does not represent the evolutionary path of any given star. The actual 'life track' of a star differs from this, and is rather more complicated.

The life of a star begins when a diffuse cloud of gas and interstellar dust, about 100 times the diameter of the sun, becomes a discrete entity and begins to contract. As it does so, it generates increasing amounts of gravitational energy. About half of this energy is radiated away in the form of heat and light, and thus, at a certain point, the newly forming object becomes visible. At this stage the large luminous body is called a *protostar*. The other half of its gravitational energy remains within the protostar as heat. As contraction continues, the internal temperature of the protostar keeps rising, and when it reaches 5 million degrees Kelvin, it is hot enough for thermonuclear reactions to begin at its core. At this point in its travels on the H-R diagram the star reaches the main sequence. By far the largest number of visible stars lie on the main sequence, and most of a star's life will be spent there.

For the thermonuclear reaction that powers a star to occur, the cloud of contracting gas and interstellar dust must have a certain minimum mass. Astrophysicists have calculated that this mass must be at least 80 times that of the planet Jupiter. Otherwise, gravitational contraction would be unable to generate a high enough temperature to start the reaction. The resulting body would not be a star at all, but a sub-stellar object called a brown dwarf, so faint as to be all but invisible in the night sky. So faint, in fact, that the existence of brown dwarfs was posited on theoretical grounds before one was actually observed.

A cut above brown dwarfs on the scale of celestial objects are red dwarfs. These are small stars, with a mass as little as one-tenth or less that of the sun. But, unlike brown dwarfs, red dwarfs are true stars, burning hydrogen into helium, and thus occupying a place on the main sequence of an H-R diagram. It is a lowly place, to be sure (the extreme lower right-hand corner) in terms of both luminosity and surface temperature. Moreover, red dwarfs burn hydrogen so slowly that they are extremely long-lived. Their life span, in fact, is to be measured in trillions, rather than billions, of years. Not only are they relatively stable in terms of remaining virtually unchanged for an incredibly long span of time, they are also thought to be the most abundant type of stars in the Universe (Martin *et al.* 1997: 523).

Red Dwarfs and Villages: A Parallel

Can we find a parallel to red dwarfs among human societies? I think so. In certain respects, we can equate red dwarfs with *villages*. Over the course of history, the village has been not only the smallest unit of human settlement, but also the most common. And here we come to a most interesting relationship that seems to apply universally, regardless of what sorts of phenomena are being studied. This is the inverse relationship that exists between *size* and *abundance.* Astrophysicists have found this relationship to hold, for example, between the atomic weight of a chemical element and its abundance in the solar system: by and large, the heavier the element, the scarcer it is. Thus, for every trillion atoms of hydrogen (atomic weight 1) there are 100 million atoms of nitrogen (atomic weight 14), 1,000 atoms of strontium (atomic weight 88), and 1 atom of uranium (atomic weight 238).

Curiously enough, the same relationship appears to hold in the animal kingdom. A number of years ago, G. Evelyn Hutchinson and Robert MacArthur pointed out that there is an inverse ratio between the number of species of mammals in a taxonomic group and the characteristic size of those species (Blackburn and Gaston 1994: 471). As an example of this relationship, we can cite the fact that there are fewer species of deer than there are of mice, and fewer species of elephants than there are of deer.

Turning to the size and frequency of socio-political units, although this relationship may no longer hold true, it certainly did so up until about 1000 AD. The autonomous village, the smallest of political units, was the most common. There were more of them than of multi-village chiefdoms, and more chiefdoms than there were states.

Although over the course of history many villages have lost their autonomy and have become incorporated into larger political units, if we focus on their internal structure we find that they remained pretty much the same. They have proved to be remarkably stable units. Indeed, as tightly integrated social units, they have frequently outlasted the overarching political structure of which they often became a part. Thus the early villages of *fellahin*, the Egyptian peasants that already existed in Predynastic times, remained as enduring settlements long after the Old and New Kingdoms had fallen by the wayside.

In summary, I think it is safe to say, without straining the parallels unduly, that in terms of abundance, stability, and duration the villages that populated the Earth can be said to be roughly comparable to the red dwarfs that populate the heavens.

The Forces of Fusion in Stars and Societies

We have seen that thermonuclear reactions, beginning with the conversion of hydrogen into helium, are what power the evolution of the stars. Just as the formation of helium in a star's interior requires overcoming the repulsive tendencies between hydrogen nuclei, so the problem in chiefdom formation requires overcoming the strongly-held political autonomy of individual villages. The creation of chiefdoms, then, like the creation of helium, consists essentially of *fusing* together elementary units, previously separate, into larger and more complex wholes.

This process, however, takes place *against the will,* so to speak, of the elementary units involved. In stars, it is *heat* that overcomes the repulsive tendency of individual atoms and causes them to fuse together. In the case of human societies, it is *warfare*. In each case, a strong force was required to achieve the resulting integration. The parallel becomes clearer when we examine more closely the corresponding fusion processes involved.

How fast the conversion of hydrogen into helium takes place within a star depends not only on temperature, but also on the *density* of the hydrogen nuclei available for the reaction. Astrophysicists have calculated that the rate of hydrogen burning in a star is proportional to the *square* of the number of hydrogen nuclei present (Wyatt and Kaler 1974: 375). Therefore, if the density of nuclei in a stellar core is *doubled,* the rate of hydrogen burning is *quadrupled.* Consequently, the more densely packed the atoms taking part in a thermonuclear reaction, the more rapidly the star will evolve.

Anthropologists generally agree that the overcoming of village autonomy and the onset of chiefdom-formation are closely geared to the density of population, especially as measured by the number of villages in a given area. That being the case, the following question now readily suggests itself: Is it possible that the force that leads to the aggregation of autonomous villages into chiefdoms is proportional not to the *first power* of the number of villages, but to the *square* of that number? Were this true, it would mean that if we *doubled* the number of villages in a designated area, we would not simple *halve* the time it would take for a chiefdom to emerge, but *quarter* it.

This is indeed an intriguing possibility. It would present us with a rather striking quantitative regularity in the development of culture. However, so lagging is the study of social evolution compared to that of stellar evolution that anthropologists have not even raised this possibility, let alone explored it. However, this is not the first time that a law of squares has been proposed in anthropology. In accounting for village splitting, it has been suggested that the tendency for an autonomous village to fission may be proportional to the square of its population (Carneiro 1987: 100).

The Life History of Stars

Let us return now to the life history of stars and, having left red dwarfs behind, let us examine stars of a larger magnitude, more typical of the ones we see in the night sky. On the H-R diagram in Fig. 3 the evolutionary track of such a star is represented. It begins as a luminous but rather cool body of gas which grows less luminous as it contracts. Thus we see the line representing it sliding down the luminosity scale. But, at the same time that the star is contracting, its surface temperature is increasing. This moves the star to the left on the H-R diagram, until we find it on the main sequence.

After spending much of its life at about the same point on the main sequence, the star becomes more luminous again but its surface temperature decreases. Looking at Fig. 3 we see that the star has now climbed into the area of red giants. From here, the star begins to increase its surface temperature, but its luminosity declines and eventually it plunges sharply down to the bottom of the H-R diagram, where, still quite hot but very dim, it becomes a white dwarf.

All stars of roughly the same mass as the sun go through these same stages in essentially the same way. Were we to plot the life history of another star of the same mass as the sun, its track, if not exactly superimposed on that of the sun, would be very closely parallel to it. In the language of anthropology, we can say that stars of this class size manifest *unilinear* evolution. That is to say, a single line of development can be said to characterize their life history.

Unilinearity and Multilinearity

If from stars we turn to states, we can say that in their development, states have run a roughly similar course. To a large extent, they have evolved *unilinearly*. They have gone from bands to autonomous villages, to chiefdoms, to states, in that order, with no skipping or inverting of stages. For example, we do not find states appearing before autonomous villages, or chiefdoms before bands, any more than white dwarfs come on the scene before red giants.

The similarity in the general evolutionary track followed by evolving societies reflects in part a similar response to common and insistent structural challenges posed to societies as they encompass more and more settlements and grow correspondingly in size. This increase in ‘social mass’ requires societies to elaborate their structure and thus to become more complex. More specifically, this is manifested by the development of successively higher levels of socio-cultural integration as societies seek to maintain themselves as viable, functioning entities. This is a point that was stressed by Julian Steward (1955: 43–63) in his discussion of cultural evolution.

However, external conditions also play a role in a society's evolution. If these conditions are sufficiently different from society to society, we can expect the structural outcomes to be different as well. Thus, arising in very different environments, the Inca and the Maya followed rather different developmental paths. They both formed states, but of markedly different kinds. And whenever we find large enough differences in the ways societies evolved, we speak of them as exhibiting *multilinear* evolution. While not actually coining the term ‘multilinear evolution’, it was Julian Steward who gave the concept great currency in his study of societies which, while evolving in the same general direction, had not followed quite the same path.

Multilinearity in Stellar Evolution

Multilinear evolution, it turns out, can also be found in astronomy. Stars as well as societies may evolve in substantially different ways. And the principal factor determining the differences in the evolution of stars is their *mass*. Astronomers have found that stars having a mass greater than 1.4 times that of the sun evolve differently from the sun. Fig. 4 shows the evolutionary track of a star with 5 times the solar mass, and it is readily apparent if we compare Fig. 3 and 4 that the path of a 5-solar-mass star across the H-R diagram is quite different from that of the sun. Having collected and concentrated much more gas and interstellar dust, a star of this size begins life as a more luminous body than did the sun. It then moves directly to the left on the H-R diagram and reaches the main sequence at a higher point than did the sun. This means that when a star of this magnitude reaches the main sequence it is considerably hotter and more luminous than the sun. Its larger mass has given it a greater surface area from which to radiate light, and has also permitted it to generate higher temperatures.

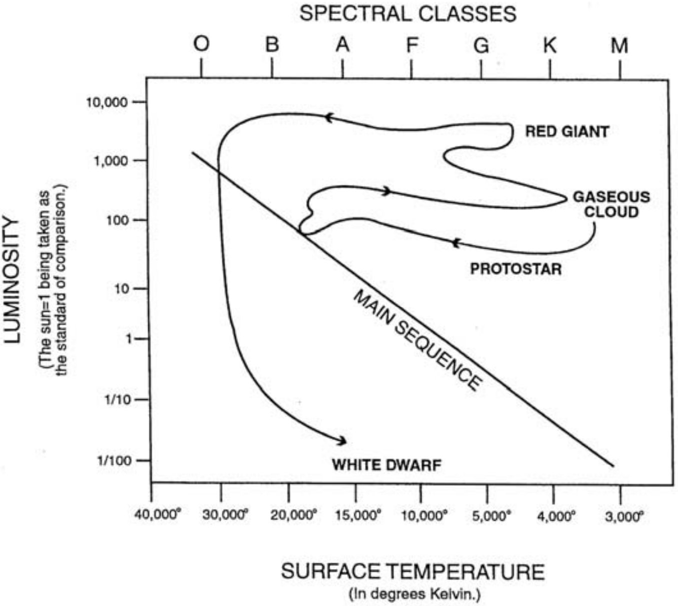

Fig. 4. Evolutionary track of a star with 5 times the mass of the Sun

This fact, incidentally, explains why the main sequence forms such a long belt of stars. Since stars of greater mass reach the main sequence at higher points, and since stellar masses vary by a factor of 750 (their range being from .08 to

60 times the solar mass), the dots representing them are distributed all along the diagonal on an H-R diagram.

Now, when a large star finally veers off the main sequences, its subsequent path on the diagram appears more erratic than the sun's, zigzagging back and forth across the top of the diagram. First, a massive star becomes a red giant or supergiant, but then it heats up again until it glows blue-white. It continues to oscillate between these two states for some time before finally plunging down the diagram and ending up at the bottom as a white dwarf – still hot, but much less luminous.

In this comparison, then, between the sun and a 5-solar-mass star we have an instance of what might be called *bilinear* evolution. Stars of 5 solar masses evolve alike, but rather differently from stars of only 1 solar mass. When we compare even more massive stars, however, the situation becomes frankly *multilinear*. For example, a star with a mass 10 times or greater than that of the sun may not end its days quietly as a white dwarf at all, but may instead explode in a gigantic burst of energy known as a supernova, ending up as a neutron star if it is substantially more massive than the sun, or a black hole if it is even bigger.

These are the sorts of evolutionary tracks which stars follow on an H-R diagram. But, just as with social evolution, the study of stellar evolution is not concerned with tracks and stages alone. It is also concerned with *process*. Astronomers and anthropologists alike are out to discover just why it is that their respective phenomena evolve as they do. Here the achievements of astronomy in working out the underlying modes of stellar evolution have been truly remarkable. Through theoretical calculations as well as from empirical observations, astronomers and astrophysicists have constructed a detailed and compelling picture of the life history of stars.

Underlying Processes of Stellar Evolution

Let me sketch briefly the internal processes that determine why stars follow the evolutionary paths they do. As we have seen, the initial phase of stellar evolution consists of the contraction of interstellar dust until it forms a glowing mass known as a *protostar*. With continued contraction, the initial temperature of a protostar increases and its size decreases until the point is reached at which the glowing object is called a star. Once a star attains a core temperature of 5 million degrees, thermonuclear reactions begin. In these reactions – called ‘hydrogen burning’ – four hydrogen nuclei are fused together to form an atom of helium. With this reaction well underway, the protostar has become a fully fledged star.

The star soon reaches a state of equilibrium, the radiation pressure generated by nuclear fusion at its core balancing the inward pressure of gravitational contraction. It is then that the star attains the main sequence, the exact point at which it reaches it depending upon its mass. The greater its mass, the higher up on the diagonal it lands. How long it will remain on the main sequence also depends on its mass. A star with the mass of the sun is destined to stay on the main sequence a long time. The sun, in fact, is estimated to have been on the main sequence for some 5 billion years, and is expected to remain there for another 5 billion.

Sooner or later, though, every star except the smallest, moves up and to the right on the H-R diagram, away from the main sequence. Why does this happen?

Through continued thermonuclear reactions, a star's core is entirely converted from hydrogen to helium. The helium core, being denser, exerts a more powerful gravitational force and contracts further. This contraction generates more heat, bringing about an increase in hydrogen burning, which is now taking place only in the outer shell, surrounding the core. Under the radiation pressure of this higher rate of thermonuclear reaction, the envelope of gas surrounding the star's core expands and, as it does so, the star becomes larger and therefore more luminous. But, as this outer envelope grows in size, it also becomes more attenuated, and so its temperature falls. Viewed by an astronomer on Earth, the star has grown both brighter and cooler. Thus, on the H-R diagram it has moved up and to the right and is now a red giant.

What happens next? As the star continues to contract, its core will reach a temperature in excess of 100 million degrees. When this point is reached, the core is hot enough for helium burning to begin, forming carbon. The star's gaseous envelope now ceases to expand and, in fact, reverses, so the star begins its retreat from the red giant phase. This involves a decrease in both luminosity and surface temperature as the star moves down and to the right on the H-R diagram, and again approaches the diagonal of the main sequence.

But, having become unstable, the star is not destined to stay on the main sequence very long. Due to the continuing effect of gravitation, further contraction takes place, raising the star's internal temperature even higher. With that, new kinds of thermonuclear reactions become possible. Helium is now burned to form carbon, and then, with carbon as the nuclear fuel, heavier elements are successively produced, with neon, oxygen, magnesium, and silicon arising in that order (Pagels 1985: 44). Finally, as the internal temperature grows even hotter, silicon atoms fuse to form iron. The internal structure of the star now consists of several concentric shells of various elements around an iron core.

Societal Parallels

Certain parallels can be said to exist between the processes just described for a star and those undergone by an evolving society. To begin with, both entities are becoming more *complex.* A star does so by producing a succession of new chemical elements, each of which has a higher atomic weight than the constituent atoms from which it was made. Likewise, a society evolves by forming an increasingly greater number and variety of social units and segments, the newer ones tending to incorporate the smaller ones that preceded it.

A further parallel can be detected. The chemical elements being produced in its interior by an evolving star are not distributed randomly throughout its mass. They are arranged in a series of shells around a central core, their position depending on when during the evolutionary process they were formed. Similarly, the structural features arising in an evolving society are not disparate bits and pieces, distributed haphazardly within it, but are arranged in an orderly fashion. Social, economic, and political institutions have their distinct levels of organization. Generally speaking, the more numerous and varied the segments of a society, the more they are likely to be grouped together into successive, more inclusive levels of socio-cultural integration, as Julian Steward (1955: 43–63) emphasized.

Back to the Stars

The final outcome of stellar evolution depends on the mass of a star. If it is not much greater than that of the sun, it will successively expel its outer gaseous envelope, and then, its nuclear furnace now turned off, its only source of energy is gravitational contraction. Reduced in size to a white dwarf, the star will continue to shine feebly for billions of years. At last, though, even this source of energy runs out and the star becomes a *black dwarf*, a totally dead and invisible object.

Now, if the mass of a star is greater than 10 times the solar mass, a very different fate awaits it. Its iron core gets hotter and hotter until it finally collapses. Under the enormous pressure produced by this collapse, electrons are forced into the nuclei of their atoms, forming neutrons and neutrinos. Then, no longer able to accommodate the incalculable pressure thus generated, the interior of the star rebounds outward, tearing the star apart and causing it to burst forth in a spectacular astronomical event known as a supernova. In this colossal explosion, a star ejects as much as 90 per cent of its material into space. All elements heavier than iron – elements that could not be formed before – are now produced through the enormously high temperature that only a supernova can generate. Supernovas, in fact, are the source of all the heavier elements encountered throughout the Universe, including those found on Earth.

The Comparison with Societies

This picture of the process of stellar evolution is certainly a dramatic and compelling one. Do we have anything to match it in anthropology? I think we do, and the parallel I would draw is with the origin and evolution of the state. From one perspective, state formation certainly involves an increase in mass – the aggregation and integration of smaller political units into larger ones. This may be likened to the capture and condensation of gas particles by a star during its early phases. Just as a brown dwarf cannot develop into a true star for lack of sufficient mass, a society cannot form a state unless it encompasses a certain minimum number of people. With a ‘social mass’ below some critical level, the maximum size a society can hope to attain may be that of a small chiefdom, but not a state.

From this point on, stellar evolution manifests two processes which are parallel to those exhibited by social evolution: one is *external* and the other *internal.* The external processes are changes in the luminosity and surface temperature of a star. The internal processes are the series of nuclear reactions which build up successively heavier elements.

In their own evolution, states reveal similar kinds of external and internal changes. Externally, the origination of a state is much like the formation of a protostar. Each involves the coalescing of diffuse and disparate material into a more compact and cohesive whole. In state formation, a number of autonomous units – first villages, and then chiefdoms – are brought together to form increasingly larger political aggregates.

Internally, first as a chiefdom and then as a state, a polity continues to elaborate its structure in order to accommodate and integrate its growing mass. New structural features are continually being developed to accomplish this. In a relatively advanced state, for example, specialized ministries, such as those of agriculture, interior, finance, and war, may be created to carry out various functions which are important for the state to control, supervise, or regulate.

Primary and Secondary Stars and States

We come now to another aspect of stellar evolution for which social evolution provides a ready parallel. This is the distinction, first made by the astronomer Walter Baade in 1942, between two classes of stars which he labelled Population I and Population II. Despite bearing the higher number, Population II stars are the older, and thus more primitive or pristine, of the two stellar populations. Population II stars were formed early in cosmic history and consist almost entirely of hydrogen, with a bit of helium thrown in. But no heavier elements are present in them. These Population II stars were formed directly from the elemental, primeval cosmic matter spewed out by the Big Bang. During most of their lives, these stars, if of moderate size, behaved in the manner already described for the sun.

In the later stages of their lives, however, Population II stars of very massive size develop internal temperatures great enough to produce heavier elements up to iron. But that is the end of the line for them. ‘An iron core cannot produce any further energy by fusion, no matter how hot and dense it becomes’ (Kaler 1999: 43). Thus they have reached the limits of nucleosynthesis. But then something dramatic happens. These stars undergo the cataclysmic explosion of a supernova and, in the tremendous heat thus generated, all the heavier elements above iron are created. But the explosive force of the supernova not only creates these elements, it ejects them far out into space in enormous quantities.

The clouds of interstellar dust formed by the disintegration and spewing forth of the material of Population II stars provide the ‘seed bed’ for the formation of new stars. These new, ‘second-generation’ stars are identifiably different in chemical composition from their predecessors. The cosmic dust that they gather and condense contains – although only in relatively tiny amounts – many of the heavier elements which first-generation (Population II) stars completely lacked. The sun is an example of such a second-generation (or third-or fourth-generation?) star, containing more than 60 of the known elements (Motz 1975: 109).

Now, what parallel to this do we find in social evolution? The most obvious one is the distinction first made by Morton Fried (1967: 231–235) between *pristine* and *secondary* states. Pristine states are those which evolved entirely on their own, before there were any other states around to copy or to borrow from. Secondary states are those which were formed later, generally in the same region as pristine states. To varying degrees, they were familiar with, and were able to incorporate, inventions and developments made by the preceding pristine states, like the Assyrian Empire, which arose out of the ashes, so to speak, of the Babylonian Empire, which preceded it. With this assist, secondary states were often able to evolve faster than pristine ones. And that brings us to the subject of rates of evolution.

Rates of Evolution

Anthropologists are well aware that not all societies have evolved at the same rate or to the same degree. For example, those societies living in the Nile Valley and along the Tigris – Euphrates around 5000 BC evolved much faster during the ensuing three millennia than those living in, say, the Congo basin or on the Baltic shore. And so it is with stars. They evolve at very different rates. The principal variable involved in determining the rate of evolution of a star is its mass. The larger it is, the faster it evolves.

In the case of human societies, however, the process is more complicated. The principal variables determining how fast a society will evolve are, as I have argued elsewhere (Carneiro 1970), population pressure, warfare, and, especially, environmental circumscription. The more tightly hemmed in autonomous villages are in a valley or on an island, the sooner warfare will lead them to coalesce and integrate into larger political units: first chiefdoms and then states. Thus the Minoans, sharply bounded by the sea on the island of Crete, were able to form a state well before one could emerge on the mainland of Europe, with its extensive and relatively unbounded expanses.

As just noted, the principal determinant of the rate of a star's evolution is its mass. Consequently, a massive star will reach the main sequence earlier and leave it sooner than a smaller one like the sun. Thus, while a star of the same mass as the sun will remain on the main sequence for some 10 billion years, a star with 5 times the solar mass will remain there only 68 million years, and one of 30 solar masses will leave the main sequence after a stay of only 5 million years.

Why do massive stars evolve so much more rapidly than stars of moderate size? The answer is that, being larger, they generate much greater pressures and temperatures in their cores, permitting thermonuclear reactions to take place much more vigorously and therefore to proceed at a much higher rate. The supergiant star Rigel in the constellation Orion, for example, consumes its nuclear fuel of hydrogen at a rate 60,000 faster than the sun (Motz 1975: 116–117).

As we have seen, a star stays on the main sequence as long as it is burning hydrogen, during which stage it is in thermodynamic equilibrium. But when 12 per cent of its mass has been converted into helium (the so-called Chandrasekhar limit), the star, which was previously in balance between radiation pressure pushing out and gravitation pushing in, becomes unstable and moves away from the main sequence and toward the area of the red giants. Moreover, it does so very rapidly. So rapidly, in fact, that the area on the H-R diagram between the main sequence and the red giants is nearly vacant. Stars move through this region so fast that very few of them have been caught in mid-passage.

Mathematically, a star's life span is inversely proportional to the cube of its mass. Thus, of two stars, if one of them is twice as large as the other, it will survive only 1/8 as long.

Anyone familiar with chemistry will note a similarity between what I have just described and the principle of mass action. According to that principle, the speed of a chemical reaction is directly proportional to the number of units – molecules, atoms, ions, *etc.* – entering into the reaction.

The analogy we find in social evolution is that larger societies – societies with more people, more elaborate social structures, and a greater inventory of culture traits – evolve faster than smaller ones. Other factors being equal, the number of new cultural elements – traits, customs, practices, institutions – generated by a society is directly proportional to the number it already has. The recognition of this relationship is by no means new. It was expressed some 80 years ago by William F. Ogburn in his book *Social Change*. There Ogburn pointed out that the number of inventions a society makes per unit of time varies directly as the size of its culture base (Ogburn 1922: 103–118).

Conclusion

So there we have it. There are indeed a number of parallels between stellar evolution as astronomers and astrophysicists have revealed it and social evolution as anthropologists have reconstructed it. Both sets of scientists make effective use of the comparative method. Both find in their phenomena distinct sequences and stages of development. Some of these sequences can be termed *unilinear*, while others are *multilinear*. Both sets of scientists attempt to lay bare the driving forces underlying the sequences they observe. Both find in the entities they study differential rates of evolution which are closely related to their size. And finally, both astronomy and astrophysics, on the one hand, and anthropology, on the other, see in the evolution of their phenomena a progression from simple, diffuse, and inchoate beginnings to a level of development in which complexity is a common and prominent feature.

As I stated earlier, astronomy may little benefit from recognition of this parallelism with anthropology. But it may help stiffen the sinews of those anthropologists who have come to doubt the validity of the evolutionary approach in their own field. This article may permit them to see more clearly that what culture has done is to take up the torch of a universal process which began eons ago with the Big Bang, and which continues, at an accelerated pace, throughout the Universe. This process has seen stars evolve to the point where, in at least one tiny corner of a particular galaxy, conditions developed which allowed a presumptuous primate to arise. And those intricate social arrangements which he devised and calls ‘culture’, he regards, in his less modest moments, as the capstone of cosmic evolution.

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Abstract

The process of evolution can be seen at work in all domains of nature. It has seemed instructive to point out a number of parallels between the development of stars and the development of human societies. For example, the use of the comparative method has been prominent in the study of evolution in both fields. Also, there are parallels between the two, such as the use of stages to distinguish significant phases of the evolutionary process, the manifestation of both multilinear and unilinear evolution in both, and differential rates of evolution among stars and societies. Pointing out these parallels, which anthropology shares with the more advanced and sophisticated science of astronomy, may help bolster anthropologists in their belief that the evolutionary approach in their own field is a valid one, capable of producing substantial results.

In his book *First Principles* (1862), published a scant three year after Darwin's *The Origin of Species,* Herbert Spencer portrayed evolution as something far beyond ‘descent with modification’. He saw it as a much broader process, a process which had manifested itself throughout the Universe, from the tiniest microorganisms to the largest galaxies. The evolution of the stars, then, was clearly within his purview.

And, as a field of astronomical research, stellar evolution has been pursued with increasing vigor and impressive results since Spencer's time. In fact, it is not too much to say that what astronomers and astrophysicists have been able to accomplish in reconstructing the process of cosmic evolution stands as one of the greatest intellectual triumphs of all time.

Spencer (1896: 373) defined evolution as, essentially, a change from simplicity to complexity. And this is still the way astronomers regard it as it manifests itself in the unfolding of the cosmos. Thus the great astrophysicist George Gamow wrote:

> ...the basic features which characterize the universe as we know it today are the direct result of some evolutionary developments which must have begun a few billion years ago... With such an assumption, the problem of scientific cosmogony can be formulated as an attempt to reconstruct the evolutionary process which led from the simplicity of the early days of creation to the present immense complexity of the universe... (Gamow 1952: 20)

For some years it has seemed to me that certain striking parallels exist between the evolution of stars and the evolution of human societies, parallels which anthropologists are barely aware of. And while a recognition of these parallels may mean very little to the powerful and sophisticated science of astronomy, it just may be of some interest and value to the fragile and beleaguered field of cultural evolution. Therefore it seems worthwhile to try to point out some of these parallels.

II. BIOLOGICAL AND SOCIAL FORMS OF EVOLUTION: CONNECTIONS AND COMPARISONS

3

Constructing a General Theory of Life: The Dynamics of Human and Non-human Systems

Graeme D. Snooks

Introduction

It is doubtful that a single workable theory of 'evolution' – which I prefer to call 'dynamics' – will ever be constructed to explain the emergence and development of both inanimate and animate systems, owing to their fundamentally different existential properties. But it is possible to construct a single general theory of life that can explain and predict the dynamics of both human and non-human systems. This has always been the objective of those studying living systems: to explain and predict the emergence of order and complexity in a universe subject to increasing entropy.

While the need for a general dynamic theory – sometimes called a 'unified theory of complexity' – has been discussed in the literature for more than a decade, the consensus is that its achievement is no closer now than in the past (Holland 1995, 1998; Casti 1999). Some scholars, however, are beginning to feel that the task is too complex, perhaps even impossible (Horgan 1996; Sardar and Ravetz 1994). It has even been suggested that an overarching theory may not really be desirable after all, and that we may have to be content with detailed empirical studies of complex systems or with simulation models of different types of agent-based systems (Chu *et al*. 2003).

A new approach to this important issue is developed in this paper. It is only possible, I argue, to explain, predict, and formulate corrective policy regarding living systems if we possess a general dynamic theory and fully understand its underlying laws. Certainly the task is difficult, but, I hope to demonstrate, it is not impossible. Indeed, the degree of difficulty has been increased unnecessarily by two research strategies pursued in complexity circles. First, many complexity theorists have attempted to develop a theory that can explain systems of both an inanimate and animate kind. I will suggest that separate dynamic theories are needed for this purpose. By employing the physics model of inanimate systems to explain the exploration of living systems, we distort those systems. Second, all complexity theorists have focused, in adopting the physics model, on the supply-side mechanisms in both types of system – on the local interactions between large numbers of constituent members. In the process they have totally ignored the demand side, which, I have long claimed, is essential to the understanding and analysis of living systems. It is argued here that by separating living from inanimate systems, and by embracing the entire demand-supply mechanism in living systems, it is possible to develop a workable general dynamic theory of life and human society – a general dynamic theory constructed on a solid foundation of laws of both life and human society (Snooks 1998; 2003: ch. 15). Both the method and the theory will be outlined briefly in this paper, as this discussion is based on a series of major books and articles published by the author over the past decade.

A Methodological Struggle

The field of complexity has become a battleground for different methods. Essentially there are three combatants: those employing the physics model are exponents of the deductive approach; those employing the agent-based models are advocates of the analogical method; and those who reject the supply-side physics model entirely, favour the inductive method of realist theory-construction. There are some, such as Joshua Epstein (1999), who wish to persuade us that agent-based modelling constitutes a new approach to knowledge creation, which can be called 'generative'. I will argue, however, that this amounts to elevating an estimating technique to the level of a scientific method. It is important to emphasise that, as all scientists employ a mix of methods in their work, advocates of a particular method are merely saying that this is the main source of the knowledge generated by their work. Nonetheless, in an interesting echo of the late nineteenth-century battle between the deductive and historical branches of economics, the current clash between methods for understanding complex systems could be thought of as the new *methodenstreit* – the new battle of the methods between deduction and induction in the wider arena of the life sciences.

The Supply-side Physics Approach

Existing approaches to complexity are based to varying degrees on the physics model of self-organisation. This deductively developed theory is often illustrated by reference to the sand-pile model made famous by Per Bak (1997). In this model, the application of an external energy source to an open system consisting of a large number of particles, causes those particles to interact energetically so as to create complex structures that build up to a critical point, and then collapse in unpredictable ways, resulting in a ‘phase transition’. It is a cycle that recurs for as long as the exogenous driving force, and the resulting state of self-organised criticality (SOC), continue to exist. This process of self-organisation is the outcome of an inanimate system obeying simple laws of physics, including those of motion, gravity, and friction.

Both the macro and micro outcomes of this model are unpredictable owing to the large number of interacting objects in real-world systems. As is well known, Newtonian precision is only possible when any interaction is confined to two or three objects. How then do we account for the order we observe in the real world of large numbers? Unpredictable outcomes are said to obey a power law – the law of large numbers – that governs the probability of fluctuations of a given size. This law tells us that while physical events of any size – such as avalanches in the sand-pile – can be generated at any time by small triggers, the probability of large events is considerably less than that of small events.

A distribution obeying a power law can be thought of as a modified random walk – a random walk punctuated by steps of any size, where the probability of occurrence decreases as the steps get bigger. In a normal random walk, all steps are the same size. But this is merely description, not explanation. What we want to know is how physicists attempt to explain these power laws. M. E. J. Newman (2005) suggests that there are a number of ‘physical mechanisms’ underlying power laws. The chief among them are the ‘Yule process’, often characterised as ‘the rich get richer’, and theory of self-organised criticality. An example of the Yule process can be found in the differential impact of population growth on the pattern of urbanisation – namely when a nation's largest cities acquire more inhabitants than its smaller cities in proportion to the existing pattern of population size. And an example of SOC is the sand-pile model discussed above. SOC is a far-from-equilibrium state, generated by a constant flow of energy from outside the system. In this state, the addition of just a single grain of sand will cause the pile to generate either a single large avalanche or a series of smaller avalanches (Bak *et al*. 1989).

These ‘explanations’, however, are unsatisfactory because they are *ad hoc,* partial, and not part of a general dynamic theory. But even more importantly, it is clear that the interactions between particles in the physics model are the result not of ‘choice’ but of the flow of energy from outside the system. ‘Self-organisation’, therefore, is a misnomer. ‘Forced-organisation’ would be a more appropriate label. While nomenclature is unimportant, provided usage is clear and consistent, in this case it does give the misleading impression that the physics model might be applicable also to living systems.

What can the physics model tell us about the *process* of change in inanimate systems? What pathways do complex systems take? Classical thermodynamics is unable to analyse, let alone resolve, this issue, because its method is limited to comparative statics rather than dynamics. It is, in other words, concerned with the equilibrium conditions that exist both before and after the occurrence of a phase transition. In contrast, complexity theory, which is an outcome of the more recent statistical physics, is concerned with non-equilibrium processes of change. What this implies is that there has been a belated recognition by physicists that real-world processes of change rarely take the form of sudden leaps between equilibrium states. With this change of focus, the challenge for the physics model became how to analyse the growth path of physical systems by employing a supply-side model of forced physical interaction. The solution, based on work by Ilya Prigogine (1981) and others from the 1950s, was to view the growth process as the outcome of a succession of bifurcations, or crisis points that offer two very different paths forward. And the path taken (rather than chosen) will be the outcome of historical contingency. While the phase-transition and non-equilibrium-bifurcation approaches are distinct, what links them is the underlying model of forced interactions.

The Supply-side Agent-based Models

The key question in complexity theory is: How relevant is the simple physics model to the analysis of living systems? The dominant contemporary answer, somewhat surprisingly, is that this physical model of supply-side interactions is highly relevant. At one end of the spectrum are those physicists who believe that the creation of a 'social physics' is highly feasible (Buchanan 2000; Ball 2004; Gribbin 2005), and at the other end are those who reject the idea of society obeying the laws of physics but maintain that adaptive agents can be substituted for particles within the basic supply-side physics model (Epstein and Axtell 1996; Axelrod 1997; Tesfatsion and Judd 2006). In between these extremes are those working on the 'evolution' of technology, who still see some advantage in focussing on the supply-side interaction between units of technology in the absence of agents (Arthur and Polak 2006). While it is not difficult to refute the idea of social physics (Snooks 2007), the work of the agent-based modellers (ABM) requires further discussion here. As will be shown, the source of all their problems is the commitment to an inappropriate analogical method – the assumption that the basic self-organisation model of inanimate systems is applicable to living systems.

The most sophisticated ABMs have been developed by economists who are unhappy with the dominant comparative-static approach adopted by their discipline. As a long-term campaigner against the static equilibrium approach in orthodox economics (Snooks 1993, 2000), I sympathise with their desire to develop a more dynamic form of economics. But their adoption of the structural characteristics of the physics model rather than the development of a realist general dynamic theory is unfortunate, as it involves a rejection of the inductive for the analogical method. In other words, by opting for the supply-side dynamic approach of statistical physics in preference to the supply-side comparative-static approach of their own discipline, ABM'ers have totally ignored the possibility of a realist demand-side approach.

The pioneers of this movement appear to have been influenced by statistical physics initially via game theory and later through contact with complexity theory (Epstein 1999; Axelrod 1984, 1987). This agent-based computational economics (ACE) group is concerned with the complex outcomes that arise from the interaction between agents that possess computing abilities and operate with bounded (rather than perfect) information. While they replace 'particles' with 'people', they accept and adopt the causal mechanism that lies at the centre of the physics model – the local interaction between agents – to explain the emergence of complexity. The ACE model, therefore, is a physics-influenced, supply-side approach to complex systems. In their own words, it is a theory about 'artificial societies' rather than real-world societies. While they have abandoned the laws of physics as an explanation of local interaction, they have imposed a set of simple artificial rules on living systems in order to mimic observed orderly patterns.

The influence of a supply-side physics is clearly reflected in the central question posed by ACE advocates, such as Epstein's (1999: 41): 'How could the decentralized local interactions of heterogeneous autonomous agents generate the given [macroscopic] regularity?' To answer this highly physics-biased question, ACE advocates develop sets of simple rules of local interaction that, through computer simulation, mimic the real-world patterns in which they are interested. In other words, they develop computerised 'artificial societies' based on the insights of complexity generated by physical systems to 'explain' the regularities in human society. It must be emphasised that the ACE model is determined not by computer simulation but by analogy. Computer simulation is merely a technique for establishing a set of artificial rules, within the context of a deductive model borrowed from statistical physics. It does not constitute a new approach – the 'generative' approach thought of as equivalent to deduction and induction – to the creation of knowledge as suggested by Epstein (1999).

This is a highly risky, even reckless, approach. If the supply-side physics model is *not* relevant to living systems – if the analogy is false – then the entire ACE program is in jeopardy. In such circumstances this approach will construct a model *not* of the universe we actually inhabit, but of a parallel and alien universe. The ACE program, therefore, runs the very real risk of entirely distorting our understanding of reality. The question that should have been asked is: What is the real-world mechanism actually responsible for the macro-societal patterns we observe, and how can it be employed to construct a general dynamic theory of life and human society? While this question is considerably more difficult to answer, it is not based on the reckless assumption that living systems can be explained using the supply-side physics model. As it turns out, this assumption cannot be substantiated. Consequently, the ACE program has difficulties explaining the dynamics of real-world (as opposed to 'artificial') living systems.

The method employed by agent-based modellers is not without its critics in the complexity community. In an interesting article in *Complexity*, Chu, Strand and Fjelland (2003: 27) argue:

> The degree of complexity involved [in living systems] is usually beyond the reach of the conventional methods of physics, but ABMs (and other approaches to complex systems, such as neural networks, genetic algorithms, *etc*.) have proven to be powerful methods in this context...
> But there is more to complexity; this addition cannot be adequately represented in ABMs, because by their very nature they are not radically open and can therefore only represent reducible contextuality. This does not mean that ABMs cannot be usefully applied to systems that are complex in this extended sense; it only means that one has to be aware of the inherent limitations of the model, which stem from the fact that the models cannot represent the full complexity of the system.

The physics and ABM models, they claim, provide oversimplifications of real-world complexity in living systems. They do not believe that these models are basically inappropriate and distorting, just that they have less than universal applicability. Chu, Strand and Fjelland (2003: 27) tell us: 'the oversimplification that we find in physics is of broad applicability, but by no means of universal applicability'. Their solution is 'to focus more on *properties* of complex systems, rather than the detailed mechanism. For instance, we would like to encourage empirical investigations into the presence and nature of radical openness and contextuality', keeping in mind 'that there is something inherently uncomputable about complex systems' (Chu *et al*. 2003: 29).

A New Demand-side Approach to Living Systems

The central argument in this paper is that the physics model for analysing complex living systems is not just an oversimplification resulting in less than universal applicability, but that it is *entirely* inappropriate. By assuming that complexity emerges from the local interactions of adaptive agents, and by establishing a set of rules of engagement that can, through computer simulation, mimic the real-world pattern in which we are interested, we are constructing 'artificial societies' that have little in common with the world we inhabit. By employing this analogical approach we are, in effect, creating alien worlds.

How should we proceed in order to avoid this problem? While it may cause angst to many, we must abandon the deductive supply-side physics model and its analogical spin-off, the supply-side agent-based model. If, that is, we wish to understand the dynamics of real-world living systems. Yet this is not to say that these models do not have important uses. Clearly the physics model has been useful in analysing and predicting outcomes in extreme and restricting circumstances, such as traffic jams, panicking crowds in confined spaces, and even *short-term* fluctuations on the stock exchange. And ACE simulations, like similar work in traditional econometrics, can be useful for 'black-box' predictions, when it does not matter how unrealistic the model is, provided its predictions are fairly accurate, if only in the short-run.

The only way to proceed is by employing the method of induction. By careful and systematic observation of the way living systems, both human and nonhuman, change over time, it is possible to construct a realist general dynamic theory. It was for precisely this reason that I have been engaged on a large-scale project – the 'global dynamic systems' (GDS) project – for the past couple of decades. In a series of books published over that time, I have been able to develop a general dynamic theory of living systems – the so-called 'dynamic-strategy theory'. As it turns out, the construction (rather than the 'emergence') of complex systems is the outcome of a process of 'strategic exchange' between the demand and supply sides of dynamic living systems, rather than the outcome of supply-side local interactions between agents. This is the breakthrough required in the quest for a general theory of complexity.

The essence of the dynamic-strategy theory is to be found in the strategic exchange between purposeful agents and their society's unfolding dynamic strategy. It is this *exchange* that lies at the very heart of the self-sustaining dynamics of living systems. Social agents are self-motivated and self-driven, and they construct complexity and order in a *creative* response to the continuously changing needs – via what I call 'strategic demand' – of their society. It is this creative exchange between the demand and supply components of a dynamic living system that generates changing genetic structures, technologies, ideas of all types, institutions, and organizations. By continuously attempting to meet society's constantly changing strategic demand, both the agents and their civilization are transformed in the long run. The creative process of exchange by which this takes place constitutes the 'life system' for the group of social agents in whom we are interested. Living systems, therefore, are 'autogenous' – or selfcreating – systems, as I have demonstrated elsewhere (Snooks 2006, 2007).

Selfcreation is an entirely new concept. In the selfcreation model, strategic exchange determines all other relationships, including the interaction between its constituent members, in any given life system. Strategic exchange, therefore, is the core dynamic process, whereas agent interaction is a derived and, hence, secondary process. What this implies is that cooperation is central to what I call the 'strategic pursuit' – or life process – while competition between agents is an attempt at the margin to improve individual strategic advantage. And cooperation is the outcome not of reiterative interactions between agents as claimed by game theorists but of the need to ensure the success of a joint strategic pursuit. A society's strategic success is immeasurably more important to every individual than changes in the individual pecking order are. Theorists of self-organisation appear to have lost sight of this critically important point – a point that has major implications for biotransition as well as technotransition.

A General Dynamic Theory of Living Systems

The concept of selfcreation is based on a realist general dynamic theory called the 'dynamic-strategy theory'. This demand-side theory, which is based on long-term, systematic observation of the fluctuating fortunes of living systems in the natural and human worlds, has been published by the author in a series of books and articles over the past two decades (Snooks 1993, 1996, 1997, 1998, 1999, 2002, 2003, 2005, 2006, 2008). It is the only endogenous demand-side dynamic theory ever to have been formally developed. As I can provide only a schematic version of the dynamic-strategy theory here, interested readers might like to consult some of these publications.

Overview

Essentially the dynamic-strategy theory consists of a self-starting and self-sustaining interaction between the organism and its society. This endogenous dynamic process occurs within the context of a largely stable physical environment, which occasionally changes in random and unsystematic ways. Most other theories, in which life is driven by asteroid impacts, massive volcanic eruptions, major climatic change, or other erratic energy inflows, are exogenous in nature. The origin of life in this theory is identified not with the ability to replicate, as the Darwinists claim, but with the establishment of an internal metabolic process (Snooks 2005). This process generates a metabolic demand for fuel that can be met only by the pursuit of a four-fold set of dynamic strategies. Replication, once the trick had been learned, was merely one of those strategies.

The dynamic-strategy approach leads us to an important conclusion, which will be of interest to all scientists concerned with the origin of life. It is that life emerged many times before the dynamic strategy of replication was finally discovered, thereby transforming it into a cumulative and exponential process. The significance of the emergence of systematic replication is that it made possible the beginning of what I have called the 'law of cumulative biological/technological change' (Snooks 2003: 287–288). This law underlies the exponential growth of life over the past 3,800 million years, which has taken place at a *constant* compound rate of growth. This discovery (Snooks 1996: 79–82, 92–95, 402–405) revealed that each major biological/technological transformation during the history of life on earth (Figs 1–3) took only one-third the time of its predecessor. In other words, the coefficient of acceleration of life on earth is a constant 3.0. A more complete explanation can be found in my article on 'The Origin of Life on Earth' in *Advances in Space Research* (Snooks 2005: 229–31). This relationship has become known as the Snooks-Panov algorithm (Nazaretyan 2005a, 2005b).

In its most general form the dynamic-strategy theory consists of four interrelated elements and one external and random force. These elements and forces include the following.

1. The internal driving force, which arises from the need of all organisms to survive and prosper, provides the theory with its self-starting and self-sustaining nature. This is the concept of the 'materialist organism', which is driven by the basic need to fuel its metabolic process. The only alternative is starvation and death.

2. The four-fold 'dynamic strategies' – genetic/technological change, family multiplication (procreation plus migration), commerce (symbiosis), and conquest – are employed by individual organisms, or 'strategists', through the process of 'strategic selection' to achieve their material objectives. Strategic selection displaces natural selection as the key not only to biological, but also technological, change.

3. The 'strategic struggle' is the main 'political' instrument by which established individuals and species ('old strategists') attempt to maintain their control over the sources of their prosperity, and by which emerging individuals and species ('new strategists') attempt to usurp such control. This is the real nature of 'agent interaction'.

4. The constraining force operating on the dynamics of a society/species/dynasty is the eventual exhaustion not of natural resources but of the dominant dynamic strategy – or, at a higher level in the dynamic process, the genetic/technological paradigm (see Figs 2 and 3). This leads to the emergence of internal and external conflict, environmental crisis, collapse, and even extinction. This is the outcome of strategic laws and not power laws.

5. Exogenous shocks, both physical (continental drift, volcanic action, asteroid attack, climate change) and biological (disease and unforseen invasion), impact randomly and marginally on this endogenously driven and shaped dynamic system. Only exhausted systems that would have collapsed anyway are terminally affected; viable ones shrug off these external impacts.

The dynamic-strategy theory, therefore, views life as a 'strategic pursuit' in which organisms adopt one of the four dynamic strategies in order to achieve the universal objective of survival and prosperity. The 'choice' is based on a trial-and-error process of what works best in any given strategic and paradigmatic environment. In the pre-human world, at times of resource abundance the genetic strategy is chosen and speciation is the outcome; when competition is moderate, organisms switch to either the family-multiplication or commerce strategies, and take their 'genetic style' to the rest of the accessible world; and when competition is intense, organisms adopt the conquest strategy, which leads to declining species diversity (*negative* speciation), environmental crisis, collapse, and extinction. The operation of this strategic sequence is the real explanation of the 'punctuated equilibria' genetic profile apparent in the fossil record. Over the history of human society the sequence has been: family-multiplication (Paleolithic era), conquest or commerce (Neolithic era), and technological change (modern era). This strategic sequence explains the dynamic profiles in Figs 2 and 3.

Dynamic Mechanism

The all-important driving force in this dynamic system, which provides the self-starting and self-sustaining process, is the ‘materialist organism’ (or ‘materialist man’), striving at all times, irrespective of the degree of competition, to increase its access to natural resources in order to ensure sufficient fuel to maintain its metabolic processes. It is the most basic force in life – a force I call ‘strategic desire’ – which can be detected in man as well as in other life forms (Snooks 2003: chs 9 and 11). More intense competition merely raises the stakes of the strategic pursuit, and leads to conquest rather than genetic change.

As organisms and their ‘societies’ exploit their strategic opportunities, the dominant dynamic strategy unfolds (until it is finally exhausted), generating a ‘strategic demand’ for a wide range of inputs required by this life-generating process. These essential inputs, which include natural resources, institutions (rules), organizations (net-working), and ‘ideas’ (genetic, technological, and cultural), are supplied within social groups in response to the promise of prosperity. This strategic exchange between the organism and its society is the dynamic mechanism that generates the long-run increase in biomass/GDP at the local and global levels.

The mechanism of strategic exchange is a *creative* process, involving an innovative response of individuals and groups to the changing requirements of their life system. It is responsible for generating new ways, both genetic and technological, of exploiting natural resources. The long-run outcome of this strategic exchange is the transformation of both the individual and its ‘society’. While the driving force originates with the individual organism, the directing and shaping force is strategic demand. Strategic demand shapes all relationships in a given society, including those between its interacting members. Hence, strategic exchange is a cooperative process aimed at maximising the success of a joint strategic pursuit, while member (or ‘agent’) interaction is merely a secondary process. This is why the physics and ABM approaches, which focus exclusively on the supply-side, are unable to generate a workable general dynamic theory of real-world living systems.

Dynamic Pathways

The development path taken by a society/species/dynasty, which consists of a series of ‘great waves’ as shown in Fig. 1, is determined by the unfolding dynamic strategy and sequence of dynamic strategies adopted by the majority of organisms. There is nothing teleological about this unfolding process, which is the blind outcome of organisms exploring their strategic opportunities on a daily basis in order to gain better access to natural resources. They do so within the framework of opportunities provided by strategic demand by ‘investing’ time and effort in this endeavour. Successful individual strategies for survival and prosperity become the dynamic strategies of entire societies/species/dynasties through the process of ‘strategic imitation’, whereby the conspicuously successful pioneers are imitated by the vast mass of followers (Snooks 1996: 212–213; 1997: 37–50). Choice is definitely not based on complex cost-benefit calculations even in modern human society, owing to the need to economise on what I suggest is the scarcest resource in the universe – intelligence (Snooks 1997: 46–49). Those that pioneer new dynamic strategies do so on a trial-and-error basis in response to strategic demand, while all others in that ‘society’ follow those who are conspicuously successful.

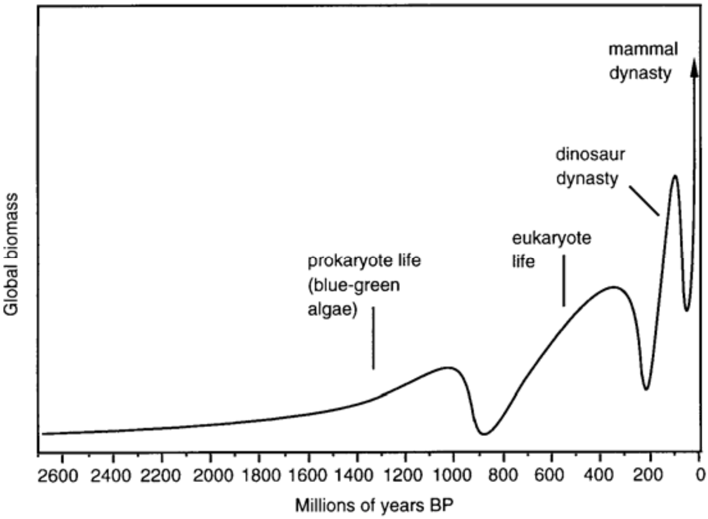

Fig. 1. The great waves of life – the past 4,000 million years

The development path of life, therefore, is an outcome of the individual/group exploitation and eventual exhaustion (when the costs of additional investment are as great as the returns) of a dynamic strategy or sequence of strategies. Once replacement strategies are no longer available, the society/species/dynasty stagnates and eventually collapses. Hence, the rise and fall of groups of organisms at all levels of existence, which generates the great-waves patterns shown in Figs 1–3, is the outcome of the strategic pursuits of the individual organisms they contain. The demand-side dynamic-strategy theory, therefore, can explain both the micro and macro aspects of both human society and life. This is something that the usual supply-side theories of complexity and self-organisation are unable to do.

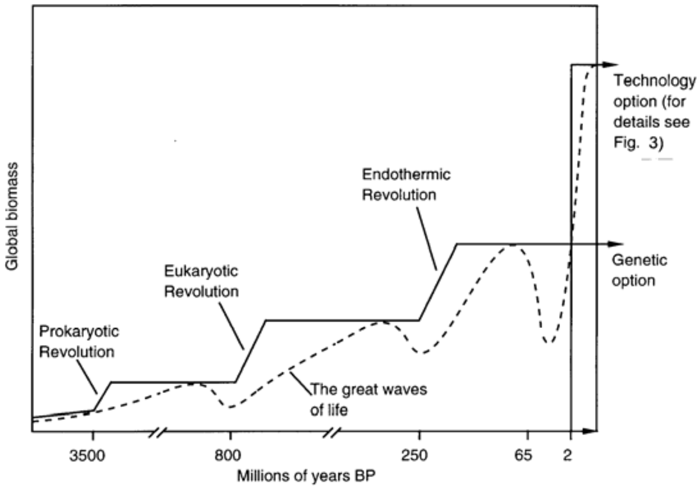

Fig. 2. The great steps of life – the past 4,000 million years

It is important to realise that dynamic pathways – the great waves of biological and technological change – taken by complex living systems are shaped by strategic demand as dynamic strategies and technological paradigms unfold. They are *not* the outcomes of supply-side constructs such as 'attractors', 'energy landscapes', self-organised criticality, or historical contingency. In other words, the dynamic pathways of living systems are the outcomes of systematic and creative decision-making in response to long-run structural changes in societal parameters. They are responses not to power laws but to strategic laws.

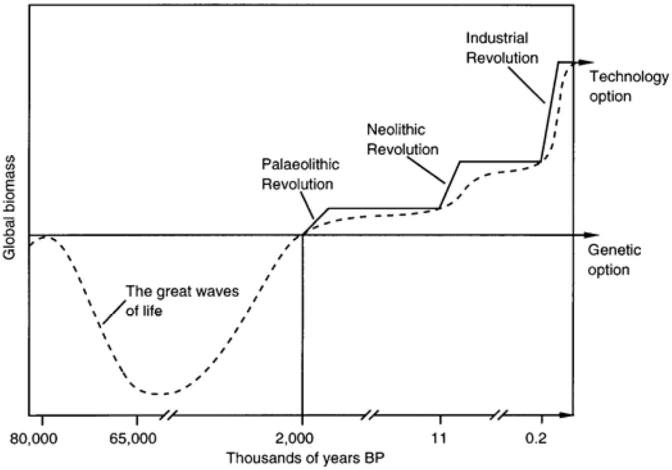

Fig. 3. The great steps of life – the past 80 million years

Strategic Selection – the Key to Selfcreation

The choice of dynamic strategies is central to this theory. Under the dynamic strategy of genetic change, the physical and instinctual characteristics of organisms are gradually transformed in order to use existing natural resources more intensively or to gain access to previously unattainable resources. The outcome of pursuing the genetic strategy is the emergence of new species, or what I call ‘genetic styles’ (to be compared with ‘technological styles’ in human society). On the other hand, the family-multiplication strategy, which consists of procreation and migration, generates a demand for those characteristics that increase fertility and mobility, in order to bring more natural resources under the control of the extended family; the commerce or symbiotic strategy requires characteristics that enable organisms to gain a monopoly over certain resources and/or services that can be exchanged for mutual benefit; and the conquest strategy demands weapons of offence and defence to forcibly extract resources from, and to defend resources against, one's neighbours. The mechanism by which these physical and instinctual changes in organisms are achieved brings us to the centrally important, and radically new, concept of ‘strategic selection’.

Strategic selection distinguishes the dynamic-strategy theory from all other theories of life. It displaces the ‘divine selection’ of the creationists and the ‘natural selection’ of the Darwinists. Strategic selection empowers the organism and removes it from the clutches of gods, genes, entropy, and blind chance. It formally recognises the dignity and power that all organisms clearly possess and, in particular, reinstates the humanism of mankind that some ultra-Darwinists and physical theorists deny. But this is not why it has been adopted. Strategic selection has been adopted because, unlike all other equivalent concepts, it works.

While only a brief outline of strategic selection can be given here, a full explanation can be found elsewhere (Snooks 2003: chs 10 and 12). Organisms respond to the ever-changing strategic demand for a variety of biological and instinctual inputs into the strategic pursuit. The reason they do so is to satisfy ‘strategic desire’ by maximising the probability of survival and prosperity. Those possessing the characteristics required by the prevailing dynamic strategy will be, on average, conspicuously more successful than their peers in gaining access to natural resources. This success will attract the attention of other organisms with similar characteristics. Through cooperative activity, these similarly gifted organisms will maximise their individual as well as group success. If of different gender they will mate and pass on their successful characteristics to at least some of their offspring, through the mechanism of ‘selective sexual reproduction’. They may even cull – or allow their stronger offspring to cull – those offspring that do not share these successful characteristics. This occurs in animal and human society alike to increase the probability of their survival and prosperity.

In the strategic selection process, only those mutations that assist the prevailing dynamic strategy are taken up, by selective sexual reproduction and cooperation between the individuals possessing them; all others are ignored by avoiding, boycotting, even destroying those regarded as ‘freaks’ and ‘mutants’. The theory of strategic selection possesses two unique characteristics. The first is that individual organisms are responsible for the process of selection, which is employed to maximise the probability of their survival and prosperity and not that of their genes. And the second is that strategic selection operates under the full range of competitive conditions, ranging from high to low levels of intensity. Strategic selection, therefore, can explain not only the origin of life and recovery from major extinctions, but also all the great diasporas of life and its great conflicts, crises, and collapses. It also explains the choice of dynamic strategies in human society (Snooks 1996, 1997).

Strategic Struggle – the Real Nature of Competitive Interaction

The real nature of competitive interaction is explained by the process of strategic struggle, which takes place within the boundaries dictated by strategic exchange. Strategic struggle is undertaken by individuals and groups in order to maintain/gain some control over their society's dynamic strategy. To do so they employ the dynamic tactics of order and chaos. The tactics of order, which include the threat of punishment or ostracism and the enforcement of customary rules, are employed by insiders to maintain and exploit the status quo; and the tactics of chaos, which include attempts to undermine the authority of the existing leadership, are employed by outsiders to disrupt the existing order as the basis of takeover. In both cases the aim is to maintain or gain some control over the dominant dynamic strategy – not to destroy it – because it is the source of survival and prosperity. In the process, political structures are transformed.

In the non-human world, combat between males of many species is not primarily about sex as usually argued, but about a struggle to maintain/gain control over the sources of their dynamic strategy – namely the territories needed to provide access to food and shelter (Snooks 2003: 209–210). These struggles permeate the entire society but are particularly significant when between leaders of different dynamic strategies or dynasties (such as between the archosaurs and therapsids) as they determine the rise and fall of genetic paradigms. Similarly in human society, these struggles occur both to maintain/gain control of the dominant dynamic strategy (such as the civil wars in Rome between the supporters and slayers of Julius Caesar) and to enable a new dynamic strategy to triumph over an old one (such as the political struggle in Britain during the first half of the nineteenth century between the new industrialists and the old commerce-based, land-owning aristocracy). The point is that these struggles and the resulting change in political structures are outcomes not of supply-side local interactions but of a systematic response to the changing strategic and paradigmatic conditions in society that are communicated via strategic demand.

Conclusions

Our understanding of the dynamics of complex living systems has been handicapped by the scientific methods we have adopted. By assuming that the supply-side physics model could be transferred either whole (as in social physics) or in part (as in ABMs) from inanimate to living systems, we have distorted the picture of reality. And we have delayed the construction of a general dynamic theory of living systems. This impasse could only be overcome by substituting the inductive for the deductive and analogical methods. Only by systematically observing the fluctuating fortunes of nature and human society has it been possible to discover the forces driving and shaping living systems. This discovery shows that the physics assumption that complexity is the outcome of supply-side interactions between local agents cannot be substantiated. Social reality is far more complex. The universal core mechanism in social reality is what I have called strategic exchange, which is a demand-supply phenomenon. It was this discovery that enabled theorists of complex systems to finally break through the physics ceiling and to achieve what many have come to think of as undoable – to construct a general dynamic theory of life. It was this discovery that enabled the construction of the dynamic-strategy theory presented in this paper.

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Abstract

The ultimate objective of theorists studying living systems is to construct a general theory of life that can explain and predict the dynamics of both human and non-human systems. Yet little progress has been made in this endeavour. Why? Because of the inappropriate methods adopted by complexity theorists. By assuming that the *supply-side* physics model – in which local interactions are said to give rise to the emergence of order and complexity – could be transferred either entirely (social physics) or partially (agent-based models, or ABMs) from the physical to the life sciences, we have distorted reality and, thereby, delayed the construction of a general dynamic theory of living systems. Is there a solution? Yes, but only if we abandon the deductive and analogical methods of complexity theorists and adopt the inductive method. With this approach it is possible to construct a *realist* and *demand-side* general dynamic theory, as in the case of the dynamic-strategy theory presented in this paper.

4

Ecological Darwinism or Preliminary Answers to Some Crucial though Seldom Asked Questions

Edmundas Lekevičius

Introduction

As a matter of fact, Darwin's theory on natural selection consists of two constituent parts: the ecological and the genetic one. The first of them ('struggle for existence') deals with a surplus in offspring and unfavourable environmental factors, which cause mortality of the former. The part of genetics focuses on undirected variability and inheritance of selected traits. Geneticists of the 20th century specified and elaborated the latter part of the theory. Meanwhile, the first part of the theory fell into the hands of ecologists and also underwent elaboration. However, ecologists did not restrict themselves to 'struggle for existence' and created something that was new in principle, *i.e.* the ecosystem conception. Many of its statements are still valuable to date. Strange as it is, until recently evolutionists have hardly made any use of this part of ecology, and it lingered where it was created. It is strange because when referring to any hypothetico-deductive theory (Darwinism is undoubtedly such a theory), it is advisable from time to time to revert to its original postulates to verify if they are in agreement with new data (Popper 1959). The ecological part of the natural selection theory deals with the way organisms react to the environment. If these relations are not restricted just to 'struggle for existence', it is not only possible but advisable to supplement the premises of the theory with the new ones. In turn, conclusions following from the original statements will change. So, if we want to have a more profound evolutionary theory which better corresponds to the present-day achievements, we must revert to Darwin's original premises and reassess them not only from the viewpoint of genetics but also from that of ecology.

I am pretty sure that the need for a new evolutionary theory is felt most strongly by those who cannot find answers to the questions concerning the 'essence' of life and the main regularities of its functioning and evolution. It is quite possible that the majority of biologists believe that all the questions of fundamental significance have already been answered. I assume such a viewpoint to be excessively superficial. I think that it is only with the help of eco-

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logical theory that it is possible to give an answer to many fundamental questions which traditional biology did not even raise. For instance:

- Why does life exhibit such a peculiar organization: with strong integration at lower levels of organization and weak integration at the higher ones?
- Why did particular species and guilds appear on the evolutionary stage at that particular time and not at any other?
- Why was the functional structure of ecosystems prone to convergence despite a multitude of stochastic factors?

The material presented in this survey raises hope that answers, tentative as they are, to these and the like questions may be perceived in the near future. Such ‘ecologizing’ of Darwinism is likely to benefit not only this theory but ecology itself as well.

The Possible Methodological Framework for the Future Evolutionary Biology

Let us start by formulating the main methodological principles, *i.e.* particular ‘recipes’ which should be followed if we want to guarantee success in devising a more extensive synthesis.

It is usually claimed that populations and ecosystems are complicated and difficult to investigate objects; subjects of study of molecular biology and especially biophysics are less complicated by comparison, therefore progress in these spheres is greater. My opinion is slightly different: the complexity of life phenomena is largely the creation of our own minds and is a consequence of research methods applied that are not entirely adequate. At first glance it seems that life is objectively complex only if we measure complexity in terms of heterogeneity or the variety of structures. Biologists who talk about the complexity of life very often appeal to the abundance of links as well. And in this regard they are right again: multicausality is the result of this abundance. However, it is quite possible that life will lose most of its complexity when the new method of logical simplification that has been ignored heretofore is applied. I will try to propose the guidelines for such simplification.

I would define *Recipe 1* in the following way: *the deductive method, especially thought experiments, should not be avoided while pursuing wider biological synthesis*. Biologists have largely ignored the deductive method. Undoubtedly, this has led to adverse consequences and it is hard to explain exactly why this has happened. It is possible that the majority of biologists identify the deductive method with axiomatic methods, which are unacceptable to most biologists, and maybe not without good reason. I am also sure that almost all biologists associate deduction with mathematical methods, which is also a real misunderstanding. We use deduction in our everyday lives, and without it we would be simply unable to understand each other. Although Darwin generated a number of ideas through deduction and without using mathematics, most biologists understand and appreciate their value.

The essence of *Recipe 2* is as follows: *while proceeding with the development of evolutionary theories (deriving evolutionary regularities from functional ones) initiated by Darwin, it is necessary to revise not only the conception of the 'struggle for existence' but also the attitude towards the nature of intra-organism links adopted in Darwin's lifetime.* The main question is: what is the nature of the 'part-whole' relationship at every level of organization, starting with macromolecules and ending with ecosystems. Such union of functional biology and evolutionary biology makes it possible to explain the maximum number of phenomena on the basis of the minimum number of statements. This is the main purpose of any logical simplification.

Recipe 3: While analyzing the causes of biological phenomena, it is recommended that the widest implications of cause-effect relationships be given consideration. Of course, this recipe can be useful only to a theorist pursuing synthesis. The well-established tradition, which encourages interest only in direct relations is potentially disastrous to theoretical work aimed at synthesis. However, it must be noted that a physicist or chemist would hardly admire this recipe, and many may claim that it would make the biological view of the world even more complex, but we should not be concerned with that; as it becomes clear through causal analysis of this type, that biotic connections are 'neatly built' and characterized by a particular hierarchy. Using this recipe, it has been established, for example, that it is not only plants that participate in the process of photosynthesis (as it is usually considered) but almost all the local ecological community (Lekevičius 1985).

Recipe 4 recommends using a qualitative or conceptual method of modeling. Even though this method is used in biology quite widely, I suppose I should describe it in greater detail. This modeling can be viewed as intermediate between verbal and mathematical modeling. Darwin's theory of natural selection can be considered as a typical verbal model. To transform it into a qualitative model, it is necessary to formulate and define its original terms and statements (premises) strictly. Qualitative models would include graph diagrams indicating only trends and various kinds of diagrams displaying connections between objects and phenomena and the like. The disadvantage of this modeling is its insufficient precision. However, there are particular advantages to using this modeling also: it does not restrict the modeler to any particular mathematical apparatus, the researcher therefore has much more freedom to raise questions and suggest hypotheses than he/she would have if mathematical modeling was employed. This kind of modeling additionally offers the opportunity to 'cover the uncoverable' (see *Recipe 3*). Furthermore, it allows adapting the method to the aims and research objects rather than the other way round, which is often the case, especially in ecology and evolutionary biology when mathematical methods are employed. Mathematical modeling could even follow from qualitative modeling as it usually happens in physics.

According to the instructions of *Recipe 5, one of the main ways to engage in logical simplification is to adopt the functional point of view.* This rule is based on the fact that the variety of structures (macromolecules, sub-cell organelles, cells, organs, genotypes, phenotypes, and species) is far richer than the variety of roles or functions that these structures perform. From the structuralist point of view, every enzyme is fairly complicated, and in order to describe this variety in detail, an exhaustive and difficult research effort is required. Meanwhile, its function is comparatively easy to identify and can be defined in a single sentence. Additionally, simplicity can be seen in the fact that the organization of life in its entirety is based on a certain hierarchical system: general functions, such as local nutrient cycling, can be fulfilled only through partial functions that are performed by individual guilds and species of the ecosystem. To attain simplicity, it is necessary to abstract from details. In our situation abstraction is easy to achieve because nature seems to have already provided it for us through the manifestation of a few functions (‘emergent’ features) present at the highest levels of organization. This sharply contrasts with the abundance of partial functions found at lower levels.

The Nature of ‘Part-Whole’ Relations

Let us conduct a thought experiment. Let us imagine an organ in isolation and try to find an answer to the question as to how long it could survive without the appropriate biotic context, in this case – the organism (1). Let us now do the same with an individual animal or plant (2) and any population (3). The results are going to be more or less as follows. The organ will cease to function very soon, the individual will, however, survive for a longer period of time, and the population will survive still longer. It does not matter if you isolate an individual plant from its biotic environment, the whole population, or all ‘autotrophs’ of a particular ecosystem. The result in all cases is going to be the same – loss of life. The only difference, when compared with animals, might lie in the fact that some ‘autotrophs’, when isolated from detritivores (= decomposers) will be able to survive for a longer time – up to a few years or a few decades, depending on the amount of supply of inorganic nutrients available at the beginning of the experiment.

This fact illustrates that functional autonomy is not characteristic of any of these structures. If the biotic environment is eliminated they can not be considered to be alive, in a sense. Following similar logic, biologists have claimed that viruses are not live organisms since they can only reproduce using the nuclear apparatus of a host's cell. This verdict does not seem to be controversial, but then, using this same logic, we may ask why we consider a deer or a lion, for example, to be alive.

Having conducted these experiments you will be forced to admit that in some sense the main feature of being alive, *i.e.* functionally autonomous, is only typical of an ecosystem, since life cannot last independently without nutrient cycling. The formula ‘only an ecosystem is living’ should be interpreted in the following way: a nutrient cycle is an emergent feature shaped by the coordinated activity of the whole ecological community (at least that of ‘autotrophs’ and detritivores). Let us call the local cycle and the energy flow that follows it the global function. The activities of individual guilds or species, then, could be treated as partial, or minor, functions, those of separate individuals – as even smaller functions, and so on, until we come to the functions of macromolecules. Eventually, we arrive at what systemologists refer to as a functional hierarchy. This concept might be more convenient to use, but it essentially means the same as functional dependence. It follows then that it is not simply integrity that is characteristic of life, but integrity based on mutualism, or links of reciprocal dependence. A biological species is not an aim *per se*, as it is usually assumed, but a means also.

This can still be expressed in a different way, by adopting the concept of labour division that Darwin (1872) was so very fond of: nutrient cycles are the outcome of common activity of individual species that are involved in labour of a narrower kind. Each of them performs a different operation. Again, specialization in reproductive or any other function is available within the population framework. This is directly analogous to the division of labour typified by the arrangement of organs, cells and macromolecules in a single living being.

There might be, in fact, several varieties of hierarchy. One kind of hierarchy is typical of clockwork mechanisms, for example, another kind of hierarchy – of a multi-cellular organism, and still another one – of a population or a community/ecosystem. Clock-parts have no capacity for reproduction. It might be claimed that the structure of a clock is therefore inflexible and completely inert, and that its parts therefore lack the ‘freedom’ to pursue their own self-interest. A multi-cellular organism has a more or less different hierarchy of functions, with cells of an organism capable of proliferating and therefore having some freedom to pursue their self-interest, although minimally. An organism is flexible and can adapt to the ever changing environment (physiological and biochemical adaptation), the freedom to pursue self-interest at the level of sub-individual structures being a prerequisite for this. Cells might even compete with each other while pursuing their individual ‘goals’; experiments with chimeras largely contributed to this conclusion (McLaren 1976; see also the review by Lekevičius 1986: ch. 3.4). As far as individuals and species are concerned, they possess even greater freedom. This freedom is so great that the majority of ecologists still conceive of nature as being governed by competition (‘biotic repulsion’) and still argue that interdependence (‘biotic attraction’) does not exist at all at the levels of population and ecological community; and even if it does, this interdependence can be ignored. Extensive biological data show that individuals and species use this freedom for their own ‘purposes’ which are usually related to generating even larger populations.

To my mind, the analogy of the two-faced Janus can be used (Koestler 1967) to reveal the essence of the part-whole relationship. The side of his face that is turned upwards, towards the higher level of organization, shines with obedience and devotion, whereas the one turned downwards is the face of an individual who recognizes only his own objectives. Biosystems can be regarded not only as multilevel, but also as multigoal systems (Mesarović *et al.* 1970) in the sense that the goals of individuals and species do not necessarily have to be the same. Their respective objectives might even be in conflict with one another, which is what we usually observe in nature. On the other hand, the fairly great freedom of action that is noticeable at these levels seems to be very useful to ecosystems when they have to adapt to drastic and unpredictable environmental changes. So, the functional hierarchy in nature is not rigid or stiff. From a functional point of view, biotic components, starting with cells and ending with species, do not only depend on each other, but are also conditionally independent, as they cooperate and compete with each other simultaneously. The interaction of these two opposite forces, ‘biotic attraction’ and ‘biotic repulsion’, determines the behaviour of life and its evolution.

The functional hierarchy cannot be realized without an adequate hierarchy of control. However, there exists no control device at these levels of organization, which is similar to that of multi-cellular organisms. Many people may consider this situation absurd, but this is nothing new for experts in systems theory. This type of control has been termed as diffusive or passive (Novoseltsev 1978; Lekevičius 1986). It is achieved through the interaction of subsystems, whose behaviour towards control is the same. During these interactions, certain constraints (positive or negative feedbacks), helping the whole to control its constituent parts, emerge. These constraints usually evolve because not all combinations of subsystems or their activities can ensure stability. Populations and ecosystems therefore adjust on their own, without any external contribution. It means that joint efforts help ecological communities not only to support local nutrient cycles, but also to ensure their conditional independence from various kinds of inner and external perturbations. In other words, global parameters, vitally important for the whole biota, are homeorhetic because of self-organization and self-regulation. Nutrient cycles are the most highly buffered features of life (Lekevičius 1986).

It might be even easier to understand how the ecosystem's functioning is controlled by considering an analogous example of capitalist economy, the laissez-faire mode in particular. The forces of ‘repulsion’ and ‘attraction’ in capitalist economy are almost equal in power, their counterbalance being nearly the same as that in nature. The initiative and the right to decide belong to individuals. Although, as a rule, they pursue self-interest rather than the interest of society, the society, guided by an ‘invisible hand’ (in fact – by the market), inevitably tends towards the universal well-being. This conception became popular in England as the paradox of private vices and public benefits.

Incidentally, Darwin was probably the first to notice parallels between the organization of economy and that of nature. They have also recently been discussed by Salthe (1985) and Lekevičius (2009a). Naturally enough, using analogies is not an appropriate way to explain something. However, I do think that it may be beneficial for the clarification of statements.

Why does life exhibit such a peculiar organization: with strong integration at lower levels of organization and weak integration at the higher ones? To answer this question, let us think what animate nature would look like if individuals of the same and different species only cooperated, *i.e.* if competition as a phenomenon completely disappeared. A preliminary answer to this and some other questions of a similar kind has been provided by GAT, the general adaptation theory (Conrad 1983; Lekevičius 1986, 1997). According to the theory, if this hypothetical situation came into being, we would probably have both ecosystems and nutrient cycles. In fact, these would not be typical ecosystems; they would have a much greater degree of integration – somewhat comparable to today's coral reef ecosystems. These ecosystem-superorganisms would perform their vital functions incredibly effectively, but would fall to pieces like a giant with clay feet as soon as the first unusual environmental change took place. Specialization and integration allow maximizing the degree of adaptation, but that is incompatible with maximum adaptability. The capacity for disintegration and the conditional freedom of subsystems are essential attributes of life on this planet, where environmental conditions are continually changing to a great degree and are very often unpredictable.

What would happen in the opposite situation, *i.e.* if these relationships were only of a competitive type? I think that the most likely final outcome would be that only one species would exist in any given location at any given time; *i.e.* the one that would have replaced all the rest species, those that are not so well adapted to struggling for existence. And within this species, a single (‘wild’) genotype that has replaced all the genotypes of lower adaptive value would exist. Naturally, there would be no ecological communities or ecosystems under these circumstances. However, as it has already been mentioned, this sort of life would have no chances of survival since none of the species can maintain a nutrient cycle on its own. To summarize, it might be claimed that life has chosen a compromise between two incompatible strategies – to be maximally efficient and not to compromise adaptability. This compromise must have conditioned the long-term existence of life. However, the problem with this kind of an answer lies in its teleological implications. We could arrive at a far better answer if we discovered the evolutionary processes through which this form of life could emerge.

On Evolutionary Interdependence of Individuals and Species

Having applied the methodological recipe advocated by us (evolutionary regularities can be deduced from principles of functioning – *Recipe 2*), we come to the conclusion that even when evolving, individuals and species cannot have autonomy. Functional dependence inevitably leads to evolutionary dependence. It is clear that the most obvious manifestation of this regularity is likely to be observed in cases of cooperation and mutualism. For instance, it is clear that organs of a multicellular organism can evolve only in a coordinated manner. Otherwise, the integrity and vitality of an organism will be destroyed. Similarly, the evolution of members of the same population, which are bound by relations of interdependence, cannot be uncoordinated. For instance, an uninterelated evolution of males and females of the same population is difficult to imagine. In these cases, loss of coadaptation is equivalent to population extinction. It is also obvious that evolutionary changes in species bounded by mutualistic relationships cannot be uncoordinated either. For example, such coevolution should be characteristic of flowering plants and insects pollinating them. The same holds true for the relations between producers and detritivores of the same ecosystem: both these ecological groups should inevitably affect the evolution of each other, as they are mutually dependent. In short, coevolution or coordinated evolution is the inevitable outcome of functional dependence.

Populations of prey and its predators like those of hosts and their parasites also coevolve. For instance, extensive available evidence shows that prey/host populations accumulate features reducing exploiter-induced mortality. In length of time, the latter, in their own turn, acquire features enabling them to continue the exploitation of their usual prey/host. It is clear that not necessarily should the initiative come from exploited populations. Such coevolution usually leads to moderate exploitation. And only in case of moderate exploitation, we have the right to assert that both partners are coadapted. In this context, I suppose, I do not violate the terminological discipline, as, to my knowledge, the terms ‘coevolution’ and ‘coadaptation’ are treated in this way by the majority of users.

In my opinion, the evolution of most species was and still is restricted from every side, as the ecospace nearest to them was and still is occupied by other species well adapted to their environment. Species do not exist in some kind of ecological vacuum – both their functioning freedom and that of evolution are restricted. Therefore prohibitions have always outnumbered permissions. Stabilizing selection and evolutionary stasis are daily routine of animate nature. Many of the evolutionarily old species can be treated as living fossils, which is not because they lack variability, but because other species (most often those that have emerged later) did not leave free ecospace for the new variations to penetrate. This approach, in my opinion, considerably differs from the opinion that has been dominant for a long time. According to that view, the rate and success of evolution are predetermined only by genetic variability; and maybe also by climatic and edaphic conditions and geographical isolation.

In this context, permission is understood as a vacant niche, and, more exactly, as a vacant environmental niche. Two terms are used in ecology: an ecological or Hutchinsonian niche, on the one hand, and an environmental niche, on the other. The first one is understood as the totality of needs. The ecologists using the term 'an environmental niche', first of all, have environmental conditions in mind, which, in their opinion, can exist and exist independently of organisms. It is only they who use the term 'a vacant niche'. They understand a vacant niche as potentially usable resources. Solar energy having no consumer, some organic or inorganic substance as a potential source of energy, electrons or carbon can be taken as examples of such resources. Of course, a live organism also can be treated as a vacant niche if it does not have consumers (predators or parasites). For more information about the vacant niche concept see the survey by Lekevičius (2009b).

An occupied niche can be viewed as prohibition for another species to occupy it. However, this prohibition can be overcome in cases of successful innovations or immigration of stronger competitors. Sometimes it is more expedient to replace this term (prohibition) by the term 'constraints', which may sound less categorical. Of course, in addition to constraints associated with the availability or absence of resources, there are other types of constraints, such as thermodynamic, climatic or edaphic constraints. Their evolutionary impact is quite well-known and we are going to discuss them as well. In essence, prohibition can be associated with the fact that not all evolutionary trajectories ensure stability of living systems. For instance, ecosystem-level constraints are, first of all, negative feedbacks, which do not permit species to evolve in such a way that the local nutrient cycle should be disturbed. So, it is possible then to view permissions as positive feedbacks and prohibitions as negative ones.

Evolutionary Assembly of Ecosystems

Ecosystem 'assembly rules' may be formulated in the following way (Lekevičius 2002). It is quite possible that since the very moment of life appearance there existed quite a simple mechanism by which ecosystems and nutrient cycles were formed – end products of some organisms' metabolism turned into waste, *i.e.* into resources potentially usable though used by nobody. Such vacant niches provoked the evolution of organisms capable of exploiting those resources. The final result was that end products of detritivores' metabolism became primary materials for producers. The formation of ecological pyramids should have followed a similar pattern: producers provoked the evolution of herbivores, the latter – that of primary predators, and so on and so forth until eventually the evolution produced common to us pyramids with large predators at the top.

So, vacant niches not only stimulate diversification, but also determine its direction. And this fact, most probably, witnesses causality. This idea can be viewed as a keystone of evolutionary theory because it is not so difficult to explain, and, at least partly, predict results of diversification from data on vacant niches.

In order to clarify the vacant niche concept and its usage, I have constructed a **table** demonstrating some steps in ecosystem evolution.

The first terrestrial organisms should have probably been heterotrophs. The main shortcoming of the first ecosystem was that decomposition was carried out far more intensively than the chemical synthesis of organic matter. This misbalance might have caused the very first in the history of life ecological crisis, which finished with the rise of the first producers. The latter could have been green and purple non-sulfur bacteria, which carried out anoxygenic photosynthesis. They used organic compounds as a source of hydrogen (electrons).

Along with these bacteria, detritus-decomposing ones, too, are likely to have been involved in local nutrient cycles of that time. Their emergence and diversity was determined by the diversity of organic substances present in detritus. Already at that time cycles must have been non-waste, and decomposition was carried out to the very inorganic nutrients.

Table. Some of the vacant niches / adaptive zones that existed in the Archean and Proterozoic, and their occupants

Description of vacant niches / adaptive zones	Hypothetic occupants
Organic substances as donors of energy, electrons and carbon. Organic substances as final electron acceptors	Protobionts
Light as an energy donor, H_2S/H_2O as an electron donor and CO_2 as a donor of carbon	Green and purple sulphur bacteria, cyanobacteria
Detritus as an energy, electron and carbon donor. S^o and SO_4^{2-} as final electron acceptors	Sulphur- and sulphate-reducing bacteria
Fe^{2+}, Mn^{2+}, H_2S, CO, H_2, CH_4, NH_4^+ as energy and electron donors, CO_2 as a carbon donor. O_2 as a final electron acceptor	Aerobic chemolithoautotrophs
Detritus as an energy, electron and carbon donor. NO_3^- as a final electron acceptor	Denitrifying bacteria
Detritus as an energy, electron and carbon donor. O_2 as a final electron acceptor	Aerobic decomposers
Biomass as an energy, electron and carbon donor. O_2 as a final electron acceptor	Protists as ‘herbivores’ and decomposer-eaters
Biomass (‘herbivorous’ and decomposer-eating protists)	Protists as primary predators
‘Herbivores’ and primary predators	Multicellular organisms as secondary predators

In the Table, attempts are made to list events in chronological order, from the appearance of protobionts to that of secondary predators. Take note of the fact that some vacant niches / adaptive zones preexisted the emergence of organisms, while others were presumably created by organisms themselves (compiled from Lekevičius 2002).

As biomass accumulated, sooner or later aquatic resources of free organic compounds had to be depleted. That could have caused the rise of true autotrophs (photolithoautotrophs). The latter could have been green or purple sulfur bacteria, which used H_2S and H_2 as a source of hydrogen (electrons). Those bacteria accumulated sulfur and sulphates as waste, so after a while evolution should have brought about organisms reducing sulfur and sulphates. The vacant niche was occupied to make the cycle become non-waste again. After some time, however, the resources of H_2S and H_2 must have run short, that should have resulted in the appearance of cyanobacteria carrying out oxygenic photosynthesis. The merit of that kind of photosynthesis is in that it uses water molecules as a source of hydrogen (electrons). However, when oxygen turned into waste, it began to accumulate in water. As a result, the evolution of oxygen resistance was triggered off. Still after a while, presumably some 2.0–2.5 billion years ago, cyanobacteria and detritivores accompanying them became aerobes. It must have been at that time that all modern aerobic chemolitotrophs came into existence. The motives for their rise were very simple: oxygen accumulating in the environment reacted by itself with the dissolved in water ferrous iron and manganese, hydrogen, carbon monoxide, sulfur, hydrogen sulfide, ammonia, and methane. The energy produced during oxidation was lost. Naturally, those vacant niches became factors stimulating and directing evolution. Thus, after a while all those niches were occupied.

The nitrogen cycle was presumably assembled in the following way (for details see in Lekevičius 2002). At the dawn of life, nitrogen compounds, especially ammonia and ammonium ions, might have apparently been much more abundant in the atmosphere and waters. Thus selection pressure, forcing organisms to acquire the ability of nitrogen fixation, might have been absent for a while. Yet there are reasons to believe that later the amount of ammonia and ammonium ions in the environment decreased to minimum, and not only because part of it converted to organic nitrogen, the biomass. Due to the presence of cyanobacteria, oxygen began to accumulate in the environment and, affected may be by lightning, reacted with ammonia and molecular nitrogen, thereby producing oxides. Besides, as it has been mentioned above, soon thereafter originated nitrifying bacteria oxidizing ammonia and ammonium ions to nitrates. I think that could have given rise to selection pressure, which induced diversification of nitrogen fixing organisms and their spread. Nitrates immediately created a vacant niche that provoked the rise of denitrificators. The latter used nitrates as unchangeable under anoxic conditions glucose oxidizers, final acceptors of electrons. Due to nitrate respiration nitrates converted to free nitrogen. The global nitrogen cycle became closed. Accumulating in the environment nitrates might have soon become an additional source of nitrogen to cyanobacteria. Thus we obtain the following picture of the evolution of the nitrogen cycle (Fig. 1). I understand that this scenario of the changes in the nitrogen cycle is rather speculative, though it, seemingly, is in accordance with the one proposed by experts (Falkowski 1997; Raven and Yin 1998; Beaumont and Robert 1999). The difference lies merely in some details of secondary importance.

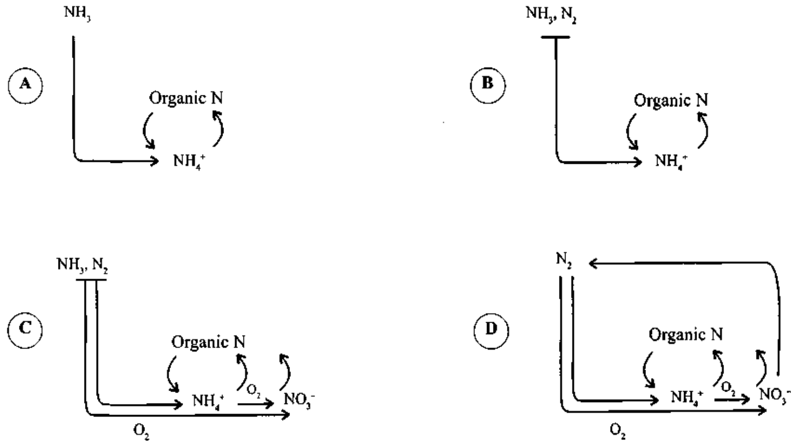

Fig. 1. Assembly of the nitrogen cycle. A – local cycles are formed; B – biological nitrogen fixation appears; C – nitrates are produced in large quantities; D – denitrification arises

There are sound reasons to believe that 2 billion years ago all modern global cycles – carbon, oxygen, nitrogen, sulfur – had been already formed. From the point of view of chemistry, they have not changed until nowadays (for details see Lekevičius 2002).

Two billion years ago, ecosystems were still composed of only two ‘functional kingdoms’– producers and detritivores. For quite a long time, some organisms exploited others not before the latter died. Accordingly, there must have been a huge adaptive zone. Its exploitation presumably started about 1.5 billion years ago, after the emergence of protozoans, although fossil records do not evidence the existence of organisms that could be called the first biophages. Hence, we are speaking about the appearance of the 2nd trophic level. Another possibility, *i.e.* the emergence of parasitism as a phenomenon at that particular time should not be ruled out either. The only certainty is that immediately upon emergence, organisms representing the 2nd trophic level automatically became an adaptive zone for the future 3rd level representatives, *i.e.* primary predators (see table). In their own turn, the latter became prey for the future bigger predators, *etc.* This self-inducing process, as a matter of fact, ended in the appearance of top predators in the Ordovician. It is quite probable that in length of time, in addition to predators, the newly emerging species acquired a set of parasites exploiting them. So, it seems that at the end of the Ordovician, a supply of vacant niches suitable for biophages was depleted.

Stages of terrestrial ecosystem development and its mechanisms did not differ much from those of marine ecosystems (for details see Lekevičius 2002):

appearance of producers (1), vegetative detritus (2), detritivores and local cycles (3), herbivores and organisms feeding on detritivores (4), primary predators (5), and so on up to the top-level predators. The latter came into existence in the late Carboniferous, approximately 300 million years ago. When the formation of the block of biophages finished in the seas and 135 million years later on land, there were almost no vacant niches left in ecosystems. Therefore cases of competitive exclusion, preconditioned by migration and the emergence of new forms, became more frequent. However, species diversification continued: life was penetrating into new territories, and what is more, the process of niche splitting was going on (Lekevičius 2002).

One may ask what there is new in such explanations of the well-known facts. In general, it is not customary in modern evolutionary biology to raise a question and to look for an explanation as to why certain guilds, let us say, aerobic chemolithoautotrophs or primary predators appeared on the evolutionary stage at that particular time and in that particular place. This can be probably explained by the fact that to find answers to questions of this kind, it is necessary to employ the deductive method, which is not popular with biologists. It has been only in this decade that somewhat wider, but still tentative use of the vacant niche term in the evolutionary theory has been started (see *Idem* 2009b). In case of failing to provide an explanation, a phenomenon itself is somewhat ignored. Another thing that makes my approach to evolution unconventional is that in respect of a population I emphasize external factors influencing the course of species evolution. Meanwhile, the conventional approach focuses all the attention on inner mechanisms. That does not mean of course that these approaches cannot be reconciled; they perfectly complement each other.

How Selection has Made Ecosystems Converge

The functional convergence of ecosystems was discovered quite long ago. Darlington (1957) wrote in his book *Zoogeography: The Geographical Distribution of Animals*:

> Neither the world nor any main part of it has been overfull of animals in one epoch and empty in the next, and no great ecological roles have been long unfilled. There have always been (except perhaps for very short periods of time) herbivores and carnivores, large and small forms, and a variety of different minor adaptations, all in reasonable proportion to each other. Existing faunas show the same balance. Every continent has a fauna reasonably proportionate to its area and climate, and each main fauna has a reasonable proportion of herbivores, carnivores, *etc.* This cannot be due to chance (Darlington 1957).

Here I would like to draw the reader's attention to one important, in my opinion, episode from the history of general ecology. It is known that the ecosystem conception was developed on the basis of empirical data obtained in the 1960s of the last century. It was discovered, for instance, that neither the number of trophic levels, nor the ecosystem structure in general is dependent on primary productivity, which is known to vary within very great limits on a world scale. Fortunately for ecologists, nature turned out to be undivided, in that respect. Otherwise, it would have been necessary to develop individual conceptions for individual ecosystems. Thus, ecosystem convergence was a trivial fact for ecologists of that time.

Time passed and ecologists of the older generation retired one after another to be replaced by young people interested in other problems. That was possibly due to the fact that in those times it was not easy to explain facts of the functional convergence of ecosystems, since they were hardly within the framework of the neo-Darwinian paradigm. It was difficult, or, according to somebody, impossible to build a bridge between a change in gene frequency in a population and a global phenomenon such as ecosystem convergence. It was ‘common knowledge’ that each species is affected by a multitude of internal and external factors and that its fate depends not only on an accidental genetic variability, but also on gene drift, climatic changes that are usually difficult to forecast, the impact of other species, and other difficult to define events. In the course of millions of years, these numerous factors must have produced such chaos of consequences in living nature that none of theorists was able to explain it. In a word, the opinion, which, by the way, persists to date, was formed that evolution is controlled by accidental forces and that it cannot be predicted. That is why the phenomenon of ecosystem convergence was and is out of place in the neo-Darwinian conception. On the contrary, facts of convergence contradicted the neo-Darwinian experience rather than supported it. However, it is known that facts do not necessarily refute theories. It is often the other way round – facts contradicting the generally accepted theory are simply ignored. Thus, it is no wonder that in the course of time the interest in that phenomenon gradually abated.

I propose using the notion of the functional convergence of ecosystems in a somewhat wider sense than that used by my colleagues some 20–30 years ago. I have in mind the invariability of ecosystem functions both in time and space. By this, I do not mean that ecosystems were not changing over time. I am inclined to take the view that approximately 2 billion years ago ecosystem metabolism finally became settled and since then nutrient cycles have been just replicated. The shape of production (energy) pyramids characteristic of local ecosystems seems to have undergone no considerable changes over the last several hundred million years despite all internal changes followed by numerous extinctions and adaptive radiations. Geographical invariance is also characteristic of these pyramids. Their form almost does not depend on the primary production, which may differ at least several ten-fold (the 10 % rule). Besides, when using the term ‘functional convergence of ecosystems’, it is necessary to have in mind the convergence at the level of individual species, too, *i.e.* a great abundance of ecological equivalents (species that have no consanguinity and live in different locations but have converged due to the fact that they occupy similar ecological niches).

As distinct from the traditional approach, I believe that all evolutionary processes are quite rigidly canalized. That role of canalization is performed by species interaction, which always and everywhere directs species evolution onto a few invariant ways. The raw material, from which evolution moulds a community, may differ. However, the final result, *i.e.* what the structure and function of that community is going to be like, is easier to predict because it often recurs both in time and space. God does not dice, so evolution could be predicted. But for this purpose of course one should have sufficient information not only about ancestral forms, but also about constraints. However, this information is as a rule lacking, because until today, in my opinion, evolutionists have not paid proper attention to factors constraining the evolution of species.

It is well-known that ecosystems may be assembled in two ways: via migration (ecological succession) and/or evolution. However, the final result does not depend on the mode of assembly, and that is evidenced by the fact of functional convergence. Probably, the same ecosystem-level constraints operate both in succession and evolution, although mechanisms are different. As a matter of fact, there are some similarities. Primary succession as a rule starts with the settlement of herbaceous plants (sometimes lichen). Then vegetative detritus is formed, niches suitable for the settlement of herbivores and detritivores (bacteria, protists, fungi and invertebrates) appear. As a result, necessary conditions for the appearance of soil are created (Olson 1958). In its own turn, the formation of soil stimulates the emergence of niches for new plants, woody plants among them. The latter change their surroundings, thus facilitating the settlement of still other plants and animals (facilitation theory – Connel and Slatyer 1977). The sequence of events is presumed to have been similar in the Palaeozoic when life occupied land (see above). However, then occupants came into existence mainly as a result of evolution *in situ*. So, I maintain that ecological succession may be interpreted as a process of niche filling as well, and it should not differ much in its course and final result (having in mind functional properties of ecosystems) from what is observed in cases of adaptive radiation and evolutionary recovery after extinction.

Odum (1969) put forward a hypothesis according to which ecological succession and evolution are characterized by the same trends of variation in ecosystem parameters (species diversity, primary production, total biomass, production and biomass ratio, efficiency of nutrient cycle). Although later this hypothesis was used as a target by many critically disposed opponents, it seems to be enjoying popularity among some ecologists and evolutionists (*e.g.*, Loreau 1998;

Solé *et al.* 2002; Lekevičius 2002, 2003) to date. In the opinion of these authors, forces directing the evolution of ecosystems are in fact the same as those controlling their routine action. Consequently, in both cases trends cannot differ much. This idea, that 'ontogeny' of ecosystems may recapitulate their 'phylogeny', I think, is quite attractive.

What is Selected *vs.* What is Making Selection

Extremist neo-Darwinians suggest that only the gene ('selfish gene') can be a unit of selection. Still others maintain that this role is more suitable for the genotype. Some evolutionists have claimed that differential survival may involve entire populations (species) and even ecosystems. Thus, there have been attempts not only to reveal mechanisms of individual features' evolution, but also to explain how parameters specific to populations and ecosystems could have evolved. So, there was hope to finally clarify how nature creates and maintains biodiversity and, on the basis of the latter, communities and nutrient cycles. Still others suggested combining all these ideas rejecting the mentality of 'either-or'. Thus the idea of hierarchic, or multilevel, selection emerged (*e.g.,* Williams 1966; Gould 1982; Wilson 1997; Gould and Lloyd 1999). According to this idea, differential survival involves all or almost all structures ranging from single genes to entire ecosystems. As far as I understand, these evolutionists do not doubt that evolving are not only individual features, but also populations, ecosystems, and even the biosphere. However, they believe that adaptation at any level requires the process of natural selection operating at that level. I think that here they make an essential mistake for they restrict the problem of selection to the question of what is being selected. What is more, they seem to be little interested in what is making that selection. Because of that, the problem becomes quasi-complicated and, unfortunately, insoluble. I am inclined to think that Darwin, however, was right in assuming that it is an individual that should be regarded as the major unit of selection.

As far as I understand, the problem of selection units has become so complicated and intricate because it has not been associated with functional biology. The imaginary wall between biological time and biological space hinders researchers from finding a solution to this problem. If this wall was demolished, the problem would immediately become quite simple and clear. The greater the integration of constituent parts of a biosystem is, the greater the possibility is that selection will affect the whole system as a unit. And on the contrary, if constituent parts of a system are functionally autonomous, they will be involved into the ever-lasting 'struggle for existence' and each of them will become a selection unit. Even ecosystem selection would be possible, if ecosystems functioned as real superorganisms. However, this is inconceivable either for populations, or for ecosystems. By the way, the question of selection units was already solved in a similar way by Rosen (1967), but his point, apparently, has been overlooked.

In my opinion, natural selection is a 'black box' turning non-directional inheritable variability into a more-or-less directed evolutionary development (Fig. 2). This is an essential attribute of selection. Differential survival and that kind of reproduction are merely external and most obvious features of selection. Quite possibly, selection may have another external form, too, but anyway it is the force constraining inheritable variability in a specific way.

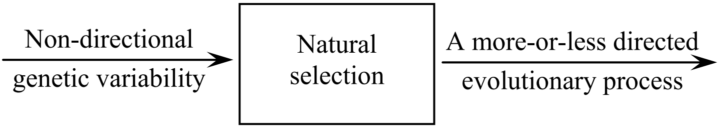

Fig. 2. Natural selection as functional constraints. Mutations and recombination create a field of potential evolutionary possibilities, whereas functional requirements constraint it in a specific way

Intraindividual constraints ('internal selection'), constraints emerging from the interactions of individuals of both the same and different species and from their interactions with abiotic surroundings are under discussion. Evolution at the levels of species and ecosystems progresses through genetic variability and differential survival and reproduction of individuals. Neither species selection nor that of entire ecosystems is necessary for the evolution to occur. Prohibitions and permissions that stimulate or suppress the spread of certain heritable variations emerge in the course of these interactions.

How does new genetic information in the form of a mutation or recombination become an attribute that changes the functioning of an individual, population and the entire ecosystem? Even the pathway of an especially successful mutation/recombination always begins from a single change in one of the cells. In the case of its success, novel genetic information passes several stages of strengthening. This may be done by means of the following mechanisms (Lekevičius 1986):

– transcription and translation of the newly emerged gene, increasing in concentration of mutant (recombinant) macromolecules in a cell;

– mitosis of cells carrying the gene;

– growth in the frequency of mutants (recombinants) in a population;

– growth of the population carrying the evolutionary novelty and widening of the species range.

Additionally, the variation has at least one more theoretical chance to be consolidated, which is to become the property of numerous species in the course of speciation.

As the novel genetic information is reinforced, an ecosystem reacts to it as to a gradually increasing internal disturbance. Individual – biochemical and physiological – mechanisms of adaptation are the first to respond. Mutants/recombinants are incorporated into adaptational and coadaptational processes at the population level after they pass barriers of internal selection. In case of success, new characters spread, but they have to prove they meet the requirements for constituent parts of an ecological community. If such coadaptation happens, evolutionary diversification might follow and novel genetic information is disseminated among several or more species. In summary, the spread of evolutionary novelty always evokes feedbacks from individual, populational and biocenotic mechanisms of adjustment, individual mechanisms being the first to react.

To sum up, traditional approach emphasizes selection units and cares about *what* is selected, whereas I propose taking interest in what *is making selection.* Differential survival and reproduction of individuals are merely external attributes and thus are the first impacts of adaptation to be noticed. It is functional constraints coordinating routine activities of individuals, populations and ecosystems that perform selection. They convert undirected hereditary variability into the far more directed evolutionary development. It is the individual that dies or produces fewer offspring, whereas structures, which may range from those of macromolecules to those of ecosystems, change and evolve. Moreover, competition is not necessary for the process of selection: it might be even more intense in the case of co-operation (for example, features disturbing inner balance of an organism are done away via internal selection, or variations reducing the co-adaptation of sexual partners are also successfully eliminated). The difference is that in case of co-operation, only the characters beneficial to all co-operating partners are selected, while in case of competition, only the characters that enhance the adaptedness of particular competitors are selected. Of course, any novelty that is beneficial for the whole population or ecosystem, must be primarily beneficial for its possessor, only then it can be spread and, in this way, strengthened.

Concluding Remarks

During the past decade, strong nihilistic trends, far stronger than before, appeared in evolutionary biology. This is how one of the most authoritative evolutionists has summarized his approach:

> Natural selection is a principle of local adaptation, not of general advance or progress. The history of life is not necessarily progressive; it is certainly not predictable. The earth's creatures have evolved through a series of contingent and fortuitous events (Gould 1994).

So, it turns out that Darwinism is suitable for the description of local phenomena of adaptation only. In this context it is worth remembering the previously published article by Gould and Lewontin (1979) expressing the authors' doubts regarding the whole adaptationist paradigm.

What way out do these authorities propose? S. J. Gould and R. C. Lewontin seem to expect much from the theories of chaos, catastrophe, and complexity.

To describe that situation I could find no better word than 'crisis'. My opinion regarding the question is somewhat untraditional: biologists should reconcile themselves to the idea that no one else will propose a suitable methodology for the description of their subjects of study. A new methodology should take root in the depth of biology itself. It should be sodden with biologists' sweat and experience. None of the chaos, catastrophe, or complexity theories can or will take root, like dozens of other exotic matters, for they have originated in a different medium. If we do not want strange methods to dictate strange to us objectives and world outlooks, we should assume the responsibility for the future of biology. I disapprove of a further depreciation of mind and reasoning, entrusting the function of thinking to the computer, being simply afraid to form daring and audacious hypotheses that do not follow directly from the data available. I dare to claim that the naked empirism combined with scientism raises monsters, *i.e.* young people who, for the sake of solidarity, cut their own wings and burden themselves with weights and lead in order to make their thinking as standard as possible. I doubt whether F. Bacon, the father of empirism, would like the scientific society so prone to standardize, but for me it is not very appealing – it is my civic position if you like. I am for the balance of induction and empirism with deduction and rationalism rather than the counterbalance between them as it is usually the case. I think that the method of hypotheses advanced by Popper (1959) will be vindicated sooner or later. Biologists should do this as soon as possible.

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Abstract

The author asserts that evolutionary regularities might be deduced from principles of life's functioning. First of all, the latter should describe the part-whole relationships and control mechanisms. The author suggests supplementing the concept of struggle for existence with the concept of functional hierarchy: no solitary individual or species is functionally autonomous, life as we know it can exist only in the form of a nutrient cycle. Only two purely biotic forces – 'biotic attraction' and 'biotic repulsion' – act in the living world. The first one maintains and increases diversity and organizes solitary parts into systems integrated to a greater or lesser degree. The second one, in the form of competition, lessens biodiversity but at the same time provides life with necessary plasticity. On that ground, tentative answers to the following questions are given: Why does life exhibit such a peculiar organization: with strong integration at lower levels of organization and weak integration at the higher ones? (1) Why did particular species and guilds appear on the evolutionary stage at that particular time and not at any other? (2) Why was the functional structure of ecosystems prone to convergence despite a multitude of stochastic factors? (3).

5

Evolutionary and Behavioural Aspects of Altruism in Animal Communities: Is There Room for Intelligence?

Zhanna Reznikova

1. The Paradox of Altruism

An individual animal can play different roles in communities in dependence of its sex, age, relatedness, rank, and last but not least, intelligence. An individual's path to the top of a hierarchically organised community may be paved by highly developed individual cognitive skills. A classic example came from Goodall's (1971) book *In the shadow of man:* Mike, the young chimpanzee, gained top rank at once by making a terrible noise with empty metal jerricans stolen from the researchers' camp.

At the same time, the upper limit of the individual's self-expression may be specified by the specific structure of communities. There are several variants of division of social roles, from division of labour in kin groups to the thin balance between altruism and ‘parasitism’ within groups of genetically unrelated individuals. Task allocation in animal communities can impose restrictions on the display of members' intelligence. For instance, rodents, termites and ants condemned to digging or baby-sitting or suicide defending can not forage, scout, or transfer pieces of information even if they are intelligent enough to do this. Furthermore, subordinate members of cooperatively breeding societies sacrifice their energy to dominating individuals serving as helpers or even as sterile workers.

Lev Tolstoy in his novel *Anna Karenina* focused attention on several dramatic dilemmas in women's life and among them the dilemma: to give birth to children or to stay in a family as a perpetual helper. In many novels of the 19th century lives of members of a facultative ‘sterile cast’, governess, were described: intelligent but poor members of the society often devoted their whole lives to caring for offspring of rich ones (recall, for example, Charlotte Brontë's Jane Eyre). Indeed, baby-sitting is one of the most costly and essential tasks in animal communities including human ones. Some members of communities serve as helpers that are physically able to breed, but most never will.

To be serious, analysing the problem of division of roles in animal societies, we face the paradox of *altruism* – that is, the situation in which some individuals subordinate their own interests and those of their immediate offspring in order to serve the interests of a larger group beyond their offspring. That altruistic behaviour is possible did not always seem natural for biologists. Darwin's followers, and among them Thomas Henry Huxley, the most enthusiastic populariser of natural selection as a factor of evolution, concentrated mainly on inter- and intraspecific competition, arguing that the ‘animal world is on about the same level as the gladiator's show’ (Huxley 1893), and thus nature is an arena for pitiless struggle between self-interested creatures. This concerns also human beings, although Darwin himself discussed the idea of how altruism can evolve in human societies in *The Descent of Man* (1871). Kropotkin (1902) was one of the first thinkers who countered these arguments and considered mutual aid as a factor of evolution, in particular of human evolution. He viewed cooperation as an ancient animal and human legacy.

In contemporary evolutionary biology, an organism is said to behave altruistically when its behaviour benefits other organisms, at a cost to itself. The costs and benefits are measured in terms of reproductive fitness, or expected number of offspring. So by behaving altruistically, an organism reduces the number of offspring it is likely to produce itself, but increases the number that other organisms are likely to produce.

Eusociality can be considered an extreme form of altruism in animal communities because sterile members of a group sacrifice the opportunity to produce their own offspring in order to help the alpha individuals to raise their young. Evolution favours individuals whose inherited predisposition enabled them to behave in ways that maximise their reproductive success. What induces individuals to be engaged in behaviour that decreases their individual fitness?

Here is one of many interesting examples of biological altruism. The trade-off between individual sacrifice and colony welfare in social insects can be easily estimated in the cases of colony defence. Thus, in the green tree ant of Australia (*Oecophylla smaragdina*) ageing workers emigrate to special ‘barrack nests’ located at the territorial boundary of the colony. When workers from neighbouring nests or other invaders cross the line, guards are the first to attack and to be attacked (Fig. 1). Hölldobler and Wilson (1990) joke that a principal difference between human beings and ants is that whereas we send our young men to war, they send their old ladies.

Fig. 1. A major worker *Oecophylla smaragdina* in the aggressive posture. Transferred from en.wikipedia; Author Tuan Cao (en:User:Tuancao1)

Charles Darwin saw that the paradox of altruistic behaviour of animals, in particular, social insects, was dangerous to his theory of evolution by natural selection. In his *Origin of Species* (1859) Darwin thought that sterile workers in a bee colony, being unable to transmit their genes, represent a special challenge to his theory of natural selection. This is because natural selection depends on the transmission of traits that convey selective advantages to the individuals, and these traits have to be determined genetically (so they are heritable). If workers are sterile, how can they transmit the 'helping traits' to the next generation? Even more simple cases of cooperation in animal communities which are not based on differentiation between sterile and fertile castes can be difficult for evolutionary explanation in terms of individual fitness.

Analysis of these problems became possible on the basis of ideas of gene dominance and fitness outlined by Ronald Fisher (1925, 1930). Haldane (1932, 1955) suggested that an individual's genes can be multiplied in a population even if that individual never reproduces, providing its actions favour the differential survival and reproduction of collateral relatives, such as siblings, nieces and cousins, to a sufficient degree. This hypothesis later came to be known as *kin selection*, the phrase coined by Maynard Smith (1974). These ideas can be illustrated by the following construction. Suppose an organism produces offspring some of which are reproducing, while others are non-reproducing but help greatly in caring for the reproducing ones. Compare this strategy with producing only offspring that reproduce. For an individual offspring it is advantageous to reproduce itself, but since it has the genes of its parent, it will follow the same strategy, that is, produce only reproducing offspring. Since we supposed that a non-reproducing child helps greatly in caring for the others, we can see that the average number of grandchildren will be greater if some of the offspring are non-reproducing. Note that here we assume that all offspring (reproducing and non-reproducing) have the same genes, and have shown that it can be advantageous for the population that an individual with some probability (or better to say, under some circumstances) becomes non-reproducing. In this construction altruism is directed at the certain groups or nearest relatives (parents, siblings, *etc*.). However, sometimes models of less direct altruism are also considered. A popular (although somewhat speculative) example concerns behaviour in populations of wild rabbits. It is assumed that some rabbits drum with their hind legs when they see a predator instead of running immediately to the nearest hole. Being warned by this alarm signal, other rabbits have time to flee. Of course, this does not mean that the drumming rabbit makes a decision to sacrifice its own life to the community (Fig. 2). It simply acts in accordance with its inherited behavioural program. Some members of a group of rabbits give alarm drums when they see predators (because they have a hypothetical 'drumming gene') but others (that lack such a gene) do not. By selfishly refusing to give an alarm signal, a rabbit can reduce the chance that it will itself be attacked, while at the same time benefiting from the alarm signals of others. However, it is possible to show that, under certain conditions, if there are sufficiently many relatives among the recipients of the altruistic behaviour, then altruistic behaviour is promoted within the population. For details and discussion of this model and accompanied ideas see Grafen (1984, 2007), Axelrod *et al.* (2004), and Rice (2004).

Fig. 2. A bunny preparing to sacrifice himself. Cartoon by P. Ryabko

2. The Main Evolutionary Concepts of Altruism in Animals

In the 1960s and 1970s two theories emerged which tried to explain evolution of altruistic behaviour: '*kin selection*' (or '*inclusive fitness*') theory, due to Hamilton (1964), and the theory of *reciprocal altruism*, due primarily to Trivers (1971) and Maynard Smith (1974).

The main mechanism of kin selection is *nepotism*, that is, preferential treatment for kin. Many social species including humans form nepotistic alliances to keep the flag of family interests flying. There is much evidence that animals behave nepotistically when facing vital problems in their life. For example, pig-tailed macaques, when helping group members who were attacked, do so most readily for close relatives, less readily for more distant relatives, and least readily for non-relatives (Massey 1977). To do so, animals must recognise their relatives, but there is no a strong correlation between nepotism and recognition ability. For example, Mateo's (2004) data on closely related species of ground squirrels support a hypothesis that kin favouritism and recognition capacities can evolve independently, depending on variation in the costs and benefits of nepotism for a given species. A highly nepotistic species, *Spermophilus beldingi*, produces odours from two different glands that correlate with relatedness (‘kin labels’). Using these odours ground squirrels make accurate discriminations among never before encountered unfamiliar kin. A closely related species *S. lateralis* similarly produces kin labels and discriminates among kin, although it shows no evidence of nepotistic behaviour.

For kin selection to occur it is not strongly necessary for individuals to recognise their kin. Returning to the example with rabbits that alarm its neighbours by drumming, it is not that these animals must have the ability to discriminate relatives from non-relatives, less still to calculate coefficients of relationship. Many animals can in fact recognize their kin, often by smell, but kin selection can operate in the absence of such an ability. If an animal behaves altruistically towards those in its immediate vicinity, then the recipients of the altruism are likely to be relatives, given that relatives tend to live near each other.

The ability to discriminate between kin and non-kin displays in many species, and is due either to the innate recognition of character traits associated with relatedness, or to the recognition of specific individuals with whom they have grown up. Nepotism is not always clearly altruistic and does not necessarily requiring genuine cognitive skills. For instance, most young plains spadefoot toads are detritivorous and congregate with kin. Some of the tadpoles become carnivorous, and such individuals live more solitarily and at least when satiated prefer to eat non-kin than kin, reducing the damage they might otherwise do to the survivorship of their relatives. Cannibalistic tiger salamander larvae *Ambystoma tigrinum* also discriminate kin and preferentially consume less-related individuals (Pfenning *et al.* 1999). Genetic analyses of numerous fish species have shown that shoals formed by larvae often consist of closely related kin (Krause *et al.* 2000). Recent experiments have shown that juvenile zebrafish can recognise and prefer their siblings to unrelated conspecifics based on olfactory cues (Mann *et al.* 2003).

Chimpanzees possibly solve much more complex problem of kin recognition. Mechanisms underlying male cooperation in chimpanzee communities are still enigmatic (van Hooff and van Schaik 1994). Chimpanzees live in unit groups, whose members form temporary parties that vary in size and composition. Females usually leave their natal groups after reaching sexual maturity whereas males do not disperse (Ghiglieri 1984). Male chimpanzees develop strong bonds with others in their communities being engaged in a variety of social behaviour. Field observations together with DNA analysis showed that such affiliations join together males of close rank and age rather than males belonging to the same matrilines (Mitani and Watts 2005). It is worth noting that females give birth to a single offspring only once every 5–6 years, so brothers obviously should have an essential disparity in years. Do chimpanzees bias their behaviour to non-kin? Although current evidence indicates that Old World monkeys are unable to discriminate paternal relatives (Erhart *et al.* 1997), a recent study suggests that chimpanzees may be able to identify kin relationships between others on the basis of facial features alone, overmatching humans in sorting photographs by features of family relatedness (Parr and de Waal 1999). This raises the intriguing possibility that male chimpanzees might be able to recognise their paternal relatives (Mitani *et al.* 2002).

The importance of kinship for the evolution of altruism is widely accepted today, on both theoretical and empirical grounds. However, as it has been noted before, altruism is not always kin-directed, and there are many examples of animals behaving altruistically towards non-relatives.

The theory of reciprocal altruism is an attempt to explain the evolution of altruism among non-kin. *Reciprocity* involves the non-simultaneous exchange of resources between unrelated individuals. The basic idea is straightforward: it may benefit an animal to behave altruistically towards another, if there is an expectation of the favour being returned in the future: ‘If you scratch my back, I'll scratch yours’. In his now classic paper ‘The evolution of reciprocal altruism’, Trivers (1971) argued that genes for cooperative and altruistic acts might be selected if individuals differentially distribute such behaviours to others that have already been cooperative and altruistic towards the donor. The cost to the animal of behaving altruistically is offset by the likelihood of this return benefit, permitting the behaviour to evolve by natural selection. This evolutionary mechanism is termed *reciprocal altruism*.

A study of blood-sharing among vampire bats suggests that reciprocation does indeed play a role in the evolution of this behaviour in addition to kinship (Wilkinson 1984). Vampire bats *Desmodus rotundus* typically live in groups composed largely of females, with a low coefficient of relatedness. It is quite common for a vampire bat to fail to feed on a given night. This is potentially fatal, for bats die if they stay without food for more than a couple of days. On any given night, bats donate blood (by regurgitation) to other members of their group who have failed to feed, thus saving them from starvation. Since vampire bats live in small groups within large colonies and associate with each other over long periods of time, the preconditions for reciprocal altruism – multiple encounters and individual recognition – are likely to be met. Wilkinson's study showed that bats tend to share food with their close associates, and are more likely to share with those who had recently shared with them. These findings provide a confirmation of reciprocal altruism theory.

Maynard Smith (1974, 1989) suggested that cooperative behaviour can be an evolutionary stable strategy, that is, a strategy for which no mutant strategy has higher fitness. His concept is based on game theory which, in turn, attempts to model how organisms make optimal decisions when these are contingent on what others do.

Cognitive aspects of reciprocal altruism are the source of much debate. Indeed, cooperation based on reciprocal altruism requires certain basic cognitive prerequisites, among which are repeated interactions, memory, and the ability to recognise individuals. Experimental evidence that reciprocal altruism relies on cognitive abilities, making current behaviour contingent upon a history of interaction, comes from primate studies. For example, de Waal and Berger (2000) made a pair of brown capuchins work for food by pulling bars to obtain trains with rewards. They found that monkeys share rewards obtained by joint effort more readily than rewards obtained individually. De Waal (1982) also demonstrated a strong tendency to 'pay' for grooming by sharing food in captive chimpanzees who based their 'service economy' on remembering reciprocal exchanges.

In many examples of cooperation among nonrelated animals such as grooming and food sharing behaviour in primates, or cooperative hunting in lions, wolves, hyenas and chimpanzees, it is still under discussion whether they can be interpreted in terms of reciprocal altruism. Several alternative concepts exist which explain evolution of altruistic and cooperative behaviour (Clutton-Brock and Parker 1995; Sober and Wilson 1998).

It is worth of noting that both kin- and non-kin-altruism in animal societies are based on great individual variability which includes behavioural, cognitive and social specialisation. Let us consider these aspects in more details.

3. A Harsh Environment for Pluralism in Animal Societies: Behavioural and Cognitive Specialisation

Two extreme approaches to consider species-specific behaviour exist in ecological and ethological studies: those that distinguish unique individualities of members of species and those that consider a population as a whole treating conspecific individuals as ecologically equivalent. Applying the ideas of evolutionary ecology helps to find a middle course and to reveal relatively stable fractions of populations that differ by sets of behavioural characteristics, a differentiation that covers routine differences of individuals by sex and age.

There are at least two levels of behavioural specialisation within populations. In some species members of a population comprise distinct groups that behave differently according to their evolutionary stable strategies. In some cases members of these groups can be easily distinguished by certain morphological markers. Besides, more flexible individual specialisation can be expressed in differences in diets, techniques of getting food, forming searching images, escaping predators, nestling and so on. Relatively stable groups can exist in populations that differ by complexes of behavioural characteristics.

3.1. Evolutionary Stable Strategies: A Battle of Behavioural Phenotypes

The theory of *evolutionary stable strategy* (or *ESS*) introduced by Maynard Smith and Price in 1973 is based on the concept of a population of organisms divided into several groups which use different strategies. A group is in a stable state if it is disadvantageous for any individual to change its strategy. In other terms the proportion of individuals using each strategy is optimal; natural selection suppresses any deviation from the current proportion.

Maynard Smith's best known work incorporated game theory into the study of how natural selection acts on different kinds of behaviour. He developed the idea of an evolutionary stable strategy as a behavioural phenotype that cannot be invaded by a mutant strategy. A classic example is a balance between hawks-like (aggressive) and doves-like (non-aggressive) individuals in natural populations. Maynard Smith and Price (1973) demonstrated that both carriers of aggressive and non-aggressive behavioural strategies can coexist comfortable and stable in populations for a long time, and neither aggressors nor non-aggressors can invade the population.

Males of many species are characterised by alternative mating strategies and thus compose a representative set of examples concerning distinct behavioural strategies of carriers of different ESS. These strategies are based on complex behaviour sequences and thus may give to observers the impression of deliberate choice of variants.

For instance, Sinervo and Lively (1996) revealed impressive mating strategies within populations of the side-blotched lizard (*Uta stansburiana*) native to California. These lizards have three mating strategies: distinct types of behaviour that constantly compete with one another in a perpetual cycle of dominance. Carriers of different behavioural strategies are marked by morphological signs. The researchers described the cycle of dominance in lizards in terms of ESS as the ‘rock-paper-scissors’ game.

In the side-blotched lizards males have one of three throat colours, each one declaring a particular strategy. Dominant, orange-throated males establish large territories within which live several females. Orange males are ultra-dominant and very aggressive owing to high levels of testosterone, and attack intruding blue-throated males that typically have more modest levels of testosterone. Blue males defend territories large enough to hold just one female. These males spend a lot of time challenging and displaying, presumably allowing males to assess one another. Territories of both orange and blue males are vulnerable to infiltration by males with yellow-striped throats – known as sneakers. Sneakers have no territory of their own to defend, and they mimic the throat colour of receptive females. It is interesting that yellows also mimic female behaviour. When a yellow male meets a dominant male, he pretends he is a female – a female that is not interested in the act. In many cases, females will nip at the male and drive him off. By co-opting the female rejection display, yellow males use a dishonest signal to fool some territory holding males. The ruse of yellows works only on orange males. Blues are not fooled by yellows. Blue males root out yellow males that enter their territories. Blue males are a little more circumspect when they engage another blue male during territory contests. Attack may or may not follow as blue males very often back down against other blue males. Indeed, neighbouring males use a series of bobs to communicate their identity, and the neighbours usually part without battle.

Thus, each strategy has strengths and weaknesses and there are strong asymmetries in contests between morphs. Trespassing yellows, with their female mimicry, can fool oranges. However, trespassing yellows are hunted down by blue males and attacked. While oranges can easily defeat blues, they are susceptible to the charms of yellows. In contrast, contests between like morphs (*e.g.,* blue *vs.* blue, orange *vs.* orange or yellow *vs.* yellow) are usually more symmetric. Field data showed that the populations of each of these three types, or morphs, of male lizard oscillate over a six-year period. When a morph population hits a low, this particular type of lizard produces the most offspring in the following year, helping to perpetuate the cycle. This arrangement somehow succeeds in maintaining substantial genetic diversity while keeping the overall population reasonably stable. This is a good example of genetically-based control over morphotype and behavioural type development (Sinervo and Colbert 2003).

3.2. Individual Behavioural and Cognitive Specialisation

An impressive example of behavioural specialisation came from the study on how insects of different sizes and level of intelligence catch jumping springtails, small inoffensive creatures that nevertheless are equipped with a jumping fork appendage (furcula) attached at the end of the abdomen. The furcula is a jumping apparatus enabling the animal to catapult itself (hence the common name springtail), thereby changing sharply the direction of movement and to escape attacks of predators. Reznikova and Panteleeva (2001, 2008) revealed springtail hunters in beetles of the family Staphylinidae as well as in several species of ants. Although beetles are taxonomically far from ants, there are three similar groups both in the beetles and ants: (1) good hunters that catch a jumping victim from the first spurt; (2) poor hunters that perform several wrong spurts until they catch a springtail; and (3) no-hunters that even do not display any interest to the victims (Fig. 3). Behavioural stereotypes were similar in ants and beetles, with one great difference: ants were able to bring their hunting technique up to standard of the next level whereas beetles were not.

It turned out later that hunting behaviour in ants incorporated several variants of development, one of them is based on maturation rather than learning, while others include elements of social learning and different levels of flexibility. There are three distinct types of behaviours relative to jumping victims in populations, and this is one of examples of individual behavioural specialisation.

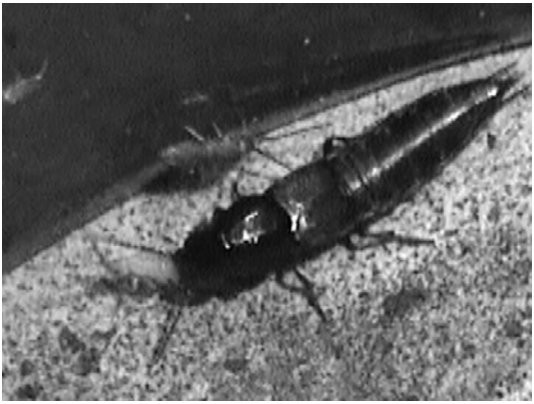

Fig. 3a

Fig. 3b

Fig. 3c

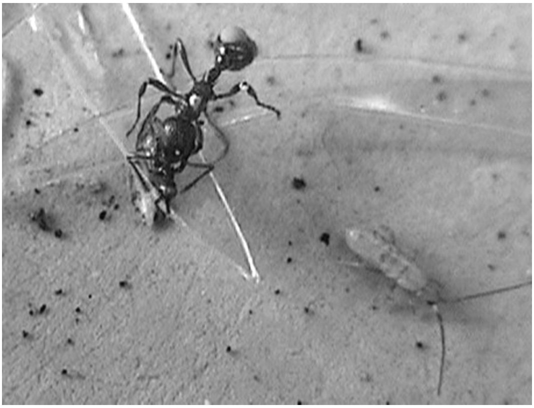

Fig. 3d

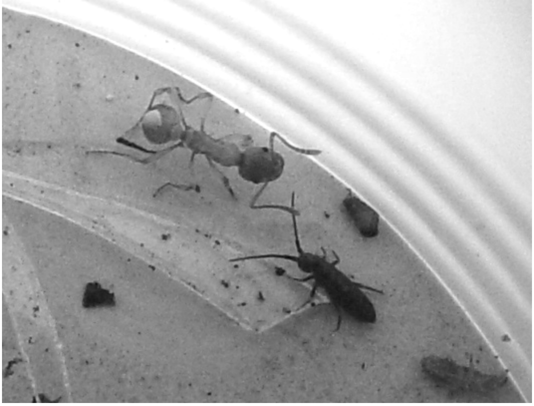

Fig. 3e

Fig. 3. Springtail hunters in beetles of the family Staphylinidae (3-a) a good hunter that catches a jumping victim from the first spurt; (3-b) a poor hunter that performs several wrong spurts until they catch a springtail; and (3-c) the no-hunter that even do not display any interest to the victim; springtail hunters in *Myrmica* ants: a good hunter (3-d) and the no-hunter (3-e). Photo by S. Panteleeva

Bolnick *et al.* (2003) present a huge collection of examples of individual behavioural and ecological specialisation for 93 species distributed across a broad range of taxonomic groups. In many species some specimens in populations are more risk-averse than others, possibly reflecting different optimisation rules. Besides, individuals vary in their prey-specific efficiency because of search image formation. Individuals also vary in social status, mating strategy, microhabitat preferences and so on. In some species individuals constitute groups on the basis of relatively stable features. Bluegill sunfish serves as a good example of differentiation of individuals relatively to their foraging strategy. When a population of bluegills was experimentally introduced to a pond, individuals quickly divided into benthic and limnetic specialists. The remanding generalists constituted 10–30 % of the population and appeared to have a lower intake rate of food.

There is an example of more complex individual specialisation in the oystercatcher *Haematopus ostralegus*. In this species individual birds specialise both on prey species and on particular prey-capture techniques such as probing mud for worms or hammering bivalves. Individuals that use bivalves tend to specialise on different hammering or stabbing techniques that reflect intraspecific variation in prey shell morphology (Fig. 4). Individuals are limited to learning a small repertoire of handling behaviours, while additional trade-offs are introduced by functional variation in bill morphology. Subdominant and juvenile birds are often restricted to sub-optimal diets rather than those they would choose in the absence of interference competition (Goss-Custard *et al.* 1984). It is interesting to note that a dabbling duck endemic to New Zealand was observed opening bivalves in a manner similar to oystercatchers'. Despite having the bill morphology of a typical dabbling duck, these birds were adept at this feeding method (Moore and Battley 2003). This enables us to suggest that behavioural specialisation could be based on highly stereotypic behaviours retained within the whole Class of animals and implemented even on the substrate of somewhat irrelevant morphology.

Fig. 4a

Fig. 4b

Fig. 4. Oystercatchers *Haematopus ostralegus* specialise on different hammering (4a) and stabbing (4b) techniques

Fig. 4c. This bird seems to find similarity between a bivalve's shell and a sheep's ear (Copyright: Omar Bronnstrom)

Fig. 4d. Oystercatchers possess enough flexibility to catch fishes as well (Copyright: Dirk Vorbusch)

In all cases described above behavioural specialisation within populations is based on intricate composition of innate predisposition and individual experience of animals to choose a way of prey handling, to avert risk or not, to dominate over conspecifics or to avoid conflicts, and so on. Some specimens can possess complex behavioural patterns that allow them to learn readily within a specific domain. This ability can be called *cognitive individual specialisation* (for details see Reznikova 2007). More exactly, cognitive specialisation in animal communities is based on the inherited ability of some individuals to form certain associations easier than others. For example, in *Myrnica* ants some members of a colony learn to catch difficult-to-handle prey much easier and earlier in the course of the ontogenetic development than others do (Reznikova and Panteleeva 2008), and in red wood ants some members of a colony display similar abilities concerning battles with enemies and competitors such as ground beetles (Reznikova and Iakovlev 2008). These individuals can serve as ‘etalons’ for those members of communities that possess poorer skills and can learn from others by means of simple forms of social learning.

4. Social Specialisation in Animal Communities

There are many gradations of social specialisation, from rigid caste division to constitutional and (or) behavioural bias towards certain roles in groups accomplishing certain tasks.

4.1. Caste Division and Polyethism in Eusocial Communities

The system of caste division was firstly described for social insects. Wheeler (1928) was the first who proposed a detailed description of caste system in social insects based on anatomy with no fewer than 30 categories. Hölldobler and Wilson (1990) define a *caste* as a group that specialises to some extent on one or more roles. *Role* means a set of closely linked behavioural acts (for example, queen care). Broadly characterised, a caste is any set of a particular morphological type, age group, or physiological state (such as inseminated *versus* barren) that performs specialised labour in the colony. A *physical caste* is distinguished not only by behaviour but also by distinctive anatomical traits. A *temporal caste*, in contrast, is distinguished by age. The term *task* is used to denote a particular sequence of acts which serves to accomplish a specific purpose, such as foraging or nest repair. Finally, the division of labour by the allocation of tasks among various castes is often referred to as *polyethism*, a term apparently first employed by Weir (1958).

A good example of division of labour in eusocial communities based on cast differentiation is existence of soldiers, that is, a specialised cast of workers that defend the colony against intruders (for a review see Judd 2000). Termites, social aphids, social thrips, and some ants produce special casts of soldiers. Some species of ants as well as eusocial shrimps and naked mole-rats show a distinct polymorphism among workers with larger individuals specialised as guards. In some species of bees and wasps guards differ from other colony members only by their aggressive behaviour but not morphologically.

Let us consider several examples of animal social systems based on caste determination and polyethism.

Eusocial insects. Eusociality is displayed in three main insect orders: Hymenoptera (ants, bees and wasps), Isoptera (termites) and Homoptera (aphids). We consider here only a rough schema. There is a great diversity of species: only ants include about 12 000 species and termites about 2 300 species. Different taxa have different numbers of castes, and different degrees of caste specification.

Ants, bees and wasps belong to the haplodiploid group Hymenoptera (it should be noted that Hymenoptera is a large group and the majority of Hymenoptera are not social). The termites, in contrast to the Hymenoptera, exhibit diploidy. The strategy of eusociality arose once in an ancestral termite, whilst it arose several times in the Hymenoptera. Recently, some species of aphids have been found to be eusocial, with many separate origins of the state. This is explicable due to their partially asexual mode of reproduction. Most aphids that are related within a colony are members of the same clone. When social aphids form a gall (a special structure of a plant) and concentrate there, some soldiers will not reproduce. This form of eusociality tends to be restricted to a few soldiers, because the sterile forms only defend and do not care for the young. Therefore, there is less potential for the development of advanced societies.

In general, in social insects most members of a community sacrifice their own reproductive potential to provide food and protection for the few reproductive members and their offspring. The so-called *primer* pheromone causes long-term physiological changes in nestmates within a colony by controlling their endocrine and/or reproductive systems. The primer pheromone is usually dispersed by only one or a few individuals (‘queens’) and may regulate sexuality and caste expression. In contrast, chemical signals that cause immediate behavioural changes in conspecifics are defined as *releaser* pheromones and are produced by numerous nestmates (Wilson 1971). The social organisation in colonies depends on the control of the proportion of different castes, and on efficient recognition and communication system.

Apis mellifera, the honey bee, has the best studied system of caste differentiation. Differences in caste-specific behaviour are understood for many years (Michener 1974), but recent molecular studies have shed new light on the mechanisms by which it occurs. In honey bees, the primary determination is between worker bees and gynes (future queens). Gynes are given a special diet that activates queen specific development. Workers assume different roles in the nest as they age, a pattern known as *temporal polyethism*. Young workers stay in the nest, and as they age they replace foragers, and are replaced by younger workers within the nest. The timing of the progression through the tasks is not fixed. The progression can be delayed, or even reversed, if young workers die. Over the winter, the progression is also delayed, so that there are workers to staff the hive early in the spring.

Some ants also have age-correlated division of labour. In ants with multiple worker castes, different morphological types assume different tasks (usually soldiers *versus* workers), but within each morphological type, work is divided in a temporal fashion.

In termites, in contrast to hymenopterans, the only adults present in colonies are the king and the queen. This one adult caste is initially winged (alate). Termite queens typically become physogastric, due to an enormous growth of the fat bodies and ovaries while the males remain relatively small. Indeed, the termite queen looks awfully fat and large in comparison to workers. For example, in the African termite, *Macrotermes subhyalinus*, the queen's body becomes so swollen with eggs that she is incapable of movement. When fully engorged, she may be 14 cm long (more than 10 times as long as a worker termite), and capable of producing up to 30 000 eggs per day.

The second true caste in termites comprises the soldiers. They are always non-reproductive and are more sclerotised and more heavily pigmented than workers. They also have highly sclerotised and powerful mundibles, which make them suitable for colony defence. Soldiers cannot feed themselves and have to be fed by workers. In some species members of the sub-cast 'minor soldiers' serve as scouts and leaders for workers being more sensible than workers to trial pheromones. Soldier termites can regulate their own numbers by inhibiting the larval development of other soldiers. Worker termites may be more or less differentiated, depending on the evolutionary status of the species. In primitive species, social tasks are accomplished by unspecialised larvae or nymphs. In the more highly developed Termitidae, and some other termites groups, workers constitute a true caste, specialised in morphology and behaviour and permanently excluded from the nymphal development pathway. In theory, each nymph can be developed to an alate and leave the natal colony. In some species the workers are dimorphic having large and small forms; in the Macrotermitinae the larger workers are the males and the smaller workers the females. Workers accomplish different tasks and subtasks in the colony. For example, in the termite *Hodotermes mossambicus*, one set of workers climbs up grass stems, cuts off pieces of grass, and drops them to the ground below (subtask 1) while the second set of workers transports the material back to the nest (subtask 2). Termites' lifetime is amazingly long for insects. Sterile workers live for 2–4 years while the primary sexuals live for at least 20 and perhaps 50 years (for details see Eggleton 2000)

Social aphids introduce a whole new direction in the evolution of eusociality. Like termites, they are diploid, but in contrast to termites, aphids reproduce both sexually and parthenogenetically, so they have the ability to produce genetically identical individuals. In these clonal stages large colonies are formed comprising of genetically identical individuals. Aphids are the only colonial species that exhibit eusocial behaviour (Alexander *et al.* 1991). Aoki (1977) was the first who found that the aphid, *Colophina clematis,* produced instars that defend the colony from intruders. Since then many species of social aphids have been described in the two families Pemphigidae and Hormaphididae (Stern and Foster 1996). Social aphids produce galls, which are tough pockets artificially induce in a plant by the aphids. All of the alates and reproductive destined instars are normally found inside the galls. The individuals on the outside are the soldiers which defend the gall from any predator that would destroy this nest and its contents. Stern and Foster (1996) describe several types of soldiers based on physical characteristic and behaviour.

Eusocial rodents. In the same way as calling termites 'white ants' one can call naked mole-rats (*Heterocephalus glaber*) 'mammalian termites'. These unique eusocial mammals share many features with termites. They spend virtually their entire lives in the total darkness of underground burrows, they are very small (7 to 8 cm long, and weigh between 25 and 40 g), and, what is the most important, they are eusocial. Besides, like in termites, in mole-rats high-cellulose diet is also rather hard to digest, and their stomachs and intestines are inhabited by bacteria, fungi, and protozoa that help break down the vegetable matter. Similarity with insects intensifised with the fact that the naked mole-rat is virtually cold-blooded; it cannot regulate its body temperature at all and requires an environment with a specific constant temperature in order to survive. These eusocial rodents cooperate to thermoregulate. By huddling together in large masses, they slow their rate of heat loss. They also behaviorally thermoregulate by basking as needed in their shallow surface tunnels, which are warmed by the sun.

These amazing creatures are neither moles nor rats. Like rats, they are rodents, but they are more closely related to porcupines and chinchillas. *Heterocephalus glaber* is known since 1842, but only in 1981 Jarvis discovered their eusocial organization system that is believed to be unique among mammals. Since that, this species has been intensively studied (see Jarvis 1981; Sherman *et al.* 1991; Bennett and Faulkes 2005). There are essential ecological reasons for which naked mole-rats have broken many mammalian rules and evolved an oddly insect-like social system. These animals are ensconced in the arid soils of central and eastern Ethiopia, central Somalia, and Kenya, where they must continually dig tunnels with their enlarged front teeth, in search for sporadic food supplies and evade the deadly jaws of snakes.

Naked mole-rats live in well-organized colonies, with up to 300 members in a group (20 to 30 is usual). A dominant female (the queen), who outweighs the others by up to 20 g, leads a colony. The queen is the only female that breeds, and she breeds with one to three males. When a female becomes a queen she actually grows longer, even though she is already an adult, by increasing the distance between the vertebrae in her spine. These animals are extremely long living; in captivity some mole-rats have lived to 25 years old. One naked mole-rat queen, as the breeding females are called, produced more than 900 pups in her 12-year lifetime at a laboratory colony. The young are born blind and weigh only about 2 g. The queen nurses them for the first month, and then the other members of the colony feed them by faeces (again like termites) until they are old enough to eat solid food (Fig. 5).

Fig. 5. Naked mole-rat (*Heterocephalus glaber*). Images from Bioimages home. Copyright: 2003 Steve Baskauf http://www.cas.vanderbilt.edu/bioimages/animals/mammalia/naked-mole-rat.htm

The breeding female (the queen) suppresses the breeding of all the other females in the colony. She sometimes leaves her nest chamber to check on her workers and to keep them unfertilized by pheromone control as well as by swoops and bites thus demonstrating that they should not ‘think’ about anything but digging tunnels and defending a colony from snakes and newcomers. The worker males are also suppressed, although they do produce some sperm. When the queen dies, several of the larger females fight, sometimes to death, to become a queen. They can regain their fertility quickly.

The majority of workers (both males and females) spend their entire lives working for the colony. Workers cooperate in burrowing, gathering food, and bringing nest material to the queen and non-workers. They use their teeth to chisel earth and to create piles of soil. There is a great deal of branching and interconnection of tunnels, with the result that a colony's total tunnel length can add up to 4 km. Tunnels connect nest chambers, toilet areas, and food sources. Burrowing is the only way these animals find food, since they do not travel above ground. Some colony members ‘farm’ succulent tubers that are formed by many of the plant species that grow in arid areas. They generally bore through the tuber, eating mainly the interior flesh while leaving the thin epidermis intact. This behaviour may allow the plant to remain healthy for some time, indeed even to continue growing, thereby providing a long-term food resource for the colony. Judd and Sherman (1996) studied captive colonies in order to determine whether successful foragers recruit colony mates, like many eusocial insects do. It has been revealed that individuals that found a new food source typically give a special vocalisation on their way back to the nest, wave the food around once they got there, and lay odour track for other nestmates to follow.

Whilst most offspring become workers, some continue to grow and become colony defenders. Their main duty is to defend the colony against predators. In particular, rufous-beaked snakes (*Rhamphiophis oxyrhynchus rostratus*) are attracted to the smell of freshly dug soil and will slither into burrows through mole hills in search of a rodent meal. Soldier mole-rats fight back with their teeth and attempt to block the entrance with dirt. If everything fails, a soldier will directly attack the snake, sometimes sacrificing its own life while others escape.

Should a breeder die, just one of defenders will become reproductive to replace it. They can occasionally disperse to found a new colony with an unrelated member of the opposite sex.

In general, caste differentiation in mole-rats bears a strong resemblance (of course, merely superficial) with termite's one. The sterility in the working females is only temporary, and not genetic. Like in termites, there are castes of fertilised queens and kings and unfertilised workers and soldiers, and workers descend from ‘nymphs’, that is, under-grown members of the colony. The life span of mole-rats is unprecedented among small rodents just like the life span of termites is unprecedented among insects. It is possible that these long living animals will surprise experimenters with their cognitive abilities.

Eusocial shrimps. Tiny marine coral-reef Crustacea offer a new data about the ecology and evolution of eusociality. Colonies of the social snapping shrimp *Synalpheus regalis* share several features with those of eusocial insects and cooperatively breeding vertebrates (Duffy 1996). *Synalpheus regalis* inhabits internal canals of tropical sponges, living in colonies of up to a several hundreds of individuals. Colonies consist of close kin groups containing adults of at least two generations which cooperatively defend the host sponge using their large and distinctive snapping claws, and in which invariably only a single female breeds. Irreversible caste differentiation is governed by the queen that typically sheds her large snapping claw and re-grows a second minor-form chela, rendering her morphologically unique among the members of the colony. It is still not completely known how the queen accomplishes social control over sexual maturation of other colony members. Both genetic data and colony structure confirm that many offspring remain in the natal sponge through adulthood. Colonies consist largely of full-sib offspring of a single breeding pair which ‘reigns’ for most or all of the colony's life. In captive colonies researchers have regularly observed a large male in association with the queen behaving aggressively with other large males approach her. The inference of monogamy from genetic data suggests that the queen associates with a single male for a prolonged period. There is a strong competition for suitable nest site and a shrimp attempting to disperse and breed on their own would have low success. Colony members discriminate between nestmates and others in their aggressive behaviour. Laboratory experiments revealed behavioural division of labour within colonies. Large males shoulder the burden of defence, leaving small juveniles free to feed and grow, and the queen free to feed and reproduce (Fig. 6). Such size- and age-related polyethism in shrimps has many similarities with poyethism in social insects (Duffy *et al.* 2002).

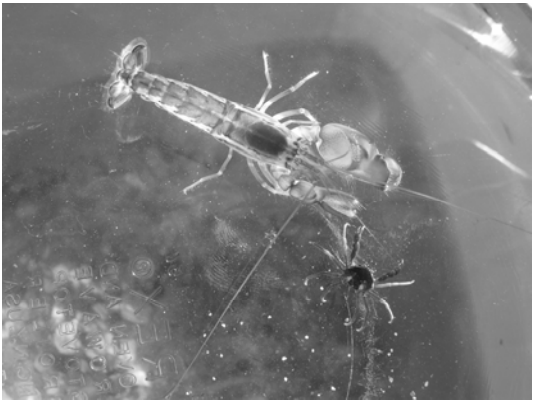

Fig. 6. Defending snapping shrimp. Photograph by A. Bray. Courtesy of A. Bray

Considering intellectual potential of social shrimps, Duffy (2003) refers to Darwin's (1871) note that 'the mental powers of the Crustacea are probably higher than might be expected'. Social shrimps demonstrate coordinated behaviour. For example, they pick up dead colony members and push out of their sponge dwelling. Recent experiments suggested coordinated snapping, during which a sentinel shrimp reacts to danger by recruiting other colony members to snap intruders. The phenomenon of 'mass snapping' begins by rhythmic snapping of one individual, following by rapid recruitment of many others. The initial one-to-one confrontation elicited a snap response from the defender. Colony members joined in with a cacophony of snapping thus providing an unequivocal signal that the sponge is already colonized. This distinctive behaviour is the first evidence for coordinated communication in the social shrimp and represents yet another remarkable convergence between social shrimps, insects and vertebrates (Tóth and Duffy 2005).

Summarising the data on caste division of labour within communities of eusocial organisms we have to admit that the correlation between cognitive and morphological specialisation in these animals is not yet completely described. Even in ants and bees which have been intensively studied for more than hundred years, it remains unclear what effect does the caste determination has on their intelligence. Further we will consider a more gentle system of division of labour in animal societies that perhaps leave more room for intelligence.

4.2. Division of Labour in Cooperative Breeders

Eusociality can be considered an extreme of cooperative breeding systems being based on irreversible caste determination. However, many vertebrate species possess more flexible social systems which are based on facultative division of labour and temporal limits on breeding for some members of communities. In cooperative breeding vertebrates, a dominant pair usually produces the majority of the offspring, whereas the cost of caring for offspring is shared by non-breeding subordinates. In certain cooperative breeding animals one or a few dominant females are the only capable of breeding; the subordinates do not have the proper hormone levels to be fertile although they are physiologically equipped for the task.

There is still a great controversy in literature about to what extent cooperative breeding can be explained in terms of kin selection theory. Results so far are mixed: while some studies have produced evidence supporting the association between kinship and contributions for cooperative activities, others have found no consistent association between contributions to helping behaviour and variation in relatedness (for reviews see Clutton-Brock *et al.* 2002).

Cognitive aspects of cooperative breeding are intriguing and have not been studied enough. Serving as helpers for the ‘royal family’ young animals gain experience that can be useful for them in future when they establish their own families. Nevertheless, in many cases helpers have no chance to have their own offspring. Somehow or other, cooperative breeding system enables helpers to sacrifice their intelligence for other members of the community. It is possible that helping individuals accomplish a wider variety of tasks and under more risky circumstances than those who have the opportunity to raise their young being given every support by helpers. Several examples will give us an impression of how division of labour occurs within communities which are based on communal breeding.

In birds about 3 percent (approximately 300 species) of species are known as cooperative breeders. Helpers (also called auxiliaries) at the nest were first described by Skutch in 1935. It was not until the mid-1960s, however, with the advent of modern behavioural ecology, that widespread attention began to focus on cooperatively breeding species (Emlen 1995).

Cooperative systems often appear to arise when environmental constraints force birds into breeding groups because the opportunities for younger birds to breed independently are severely limited. Limitations may include a shortage of territory openings, a shortage of sexual partners, and unpredictable availability of resources. That cooperative breeding is a common strategy in arid and semiarid portions of Africa and Australia lends strong support to this line of reasoning. For some species the role of ecology is not completely clear (Arnold and Owens 1999).

Cooperative breeding may be viewed primarily as a means by which young adults put off the start of their own breeding in order to maximize their lifetime reproductive output, and in the process occasionally promote genes identical with their own via kin selection. There are two types of cooperative arrangements: those in which mature nonbreeders help protect and rear the young, but are not parents of any of them, and those where there is some degree of shared parentage of offspring. Cooperative breeders may exhibit shared maternity, shared paternity, or both.

The best-studied North American cooperative breeders, the Scrub-Jay, Gray-breasted (Mexican) Jay, Groove-billed Ani, and Acorn Woodpecker provide good examples of communal breeding (see Ehrlich *et al.* 1988). Scrub-Jays in Florida reside in permanent, group-defended territories. Woolfenden and Fitzpatrick (1984) have found that groups consist of a permanently bonded monogamous pair and one to six helpers, generally the pair's offspring of previous seasons. About half the territories are occupied by pairs without helpers, and most other pairs have only one or two helpers. Although pairing and breeding can occur after one year spent as a helper, birds often spend several years as non-breeding auxiliaries. Males may remain in this subsidiary role for up to six years; females generally disperse and pair after one or two years of helping. Helpers participate in all non-sexual activities except nest construction, egg lying, and incubation. Pairs with helpers are more successful – they fledge one and a half times younger than pairs without helpers. Like the Florida Scrub-Jays, the closely related Gray-breasted Jays live in permanent group-defended territories, and breeding adults are monogamous. Brown (1974) has shown that the cooperative system of this species is more complex than that of its southeastern relative in several ways. Gray-breasted Jay groups are much larger, ranging from 8 to 18 individuals; thus, they usually include offspring from more than just the preceding year. Within each group, two and sometimes three breeding pairs nest separately but simultaneously each season, and some interference among them often occurs. Interference usually involves theft of nest-lining materials, but can include tossing of eggs from nests by females of rival nests. Although the laying female does all the incubating, she is fed on the nest both by her mate and by auxiliaries. Nestlings receive more than half of their feeding from auxiliaries.

Acorn Woodpecker group of communal breeders is composed from up to 15 members whose territories are based on the defence and maintenance of granaries in which they store acorns (Koenig and Dickinson 2004). Groups consist largely of siblings, their cousins, and their parents. Some of the sexually mature birds are non-breeding helpers. Within each group, up to four males may mate with one (or occasionally two) females, and all eggs are laid in a single nest. Thus paternity and sometimes maternity of the communal clutch is shared.

In mammals more than 100 species have been described as cooperative breeders, and among them are cooperative carnivorous, mongooses (meerkats, dwarf mongooses), primates (marmosets and tamarins), as well as several species of rodents and shrews. As it was noted before, some rodent species possess facultative communality in dependence of their habitat and many ecological factors.

The painted hunting dog (African wild dog) *Lycaon pictus* provides a good example of obligate cooperative breeding. These dogs live in packs of up to 20 adults, in which most of the time only the alpha pair breeds. The remaining adults are reproductively suppressed and help to raise the pups; they must wait to breed until their circumstances improve, either through the death of a higher-ranking female or by finding a mate with an unoccupied territory (Fuller *et al.* 1992). Baby sitting is a costly task and this includes: watching pups to prevent loss, alerting them to danger (lions, hyenas), protecting them from smaller predators or alien dogs, and moving them under cover in heavy rain. Other members of the pack are also involved in caring for common babies: they feed pups with regurgitated meat when return from successful hunting. Baby sitting is not an obligatory load for pack members, as they can choose between hunting and guarding young. Researchers observed situations where a dog returned to a den to baby-sit after encountering a predator close by (Malcolm and Marten 1982). At the same time, *Lycaon* hunt cooperatively and baby sitting draws a member of a pack away from hunting where both efficiency and the risk to lose prey for kleptoparasites depend on the size of the party (Gorman *et al.* 1998). It is worth to note that in contrast to queens in eusocial communities that are specialised baby-machines, the breeding female in wild dogs, as in other cooperative carnivorous, is often an experienced hunter, and her presence in the hunting pack may increase efficiency of enterprise. Besides, there is a threshold for the group size to survive. Smaller packs need to hunt more often to feed their pups, especially when using a pup guard (Courchamp *et al.* 2002).

Another impressing example of obligatory communal breeding in mammals comes from small arboreal monkeys, marmosets and tamarins of the family Callitrichidae endemic to the Northern half of South America. Within the family, cooperative breeding strategies are widespread and virtually all species are characterised by small territorial groups of approximately 4–15 individuals, where reproduction is monopolised by one or a small number of dominant individuals. Typically one dominant female breeds, normally producing dyzigotic twins. An important role of helpers in the group is to assist in the care of the dominant female's offspring. This is principally by sharing the burden of carrying the relatively bulky twin infants around their arboreal habitat. Each group member helps rear the young, which involves food sharing, caring and defence against predators (Snowdon and Soini 1988).

Life history of Callitrichidae can serve as an example of cooperative breeding in groups consisting both of related and unrelated individuals. Helping behaviour in these primates is thus possibly governed by mechanisms of reciprocal rather than kin altruism. This raises a question to what extend cognitive abilities allow these small primates to calculate reciprocity in their groups. Hauser *et al.* (2003) have conducted experiments on food sharing within groups of cotton-top tamarins (*Saguinus oedipus*) concentrating on psychological mechanisms of reciprocity. The design of experiments was based on animals' tool-using abilities. The apparatus consisted of a tray with an inverted L-shaped tool. When food was on the actor's side, pulling the tool's stem brought the food within rich. Similarly with experimental paradigm used in many experiments on social learning (for details see Reznikova 2007) where researchers trained several animals to be the demonstrators of new skills, here again stooge ‘altruists’ and ‘defectors’ were specially trained to pull pieces of food to their partners or to themselves. Results clearly showed that tamarins discriminate between altruistic and selfish actions, identify and recall conscpecifics by their cooperativeness and give more food to those who give food back. Special series of experiments also demonstrated that tamarins give food to genetically unrelated conspecifics even though they obtain no immediate benefit from doing so. Tamarins therefore have the psychological capacity for reciprocally mediated altruism.

The ability to estimate partner's cooperativeness and remember the history of inter-individual relationships is particularly important for those communal breeders that incorporate both kin and non-kin into their communities, and whose altruistic acts are costly. This is well illustrated by experiments of Clutton Brock *et al.* (2000) on individual contributions to babysitting in a cooperative mongoose, *Suricata suricatta*.

Meerkats (suricates) are desert-adapted animals living in groups of 3–25 animals that typically include a dominant female that is responsible for more than 75 % of all breeding attempts, a dominant male that fathers most of the offspring born in the group and a number of helpers of both sexes. A dominate female controls the presence of subordinate adult females in the group. During the first month of pup's life babysitters usually remain at the burrow with young for a full day while the rest of the group is foraging and feed little or not at all during their period of babysitting. Clutton-Brock *et al.* (2000) have shown how costly babysitting is: helpers suffer substantial weight losses. It is important that large differences in contribution exist between helpers. These differences are correlated with such characteristics of group members as age, sex, and weight, but, surprisingly, not with their kinship to the young raising. In field experiments researchers regularly provided some group members with food (boiled eggs) matching them with controls of the same sex and age. It turned out that feeding essentially increased contribution of helpers to babysitting. So a regular salary may increase and equalise individual contributions of co-operators. However, in natural situations meerkats cannot rely on donations from above, they rather depend on their ability to distinguish between more and less conscientious cooperators (Fig. 7).

Fig. 7. A daily procedure of feeding and weighing meerkats. Photograph by L. Hollén. Courtesy of L. Hollén

4.3. Teams in Animal Societies

In group living animals division of labour is sometimes based on coordinated activities of group members. In relatively rare cases individuals form groups in which the members stay together for extended periods to accomplish a certain task. Such groups are called teams or cliques (Hölldobler and Wilson 1990; Anderson and Franks 2001).

For example, when working together to dig tunnels, naked mole-rats line up nose-to-tail and operate like a conveyor belt. A digger mole-rat at the front uses its teeth to break through new soil. Behind the digger, sweepers use their feet and the fine hairs between their toes to whisk the dirt backwards. At the back of the line a trailing member of the group kicks the dirt up onto the surface of the ground, creating a distinctive volcano-shaped mole hill. One of folk names of naked mole-rats is ‘sand puppies’. There are several other creatures that join efforts of group members to survive in the running sand. Desert ants *Cataglyphis pallida* demonstrate the same manner of coordinated working digging tunnels like a conveyor belt.

There are several examples of hunting teams in vertebrates. Usually individuals coordinate efforts so that one or more individuals chase the prey, or flush it from hiding, while others head off its escape. For instance, in chimpanzees (*Pan troglodytes*), some group members chase and surround the prey (usually juvenile baboons) forcing it to climb a tree while at the same time other chimpanzees climb adjacent trees ready to capture the prey when it attempts to leap across to escape. In African wild dogs (*Lycaon pictus*) some individuals chase the prey, and can change leaders during the chase (van Lawick-Goodall, Hugo and Jane 1970).

The most organised teams in animal societies are based on discrete division of labour that may be called ‘professional specialisation’. Stander (1992) has shown that lion teams can be particularly organized in that an individual will tend to stick to a particular position (subtask) during the hunting on successive hunts. That is, some lions can be classed as ‘wingers’, individuals who always tend to go around the prey and approach it from the front or from the side, while others are better classified as ‘centres’, individuals who remain chasing directly behind the prey. Perhaps the most organized hunting teams in vertebrates occur in Galapagos and Harris' Hawks (Faaborg *et al.* 1995). Hawks hunt cooperatively with several birds simultaneously swooping on their prey on such animals as wood rats, jackrabbits and other birds. However, if the prey item finds cover, some birds land and surround it, while one or two hawks will walk or fly into the vegetation to kill the prey. Once the prey is killed, all the birds feed together on the prey.

Until recently, the existence of teams within insect colonies, possibly based on individual identification, has not been known. According to Hölldobler and Wilson (1990), ants do not appear to recognise each other as individuals. Indeed, their classificatory ability is limited to recognition of nestmates, different castes such as majors and minors, the various growth stages among immature nestmates, and possibly also kin groups within the colony. There are, however, several examples showing elements of team task distribution. In swarm-raiding army ants, large prey items are transported by the structured teams which include members of different castes (Franks 1986). In the desert ant *Pheidole pallidula* Ruzsky, minor workers pin down intruding ants and later major workers arrive to decapitate the intruders (Detrain and Deneubourg 1997). Robson and Traniello (2002) found complex relations between discovering and foraging individuals in group retrieving ant species; removal of the discovering ant during the process of recruitment led to dissolution of the retrieval group.

The question of constant membership and individual recognition within group of workers in ant colonies has been so far obscure. Reznikova and Ryabko's (1994, 2003) findings on teams in ants are connected with the discovery of the existence of complex communicative system in group retrieving ant species by means of the special maze called ‘binary tree’ (for details see Ryabko and Reznikova 2009). Such communication system is based on scouts-foragers informative contacts where each scout transfers messages to a small (5 animals in average) constant group of foragers and does not pass the information to other groups. The ants thus work as co-ordinated groups which may be called teams. Does this necessarily mean that they recognise each other as individuals? Indeed, it is possible that the animals presume on recognition of specialists' roles rather than their personal traits.

Donald Michie (personal communication) has referred to his experience as a Rugby player. Being a scrum half, he was always confident on his ability to spot his opposite number (that is, another scrum half) when meeting an opposing team socially before the game. To be adapted to the scrum half's specialist role, one must typically be small, resilient, agile, not necessarily a fast runner. The only other typically agile team member is the fly half, but he has also to be a fast accelerator and need not be resilient. A year later he might still recognise one of that same team's forwards, for example, but not remember the face of the scrum half.

One can find it hard to say that ants are able to recognise each other personally. That a scout can distinguish members of its own team from members of another team is not the same thing as individual recognition. Continuing the use of the metaphor from football, one can imagine a team manager who might be able to distinguish players of his own team from those of a different team (for example by the patterns of their shirts), and this is yet not to distinguish same-team players one from another.

We have not yet distinguished reliable behavioural signs in ants indicating personal recognition like the well-knowing 'eyebrow flash' in humans (see Eibl-Eibesfeldt 1989); neither are we able to train ants for distinguishing between pictures of different individuals like in Kendrick *et al.'s* (2001) experiments with sheep (for details see Reznikova 2007). Nevertheless, we can be confident on at least circumstantial evidences that group-retrieving ant species possess personalised teams as functional structures within their colonies.

The first evidence comes from ontogenetic studies. Reznikova and Novgorodova (1998) observed the ontogenetic trajectories of 80 newly hatched *F. sanguinea* ants in one of laboratory colonies and watched the processes of shaping of teams. There were 16 working teams in that colony which mastered the 'binary tree' maze. From 80 individually marked naive ants, 17 entered 7 different working teams, 1 to 4 individuals in each. Only 3 became scouts, 2 of them starting as foragers joining 2 different teams and 1 starting as a scout at once. The 3 new groups were composed of workers of different ages, mainly from reserve ones. The age at which the ants were capable to take part in the working groups as foragers ranged from 18 to 30 days, and the ants could become scouts at the age of 28 to 36 days. Constancy of membership was examined in two colonies of *F. sanguinea* and *F. polyctena*. In a separate experiment researchers isolated all team members from 9 scouts. 3 scouts appeared to mobilize their previous acquaintances and attract new foragers, 4 scouts were working solely, and 2 ceased to appear on the arenas. In another experiment we removed scouts from 5 *F. polyctena* teams. It was possible to see foragers from those groups on the arenas without their scouts. 15 times different foragers were placed on the trough with the food, but after their return to home they contacted other ants only rarely and occasionally. These results suggest that formation of teams in group retrieving ants is a complex process which is based on extensible relations and possibly include individual identification.

Another evidence of existence of teams in ants is based on division of labour within groups of aphid tenders discovered in red wood ants. It is well known that ants look after symbiotic aphids, protect them from adverse conditions, and in return, ants ‘milk’ the aphids, whose sweet excretions are one of the main sources of carbohydrate for adult ants. In an ant family, there is a group of ants dealing with aphids (aphid-milkers), which has a constant composition. Reznikova and Novgorodova (1998) were the first to describe a system of intricate division of labour (professional specialisation) in aphid milkers: ‘shepherds’ only look after aphids and milk them, ‘guards’ only guard the aphid colony and protect them from external factors, ‘transit’ ants transfer the food to the nest, and ‘scouts’ search for the new colonies (see Fig. 8). This professional specialisation increases the efficiency of ant-aphid mutualistic relations. When ants were experimentally forced to change their roles, much food was lost. The ants belonging to the same aphid tending group, distinguish at least 2–3 shepherds from 2–3 guards within this group. Such professional specialisation was only found in the same species that exhibited the complex communication system in experiments of Reznikova and Ryabko (1994, 2003).

Fig. 8a. ‘Shepherd’ milking aphids and a ‘guard’ (with open mandibles) protecting an aphid colony

Fig. 8b. 'Transit' ant is receiving the food from a shepherd in order to transport it to the nest; a 'guard' is also present here. Photographs by T. Novgorodova

5. Social Intelligence in Animals

Since the second part of the twentieth century a growing body of field data about wild social life have led researchers to the idea that social animals should display advanced cognitive abilities within specific domains related to social living and that intelligence is not a monolithic functional entity but includes a number of specialised mental abilities to cope with life in complex and changeable social environment. Thus, to the primary components of intelligence, such as the ability for flexible problem solving and the ability to cope with novel situations, we can add the ability for solving social problems.

According to the *social intelligence hypothesis,* which was first articulated by Jolly (1966) and Humphrey (1976), complex social interactions (including cooperation, competition, manipulation, and deception) can occur when animals live in large and stable social groups. After spending three months with Dian Fossey and her gorillas in Rwanda (see Fossey 1983), Humphrey wrote a review essay in 1976 titled 'The Social Function of Intellect' on the evolution of cognitive skills. He argued that primate and human intelligence is an adaptation to social problem-solving, well suited to forward planning in social interaction but less suited to non-social domains. These subforms of intelligence assumed the name 'Machiavellian intelligence' after the 16th century Italian politician and author, Niccolò Machiavelli. It provides individuals or groups with a means of social manipulation in order to attain particular goals. In 1532 Machiavelli published his book *The Prince.* Giving somewhat cynical recommendations to an aspiring prince, he was prescient in his realisation that an individual's success is often most effectively promoted by seemingly altruistic, honest, and prosocial behaviour. According to Machiavelli's *real politic,* a popular leader had to give the impression of being sincere, trustworthy, and merciful. To retain his power, however, a prince can set himself above all moral rules and use cunning, lies, and force. Skill in deception and maintaining alliances are two of the prince's most important properties. ‘Machiavellian intelligence’ seemed an appropriate metaphor that inspired primatologists to explicit comparison between the animal social strategies and some of the advice offered five centuries earlier.

De Waal, in his book *Chimpanzee Politics* (1982), describes how clever high-ranking chimpanzees are at manipulating others. Byrne and Whiten (1988) propose that the ability to use other individuals as tools, manipulating the social environment in order to meet preconceived goals, is an important factor in the evolution of primate intelligence. In order to compete successfully within groups, apes and monkeys have to recognise who outranks whom, who is closely bonded to whom, and who is likely to be allied to whom.

Skilfulness in navigating social landscape is based on the advanced ability that seems to be unique to primates, that is the ability to keep track of how other animals relate to each other and thus to recognise the close relationships that exist among individuals (Cheney and Seyfarth 2003; Kitchen *et al.* 2005).

Experimental evidence for animals' ability for tracking social and kin relations came from the laboratory study performed by Dasser (1988) on captive longtail macaques *Macaca fascicularis.* The monkeys were shown a pair of slides of members of the group, and their task was to identify another pair of photographs which ‘matched’ the first one. The first pair could be, for example, a mother and a daughter, two sisters, or two unrelated individuals. The macaques quickly learned to identify the right kinship patterns. The experiment indicates that they do not just recognise their own offspring and siblings, but that they also keep track of other individuals' kinship relations. For example, in one test, Dasser trained a female to choose between slides of one mother – offspring pair and slides of two unrelated individuals. Having been trained to respond to one mother – offspring pair, the monkey was then tested with 14 novel slides of different mothers and offspring paired with an equal number of novel pairs of unrelated animals. In all tests, she correctly selected the mother – offspring pairs. Dasser suggests that the monkeys can use the abstract category to classify pairs of individuals that was analogous to our concept of ‘mother – child affiliation’.

The experiments of Parr and de Waal (1999) demonstrated chimpanzees as being able to judge about mother – offspring relationships by comparing pairs of photographs of mothers and sons and mothers and daughters. Surprisingly, within mother – offspring category, the chimpanzees could find similarities between mothers and sons much better than between mothers and daughters. The authors suggest that facial similarities are more noticeable to chimpanzees in males in view of their male philopatric society and the tendency towards ‘political’ alliances in which males incur great risk on behalf of other males (de Waal 1982). Phenotypic matching might assist the recognition of subsets of related males who tend to support each other.

A number of naturalistic studies have suggested that monkeys recognise the close associates of other group members. For example, play-back experiments using the contact calls of rhesus macaques have demonstrated that females not only distinguish the identities of different signallers but also categorise signallers according to matrilineal kinship (Rendall *et al.* 1996). In play-back experiments with vervet monkeys Cheney and Seyfarth (1990) found that when females were played the scream of an unrelated juvenile, they were more likely to look towards that juvenile's mother than towards other females. Also Cheney and Seyfarth (1990, 2003) argue that vervets can perform vendettas: they prefer to attack relatives of the individuals who have attacked their own relatives.

Knowledge of the relationship between other group members, the so-called *third-party relationships,* play a particular important role in formation of coalitions, helping individuals to predict who will support or intervene against them when they are fighting with particular opponents, and to assess which potential allies will be effective in coalitions against their opponents (Tomasello and Call 1997). There is much evidence that monkeys and apes cultivate relationships with powerful supporters. Silk (1999) has demonstrated that male bonnet macaques put their knowledge of their own relationships with other males and their knowledge of relationships among other males to good use when they recruit coalitions. By selectively soliciting males that most frequently supported them and animals that outranked them and their opponents, males focused their recruitment efforts on the candidates that were most likely to intervene on their behalf and those whose support was most likely to be effective in defeating their opponents. They avoided soliciting top-ranking males that were more loyal to their opponents than to themselves. For this they have to have some knowledge of the pattering of support amongst other individuals, another kind of third-party knowledge.

Although not so well studied as monkeys and apes, several non primate species also show the ability to acquire information about many different individual social relationships. Male dolphins form dyadic and triadic alliances when competing over access to females, and allies with the greatest degrees of partner fidelity are most successful (Connor *et al.* 1992). Analysis of patterns of alliance formation in hyenas suggests that they do monitor other individuals' interactions and extrapolate information about other animals' relative ranks from their observations. During competitive interactions over meat, hyenas often solicit support from other, uninvolved individuals. When choosing to join ongoing skirmishes, hyenas that are dominant to both of the contestants almost always support the more dominant of the two individuals. When the ally is intermediate in rank between the two opponents, it inevitably supports the dominant individual. These data enable researchers to suggest that hyenas are able to infer transitive rank relations among other group members. However, unlike monkeys, they showed no evidence for recognising third-party relationships (Engh *et al.* 2005).

Conclusion

Altruistic behaviour of animals is still enigmatic for evolutionary biologists in many aspects, although a great deal of data have been analysed and rational concepts have been developed such as the theory of inclusive fitness and the theory of reciprocal altruism. Altruistic behaviour in animal societies is based, to a greater or lesser extent, on the division of roles between individuals in dependence of their behavioural, cognitive and social specialisation. There are many gradations of social specialisation, from rigid caste division to constitutional and (or) behavioural bias towards certain roles in groups accomplishing certain tasks. In some situations behavioural, cognitive and social specialisation can be congruent; maybe this is the formula for happiness in animal societies.

To navigate social landscape, animals need a surplus of intelligence that overcomes the immediate survival needs, such as eating, avoiding predators, feeding offspring, *etc.*, and this surplus intelligence might have been advantageous for social manipulation. There is much work to be done to evaluate the role of intelligence in maintaining cooperative behaviour. We can assume that cooperation that is based on reciprocal altruism requires more advanced cognitive skills than altruism towards kin because reciprocity demands remembering and discounting levels of cooperativeness among individuals. Specific cognitive adaptations can be expected in some species such as specific concentration of attention and calculation of mutual aids.

However, we should not expect to find a linear correlation between social complexity and levels of intelligence in non-human species. Although experiments based on pair comparison of intellectual abilities in group-living and solitary species have brought some positive results, we should take into consideration that animals that live in solitary in complex and risky environment relay on their own memory and learning skills and may enjoy freedom of restrictions and obligations imposed upon them by their possibly narrow roles within a community.

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Abstract

Altruistic behaviour of animals is still enigmatic for evolutionary biologists in many aspects, although a great deal of data have been analysed and rational concepts have been developed such as the theory of inclusive fitness and the theory of reciprocal altruism. Altruistic behaviour in animal societies is based, to a greater or lesser extent, on the division of roles between individuals in dependence of their behavioural, cognitive and social specialisation. It is a challenging problem to find room for intelligence within the framework of social specialisation in animal communities. In this review characteristics of different levels of sociality are considered, and the role of flexibility of individual behaviour in functional structure of animal communities is analysed. In some situations behavioural, cognitive and social specialisation can be congruent; maybe this is the formula for happiness in animal societies.

6

Biological and Social Aromorphoses: A Comparison between Two Forms of Macroevolution*

Leonid E. Grinin, Alexander V. Markov,
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Introduction

The discussions among the evolutionists on the possibilities and limits of the application of the Darwinian theory to the study of social evolution have been going on for more than a century and a half (on the recent discussions see, *e.g.*, Hallpike 1986; Pomper and Shaw 2002; Mesoudi, Whiten, and Laland 2006; Aunger 2006; Barkow 2006; Blackmore 2006; Mulder, McElreath, and Schroeder 2006; Borsboom 2006; Bridgeman 2006; Cronk 2006; Dennett and McKay 2006; Fuentes 2006; Kelly *et al.* 2006; Kincaid 2006; Knudsen and Hodgson 2006; Lyman 2006; Mende and Wermke 2006; O'Brien 2006; Pagel 2006; Read 2006; Reader 2006; Sopher 2006; Tehrani 2006; Wimsatt 2006). We have already analyzed some approaches connected with the comparison between biological and social evolution; we have also expressed our own position on this point (Grinin and Korotayev 2007a, 2009a; Grinin, Markov, and Korotayev 2008: 145–152). Unfortunately, in most cases we observe an excessive polarization of positions, some of which imply an almost total rejection of the Darwinian theory applicability to the study of social evolution (see, *e.g.,* Hallpike 1986), whereas the opposite camp insists that the cultural evolution demonstrates all the key Darwininian evolutionary traits and that is why the structure of the research in cultural evolution should share all the fundamental traits of the structure of the research in biological evolution (Mesoudi, Whiten, and Laland 2006). We believe that we need now somehow different approaches that are more constructive and more congruent with current trend toward interdisciplinary science.

The human need to comprehend the world in its unity seems to have appeared with the very development of abstract thinking. As regards evolutionary ideas with respect to the general order of the world transformation, they can be found

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in philosophical constructions of Ancient India or Greece (see, *e.g.,* Vorontsov 1999). However, the first ideas of scientific approach to evolution only emerged in the 18th century. In the 19th century the evolutionary ideas became a component of scientific thinking. As they were supported by an impressive body of empirical evidence, they were gradually established in geology, cosmology, and, in a virtually parallel manner in biology and social sciences, producing a mutual influence. In the last decades of the 19th century the idea of evolution (accompanied by the one of progress) as a general course of development of nature and society (and the matter in general) became one of the major components of science and philosophy. This idea made it possible to see the picture of the development of the world as a whole. However, such approaches were based on rather naïve belief in the linearity of development and universality of general laws, in the overall complete concordance between nature and knowledge (see, *e.g*., Bunzl 1997: 105). That is why the evolutionism of the positivist philosophy soon stopped satisfying the fast developing science and began to be rejected together with the idea of uninterrupted progress (Parsons 2000: 44).

However, the evolutionary concepts did not die; the academic community returned to them at a new level of scientific knowledge and actively developed them (and not only in biology, but also in sociology and cultural anthropology).[1] In recent decades a considerable number of authors tried to connect biological and social evolution; yet, in general, evolutionism develops quite independently in biology and social sciences (note that it is developed much more actively and effectively in biology). In most cases those biologists and sociologists who study the evolution do not know that many problems and ideas are rather similar in the both realms. Authors of this article have found this with their own experience, when solutions discovered in one realm turned out to be applicable in the other. That is why we believe that it is highly desirable to create a general field of evolutionary studies (see the Introduction to this Almanac for more detail).

Yet, at the present-day level of scientific development we need such approaches that allow considering macroevolution at a transdisciplinary scale, such approaches that both secure the operationalization of the employed terminology and theoretical statements, and do not reduce one form of macroevolution to another.[2] In other words, the activities aimed at the unification of

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[1] Evolutionary ideas have been also developed rather actively with respect to non-biological natural systems; however, we do not consider this aspect in the present article. Yet, this point is treated in the Introduction to the present issue of the Almanac.

[2] Sometimes this is done using such 'common denominators' as energy or entropy (see, *e.g.,* Chaisson 2001, 2005, 2006; on the analysis of such an approach see Spier 2005; see also his contribution to the present issue of the Almanac). A search of such a 'denominator' is very important, as it could indicate some common fundamental characteristics of all the forms of the matter. Yet, there is some risk to exaggerate its potential for the understanding of specific features of each type of macroevolution and their driving forces.

the research tools with respect to various types of macroevolution should not be mechanical. In this article we try to present some research tools that can help to work out such approaches that could be common for both biological and social macroevolution.

In this article we discuss a group of 'rules' and 'laws' that can be applied to the both types of macroevolution. In the meantime we try to demonstrate not only similarities in those rules, but also significant differences that we encounter when applying them to biological evolution, on the one hand, and social evolution, on the other.

When we speak about macroevolutionary rules, we imply that they do not denote any sorts of rigid functional dependencies and relationships that must be observed in all the phenomena of a given class; they rather denote some principles or trends that tend to be supported empirically and that, consequently, allow to provide more adequate explanations for complex processes and phenomena, which would be accounted for in a worse or less complete way if those rules were not taken into account (see also, *e.g.,* Chernykh 1986).

We denote as a **scientific** law a certain statement (that can be expressed both verbally and mathematically), which is produced on the basis of generalization of a set of phenomena of a certain class on the basis of common approach, logic and rules of interpretation and which maintain that something will take place (or will not take place) in this or that degree of completeness under rigorously identified conditions (see, *e.g.,* Grinin 2006; Grinin and Korotayev 2007a, 2009a; Grinin, Markov, and Korotayev 2008: 8–9).

All the analyzed rules are connected with the transition of biological and social systems to new qualitative levels or with 'novelty' (see, *e.g.,* Rautian 2006; Nikolis and Prigozhin 1979, 2003; Eygen and Vinkler 1979; Ebeling, Engel', and Faystel' 2001; Prigozhin 2002; Glensdorf and Prigozhin 2003; Prigozhin and Stengers 2003; Ebeling 2004).

We have presented a more or less complete system of evolutionary rules, laws, and principles in our monograph (Grinin, Markov, and Korotayev 2008). In this article we single out first of all those rules and laws of macroevolution that are connected with the most important evolutionary changes (as regards the increase in proximate and ultimate potential and advantages of biological and social taxa) that (following a number of biologists) we denote as **aromorphoses**.

Biological and Social Aromorphoses

Thus, one of the important terms that we use in this article is *aromorphosis.* The aromorphosis is understood by Russian biologists along the lines suggested by Severtsov (Severtsov A. N. 1939, 1967). As any broad biological generalization, the notion of 'aromorphosis' remains a bit vague; it appears difficult to define it in a perfectly rigorous and unequivocal way. Initially, aromorphosis was understood as such a direction of evolution, within which the **biological**

success of a group is achieved through **morphophysiological progress** (Severtsov A. N. 1939, 1967), whereas the 'biological success' of a group can be estimated using such measures as levels of achieved diversity, biomass, and abundance. As regards 'morphophysiological progress', Severtsov defined it as the increase in energy of vital functions. However, later such an 'energy-centered' approach was criticized as too limited (Tatarinov 1976). Shmal'gauzen (1969) emphasized the importance of such a criterion (or symptom) of aromorphosis as the **growth of organismal complexity** that is tightly connected with the **expansion of conditions of existence and increase in their complexity**.

The importance of 'ecological' component of aromorphosis (expansion of adaptive zones and environmental conditions) has been underlined by a number of researchers. As a result a few quite reasonable definitions of the aromorphosis have been proposed, for example:

1. *Aromorphosis is an expansion of living conditions connected with an increase in complexity of organization and vital functions* (Shmal'gauzen 1969: 409).
2. *Aromorphosis is an increase in the organization level that makes it possible for aromorphic organisms to exist in more diverse environments in comparison with their ancestors; this makes it possible for an aromorphic taxon to expand its adaptive zone* (Severtsov A. S. 2007: 30–31).

In the meantime we do not find it reasonable to identify 'aromorphosis' with 'evolutionary progress' (Davitashvili 1972: 10). The notion of evolutionary progress is much wider than arogenic changes, though aromorphosis constitute a major component of evolutionary progress. On the other hand, we are not ready to agree with the statement of Timofeev-Ressovsky *et al.* (1969: 226–228) that if the evolutionary regress is accompanied by the movement to a new adaptive zone due to the acquisition by the respective group of some new characteristics, then we can extend the notion of aromorphosis (or arogenesis in terminology of Timofeev-Ressovsky *et al.* [1969: 224]) to the regressive phenomena.

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

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

The notion of 'aromorphosis' (or its analogue) does not appear to have been worked out with respect to social evolution. We believe that the adaptation of this notion for the theory of social evolution could be an important step forward for the development of this theory itself, and for the general theory of macroevolution. We tend to agree with Claessen's proposal to consider macroevolution as 'the process by which structural reorganization is affected through time, eventually producing a form or structure which is qualitatively different from the ancestral form' (Claessen 2000: 2).[3] Though this definition belongs to Voget (1975: 862), yet it was Claessen who supported this definition most systematically in the realm of sociocultural anthropology (Claessen and van de Velde 1982: 11ff.; 1985: 6ff.; 1987: 1; Claessen 1989: 234; Claessen and Oosten 1996 *etc.;* see also, *e.g.*, Collins 1988: 12–13; Sanderson 2007; Bondarenko, Grinin, and Korotayev 2002, 2011 in this volume). If we base ourselves on this definition, then we can interpret *social* macroevolution as a process of structural reorganization of societies and institutions, as a result of which we observe the formation of such a structure that is qualitatively different from the ancestral structure and that usually gives to a respective society some advantage in its interaction with natural and social environments in the present or in the future (see Grinin and Korotayev 2009a).

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

Thus, we believe that the use of some important theoretical achievements of biological macroevolutionary theory (including some of its terms) in the field of the study of social evolution (this naturally implies the necessity to take into account the specific features of social evolution) may be rather productive (for some experience of such borrowings see, *e.g.,* Korotayev 1997, 2003; Grinin and Korotayev 2007b, 2008a, 2008b, 2009a, 2009b, 2009c; Grinin, Markov, and Korotayev 2008).[4] Such an approach is quite justified, as it is quite typical for social

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[3] It seems necessary to emphasize that, though Claessen and Voget speak about the evolution as a whole, their definition is still more applicable to macroevolution, whereas its applicability to microevolution (and, especially, to biological microevolution) seems to be rather limited.

[4] As well as the other way round. It appears appropriate at this point to recollect that Charles Darwin borrowed a number of important notions for his theory from social sciences, in particular

sciences (that are reaching their maturity significantly later than the natural ones) to borrow from natural sciences – from geology to complexity studies. And if a social science lacks a convenient term, why not to take it from a more developed science?

In the process of our work aimed at the adaptation of some biological terms to the description of socioevolutionary phenomena it has been found out that such an approach is rather productive as regards the comparison between various aspects of social and biological macroevolution. On the other hand, the opposite influence is also possible. For example, the hyperbolic growth models designed initially for the mathematical description of the social macroevolution turned out to be well applicable to the description of the biological evolution (see, *e.g.,* Markov and Korotayev 2007, 2008, 2009). In addition to this, as has already been mentioned above, quite a few ideas that have been developed by us with respect to the social evolution have turned out to be applicable to the biological evolution (we can mention as an example the rule of special/exceptional conditions for the emergence of aromorphoses, where we just substituted 'newness/novelty' with 'aromorphosis'; the same is true for the 'rule of the arogenic relay-race').

The social aromorphosis can be defined as a universal / widely diffused social innovation that increases social systems' complexity, adaptability, integrity, and interconnectedness (see Grinin and Korotayev 2007a, 2008a, 2009a; Grinin, Markov, and Korotayev 2008, 2009a, 2009b).

Social aromorphoses lead to the following results:

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

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

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

d) more rapid evolution toward the formation of supercomplex maximum supersystems (world-systems, the World System, and, finally, the humankind as a single system, see note 5) in whose framework each particular social system (while remaining autonomous) becomes a component of such a supersystem and develops within it through specialization, the intersystem functional differentiation.

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from theories of Thomas Malthus and Herbert Spencer (see, *e.g.*, Mayr 1981: 18–19). Darwin himself points out that the struggle for survival is Malthus doctrine spread to both realms of animals and plants (Darwin 1991: 23). See also Lekevičius 2009.

Within the process of social macroevolution, a certain role is played by aromorphoses of all levels; yet, we believe that an especially important role is played by aromorphoses possessing characteristics (c) and (d), as they belong to aromorphoses of the highest type that influenced not only the historical fate of particular societies, but also the course of historical process as a whole.

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

- formation of the egalitarian food-sharing system among the early humans that increased the human adaptability to natural environments and stability of human communities in the most significant way;
- origins of early systems of social kinship that created a universally convenient system of social structuration;
- transition to food production that led to an immense artificial increase in the quantities of useful (for humans) biomass;
- introduction of developed irrigation systems that established an economic basis for early civilizations and states;
- formation of cities (the further urbanization process also included many important arogenic sociocultural changes);
- development of the social division of labor that secured the elaboration of crafts, trade, administration, and culture;
- state formation that led to a qualitative transformation of all the social, ethnic, and political processes;
- invention of writing that served as a basis for the revolution in information processing technologies involving the development of elaborate administrative systems, literature, science;
- transition to iron metallurgy, which made it possible to finalize the formation of the World System in its main Afroeurasian borders;[5]

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[5] *World-system* is a maximum system of human societies, beyond whose borders no significant contacts/interactions (between parts of the given world-system and parts of the other world-systems) exist. This implies that there could be some contacts between societies of the given world-system and societies of the other world-systems, but this contacts should be insignificant; that is even after a long time such contacts do not lead to any significant changes within the respective systems (see Grinin and Korotayev 2009a for more detail). For example, early travels of Scandinavians to the New World (and even their settlement there) did not alter in any significant way the social macroevolution of either Europe or Americas (see, *e.g.,* Slezkin 1983: 16). For example, with respect to the 15th century one may speak about the American, Australian, Afroeurasian, and some other (smaller) world-systems. We denote as the **World System** a world-system that emerged between the 10th and 8th millennia BCE in West Asia, and then, through a series of expansions/incorporations developed into the Afroeurasian world-system (= the World System). The Modern World System (that actually encompasses the whole world) emerged as a result of the expansion of this very system, and that is why, following Andre Gunder Frank (1990, 1993; Frank and Gills 1993) we denote it as the main world-system, that is, as the World System. One can use as a formal justification for the designation of this world-system as the World System the point that in the recent millennia it encompassed more than a half of the world population. Note that we also find it appropriate to speak about biological world-systems, which we define as

- formation of world religions that made it possible to draw together culturally, ideologically, and ethnically hundreds of previously alien peoples and societies;
- invention of book-printing that triggered the second information revolution;
- formation of science of a new type – mathematically-based science that lead to a radical increase in the innovation production;
- formation of developed market systems that laid basis for the industrial revolution;
- invention of computer technologies, *etc.*

Each of those aromorphoses had a number of various (and frequently very evolutionary important) consequences that generally contributed to the increase in the potential of respective societies as regards carrying capacity of their territories, stability of their systems and so on.

There are some important similarities between the evolutionary algorithms of biological and social aromorphoses. Thus, it has been noticed that the basis of aromorphosis 'is usually formed by some particular evolutionary change that... creates significant advantages for an organism, puts it in favorite conditions for reproduction, multiplies its numbers and its variability..., thus accelerating the speed of its further evolution. In those favorable conditions, the total restructurization of the whole organization takes place afterwards' (Shmal'gauzen 1969: 410; see also Severtsov A. S. 1987: 64–76). And then, in course of adaptive radiation those changes in organization diffuse more or less widely (frequently with significant variations).

A similar pattern is observed within social macroevolution. Take, *e.g.,* the invention of iron metallurgy. As is well known, the iron production was practiced sporadically already in the 3rd millennium BCE; however, the regular production of low-grade steel actually began in the mid 2nd millennium BCE somewhere in Asia Minor (see, *e.g*., Chubarov 1991: 109) within the Hittite Kingdom that guarded its monopoly. However, the very technology of iron production was still rather primitive and it did not secure to its owner any overwhelming advantages. The fall of the Hittite Kingdom led to the end of this monopoly and made it possible for the iron production technology to diffuse (Grakhov 1977: 17; Brey and Tramp 1990: 82; Giorgadze 2000: 122–123; Dyakonov 2004: 400). One could observe a process that was similar to what is called 'adaptive radiation' in biology. In the first half of the 1st millennium BCE

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flora and fauna of those landmasses that have contacts within themselves (such contacts could be episodic; but they should be sufficient for the exchange of main bioevolutionary innovations) but lack such contacts with the ones of the other landmasses. For example, it seems possible to speak about such biological world-systems as North-American-Afroeurasian, South American (that had existed before South America was connected with North America), or Sahul (New-Guinea-Australian) ones (see Grinin, Markov, and Korotayev 2008; Markov and Korotayev 2008).

the technologies of iron production and processing (yet with some significant variations connected, among other things, with different types of ores and fuels) diffused within the whole of the Middle East and most of Europe, and then throughout the whole Afroeurasian world-system (Chubarov 1991: 109, 114; Grakhov 1977: 21; Kolosovskaya and Shkunaev 1988: 211–212; Davis 2005: 61; Zlatkovskaya 1971: 47). Diffusion of the iron industry led to revolutionary changes in different spheres of life: one could observe a significant progress in plough agriculture (and consequently in the agrarian system as a whole); an intensive development of crafts; the transformation of barbarian societies into civilizations; the formation of new types of armies (that is, the mass ones armed with relatively cheap but effective iron weapons); the emergence of significantly more developed systems of taxation (and, hence, information collection and processing systems) that were necessary to support those armies, *etc.*

There are both significant similarities and significant differences between biological and social macroevolution; their analysis goes beyond the scope of the present article (this analysis has been undertaken by us earlier: Grinin and Korotayev 2007a, 2009a; Grinin, Markov, and Korotayev 2008, 2009a, 2009b). It appears sufficient to mention one such difference that seems to be the most fundamental: the biological evolution is predominantly additive/cumulative, whereas the social evolution is predominantly displacing. In this regard the difference between social and biological aromorphoses is similar to the difference between the overall patterns of both types of macroevolution: the development of biological aromorphoses tends to contribute to the increase in biodiversity,[6] whereas the diffusion of social aromorphoses tends (but just tends!) to lead to the replacement of more simple social forms with more complex ones. Thus, with the diffusion of iron technologies all the societies that confronted this diffusion had to borrow this technology, otherwise they risked to be absorbed or destroyed by those societies that possessed this technology.

Let us consider now what can be regarded as main criteria of biological aromorphosis, and whether those criteria fit social aromorphoses. By now the following criteria have been suggested:

1) the growth of organization level (~ increase in organization complexity) that is frequently accompanied by the growth of the ‘general energy of vital functions’ – a **morphophysiological** or **structural-functional** criterion;

2) the expansion of conditions of existence, the increase in independence of the organism from the fluctuations of external environments (in historical perspective this corresponds more or less to the expansion of the adaptive zone) – an **ecological** criterion;

3) ‘biological success’, or ‘biological progress’ that is achieved, according to A. N. Severtsov, through the first two points. The extent of biological progress can be estimated taking into consideration increases in morphophysi-

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[6] Quantitative characteristics of biodiversity are displayed in Fig. 1.

ological, taxonomic, and ecological diversity, in abundance of organisms, and the overall biomass of the respective group. Due to biological progress, one can observe a wide diffusion of traits acquired by an aromorphic taxon – a **biological** criterion.

It is quite clear that all those criteria are not quite rigorous, and Criteria 2 and 3 can be only applied in retrospective.

On the other hand, all the three criteria are quite applicable to many social aromorphoses. One can take as an example the creation of irrigation systems that secured a basis for civilizations, states (and their analogues) in the valleys of large rivers first in the Middle East (since the 4th millennium BCE), and then in some other regions (in the 3rd and 2nd millennia BCE). It is well known that this basis secured a vigorous demographic growth and a qualitative growth of complexity of social systems (Criterion 1).

The irrigation secured the development of extensive food storage, as well as systems of social exchange and (to a certain extent) social insurance. All these expanded the conditions of existence, increased radically the degree of independence of social organisms from the fluctuations of external ecological (and even social) environments (Criterion 2). The very fact of rather long periods of existence of Middle Eastern (and other irrigation-based) civilizations (as well as some states of this group) can be regarded as an evidence for this.

Finally, on the basis of the two above-mentioned points we can observe an undeniable flourishing and expansion of irrigation civilization (Criterion 3) that may be estimated with a number of objective criteria: for example, through the growth of cultural-economic diversity of social units and formations (such as various temple, town, and trade communities), through population growth, and the increase in the size of territory controlled by polities of a new, aromorphic type.

As regards the social aromorphosis, one may add an important criterion (note that it is also applicable to the biological aromorphosis, yet at a more restricted scale, as the latter can only diffuse widely within a certain taxon, but not outside it, though it is not possible to exclude entirely the possibility of existence of a special type of supra-taxon aromorphoses that may be denoted as ecosystem aromorphoses). This criterion may be denoted as a criterion of diffusion (degree of **expandability**, and, hence, **adaptability)**, that is the capability to borrow aromorphic innovations and to use them in new conditions.[7] With respect to many social aromorphoses this criterion sometimes becomes the most important (as we could see above as regards the borrowing of technologies of iron-making). The wider an aromorphosis' capability to proliferate and adapt to various conditions, the weaker the competitive capabilities of those societies that rejected it or failed to borrow it. Thus, this feature of social

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[7] It is very clear, however, that with reference to social evolution the adaptability criterion has its limitations.

aromorphoses produces a trend toward the convergence of various lines of social macroevolution and gives to social macroevolution certain features of a displacing process. In contrast, in biological macroevolution, though aromorphoses can diffuse rather widely so that this diffusion can produce a new phylum or subphylum (take, for example, such an aromorphoses as the emergence of the vertebral column), however, this does not lead to the displacement of other phyla/subphyla that are not capable for such a modification (and have no 'need' for it).

Returning to the classification of qualitative changes in the framework of biological macroevolution, it should be mentioned that in cases when Criterion 2 is not applicable to the given evolutionary shift (the development occurs within the limits of an old adaptive zone, or the adaptive zone is changed without its expansion), it appears more appropriate to speak about the ***allomorphosis;***[8] the contraction of adaptive zone (including those cases when it is accompanied by the development of sometimes complex and perfect, but partial adaptations) is denoted as ***ecological specialization***. For those evolutionary events that satisfy Criterion 2, but not Criterion 1 (the expansion of adaptive zone without increase in organization complexity) the term ***epektomorphosis*** was suggested (Iordansky 2001). One can mention following examples of epektomorphoses: the development of skin respiration in amphibians, the development of the shell in mollusks, the development of the special axial skeleton and musculature in snakes (*Ibid.:* 361).[9] As regards the biological progress (Criterion 3), it may be achieved in a number of non-arogenic ways, including morpho-physiological regress (decrease in organismal complexity), ecological specialization, allomorphosis, epektomorphosis, *etc.* (Shmal'gauzen 1939, 1969; Matveev 1967; Severtsov A. S. 1987; Iordansky 2001; Timofeev-Ressovsky *et al.* 1969, *etc.*).

Phenomena of a partial social progress accompanied by antiprogressive and regressive (involving the decrease of societal complexity) shifts are not rare in social macroevolution. Thus, a collapse of a large empire can lead to a progress in the development of local institutions, to the formation of local feudal states and dynasties, to the growth of cities, *etc.,* for which one can easily find many examples in the history of Western Europe, Russia, as well as in certain periods of Chinese history.

Numerous examples of evolutionary transformations satisfying Criteria 1 and 2 (but not 3) can be observed in periods of formation of new major taxa. For example, in the course of mammalization (that is the formation of mammal

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[8] Quite wide-spread changes of specialization of foragers (*e.g.,* change of the focus on hunting to the focus on gathering), as well as, *e.g.,* transition from extensive plant cultivation to extensive animal husbandry (and *vice versa*) could serve as examples of 'social allomorphoses'.

[9] Within social macroevolution one can mention as an example a high level of development of some crafts in some communities of simple agriculturalists that did not lead to any significant growth of the overall complexity of respective social systems.

traits) many groups of theriodont reptiles acquired progressive 'mammalian' traits in a parallel way, which was accompanied by the expansion of their potential adaptive zone; however, only one of those lines realized fully its potentials and became aromorphic giving birth to mammals (Tatarinov 1976).

Such examples can be also found with respect to social macroevolution. Thus, in the period when the complexity of late primitive societies increased, one could observe the intensification of politogenetic processes, as a result of which societies of different types acquired similar traits that enhanced functional differentiation and social stratification, alienation of power from the majority of population and its concentration by certain groups, as well as the expansion of the possibilities of societal administration. There were many types of such complex societies, but only one line managed to realize fully the respective potential and became aromorphic giving birth to the state formation process (see Grinin and Korotayev 2009a, 2009b; Grinin 2009 for more detail).

The Rule of Aromorphosis

As the role of aromorphoses in the evolution of biosphere is very important, some scientists prefer to speak about the 'rule of progressive evolution', or the 'rule of aromorphosis'. According to Rautian (1988a: 103; see also 1988b), an aromorphosis is usually accompanied by penetration into a previously inaccessible adaptive zone and formation of a new adaptive zone through a radical reorganization of relationship with the previously exploited environmental factors. The systematic nature and mutual coordination of progressive changes increases the general organizational superiority of an aromorphosis owner over the environment, that makes it possible to use the environmental factors in a more diverse, active, and selective way. The organizational superiority is the most important precondition for the elaboration of a specific adaptation to the environmental factors based on the growth of vital capacity rather than fertility (Shmal'gauzen 1939, 1968).

Yet, as we have seen above, the role of social aromorphoses in social macroevolution is not less important. That is why it appears possible to speak about a single **rule of aromorphosis** (biological and social) in macroevolution that may be rendered as follows: *in course of macroevolutionary process from time to time one may observe within particular groups of systems such potentially significant changes (innovations) that turn out ultimately (but not immediately) to secure a radical qualitative reorganization of large groups of (biological or social) organisms, as a result of which the following is observed:* 1) *the emergence of an opportunity to exploit new adaptive zones and previously unexploited resources (or a radical expansion of exploitation of old zones and resources);* 2) *the increase in organisms' resilience;* 3) *the growth of the level of organization of the respective system;* 4) *organisms acquire other* *potentially important evolutionary advantages. Those transformations lead to the 'flourishing' of respective groups and further evolutionary progress; in social macroevolution they also lead to the acceleration of development and the increase in the degree of suprasocietal integration.*

As regards mechanisms of emergence of major aromorphoses, we believe they should be analyzed in two aspects.

The first is the aspect of general evolutionary context. An evolutionarily perspective aromorphic 'model' emerges as one of many types of qualitative change in the process of reaction to changing conditions and more complex tasks. In this respect both evolutionarily pass-through transformations and evolutionary blind-alleys (if they led to important changes and solutions of pressing evolutionary tasks) can be regarded as somehow equivalent at a certain level of analysis. This provides an additional explanation for the difficulty of differentiation between such notions as *aromorphosis, allomorphosis, epektomorphosis, etc.,* as all of them designate versions of evolutionary solutions in answer to changing conditions and circumstances, and there is no 'Berlin wall' between the respective types of evolutionary solutions. In other words, there is no fatality in the way to new aromorphoses; there is only an objective need to 'find an answer' to changing conditions, new problems and challenges.

The second is the aspect of exceptionality (see below the rule of exceptional conditions for the emergence of an aromorphosis). Only one of many concrete changes (models) turns out to be sufficiently perspective and universal when it proves its competitive advantages and starts to gradually diffuse, be borrowed and transmitted. The reasons for such exceptionality should be studied specially for every particular case. However, the general answer why some major aromorhic transformation was realized could sound as follows: *it took place as one of many reactions to environmental, resource, structural, factor changes (or any other substantial changes).* Yet, in different taxa and in different societies the reaction to the growing complexity of tasks (changing conditions) was very different with respect both to its contents and to its evolutionary perspectiveness. Only some of many models turned out to be evolutionary perspective. However, their advantages did not manifest themselves immediately, and for a long time different models could compete among themselves.

Hence, it seems possible to agree with the statement that the aromorphosis is a transformation that is qualitative with respect to its consequences but that is not accompanied by qualitatively specific modes of evolution (Rautian 2006). Putting this in a different way, the statement that the aromorphosis has no specificity is only true with respect to mechanisms of its emergence and primary fixation, but not with respect to its evolutionary consequences.

Timofeev-Ressovsky, Vorontsov, and Yablokov maintain the following: 'Thus, there is no doubt that there are sufficient grounds to subdivide all the adaptations into two major types according to their wideness and their evolutionary potential: [1] particular adaptations that lead to specialization, and [2] general adaptations that lead to the expansion of the evolutionary potential of a group and to transition to new adaptive zones.[10] It is not easy to draw a clear line between those two extreme types, but such a "blurriness" of borders stems naturally from the complexity and diversity of natural conditions' (Timofeev-Ressovsky, Vorontsov, and Yablokov 1969: 253). It remains for us to add that the above mentioned 'general adaptations' are just **aromorphoses**.

Further we shall consider in more detail *some mechanisms and rules of formation and diffusion of aromorphoses in the biological and social world.*

Rules Connected with the Aromorphoses' Characteristics

1. Rule of the aromorphic 'relay-race'

The same group of organisms or societies cannot remain permanently the evolutionary leader that constantly gives birth to a chain of aromorphoses. Aromorphic potentialities are limited by numerous circumstances, including the structure of the organism (society) itself, environmental conditions, degree of specialization, *etc.* It is evident that 'indeterminately continuous and directed adaptation progress is impossible due to the fact that such a progress is accompanied by a conflict between the stability (the acquired level of adaptation) and the freedom of creativity (perspectives of future adaptation)' (Rautian 1988a: 104).

Any direction of adaptation can become exhausted due to the accumulation of inadaptivity burden (as any adaptation constitutes a sort of trade-off, see below for more detail). This is sometimes denoted as a 'blind alley of specialization'. Finally this usually leads to decline, *i.e.* biological regress (decrease of diversity, abundance, biomass). However, later the situation sometimes changed, leading to a new cycle of adaptation (progressive specialization) in a similar direction, 'whose initial stages are naturally characterized by a lower level of specialization in comparison to the latest phases of a previous cycle' (Rautian 1988a: 100).

As regards social evolution, this idea may be connected with the cycles of growth and disintegration of empires and civilizations; within those cycles one may observe firstly a certain 'regression' toward simpler social systems with subsequent increase in their complexity (that could sometimes reach a level that was significantly higher than the one attested during the peak of a previous cycle (see, *e.g.,* Kul'pin 1990; Grinin 1997–2001, 2003a; Korotayev, Malkov, and Khalturina 2006b; Korotayev and Khaltourina 2006). Well-known cycles of centralization – decentralization/feudalization of the early states sometimes

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[10] According to them, *e.g.,* internal skeleton of vertebrates, external skeleton of arthropoda, or development of vascular system can serve as examples of such adaptations (Timofeev-Ressovsky *et al.* 1969: 252).

ended with the emergence of centralized states of a new more developed type (see, *e.g.,* Grinin 2007a, 2007b, 2007c, 2009; Grinin and Korotayev 2007a).

This suggests the following important conclusions: a) aromorphoses that increase the level of system complexity emerge in new taxa, societies (or in the same societies, but on the basis of new political structures); b) however, those systems are not entirely alien within the macroevolutionary arogenic line. Within biological evolution new leaders are always direct descendants of those groups from whom they have inherited the previous aromorphic traits, whereas in social evolution we can only speak about a certain degree of continuity and succession. This way, one can observe the emergence of a sort of aromorphic 'relay-race' from some systems to others, from one level of organization to another, which makes it possible to trace a sort of trajectories of major aromorphic changes. For example, in Europe, the transition from the Middle Ages to the Modern Age (even if we only take into account technological and commercial aspects of this process) began in Northern Italy, from where the 'relay-race' passed to Portugal and Spain that made the main contribution to the Great Geographic Discoveries (yet, not without help and direction on the part of Genoese seamen and bankers), whereas a part of their achievements was acquired by Germany. Then, as a result of Reformation that began in Germany and the influx of the New World gold, the Netherlands became the avant-garde part of the World System, whereas later the 'baton was picked up' by Britain (where the Industrial Revolution began). Britain occupied the leading positions for many decades until the 'baton was picked up' by the USA. Note that at every stage one could observe important aromorphoses based on the previous achievements.

Thus, the rule of the aromorphic relay-race that we have proposed indicates that a chain of major aromorphoses emerges due to succession of various taxa and societies with a rather complex evolutionary trajectory that is far from a strait line; within this trajectory one can observe constant fluctuations, regressions, zigzags. As a result, the trajectory of the aromorphic 'relay-race' can be only traced retrospectively. Such a composite 'relay-race' evolutionary trajectory may well be denoted as an arogenic line of evolution. However, it is important to take into account the point that the above-mentioned rule confirms an important conclusion by Rautian (1988a, 2006); according to him, the arogenesis as a specific form of evolution (as is interpreted by Takhtadgyan [1966]) that leads directly (without any modus change) to an aromorphoses turns out to be theoretically impossible; such aromorphoses can never emerge. 'The necessity to change specialization directions implies a risk of extinction in the way to aromorphosis' (Rautian 1988a: 104).

2. Rule of rarity of major aromorphoses

The impossibility of the arogenesis as a straight continuous line of changes accounts for the rarity of aromorphoses as a sort of interruptions of graduality. Actually, the more important the aromorphosis, the more rarely it is observed. On the other hand, the rarity of emergence of aromorphoses only emphasizes the evolutionary importance of major aromorphoses. In general, we can maintain that the more important the aromorphosis is, the lower the probability of its occurrence is.[11] The rarity of major aromorphoses, on the one hand, and a certain rapidity and suddenness of changes caused by them, on the other hand, produced some vagueness regarding the point whether the aromorphosis should be understood as a relatively brief phylogenetic event, or it should be regarded as a prolonged process even at the geological time scale (Rautian 2006). We believe that (both biological and social) aromorphoses can be considered (depending on the respective context) in the both aspects. In certain places some major changes can occur relatively quickly; yet, the formation of the whole necessary chain of evolutionary arogenic changes and the wide proliferation of the respective 'innovation' need a long time. For example, in some areas of West Asia the primary transition to agriculture occurred quite rapidly (within a few centuries); however, the improvement and diffusion of primary agricultural technologies took a few millennia that we include in the total period of agricultural revolution (10 000–5 500 BP [Grinin 2003a; Grinin and Korotayev 2009b]). This dualism is directly connected with **the rule of delayed aromorphosis** that will be considered below.

The rule of the rarity of major aromorphoses correlates with **the rule of inversed relationship between a taxon's rank and the frequency of the emergence of such taxa in phylogenesis**, that is trivial in some sense, as within almost any natural set of any objects one can observe a negative correlation between the size (scale, importance) of certain objects and their number: the number of large animals is always smaller than the number of small animals; the number of great writers is always smaller than the number of mediocre ones, *etc*. This is even more clear with respect to taxa of different ranks. Thus, the number of genera can never be higher that the number of species, whatever sample we use; consequently, the frequency of the emergence of new genera is always lower than the frequency of the emergence of new species.

Thus, major aromorphoses are very rare, which emphasizes their status of the most important evolutionary events, each of which gave birth to a whole chain of diverse transformations that in their turn led to new changes; thus, in the framework of one major aromorphosis we can observe a great number of

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[11] However, the significance of this rule gradually diminishes with respect to social (and, possibly, also biological macroevolution) due to the acceleration of the macroevolution's speed, as well as due to another rule – the rule of the growth of new aromorphoses probability (see Grinin, Markov, and Korotayev 2008 for more detail).

other changes with various degrees of importance. Take, for example, the Industrial Revolution of the 18th and 19th centuries. It was connected with immense transformations in transportation, communications, finance, education, demographic processes (including migrations), modern nation and state formation, *etc.* (see in particular Grinin 2003a, 2007c).

In the biological evolution aromorphoses only emerge in very few phylogenetic branches. However, in any given moment of geological history in biosphere one could observe a certain number of aromorphic groups, which testify for the typicality of aromorphoses for the evolution of biota as a whole (Rautian 1988a).

3. The rule of special (exceptional) conditions for the emergence of aromorphoses

Primary direct transition to the aromorphoses occurs (figuratively speaking) in 'narrow places' (for a very limited number of systems).[12] However, this should not be interpreted in the sense that aromorphoses emerge in isolated systems. On the contrary, the emergence of aromorphoses need a great diversity of interacting systems (see below). We mean that in the given moment among many forms only very few combine within themselves all the conditions (some of which are often unique) that are necessary for an aromorphic transformation.[13] Mayr (1974: 403–411) suggests a number of interesting ideas and calculations regarding this point.

Consider, for example, the primary transition to agriculture. Independent invention of agriculture (whatever species were domesticated) only took place in particular zones (see, *e.g.,* Deopik 1977: 15 with respect to South-East Asia). In other words, this needed very special natural conditions. In order to stimulate people to move from foraging to agriculture powerful factors were necessary, and there is no unanimity with respect to those factors. Even more so, special circumstances were necessary in order that agriculture could become an impor-

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[12] In consequent periods, in the process of adaptive radiation in biological macroevolution and in the process of innovation diffusion in social macroevolution, aromorphic changes become more wide-spread.

[13] It appears necessary to underline that, within the present context, the determinative 'exceptional' (with respect to conditions that are necessary for emergence and full-scale realization of aromorphoses) has two aspects, or even two degrees. The first is the very rarity of the appearance of respective structural and/or other changes that are necessary for the emergence of an aromorphosis. However, a certain combination of 'exceptional' conditions is frequently also necessary for the emergence of many non-aromorphic adaptations. However, allomorphic, degenerational, *etc.* changes do not imply the exceptionality of the second degree, that is the exceptionality of evolutionary results. Indeed, such changes should have a progressive potential and allow at the same time to raise in the subsequent period the level of taxa organization, to expand conditions of their existence and to increase the degree of the organism's independence from the fluctuations of external conditions. Thus, one may say in a figurative way that we are dealing in such cases with exceptional conditions "squared", that is with rare conditions for the changes themselves coupled with the rarity of evolutionary qualitative consequences.

tant (and not just marginal) sector of primitive economy. Yet, among all the domesticated species a special role in the aromorphic evolution was played by the cultivation of cereals.

Consequently, the degree of uniqueness of the required natural and social conditions becomes even higher. Hence, it is not surprising that, though many hunter-gatherers knew technologies of plant cultivation and many other 'secrets' of agriculture (including irrigation) (see, *e.g.,* Kabo 1980, 1986; Shnirel'man 1989), there was a great distance from this knowledge to the actual transition to agriculture. Many scientists suggest that the cereal agriculture emerged first in certain highland zones with suitable microclimate and high diversity of respective plants.[14] Note here the hypothesis that was proposed quite long ago (*e.g.,* Shnirel'man 1989: 273); according to this hypothesis, the most ancient agriculture emerged in such mountainous zones where there was a periphery of natural habitats of wild ancestors of the domesticates, as it was this periphery where a need in agriculture was felt in an especially acute form. It was also suggested that in such places climatic fluctuations pushed people not only to gather plants, but also to try to support their reproduction through the creation of favorable conditions (Mellart 1982: 128).

Thus, the primary transition to agriculture needed the concurrence of time, place, various contingent factors, favorable social characteristics, presence of individuals with certain personal qualities, *etc.*; that is a rather large number of conditions should have been satisfied, which illustrates the validity of the above mentioned evolutionary rule, according to which special circumstances are necessary in order that an aromorphosis could emerge. In the meantime it is important to emphasize that West Asia was not isolated, in the respective age it was a relatively highly developed region tightly connected with its neighbors (see Grinin and Korotayev 2009a for more detail).

This makes it possible to arrive at a conclusion, which is very important for the study of the both types of macroevolution (though it seems a bit more relevant for social macroevolution): in order that a major aromorphosis could emerge, a 'wide scene of action' is necessary. We will clarify this point using as an example the Industrial Revolution in the 18th century England. There are a lot of discussions why the Industrial Revolution started in England. Dozens of explanations have been proposed, and each of them is true in some respect. Below we shall sum up various views, including ones of the authors of the present article (Grinin 2003b: 345–346). As is always observed with the start of a major aromorphosis, one can find in this case a unique combination of internal and external factors, as well as peculiarities of the previous development of the respective society.

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[14] This seems to have occurred 'only in certain zones – highland arid areas with warm a subtropical climate that create abundance of natural microzones in a relatively small territory and possess a very reach flora, including wild cereals' (Gulyaev 1972: 50–51).

In particular, one can mention a relatively small degree of the prevalence of serfdom in England and its early abolition; less rigid social barriers, including the possibility for the nobility to engage into commerce, as well as the possibility for rich commoners to become 'gentlemen'; high level of development of private property and legal relationships (including effective legal guarantees of private property inviolability); a fortunate (without a civil war) reformation of the religious subsystem, *etc.*; the favorable external market conditions of the previous centuries (amplified by the well-known inflationary processes of the 16th century – the so-called 'Price Revolution'[15]). One should also mention the optimum proportions of territory and population. The insular geographic position and respective external security were also very important. There is no doubt that Britain also benefited from the European wars (as highly qualified staff from various European countries moved to this country) and geographic discoveries. The possibility for 'excessive' population to move to colonies gave an early impetus for the development of labor-saving technologies. Finally, one should note an immense role of English political revolutions that ultimately transformed the English political system into a constitutional monarchy, which provided favorable political conditions for the development of capitalism. England managed to defeat its main competitor – the Netherlands.

Hence, by the 18th century England managed to solve main internal and external problems, and this way to secure conditions for the start of unprecedented breakthrough. Naturally, one can single out among those factors more and less important, determined and random ones. Yet, in this case it is important for us that, in order that this particular aromorphosis could emerge in the respective particular time and place, a unique combination of many circumstances and causes was necessary.

However, we would like to maintain once again that the emergence of significant social aromorphoses needs a certain social scale (that is much larger than the scale of an individual society – this is often the scale of the World System) and a high 'species diversity' of certain social forms (see, *e.g.,* Grinin 1997a, 1997b, 2003a)[16] (see below 'the rule of sufficient diversity'). The emergence of the primary system of machine production in the English cotton industry in 1730–1760 with subsequent development of systems of steam engines was determined, on the one hand, by the general level of development, integrity and needs of Europe and the World System as a whole; on the other hand, it was determined by unique peculiarities of the preceding history of Great Britain

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[15] See Grinin, Korotayev, and Malkov 2008 for more detail.

[16] At this point it appears appropriate to notice that in biology (in macroevolutionary theory, in ecology, *etc.*) **diversity** is one of the key indicators, which is an object of intensive attention on the part of biologists, whereas in sociology the idea of **diversity** is used, unfortunately, much less frequently, especially as regards its quantitative analysis. In the meantime, one can find here many possibilities for the development of many important parts of the theory of social evolution and macroevolution.

(see Grinin 2003a: 139–140 for more detail) and some events that might look rather accidental with respect to the formation of machine industry. Note among them the prohibition to import to Britain Indian, Chinese, and Persian cotton print textiles. This was a usual protectionist measure that was taken under the pressure of the producers of wool textiles (Mantu 1937: 160). In this age a lot of such measures were taken in various European countries; yet, usually they did not have any revolutionary consequences. As the respective law was passed after a serious struggle (and, hence, there were some chances for it not to pass at all; thus, we are dealing here just with a contingency), one may ask a question: how would the machine mode of production have emerged, if the above-mentioned law had not been passed? We believe that in this case the transition to the new mode of production might have taken significantly more time; this transition might even have taken place in another country (*e.g.,* in Belgium). However, there was a very high probability that such an aromorphosis would have emerged (see McNeill 1990 for interesting comments regarding this point). Thus, the prohibition to import textiles played a role of fortunate contingency.

However, the fact that a usual protectionist measure performed the trigger function within the process of formation and development of the new production function, is accounted for by the point that both the World System as a whole and England as its rather developed but semiperipheral part (note that the semiperiphery is precisely the zone where aromorphic changes are most likely) were ready for such a breakthrough. The early capitalist system and industrial production principle had already emerged (see, *e.g.,* Grinin 2003a: 123–138; 2007c: 73–78), colonial empires had formed, and the world trade had developed in a rather vigorous way (as a result of which Europe found itself flooded with Indian textiles). One should also take into account the presence of a very serious technological progress. In particular, by the late 18th century there was a 150-year history of the steam engine (see, *e.g.,* Mantu 1937: 264).

That is why in some sense one may maintain that the emergence of a new social aromorphic trait **is always a result of synthesis of suprasocietal (civilizational, regional, world-system, or even panhuman) scale of development and peculiarities of the society that produced the respective innovation.**

As regards biological macroevolution, we have already noticed above (for example) the situation when within the ‘mammalization’ process many groups of reptiles independently acquired progressive ‘mammalian’ characteristics, which was accompanied by the expansion of their potential adaptive zone; yet, only one of those lines was capable to realize fully its potentialities and became aromorphic, giving birth to the mammals (Tatarinov 1976). As is well known, in the subsequent epochs mammals populated immense spaces of land and ocean. However, the whole process from the first steps made by some groups of reptiles toward ‘mammalization’ (Late Permian, 270–250 million years BP) till the occupation by the mammals of dominant positions in the terrestrial ecosystems (Early Cainozoic, 65–55 million BP) needed a rather long time – c. 200 million years.

Other aromorhic transformations ('arthropodization' – emergence of arthropods, 'ornitization' – emergence of birds, 'angiospermization' – emergence of angiosperms, as well as hominization, sapientization, *etc.*) occurred in a similar manner. In all those cases aromorphic transformations (that were realized each in a single evolutionary line) were prepared and directed by long parallel development of many lineages, as well as by concomitant development of corresponding ecosystems and the biosphere as a whole.

Rules Connected with the Aromorphosis Formation Mechanism

1. Principle that organs' functions change in evolution

The principle that organs' functions change was first spelled out by Dorn in 1875. An important point (on which this principle is based) is that all the organs of biological organisms (or, at least of complex organisms) are multifunctional.[17] A. N. Severtsov (1939) described a system of moduses of organogenesis that was based on two categories of facts that are observed objectively in nature: 1) all the organs are multifunctional; 2) any function may experience a quantitative change. We do not know a single monofunctional organ in any biological organism; what is more, the number of known functions for any organ tends to increase with its more profound study (see also Timofeev-Ressovsky *et al.* 1969).

However, notwithstanding the intensive study of organogenesis undertaken by Severtsov and his school, the full and definitive analysis of this issue is still absent. More than 15 moduses of organogenesis are known; for example, Timofeev-Ressovsky *et al.* (1969: 216) mention (on the basis of research conducted by other scientists) the following moduses: change of functions, substitution of organs (Kleinenberg 1886), expansion of functions (Plate 1912), physiological substitution (Fedotov 1927), reduction of the number of functions, intensification of functions, substitution of functions (Severtsov A. N. 1935), oligomerization and polymerization of homodynamic and homonomous organs (Dogel' 1954), heterobathmy (Takhtadgyan 1959), compensation and uneven rates of transformation of organs (Vorontsov 1961).

The principle of change of functions and polyfunctionality of organs are tightly connected with the notion of 'preadaptation', that is predisposition, the presence of certain opportunities (organs, functions) to settle new ecological zones. That is, many organs have some real but weakly used functions, which in future (in changed environment) may increase their significance; in addition to that the polyfunctionality implies that in the future an organ may start performing such a function that does not exist at present, but that is similar in some important points with the already existing functions; that is producing the so-called 'preadaptation effect'. The notion of 'preadaptation' (or exaptation) was proposed more than a century ago, but it was not easily accepted by

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[17] Social institutions usually are also polyfunctional.

the academic community and was a subject of rather vivid discussions (see, *e.g.,* Georgievsky 1974). The settlement of any new environment by any type of organisms is only realizable if those organisms have such features that make it possible for them to survive in that new environment. It is very important that such features must form before that start of the settling of the new environment (these are such features that are called *preadaptive*) (Iordansky 2001: 125–130, 350; see also Huxley 1943: 449–457).

As was pointed out by Grant (1991: ch. 34), preadaptation makes it possible to bypass morphological limitations in a rather economic way. When a new function becomes necessary, it turns out to be easier to modify for this purpose an already existing organ rather than to 'create' a new one. Thus, Grant emphasizes that in the evolutionary process major morphological changes occur 'along the least resistance lines'. According to Timofeev-Ressovsky, Vorontsov, and Yablokov those ontogenetic differentiations that have been realized and have an adaptive potential may come out to an evolutionary arena of a larger scale involving new phyla through the phylogenetic processes. According to them, a clear example of this sort is represented by the haemoglobin that serves as an oxygen carrier in many groups of animals. Haemoglobin is likely to have emerged in addition to a few other similar compounds, it was used as an oxygen carrier within a number of taxa until it turned out to be the most effective oxygen transporter that made it possible for a few groups of vertebrates to settle very diverse adaptive zones (Timofeev-Ressovsky, Vorontsov, and Yablokov 1969: 263). We would like to add that the case of haemoglobin is also a good illustration for the rule of delayed aromorphosis that will be discussed in more detail below.

Due to preadaptations, within the process of biological evolution some organs and other components of the organism can change their main functions with the change of environments. Within such situations a functional role of a certain organ may grow substantially. A classical example of preadaptation is provided by the presence of a special type of fins in Sarcopterygii. The construction of the limbs that is typical for land-based tetrapods emerged around 360–370 million BP in the late Devonian period in animals that practiced a fully water-based way of life (the first tetrapods – descendants of Sarcopterygii – such as *Ichthyostega*, *Acanthostega* and some other similar forms). It was considerably later (in the Carboniferous period) that the first tetrapods capable to live on the land emerged. Thus, the lag between the formation of the tetrapod limb and the beginning of its use on land was as long as 20–30 million years. Though the limbs of the first tetrapods were used to move in the water, their construction turned out to be 'preadapted' for life on the land, which up to a considerable extent secured the successful colonization of terrestrial ecological niches by the tetrapods (see, *e.g.,* Long and Gordon 2004).

Something similar may be detected within the social macroevolution. In the Ancient Period, as well as in the Middle Ages the growth of large scale land ownership against the background of declining state organization tended to lead to the so-called 'feudalization', to the appropriation of state resources and power over population by local magnates, to the replacement of state power by the power of local magnates. In bureaucratic states (such as medieval China) the growth of land possessions of high officials meant that they became less dependent on the central power and used their own powers for their self-enrichment. Such a process tended to lead to an actual 'privatization' of the state, the decline of the level of life of the commoner population, and, finally, to a political-demographic collapse (naturally, in combination with a number of other factors [see, *e.g.,* Korotayev, Malkov, and Khalturina 2006b]). That is why the Chinese state tended to counteract the growth of such land ownership; and usually it was strong when the private land ownership (especially by high officials and local magnates) was very strictly limited. Hence, within the above described conditions of a centralized agrarian state the large-scale private ownership did not have many positive functions which it had in democratic industrial and postindustrial states. The private property acquires such positive qualities and functions within certain evolutionary types of social systems. In totalitarian or superbureaucratic societies even in the context of industrial production principle, the large-scale private property may have the above described negative functions that lead to the 'privatization of the state' (and we could observe this directly in Yeltsin's Russia). The same can be said about some types of monetary private property that in the Ancient period and Middle Ages were frequently parasitic, exploiting ruthlessly the population through usury and tax-farming. It is not accidental at all that due to those parasitic characteristics many religions stigmatized large scale/monetary private property opposing to it the labor property of commoners (let us recollect that the communist ideas have religious roots). It was only the restriction of interest rates, the expansion of opportunities to use monetary capitals in order to increase the real production and mass trade that led to the situation when monetary private property acquired many positive and important 'progressive' functions that look today as being inherent primordially in this institution; whereas the idea of primordial 'progressiveness' of private property makes it difficult to understand complex dynamics of functional development of private property and the reasons why most states tried to restrict it (see Grinin 1999 for more detail).

Thus, according to the law of the functions' mobility (or functions' change) formulated by one of the authors of the present article, *within the overall system one may observe the change of number of functions, their hierarchy, quality,* a quantitative change*, and other characteristics of function realization* (Grinin 1999). In other words some functions performed by a certain social institution may be insignificant or unused (that is in a sort of social preadaptation) for a long period of time; but under certain conditions their presence could turn out to be extremely important. Later this function may become leading or even the main. Thus the private property's function to secure the extended industrial production through the private interest (that was either absent or weakly manifested in the preindustrial societies) became one of the most important functions of the private property institution in the conditions of the industrial production principle and within a certain type of the states. One more clear example can be provided by weakly functional administrative borders between the republics of the USSR that played a purely administrative role and could be arbitrarily changed at any time. Naturally, the crossing of those borders went unnoticed for the Soviet citizens. However, the importance of those borders grew dramatically after the break-down of the USSR, after which the crossing of those borders became a complex and difficult operation, while any attempts to change those borders get across the principle of their 'involiability'.[18]

In general, the idea that aromorphoses are in some way prepared, that there are some latent prerequisites for future aromorphoses, seems to be even more important as regards social evolution than with respect to biological evolution. One can recollect the 'preadaptation' of the Greek *polis*, or medieval Italian republics with respect to the development of civil arts that gave birth to the creation of a great culture (including the Renaissance one). Or take the hidden potential (preadaptation) of Protestantism to facilitate a rapid development of capitalism discovered by Max Weber (2002 [1904]). It was further shown (see, *e.g.,* Korotayev, Malkov, and Khalturina 2006a) that the positive influence of Protestantism on the genesis of capitalism and modernization is connected with the point that Protestants (unlike Catholics) regarded the reading of Bible as an extremely important duty of any Christian; though it is perfectly clear that the spiritual leaders of Protestantism instructed their followers to read the Bible for religious reasons (and, of course, not in order to promote economic growth). However, as the level of literacy and education among the Protestants turned out to be significantly higher than among the Catholics (as well as the followers of other confessions) who had no religious stimulus to become literate (see, *e.g.,* Malerb 1997: 139–157), this turned out to be very important for the development of capitalism in the protestant countries (see Korotayev, Malkov, and Khalturina 2006a for more details).

It also appears reasonable to mention here that biology has the notion of constitutional preadaptation that actually unites morphofunctional and genetic-ecological aspects of preadaptation (Iordansky 2001), that is, a whole set of various peculiarities and adaptations that are ultimately capable to change

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[18] Similar metamorphoses took place with respect to the borders between colonies belonging to one state after those colonies became independent.

the way of life of representatives of a given taxon. Actually, for their realization constitutional preadaptations need some impulse, event, key mutations. In this respect constitutional preadaptation is tightly connected with the notion of key aromorphosis that finalizes a set of changes giving a vigorous impulse to further transformations. It is not surprising that Iordansky (Iordansky 2001: 133) cites as an example of constitutional preadaptation the tetrapods' ancestors – Sarcopterygii (see the example above).

The notion of constitutional preadaptation appears to be rather relevant for social macroevolution, especially for those cases when we observe special and even unique conditions (an example of England that in the 18th century possessed such peculiarities that made the Industrial Revolution possible is rather salient in this regard).

2. Rule of delayed aromorphosis

Some economists distinguish between 'inventions' and 'innovations', defining as innovations those inventions that have been actually introduced into economic systems and produced actual economic effect (see, *e.g.,* Schumpeter 1926). It is not infrequent that in order that such innovations could be realized we should have a whole set of various inventions whose combining into a system could produce a vigorous economic effect. The same way biologists-evolutionists distinguish between biological 'inventions' and biological 'innovations'. The biological 'invention' corresponds to the emergence of a new trait as a result of some genetic change and its further fixation within a population under the influence of natural selection or genetic drift. The biological 'innovation' corresponds to the achievement of biological progress (the growth of diversity, numbers, biomass, role in the biosphere) based on the given 'invention' (Erwin and Krakauer 2004).

A number of evolutionary changes (including minor aromorphoses) can continue the formation of a certain system for a rather long time, preparing conditions for a major aromorphosis. Sometimes many necessary conditions for such an aromorphosis have already emerged, the key morphophysiological changes have already taken place, but there are no sufficient conditions for their wide proliferation (that is, for the achievement of biological progress). Thus, it is well known that mammals had emerged long before the moment when this group started to occupy a dominant position within the land ecosystems. The mammals emerged in the late Triassic period (c. 220 million BP), whereas their vigorous expansion and adaptive radiation only took place in the Cenozoic (since 65 million BP), that is in this case the interval between the 'invention' and 'innovation' was much more than 100 million years (numerous new findings provide evidence on a high diversity of Mesozoic [and, especially, Cretaceous] mammals; however, in general, mammals remained a 'subordinate' group that evolved 'in the shadow' of the dominant groups of reptiles). There appear to have been a considerable number of 'delayed aromorphoses' at the early stages of the evolution of life. Thus, according to discovered biomarkers (remains of organic molecules that are typical for the eukaryotes), the first eukaryotes emerged c. 2.7 billion BP; however, they started playing a noticeable role in marine biocenoses not earlier than 1.9–1.5 billion BP. Their diffusion might have been restricted initially by low concentrations of oxygen in the atmosphere and hydrosphere; though some evidence suggests that by the moment of the emergence of the first eukaryotes the atmosphere and hydrosphere might have been oxygenized quite significantly (Rozanov 2003). The first multicellular animals appear to have emerged c. 1.5 billion BP; however, their wide diffusion in the ocean only began c. 0.6 billion BP (in the Ediacaran period of the Neoproterozoic era) (Fedonkin 2006).

In social evolution for long periods of time many inventions do not play either the role that they start playing in other circumstances. It appears sufficient to recollect that gunpowder and compass did not make a revolution within the Chinese civilization. They did it within the European civilization, and then within the World System. We may also return to the above mentioned example of the emergence of cotton industry in England that triggered the beginning of the industrial breakthrough (the second phase of the Industrial Revolution) and the transition to the industrial production (first in England, and later – within the World System as a whole); one should mention that by that time machines had existed for centuries (whereas the simplest ones had existed for millennia). Even the history of the steam engine was as deep as a century and a half by that time. There were some sufficiently mechanized branches of industry (like some branches of mining industry, for example [see Grinin 2003a for details]). The cotton industry also existed for quite a long time (whereas in India it existed for many centuries). There were also such important preconditions as patent law, developed private property, *etc.*); however, the system first lacked an effective loom though there was a great need in it due to a very high demand for cotton textile. When it appeared (as John Kay's shuttle loom) in the 1730s, the system confronted the absence of an effecting spinning wheel (and the spinners lagged far behind the weavers, which hindered greatly the technological process as a whole). When more than 30 years later the famous spinning jenny was invented, one could observe the emergence of that very previously lacking element whose emergence was able to transform a delayed aromorphoses into an actual one. In subsequent years the cotton industry developed so vigorously that already 20 years later one could observe the emergence of a fully mechanized branch of industry based on the use of water energy and soon after the energy of steam (subsequently one could also observe the formation of more and more new mechanized industrial branches).

As regards the causes of the long periods of time during which many biological and social aromorphoses failed to proliferate to any considerable degree, one should take into consideration the point, that evolutionary promising and effective aromorphoses were frequently not quite successful and promising within concrete circumstances of their emergence. It was rather often when an opposite pattern was observed.

Even when an evolutionary promising form already existed, there was usually necessary a long ‘incubation period’ and **special conditions**, in order that this form could prove its unusual effectiveness.

3. Key aromorphosis rule

This rule is rather tightly connected with the previous one, as it accounts for one of the possible causes of ‘delays’ in the aromorphoses' formation. The notion of ‘key aromorphoses’ was suggested by N. N. Iordansky (1977, 2001) to account for the mechanism that directs consecutive acquisitions of a complex set of mutually coordinated features within the phylogenesis. According to Iordansky, the key aromorphosis is a morphophysiological trait whose formation, first of all, has an important significance for its owner by itself, and, secondly, alters in a significant way the relationships between its functional subsystems, which opens on the basis of previous organization a new perspective direction of specialization and new opportunities for the functioning and evolution of subsystems (Rautian 1988a).

A clear example of the key aromorphosis is provided by the energization of the lung respiration through the optimization of the air absorption into the lungs – a transformation that opened the way to the emergence of reptiles from their amphibian ancestors. This morphophysiological transformation made it possible to take from the skin the function of respiratory metabolism. In its turn, this made it possible to make the skin dry and keratinizing so that it could serve for the mechanical and hydroisolating protection of the organism. The venous blood lost the function of the oxygen transportation from the skin to the heart, and this made it possible to divide the venous blood stream and the arterial blood stream; finally, this paved way for the emergence of the four-chamber heart. The notion of key aromorphosis emphasizes the role of some new traits in the realization of the organism's hidden evolutionary potential whose actualization was hardly possible (or just impossible) prior to the emergence of the key aromorphosis. The specificity of the key aromorphosis is connected with the far reaching consequences of its emergence for its owner *(Ibid.)*.

One can find a very considerable number of key aromorphoses in social evolution. It makes sense to subdivide them according to their rank as well as according to their form creating potential. Note also that in some cases (when objective conditions ‘demand’ a certain innovation) concrete time and locations of its emergence do not play any decisive role. Thus, if the spinning jenny had not been invented, the industrial revolution would have still occurred on the basis of some other mechanized spinning wheel. The same way one would expect emergence of some other steam engine instead of Watt's one. If not Columbus, America would have soon been discovered by someone else. Thus, the further 'physiognomy of events' (to use Plekhanov's [Plekhanov 1956]) would have been quite similar (though, of course, it would not have been entirely similar). We deal with a rather different situation when we confront the emergence of world religions, as their essence, organization, cult, and ideology are very tightly connected with the personalities of their founders, recorded texts of sacred scriptures, and concrete events. All these usually gave an emerging religion a rather special form and character that could not be easily changed in future (and, actually, some traits could not be changed at all). It is evident that the religion founded by some person other than Muhammad[19] in the early 7th century (if it had become a world religion) would have had another shape, different ethical norms, it would have had a different connection with politics, different organization principles *etc.* In this respect, each such event is analogous to the emergence of a new major taxon in biology. Thus, in particular, while interpreting the above-mentioned example, it may be said that, if the reptiles' ancestors had not 'learned to breath with their breast' (and continued, like frogs, to pump air to their lungs through the expansions and contractions of their oral cavities), no reptiles would ever emerge.

No doubt, the discovery of the use of fire at the dawn of human history, the transition to agriculture, the invention of metallurgy (note that for all the cases above we do not know names of the inventors), the transition to statehood (and some of its analogues) *etc.,* also included some key innovations that launched these major social aromorphoses that transformed the whole life of people. We know much more details with respect to key aromorphoses/innovations of Modern history, for example, the ones that secured the Great Geographic Discoveries (such as, for example, fore and aft sail that made it possible to navigate forward with a cross-wind). We can also indicate with a considerable degree of accuracy the key aromorphoses of the age of the Industrial Revolution in England in the 18th century.

With respect to both social and biological macroevolution it is frequently difficult to identify the key aromorphosis within a group of them. However, as within social macroevolution (in contrast with biological one) an immense role is played by the conscious activities of people (including activities of concrete significant personalities), it is not infrequent that a role of the creator of such an integrating 'aromorphosis' is played by an outstanding personality. Thus, the key aromorphosis rule has significant peculiarities with respect to social macroevolution (for the analysis of the personality role in social macroevolution and in the historical process, the causes of fluctuations of this role as regards different situations, epochs and social systems see, *e.g.,* Grinin 1997b, 2006, 2008;

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[19] Naturally, we discuss here the reconstructions of some students of Islam, and not the beliefs of the Muslims themselves.

Korotayev 1999, 2003: 116–144). In many cases this was an outstanding personality that was capable of giving to an institution, invention, organization, state, idea *etc.* a certain form, to create a new organization, ideology, to concentrate efforts of many people *etc.*

Important consequences of a key aromorphosis emergence (within both biological and social macroevolution) are as follows: a) its wide diffusion;[20] b) prevalence of respective aromorphic structures in certain conditions; c) further gradual perfection of an aromorphic system.

4. Rule of 'block assemblage' (modularity) in evolution

When a system reaches a certain level of sophistication and maturity, it may start being used as a whole within the process of evolution (as a single unit, a single block). In process of adaptations and specialization this block experiences a sort of adjustment for the needs of a particular (biological or social) organism. In course of divergence (of species from their common ancestor) the systems of respiration, circulation of blood, heart, system of reproduction (or, with respect to social evolution, say, subsystem of taxation, or military subsystem) *etc.* are copied (inherited) with local variations from species to species, from taxon to taxon (this may be accompanied by partial ameliorations; and if this is a real aromorphosis, with time its significance tends to increase rather than decrease). In social evolution (after reaching a certain level of maturity) there could be the copying (as a whole) of religions, systems of law and administration, technological, monetary, and other systems. This makes it possible to speak about the evolutionary 'block assemblage', which implies the use of already 'tested' blocks, subsystems, units for the formation of new systems (organisms). Such a 'block assemblage' accelerates strongly the evolution speed. The block assemblage principle manifests itself in the following:

- At the molecular-genetic level it manifests itself in the origins of new genes and gene networks through the recombination of the already existing DNA fragments that have been already 'approved' by natural selection (Ratner 1992; Gillespi *et al.* 1986).
- It is also manifested with the emergence of aromorphoses through the following pattern: 'the multiplication of same-type modules – differentiation and division of functions between them'. The classical examples are the emergence of multicellular organisms, the evolution of metameric (that is, consisting of the same-type segments – metameres) animals, coloniality. In social evolution we can observe a rather close similarity in this respect when we are dealing, for example, with the formation of multicommunity societies from the monocommunity one with subsequent differentiation and the division of functions between different communities belonging to one society. This

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[20] To use Teilhard de Chardin's words (1987), what looked at the beginning as a lucky event or way to survive could be transformed into a tool of progress and conquest.

process could produce simple chiefdoms and later complex chiefdoms (consisting of simple ones) as well as their analogues (see, *e.g.,* Carneiro 1970, 1998).

- This principle also manifests itself in course of aromorphoses based on the integration of symbiotic complexes. The most important aromorphosis of this type is the emergence of eukaryotic cell that can be regarded as a result of the development of integrative processes in the community of prokaryotes (Markov and Kulikov 2005). In social evolution one could find here an analogue in the early city that can be regarded as a symbiosis of a few different heterogeneous complexes, subsystems, and relationships (the royal palace, temple, citadel, popular assembly, *etc.*). Another salient example is provided here by the formation of the developed market system that can be regarded as a complex heterarchical structure that comprises heterogeneous producers of heterogeneous commodities and supports their reproduction.

One of the first authors of the idea of the block assemblage principle (as well as the idea of natural selection) seems to be Empedocles (c. 490–430 BCE) who believed that animals were 'assembled' in a random way out of finished components (legs, heads, *etc.*), whereas the effectively acting combinations survived, while ineffectively acting ones died (Asmus 2001).

At present a number of scientists discusses the 'block principle' in biological evolution (see, *e.g.,* Krasilov 1984: 11, Ratner *et al.* 1985: 245; Chaikovsky 2003: 283); yet almost nobody seems to apply this principle to the social evolution.

Krasilov (1984: 11) notes that 'evolution seems to use the block assemblage technology'. 'Principle of self-organization of proteins and RNA reflects stages of block substructures' formation' (Ratner *et al.* 1985: 245). 'The new is almost always created through the combining of previous blocks; new blocks emerge very rarely' (Chaikovsky 2003: 283).[21]

The block assemblage principle of the formation of new subsystems, systems, and groups is rather universal. It is manifested not only with the formation of new species and communities, but also with the transformation of the already existing ones. Both biological and social systems can borrow from each other separate 'inventions' and new structural elements.

For example, one can widely find among the prokaryotes the ability of 'natural transformation' – to absorb DNA from the environment and to build it in the prokaryotic organism's genome, which leads immediately to the transformation of its phenotype.

Horizontal exchange of genes makes many useful 'inventions' literally a common property within communities of microbes. Precisely this picture is observed in the communities of planktonic microbes with respect to the genes

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[21] See also Haitun 2005: 92–96, 102–103.

of proteorhodopsins (proteins that make it possible to utilize partly the sun light energy). In contrast with those proteins that take part in the performance of real photosynthesis, proteorhodopsins do not need the 'help' of many other specialized proteins for their effective work, that is why in order to acquire a useful function it is sufficient for the microorganisms to borrow a single gene (Frigaard *et al.* 2006).

A special version of the manifestation of the rule of 'block' assemblage is represented by complex borrowings of whole gene systems. On the one hand, such events occur much more rarely; on the other hand, their consequences tend to be much more significant. A special and rather wide-spread (and especially important for arogenic direction of biological macroevolution) kind of 'new element borrowing' is the emergence of symbiotic systems, which could lead sometimes to the transformation of several different organisms into a new single organism. The role of such systems is often underestimated, but in reality all the functioning of modern biosphere is based just on such systems. We could mention here as examples the land plants (that would not have achieved their evolutionary success without their symbiosis with the nitrogen-fixing bacteria and mycorrhiza fungi, as well as without cooperation with pollinating insects), herbivorous animals (neither insects nor vertebrates are able to digest the most wide-spread types of plant food without their symbiosis with specialized microorganisms; whereas it is the processing of the plant food that is the main ecological, biospheric role of animals!). Among the complex biological organisms (in contrast with human societies) large-scale 'borrowings' (in the form of the borrowing of the alien genetic material) occur extremely rarely, but these are such borrowings with which many very important aromorphoses are connected.

In the same way we can consider those aromorphoses that are based on special 'symbioses' of complex organisms with mobile genetic elements (MGE), such as viruses, as well as transposons and retrotransposons (that cannot be transmitted horizontally as freely as viruses; yet, sometimes such a transmission still takes place). In this case, quite a long time may pass between the acquisition of some MGE and its 'involvement' into the formation of a new aromorphic organism structure. One can mention the following as examples:

1) emergence of the system of the restoration of the end parts of the chromosomes (telomeres) that plays a key role in cell differentiation and the regulation of the life span among the eukaryotes (this system is based on the mechanism of the synthesis of DNA fragments on the basis of RNA-matrix that was borrowed by complex organisms from the retrotransposons);

2) formation of the adaptive immunity system whose key components (RAG proteins performing the V-(D)-J recombination) descend from enzymes typical for transposons. V-(D)-J recombination is a process, as a result of which

we observe in lymphocytes the formation of genes of antibodies (protective proteins) through the combining of genetic 'billets' – ready-made blocks of three types (V, D, and J). As we see, the 'block assemblage' principle is manifested here too. In this case it is used for the creation through the combinatory way of millions of various antibodies from a relatively small number (several hundred) of initial blocks.

History and social macroevolution attest a great number of evolutionary block assemblage, when one could observe wholesale borrowings of religions, and religious organizations, writing system, systems of political organization and law, military organization *etc.*

5. Rule of non-specialized ancestor

For the emergence of an aromorphosis (*i.e.,* an evolutionary transition to a qualitatively higher complexity level) any excessive specialization usually turns out to be an insurmountable obstacle. *Ceteris paribus*, less specialized, more flexible forms evolve easier. With respect to biological evolution this idea was formulated in the late 19th century by Cope. It is known as the rule of descent from non-specialized ancestors; according to this rule, new major groups do not descend from the most specialized representatives of the ancestor groups – they descend from comparatively weakly specialized ones (see Markov and Naymark 1998 for more detail on this rule).[22]

This rule is also applicable to social macroevolution. Thus, we could see above that the transition to the cultivation of cereals needed the combination of various natural conditions, which by itself hindered a narrow specialization (that is why it is hardly surprising that specialized hunters, gatherers, and fishers usually tended not to move to agriculture, as they were highly successful in their ecological zones). The integrated agricultural economy (unifying plant cultivation and animal husbandry) turned out to be much more evolutionarily perspective than both the specialized (usually nomadic) animal husbandry and pure plant cultivation (see, *e.g.,* Onischuk 1995). In a similar way, new types of pre-machine industries usually emerged not in highly specialized cities (with strong positions of guilds), but rather outside the city walls (see Grinin 2003a for more detail).

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[22] Vorontsov believes that this rule has been excessively absolutized, and that even stenoecic organisms (that is, organisms that can only exist in particular environmental conditions) are capable of giving birth to new directions. From his point of view, the stenoecicity is achieved by specialization of only some part of the system of organs, whereas some other subsystems of this system remain weakly specialized, and that is why (when conditions change) they may turn to be more appropriate for a transformation in another direction (Vorontsov 1999: 596–597). This observation seems to be quite reasonable; however, even having taken Vorontsov's idea into account, we should maintain that, in any case, the transition to qualitatively new forms is connected just with unspecialized forms and organs.

Rules Connected with Special Characteristics of Environment that is Necessary for the Aromorphoses' Emergence

1. Sufficient diversity rule

The aromorphoses are frequently delayed, they are rare, the aromorphic evolution follows a relay-race pattern. Thus, the emergence of a new branch of arogenic evolution, a new arogenic direction needs a certain evolutionary environment. In particular, it is usually necessary that the niches accessible for the given (low) evolutionary level are filled (that is, there is a sufficient diversity at this level). The non-arogenic types of transformations are by definition more wide-spread in evolution. This is connected with one of the phylogenetic rules of Cope (1904), according to which the group raises its taxonomic diversity prior to its extinction.[23]

The diversity in nature and society is supported by various mechanisms. For example, there is an ecological principle, according to which the predators tend to support the diversity of their prey. If a certain type of prey becomes too numerous it is eaten first of all until the balance is restored (Kouen 1982: 57).[24] The same effect may be produced by pathogens causing epidemics among the most numerous species.

As regards social systems, one may recollect the principal way of market optimization: if a certain commodity is scarce (and, hence, its production and marketing are very profitable), more and more capital is moved to this sphere until the commodity's scarcity is eliminated, profits come down to a normal level, after which excessive capital will move to another sphere of another commodity's scarcity (and, hence, very high profitability). Note that such mechanisms do not only support diversity, they also increase it. In addition, the certain phases of respective cycles may be accompanied by crises that could become an important source of innovations and even aromorphoses.

Aromorphoses need to be supported by an objective necessity to look for new ways of development. When the niches are filled in more and more,

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[23] Shishkin emphasizes that the growth of diversity is observed not only prior to extinctions of groups, but also with the *growth of the speed of evolution*. Both cases can be reduced to the situation, within which the change of conditions of existence makes the sustainable reproduction of the former organization impossible; and this stimulates the search for the stabilizing version (Shishkin 1988: 168–169). This point appears to provide a partial explanation for the explosive growth of diversity in certain periods, as here we seem to observe positive feedbacks of the first and second orders when the accelerating speed of evolution provokes the growth of diversity, whereas the growth of diversity accelerates the speed of evolution (among other things through the emergence of aromorphoses and innovations, allomorphoses and specializations).

[24] The above mentioned diversity of ‘blocks’ can also arose due to different causes, including the diversification of similar components of a system (for example, the divergence of functions of duplicated genes, specialization of polyps in Siphonophorae).

the competition increases and the 'search' for a breakthrough, for a new aromorphosis intensifies.

Within biological evolution 'the rule of sufficient diversity' has some additional aspects:

1) Due to ecological coherence of the biosphere, the emergence of a new aromorphic group frequently implies the following necessary condition: the presence of sufficient diversity of other organisms that could serve as food for a new group, create certain conditions for reproduction *etc.* For example, the coming of the vertebrates from the ocean to the land would have been impossible if there had not been a sufficient diversity of plants and arthropods. Many scientists suggest the presence of positive feedback between the number of existing species and the speed of the emergence of new species (Emerson and Kolm 2005; Erwin 2005; Markov and Korotayev 2007b). In particular, the emergence of new species and the growth of diversity lead to the formation of new niches that can be filled in by a subsequent 'generation' of new species. We would suggest to denote the accumulating effect of the growth of the number of new taxa in conjunction with the emergence/change of taxa connected with them as a 'diversity multiplicator'.

2) The realization of the 'block assemblage principle' needs a sufficient diversity of 'blocks'. For example, the emergence of the eukaryotic cell from a community of prokaryotes would have been impossible if the prokaryotes had not been sufficiently diverse by that time. One can trace a similar regularity in social evolution. For example, the emergence of developed market systems is impossible without a high degree of diversity of producers. Even to a more considerable extent this is manifested in the search for technical solutions, as the invention of new machines always implies a sufficient diversity of materials, components (including finished units and blocks), technologies.

3) As the evolutionary innovations usually emerge through 'trial and error', the current level of biodiversity and variability (~ number of 'trials') should correlate positively with the frequency of the emergence of innovations (including the aromorphic ones).

4) Note that relationships between the diversity and the level of intraspecific and interspecific competition are very complex and ambiguous.[25]

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[25] For example, in isolated islands ecological systems are usually much poorer in comparison with continental ones; in this case a weak interspecific competition may contribute to the development of imbalanced one-sided adaptations, to the emergence of aberrant, bizarre forms (one could mention as examples such wide-spread phenomena as 'island gigantism' and 'island dwarfism'). The intraspecific competition stimulates the growth of variability (the intraspecific diversity) and contributes to the speciation (that is, the increase in the diversity of species). In this case, the growth of diversity is the result of intraspecific competition and, theoretically, it can contribute to the decrease of this competition (that, most likely, will be very short-term). A sharp interspecific competition (for example, in saturated ecological systems with numerous diverse spe-

The competition is considered to be an important precondition for the effectiveness of directed selection. It is believed that with a low level of competition the adaptations are perfected by the selection not to the maximum level, but rather to some satisfactory level, after which the intensity of selection substantially decreases (see, *e.g.,* Iordansky 2001: 134). In general, the average level of the fitness of a population with respect to its environment never reaches its theoretical maximum, whereas this level decreases with the change of environment (Berdnikov 1990: 23). We think that these ideas can be formulated as a separate rule – for example, as a **rule of the dependence of the selection effectiveness on the degree of intergroup competition**. First of all, this rule explains why the aromorphosis realization needs a sufficient diversity, with the increase in which (*ceteris paribus*) the probability of aromorphoses increases (because the search for the responses to the changing environment in conditions of a tough competition is going in many different directions, including the search for new adaptive zones). Secondly, this rule can be well applied to social macroevolution. For example, in the absence of external enemies an army tends to degenerate;[26] in the absence of competition producers do not strive after the improvement of the production parameters (to decrease the production costs, to improve the quality), *etc.* Thirdly, it is connected with the adaptive compromise principle (for more detail see Grinin, Markov, and Korotayev 2008).

2. Diversity growth rule

As has been already mentioned, the fact that biological evolution is a predominantly additive process, whereas social evolution is (to a very considerable extent) a displacing process is expressed rather distinctly in the historical dynamics of diversity. One of the most important regularities of biological evolution is the growth of biodiversity. Sometimes this regularity is regarded as a law (Alexeev 1998). In social evolution an analogous trend (that is, the accelerating growth of the diversity of social organisms) is traced in most respects up to the 19th century; however, within the 19th century this trend was changed (in most respects) with the opposite trend – toward the decrease of diversity of so-cieties.[27]

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cies) may have an opposite effect; that is, it may limit the growth if intra- and interspecific diversity. However, aromorphoses tend to occur more frequently just in saturated diverse communities rather than in communities with low diversity. This can be seen, for example, when we compare the speed of progressive evolution of vertebrates in different parts of the world: usually, this speed is higher in those parts of the world where we find a higher biological diversity.

[26] It is not coincidental that defeats lead to military (as well as political, social, *etc.*) reforms more frequently than victories.

[27] In social evolution one could observe a long-term trend toward the growth of societies' sizes, whereas this growth was not only due to the increase in population of particular polities caused by natural demographic growth; it was also due to the unification, integration and incorporation of smaller societies into larger ones. This way thousands of independent agrarian communities could be united into one state, hundreds of small ethnic groups with their particular languages could get merged into one nation with one language, dozens and hundreds of small states could be conquered by one empire *etc.* One may also recollect how many local religions disappeared

However, with such a conclusion it appears important to distinguish diversity parameters at the levels of higher taxa and the levels of lower taxa. In particular, one can single out social 'taxa' of a higher level (corresponding to families, orders, and even classes and phyla in biology), such as tribes, chiefdoms, states that consist of lower-order taxa.[28] With the development of more aromorphic taxa (for example, with the transition of complex chiefdoms and their analogues into states) the number of lower-order taxa within less aromorphic higher-order taxa might have decreased. In other words, the number of higher order taxa tended to grow up to the 19th century (whereas the number of lower order taxa of some archaic types of social organisms is likely to have started decreasing some time before that).

Within social macroevolution the emergence of a new aromorphic taxon usually tended to lead in the very long run to the decline of diversity within older taxa (*e.g.,* within the chiefdom taxon after the formation of a taxon of the states), whereas within a new taxon the diversity tended to increase. Yet, the older taxa themselves could co-exist with the new ones for many millennia.

Indeed, for example, the formation of simple chiefdoms (and their analogues) did not lead to the disappearance of simple independent communities, the emergence of complex chiefdoms (and their analogues) did not lead immediately to the disappearance of simple chiefdoms; the formation of early states (and their analogues) did not lead to the extinction of simple chiefdoms, the formation of early states (and their analogues) did not result in the disappearance of chiefdoms and independent communities, the emergence of developed states (and their analogues) did not lead to the disappearance of independent communities, chiefdoms, early states, and their analogues. Even the formation of the first mature states in the 18th and early 19th centuries did not result in the immediate extinction of all independent communities, simple and complex chiefdoms, early and developed states, and their analogues.

As a result, the diversity of political system (with respect to the higher-order taxa) reached its maximum in the 19th century when one could observe the coexistence of *all* the above mentioned political forms. What is more, in this period the maximum diversity could be observed as regards not only political

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with the expansion of the world religions. Yet, up to the 19th century, say, the disappearance of particular local religions did not lead to the decrease of religious diversity. Indeed, if predators eat 50 (or even 90 %) of individual prey animals in each of species of artiodactyls, this will not result in any decrease of the specific diversity of artiodactyls. The same way, prior to the 19th century, the replacement of local religions by the world religions does not appear to have led to the decrease of the 'generic diversity' of local religions – though the diffusion of world religions led to the extinction of many **particular** animistic, totemistic, shamanistic *etc.* religions, we have absolutely no evidence on the extinction of any **'genus'** of such religions (*e.g.,* animism, totemism, or shamanism).

[28] For example, chiefdoms could be simple, complex, and supercomplex; they could be ruled by a single chief, or by two (sacred and secular) chiefs; they could have very different economic foundations *etc.;* thus, depending on criteria, one can easily identify dozens of chiefdoms' 'genera' (and hundreds of chiefdoms' species).

parameters, but all the other parameters of sociocultural systems. For example, by the mid 19th century one could observe the maximum diversity of economic forms with the simultaneous coexistence of numerous types of non-specialized nomadic hunter-gatherers, specialized sedentary foragers, early extensive agriculturalists, nomadic pastoralists, societies specializing in trade and/or various crafts, developed intensive agriculturalists, and the first industrial societies. We could also see, for example, the maximum diversity of religious forms (the coexistence of very diverse animistic, totemistic, fetishistic, shamanistic, polytheist *etc.* religions, in addition to numerous denominations and sects of the world and syncretic religions), and so on.

The systematic decline of the diversity of political, social, economic *etc.* forms/taxa only began since the mid 19th century, when according to this indicator the social macroevolution became radically different from the biological macroevolution.[29]

Yet, in social evolution one can also observe the growth of diversity in certain respects; however, it is achieved in a way that is different from the one observed with respect to biological evolution: through the differentiation of institutions, relationships, social groups, the growth of the diversity of specializations within one profession, the increase in the diversity of information, in the nomenclatures of various artifacts *etc.* This trend can be denoted as the **growth of the diversity of human activities' results.** There is no doubt that this growth is very considerable, and its speed is accelerating. In the meantime, as has already been mentioned, in social evolution of recent decades we observe a constant strong opposite trend toward the replacement and unification (of cultures, languages, religions, economic systems, institutions, tastes *etc.*). It is clear that at present the globalization processes lead to the decrease of ethnic and cultural diversity.

The growth of diversity of forms leads directly to the growth of probability of the emergence of new aromorphoses. Timofeev-Ressovsky, Vorontsov, and Yablokov maintain that such a growth leads in general to the growth of complexity of the biosphere as a whole and, consequently, to the growth of complexity of relationships of every group of organisms with its environment (Timofeev-Ressovsky, Vorontsov, and Yablokov 1969: 282). New perspective taxa acquired sooner or later special aromorphic characteristics that made it possible to use those evolutionary advantages on a wider scale. Thus, though such wide-range arogenic adaptations were very rare, their frequency tended to increase with the diversity accumulation, because the dense competitive environment generated more frequently extraordinary responses to ordinary challenges. Formation of major aromorphoses occurs against the background of extinction and evolutionary failures of numerous biological and social systems.

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[29] Note that we observe simultaneously a real accelerating decrease of biodiversity (though in the same time human activities lead to the increase in diversity of a small number of species of domestic plants and animals).

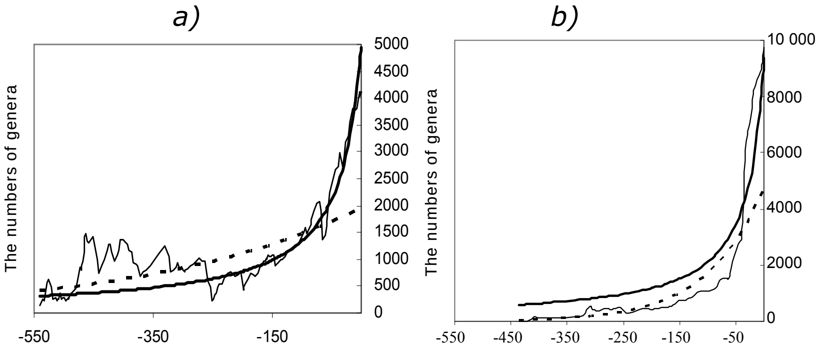

Fig. 1. The growth of diversity (the numbers of genera) of the marine *(a)* and continental *(b)* organisms during the Phanerozoic (542–0 mln years BP)

X-axis indicates time in mln years BP. Broken lines indicate exponential trends, solid lines indicate hyperbolic trends (for more detail see Markov and Korotayev 2007a, 2008, 2009; Grinin, Markov, and Korotayev 2008: Appendix 5)

The Rule of 'Payment' for the Aromorphic Progress (Instead of a Conclusion)

The emergence of major aromorphoses takes place against the background of extinctions and unsuccessful evolutionary 'attempts' of many organisms (societies) and groups.

In particular, 'as is demonstrated by the paleontological chronicle, only a few relatively not numerous groups get from one adaptive zone to another. This transition is usually conducted with a great (evolutionary) speed, whereas many groups die out in interzone spaces without reaching new optimal adaptive zones. Yet, even a single branch, having found itself in a new adaptive zone, starts a new period of allogenesis'[30] (Timofeev-Ressovsky, Vorontsov, and Yablokov 1969: 224).

Speaking about social evolution, one may mention that it should not be compared with a wide ladder along which all the societies should move independently in the same upward direction; it should be rather compared with an extremely complex labyrinth, an arogenic way out of which can be found without borrowings only by a very few societies (yet, even such societies may only find independently a part of this way, whereas no society has managed to find the whole of this way entirely without borrowings from the other societies). In other words, the evolution of a concrete society cannot be usually

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[30] Note that Timofeev-Ressovsky and his colleagues discuss here adaptive radiation or cladogenesis, that is, the direction (rather than level) of evolutionary changes. – *L. G., A. M., A. K.*

regarded as a small-scale repetition of the main line of the arogenic evolutionary development. This can only be done with respect to a very few of them, only for certain parts of their history (and always with very considerable reservations). The point is that throughout most of the human history the evolutionary breakthrough to a new level could only happen at the expense of extinction, stagnation, movement sideways of many other societies.

One can trace here a certain similarity with biological evolution. One may recall numerous (but finally unsuccessful) ‘attempts’ of prokaryotes to become multicellular; and not less numerous (but successful on a few occasions) similar attempts on the part of eukaryotes. During the periods of mass extinctions one could observe a sort of ‘preliminary selection’ of more resilient taxa. This also means that extinct taxa clear the evolutionary space for new potential leaders who get better starting conditions than they did before the extinctions.

Thus, we believe that, on the one hand, the emergence of perspective morphological forms, institutions, relationships is accounted for by internal characteristics of biological and social organisms; however, on the other hand, this could be regarded as a result of the presence of a sufficient number of other forms whose evolutionary ‘successes’ and ‘failures’ have paved way for the emergence of a ‘successful’ version.

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Abstract

The comparison between biological and social macroevolution is a very important (though insufficiently studied) subject whose analysis renders new significant possibilities to comprehend the processes, trends, mechanisms, and peculiarities of each of the two types of macroevolution. Of course, there are a few rather important (and very understandable) differences between them; however, it appears possible to identify a number of fundamental similarities. One may single out at least three fundamental sets of factors determining those similarities. First of all, those similarities stem from the fact that in both cases we are dealing with very complex non-equilibrium (but rather stable) systems whose principles of functioning and evolution are described by the General Systems' Theory, as well as by a number of cybernetic principles and laws.

Secondly, in both cases we do not deal with isolated systems; in both cases we deal with a complex interaction between systems of (both biological and societal) organisms and external environment, whereas the reaction of systems to external challenges can be described in terms of certain general principles (that, however, express themselves rather differently within the biological reality, on the one hand, and within the social reality, on the other).

Thirdly, it is necessary to mention a direct 'genetic' link between the two types of macroevolution and their mutual influence.

It is important to emphasize that the very similarity of the principles and regularities of the two types of macroevolution does not imply their identity. Rather significant similarities are frequently accompanied by enormous differences. For example, genomes of the chimpanzees and the humans are very similar – with differences constituting just a few per cent; however, there are enormous intellectual and social differences between the chimpanzees and the humans that arise from the apparently 'insignificant' difference between the two genomes.

In certain respects it appears reasonable to consider the biological and social macroevolution as a single macroevolutionary process. This implies the necessity to comprehend the general laws and regularities that describe this process; though their manifestations may display significant variations depending on properties of a concrete evolving entity (biological or social one). An important notion that may contribute to the improvement of the operationalization level as regards the comparison between the two types of macroevolution is the one that we suggested some time ago – the **social aromorphosis** (that was developed as a counterpart to the notion of biological aromorphosis well established within Russian evolutionary biology). We regard social aromorphosis as a rare qualitative macrochange that increases in a very significant way complexity, adaptability, and mutual influence of the social systems, that opens new possibilities for social macrodevelopment. In our paper we discuss a number of regularities that describe biological and social macroevolution and that employ the notions of social and biological aromorphosis such as ones of the 'module evolution' (or the evolutionary 'block assemblage'), 'payment for arogenic progress' *etc.*

III. Aspects of Social Evolution

7

Social Evolution: Alternatives and Variations (Introduction)*

Dmitri M. Bondarenko, Leonid E. Grinin, Andrey V. Korotayev

It has always been peculiar to evolutionists to compare social and biological evolution, the latter as visualized by Charles Darwin.[1] But it also seems possible and correct to draw an analogy with another great discovery in the field of evolutionary biology, with the homologous series of Nikolay Vavilov (1921, 1927, 1967). However, there is no complete identity between cultural parallelism and biological homologous series. Vavilov studied the morphological homology, whereas our focus within the realm of social evolution is the functional one. No doubt, the morphological homomorphism also happens in the process of social evolution (*e.g.,* in the Hawaii Islands where a type of the sociocultural organization surprisingly similar with the ones of other highly developed parts of Polynesia had independently formed by the end of the 18th century [Sahlins 1972/1958; Goldman 1970; Earle 1978; Johnson and Earle 2000; Seaton 1978]). But this topic is beyond the present article's *problematique.*

What is important for us here is that there are reasons to suppose that an equal level of sociopolitical (and cultural) complexity (which makes it pos-

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[1] See *e.g.,* Hallpike 1986; Pomper and Shaw 2002; Mesoudi *et al.* 2006; Aunger 2006; Barkow 2006; Blackmore 2006; Mulder *et al.* 2006; Borsboom 2006; Bridgeman 2006; Cronk 2006; Dennett and McKay 2006; Fuentes 2006; Kelly *et al.* 2006; Kincaid 2006; Knudsen and Hodgson 2006; Lyman 2006; Mende and Wermke 2006; O'Brien 2006; Pagel 2006; Read 2006; Reader 2006; Sopher 2006; Tehrani 2006; Wimsatt 2006; on such comparisons, as well as our own ideas about similarities and differences between social and biological evolution, in more details see Grinin and Korotayev 2007a, 2009b; Grinin, Markov, and Korotayev 2008: 145–152; 2009. Note, however, that in fact frequently this was essentially Spencerian vision which was implied in such cases; that is the evolution was perceived as 'a change from an incoherent homogeneity to a coherent heterogeneity' (Spencer 1972 [1862]: 71).

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sible to solve equally difficult problems faced by societies) can be achieved not only in various forms but on essentially different evolutionary pathways, too. Thus, it is possible to achieve the same level of system complexity through differing pathways of evolution which appeared simultaneously (and even prior to the formation of *Homo sapiens sapiens* [Butovskaya and Feinberg 1993; Butovskaya 1994, 2000; Butovskaya, Korotayev, and Kazankov 2000]) and increased in quantity throughout almost whole sociocultural advancement (Pavlenko 1996: 229–251; 2000). Diversity could be regarded as one of the most important preconditions of the evolutionary process. This implies that the transition to any qualitatively higher level of socio-cultural complexity is normally impossible without a sufficient level of variability at the preceding complexity level (among both the given culture's predecessors and contemporaries).[2]

Within the first level of analysis, all evolutionary variability can be reduced to two principally different groups of homologous series (Bondarenko 1997: 12–15; 1998a, 2000b; Bondarenko and Korotayev 1999, 2000b; Korotayev *et al.* 2000). Earlier these alternatives were distinguished either as ‘hierarchical’ *vs.* ‘non-hierarchical’ (*e.g.,* Bondarenko and Korotayev 2000a), or ‘hierarchical’ *vs.* ‘heterarchical’ (*e.g.,* Ehrenreich *et al.* 1995; Crumley 2001).

In one of the publications on the problem of heterarchy the latter is defined as ‘...the relation of elements to one another when they are unranked or when they possess the potential for being ranked in a number of different ways’ (Ehrenreich *et al.* 1995: 3; see also Crumley 1979: 144). It is clear that the second version of heterarchy is more relevant for the study of the complex societies.

However, when we have a system of elements which ‘possess the potential for being ranked in a number of different ways’, it seems impossible to speak about the absence of hierarchy. In this case we rather deal with a system of heterarchically arranged hierarchies. Hence, it does not appear reasonable to denote the heterarchy alternative as ‘hierarchy’. We would rather suggest designating it as ‘homoarchy’ which could be defined as the relation of elements to one another when they possess the potential for being ranked in one way only. Totalitarian regimes of any time give us plenty of examples of such a sociocultural situation when the ruled have no chances to get ranked above the rulers in any possible contexts. This stands in a sharp contrast with, say, an archetypal example of a complex heterarchical system – the civil community (*polis*) of Athens (the 5th–4th centuries BC) where the citizens ranked lower within one hierarchy (*e.g.,* the military one) could well be ranked higher in many other possible respects (*e.g.,* economically, or within the subsystem of civil/religious

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[2] This can also be called *the rule of suddicient variability* (see Grinin, Markov, and Korotayev 2008: 68–71).

magistrates). Consequently, it was impossible to say that one citizen was higher than any other in any absolute sense.

On the other hand, it seems necessary to stress that it appears impossible to find not only any cultures totally lacking any hierarchies (including informal ones), but also any totally homoarchical cultures. Hence, though in order to simplify our analysis in this paper we speak about heterarchical and homoarchical evolutionary pathways for our analysis' simplifying, in fact we are dealing here with heterarchy-homoarchy axis along which one could range all the known human cultures. Within this range there does not seem to be any distinct border between homoarchical and heterarchical cultures; hence, in reality it might be more appropriate to speak not about just two evolutionary pathways (heterarchical and homoarchical), but about a potentially infinite number of such pathways, and, thus, finally not about evolutionary pathways, but rather about evolutionary probability field (see for details Korotayev 1992, 1999, 2003c, 2004; Korotayev *et al.* 2000). Yet, as was mentioned above, in order to simplify our analysis we speak about just two alternative pathways.

In particular, until recently it was considered self-evident that just the formation of the state marked the end of the 'Primitive Epoch' and alternatives to the state did not actually exist.[3] All the stateless societies were considered pre-state ones, standing on the single evolutionary staircase squarely below the states. Nowadays postulates about the state as the only possible form of political and sociocultural organization of the post-primitive society, about *a priori* higher level of development of a state society in comparison with any non-state one are subjected to rigid criticism. It has become evident that the non-state societies are not necessarily less complex and less efficient. The problem of existence of non-state but not primitive (*i.e.* principally non- and not pre-state) societies, alternatives to the state (as the allegedly inevitable post-primitive form of the sociopolitical organization) deserves attention.

Of course, in no way do we reject the fact of existence and importance of the states in world history. What we argue, is that the state is not the only possible post-primitive evolutionary political form. From our point of view, the state is nothing more than one of many forms of the post-primitive sociopolitical organization; these forms are alternative to each other and are able in certain conditions to transform to one another without any loss in the general level of complexity. Hence, the degree of sociopolitical centralization and 'homoarchization' is not a perfect criterion for evaluating a society's evolutionary level, though it is regarded as such within unilinear concepts of social evolution.

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[3] Throughout the present article the state is understood as '...a sufficiently stable political unit characterized by the organization of power and administration which is separated from the population, and claims a supreme right to govern certain territory and population, *i.e.* to demand from it certain actions irrespective of its agreement or disagreement to do this, and possessing resources and forces to achieve these claims' (Grinin 1997: 20; see also Grinin 2000c: 190).

As Brumfiel wrote several years ago, 'the coupling of [sociopolitical] differentiation and hierarchy is so firm in our minds that it takes tremendous intellectual efforts even imagine what differentiation without hierarchy could be' (Brumfiel 1995: 130).[4] Usually, even if the very existence of complex but non-homoarchical cultures is recognized, they are regarded as a historical fortuity, as an anomaly. Such cultures are declared as if capable to reach rather low levels of complexity only, as if incapable to find internal stability (Tuden and Marshall 1972: 454–456).

Thus, on the further level of analysis the dichotomy turns out not to be rigid at all as far as actual organization of any society employs both vertical (dominance – subordination) and horizontal (apprehended as ties among equals) links. Furthermore, in the course of their history, societies (including archaic cultures) turn out capable to change models of sociopolitical organization radically, transforming from homoarchical into heterarchical or *vice versa* (Korotayev 1995d, 2006; Korotayev, Kradin, and Lynsha 2000; Korotayev, Klimenko, and Prusakov 2007; Crumley 1987: 164–165; 1995: 4; 2001; Bondarenko and Korotayev 2000c; Dozhdev 2000; Kradin 2000a). Perhaps the most well known historical example of the latter case is Rome where the Republic was established and further democratized with the Plebian political victories. Note that in the course of such transformations the organizational background changes, but the overall level of cultural complexity may not only increase or decrease but may well stay practically the same (for example in ancient and medieval history of Europe, the Americas, Asia, see on this Korotayev 1995d, 1996b, 1996c, 1997, 1998, 2000c, 2000d, 2006; Korotayev, Klimenko, and Prusakov 2007; van der Vliet 1987; Ferguson 1991; Korotayev 1995a, 1996a; Levy 1995; Lynsha 1998; Beliaev 2000b; Chamblee 2000: 15–35; Dozhdev 2000; Kowalewski 2000; Kradin 2000a; Grinin 2004b, 2004c*;* 2007g, 2007h).

Nevertheless, vertical and horizontal links play different parts in different societies at every concrete moment. Already among the primates with the same level of morphological and cognitive development, and even among primate populations belonging to the same species, one could observe both more and less heterarchically/homoarchically organized groups. Hence, the non-linearity of sociopolitical evolution originates already before the *Homo sapiens sapiens* formation (Butovskaya and Feinberg 1993; Butovskaya 1994; Butovskaya, Korotayev, and Kazankov 2000).

Let us consider now in more details one of the most influential and widespread unilineal evolutionary schemes, the one proposed by Service (1971 [1962];

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[4] See also its fundamental criticism by Mann (1986), the most radically negative attitude to this scheme expressed in categories of social evolution 'trajectories alternativity' by Yoffee (1993), several collective works of recent years (Patterson and Gailey 1987; Ehrenreich *et al.* 1995; Kradin and Lynsha 1995; Kradin *et al.* 2000; Bondarenko and Korotayev 2000a), proceedings of recent international conferences (Butovskaya *et al.* 1998; Bondareko and Sledzevski 2000).

its outline is, however, already contained in Sahlins's well-known article [Sahlins 1960: 37]): *band – tribe – chiefdom – state.* The scheme implies that the growth of the political complexity (at least up to the stage of the agrarian state) is inevitably accompanied by the growth of the inequality, stratification, the social distance between the rulers and the ruled, the 'authoritarianism' and hierarchization of the political system, decrease of the political participation of the main mass of population *etc.* Of course, these two sets of parameters seem to be related rather closely. It is evident that we observe here a certain correlation, and a rather strong one. But, no doubt, this is just a correlation, and by no means a functional dependence. Of course, this correlation implies a perfectly possible line of sociopolitical evolution – from an egalitarian, acephalous band, through a big-man village community with much more pronounced inequality and political hierarchy, to an 'authoritarian' village community with a strong power of its chief (found, *e.g.,* among some Indians of the North-West Coast – see, *e.g.,* Carneiro 2000), and than through the true chiefdoms having even more pronounced stratification and concentration of the political power in the hands of the chief, to the complex chiefdoms where the political inequality parameters reach a qualitatively higher levels, and finally to the agrarian state where all such parameters reach their culmination (though one could move even further, up to the level of the 'empire' [*e.g.,* Adams 1975], see an example of such a line in Johnson and Earle 2000: 246, 304). However, it is very important to stress that on each level of the growing political complexity one could find easily evident alternatives to this evolutionary line.

Let us start with the human societies of the simplest level of sociocultural complexity. Indeed, one can easily observe that acephalous egalitarian bands are found among most of the unspecialized hunter-gatherers. However, as has been shown by Woodburn (1972, 1979, 1980, 1982, 1988a, 1988b) and Artemova (1987, 1991, 1993, 2000a, 2000b; see also Chudinova 1981; Whyte 1978: 49–94), some of such hunter-gatherers (the inegalitarian ones, first of all most of the Australian aborigine see also Bern 1979) display a significantly different type of sociopolitical organization with much more structured political leadership concentrated in the hands of relatively hierarchically organized elders, with a pronounced degree of inequality both between the men and women, and among the men themselves.[5]

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[5] James Woodburn and Olga Artemova deal almost exclusively with examples of 'non-egalitarian' Australian Aborigenes and 'egalitarian' peoples of Africa (the Hadza, San, Pygmies), analogous to them by the socio-cultural complexity level. However, the evidence from other continents' societies confirm that organization of cultures of the same complexity level along either heterarchic or homoarchic lines is characteristic of the humankind from the typologically earliest ones (Bondarenko 2006). The examples of the peoples leaving in the same cultural area and basing their subsistence on similar means, like fishers of the Far East – the 'egalitarian' Itelmens and 'non-egalitarian' Nanais, are especially instructive (Krasheninnikov 1949; Lopatin 1922; see also Sem 1959; Smolyak 1970; Krushanov 1990; Shnirel'man 1993; 1994; Orlova 1999; Bulgakova 2001, 2002; Bereznitsky 2003; Volodin 2003).

On the next level of the political complexity we can also find communities with both homoarchical and heterarchical political organization. One can mention *e.g.,* the well-known contrast between the Indians of the Californian North-West and South-East:

> The Californian chiefs were in the center of economic life, they exercised their control over the production, distribution and exchange of the social product, and their power and authority were based mainly on this. Gradually the power of the chiefs and elders acquired the hereditary character, it became a typical phenomenon for California... Only the tribes populating the North-West of California, notwithstanding their respectively developed and complex material culture, lacked the explicitly expressed social roles of the chiefs characteristic for the rest of California. At the meantime they new slavery... The population of this region had an idea of personal wealth... (Kabo 1986: 20).

One can also immediately recall the socio-culturally complex communities of the Ifugao (*e.g.,* Barton 1922; Meshkov 1982: 183–197) lacking any pronounced authoritarian political leadership compared with the one of the communities of the North-West Coast, but with a comparable level of overall sociopolitical and sociocultural complexity.

Hence, already on the levels of simple and middle range communities we observe several types of alternative sociopolitical forms, each of which should be denoted with a separate term. The possible alternatives to the chiefdom in the prehistoric Southwest Asia, heterarchical systems of complex acephalous communities with a pronounced autonomy of single family households have been analyzed recently by Berezkin who suggests reasonably Apa Tanis as their ethnographic parallel (1995a, 1995b, 2000). Frantsouzoff finds an even more developed example of such type of polities in ancient South Arabia in Wadi Hadramawt of the 1st millennium BC (Frantsouzoff 1995, 1997, 2000a, 2000b).

One of the present authors has pointed out elsewhere (Grinin 2007g) that probably some intertribal secret societies can also be considered as a form of political organization alternative to the chiefdom (see, *e.g.*, Kubbel' 1988a: 241), as well as, for example, complex age-grade systems that allowed creation of firm horizontal ties between separate communities within a tribe and between related tribes (on the role of such an age-grade system among some Naga tribes of mountainous North-East India see, *e.g.*, Maretina 1995: 83; on some other examples see Kalinovskaya 1976; van Gennep 2002, *etc.*).

As an analogue to the chiefdom the organized groups of turncoats, adventurers or criminals of different sorts that do not recognize any official authorities can be considered too (see Grinin 2007g). Not infrequently such armed communities were created as counterbalance to the consolidating official power of a new state. 'This part of the population that has separated itself and does not recognize laws often acquires considerable power due to freedom of being anyway restricted by the law..., as well as to respect of the bravest and poorest from the neighboring tribes' (Ratzel' 1902, vol. 1: 445).

Another evident alternative to the chiefdom is constituted by the tribal organization. As is well known, the tribe has found itself on the brink of being evicted from the evolutionary models (Townsend 1985: 146; Carneiro 1987: 760). However, the political forms entirely identical with what was described by Service as the tribe could be actually found in, *e.g.,* medieval and modern Middle East (up to the present): these tribal systems normally comprise several communities and often have precisely the type of political leadership described by Service as typical for the tribe (Service 1971 [1962]: 103–104; Dresch 1984: 39, 41).

What is important, is that we are dealing here with some type of polity that could not be identified either with bands, or with village communities (because such tribes normally comprise more than one community), or with chiefdoms (because they have an entirely different type of political leadership), or, naturally, with states. They could not be inserted easily either in the scheme somewhere between the village and the chiefdom. Indeed, as has been shown convincingly by Carneiro (see, *e.g.,* 1970, 1981, 1987, 1991, 2000), chiefdoms normally arose as a result of political centralization of a few communities without the stage of the tribe preceding this. On the other hand, a considerable amount of evidence could be produced suggesting that in the Middle East many tribes arose as a result of political decentralization of chiefdoms which preceded the tribes in time. It is also important to stress that this could not in any way be identified with a 'regression', 'decline', or 'degeneration', as we can observe in many of such cases that political decentralization is accompanied by the increase (rather than decrease) of overall sociocultural complexity (Korotayev 1995a, 1995c, 1995d, 1996a, 1996b, 1996c, 1997, 1998, 2000a, 2000b). Hence, in many respects tribal systems of the Middle Eastern type appear to be chiefdom alternatives (rather than chiefdom predecessors).

Large complex chiefdoms could have analogues too. First and foremost, those were large tribal confederations or federations. Not infrequently, however, in such cases the bottom structure was represented by a sort of chiefdom while the top one was formed by the tribal council without a permanent leader (the council of chiefs or elders). This was the case of some American Indians tribes' structure. The tribes of the Iroquois had another organization system: family-clan units were headed by clan elders (*sachem*s) who were the tribal council members. At the same time the Iroquois confederation also had the supreme administrative level – the League council in which clan chiefs of each tribe were represented (fifty persons in total [see Fenton 1978: 122]) and in which consensus for making up decisions was necessary. As it organized a great number of people and provided exceptionally high level of integration, we regard the Iroquois political system as an analogue (though incomplete) not to the chiefdom but to the early state (for details see Grinin 2007g; Grinin and Korotayev 2009b: Essay 5). Such analogues to the chiefdom as communities federations and confederations of, for example, the highlanders are also worth noting (see, *e.g.,* Aglarov 1988; Korotayev 1995e, 1995f, 2006b; Grinin 2007g).

We have argued elsewhere (Korotayev 1995b, 1995c, 1995e) that in general there is an evident evolutionary alternative to the development of the rigid supra-communal political structures (chiefdom – complex chiefdom – state) constituted by the development of internal communal structures together with soft supra-communal systems not alienating communal sovereignty (various confederations, amphictyonies, *etc.*). One of the most impressive results of the sociopolitical development along this evolutionary line is the Greek *poleis* (see Berent [1994, 1996, 2000a, 2000b] regarding the statelessness of this type of political systems) some of which reached overall levels of complexity quite comparable not only with the ones of chiefdoms, but also with the one of states. The same can be said about its Roman analogue, the *civitas* (Shtaerman 1989). Note that *polis/civitas* as a form of sociopolitical organization was known far beyond the Classical world, both in geographical and chronological sense (Korotayev 1995b; Bondarenko 1998b), though quite a number of scholars still insist on its uniqueness.[6]

The 'tribal' and *'polis'* series seem to constitute separate evolutionary lines, with some distinctive features: the *'polis'* forms imply the power of the 'magistrates' elected in one or another way for fixed periods and controlled by the people in the absence (or near-absence) of any formal bureaucracy. Within the tribal systems we observe the absence of any offices whose holders would be obeyed simply because they hold posts of a certain type, and the order is sustained by elaborate mechanisms of mediation and search for consensus.

There is also a considerable number of other complex stateless polities (like the ones of the Cossacks of Ukraine and Southern Russia till the end of the 17th century [Chirkin 1955; Rozner 1970; Nikitin 1987; Shtyrbul 2006; Grinin 2007g: 179–180], the Celts of the 5th–1st centuries BC [Grinin 1997: 32–

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[6] It should be noted that contrary to the first and third authors of the present article, its second author regards the majority of Greek *poleis* and the Roman polity as early state of a specific type (see Bondarenko 1998b, 2000b, 2004b, 2006; Korotayev 1995b, 1995e, 1995f *vs.* Grinin 2004a, 2004b, 2006b, 2007g); however, we clearly deal with an alternative of social evolution in this case too: even if these polities are considered as early states, they definitely were early states of a very specific type (see also, however, note 14). Bouzek (1990: 172) is right both in his irony about endless academic debates and in representation of the Greeks' own distinction between their *polis* and other peoples' states: 'The Greeks had fewer problems than we have with the definition of the state. They saw kingdoms and kings in all parts of the world where they met one ruler, and not the council of a *polis* or ethnos'.

33; 2003: 141–142; 2004c: 97–98; 2006b: 95–96; 2007a: 173; 2007g: 182–184; Grinin and Korotayev 2009b: 435–436; Kradin 2001: 149], or the Icelandic polity of the ‘Age of Democracy’ till the middle of the 13th century [Ol'geirsson 1957; Gurevich 1972; Steblin-Kamenskiy 1984; Hjaul'marsson 2003; Grinin 2003: 139; 2004c: 95; 2006b: 93; 2007a: 172; 2007g: 179; Grinin and Korotayev 2009b: 432) which could not yet be denoted with any commonly accepted terms, and whose own self-designations are often too complex (like *Kazach'e Vojsko)* to have any chance to get transformed to general terms.

There were a great many of historically and ethnographically known polities that a) surpassed considerably typical prestate socio-political forms (like simple chiefdoms, tribes, local communities) in size, complexity level and some other parameters; b) were not inferior to the early-state systems in size, socio-cultural and/or political complexity; c) at the same time, basically differed from the early state in their political order, power and administration structure (Alexeev *et al.* 2004; Beliaev *et al.* 2002; Bondarenko 1995a, 1995b, 2000a, 2000b, 2001; Bondarenko, Grinin, and Korotayev 2002, 2004; Bondarenko and Korotayev 2000a, 2000c; Bondarenko and Sledzevski 2000; Crumley 1995, 2001, 2005; Grinin 2000c, 2002a, 2002b, 2003, 2004c, 2007a, 2007b; Grinin *et al.* 2004, 2006; Korotayev 1995b; Kradin *et al.* 2000; Kradin, Bondarenko, and Barfield 2003; Kradin and Lynsha 1995; McIntosh 1999; Possehl 1998; Schaedel 1995; Bondarenko, Grinin, and Korotayev 2006; Bondarenko and Korotayev 2002; Girenko 1993; Grinin 1997–2001 [1997, № 5], 2001–2006, 2002c, 2006d, 2007g, 2007h, 2007i; Grinin and Korotayev 2009b; Korotayev 1995d, 1995e, 1996b, 1997, 2000c, 2000d, 2006; Kradin and Lynsha 1995; Kradin and Bondarenko 2002; Popov 1995a, 1995b, 2000; Shtyrbul 2006).

Elsewhere we have designated the non-state societies comparable to the state in complexity and the functions performed as **the early state analogues or alternatives to the state** (Bondarenko, Grinin, and Korotayev 2002, 2004; Bondarenko 1995b, 2000a, 2000b, 2005a, 2006, 2007a, 2007b, 2007c; Bondarenko and Korotayev 2000a, 2000c; Bondarenko and Nemirovskiy 2007; Grinin 1997–2001, 2001–2006, 2000c, 2002a, 2002b, 2002c, 2003, 2004a, 2004b, 2004c, 2006a, 2006b, 2006c, 2006d, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f, 2007g, 2007h, 2008; Grinin and Korotayev 2007a, 2007b, 2009a, 2009b; Grinin *et al.* 2004, 2006; Korotayev 2000c, 2003c; Korotayev, Kradin, and Lynsha 2000; Korotayev *et al.* 2000). We provide a classification of such societies below.

But let us return to the Service – Sahlins's scheme. There is another evident problem with Service's scheme. It is evidently pre-‘Wallersteinian’, not touched by any world-system discussions, quite confident about the possibility of the use of a single polity as a unit of social evolution. It might be not so important if Service spoke about the typology of polities; yet, he speaks about the 'levels of cultural integration', and within such a context the world-system dimension should be evidently taken into consideration.[7]

The point is that the same overall level of complexity could be achieved both through the development of a single polity and through the development of a politically uncentralized interpolity network. This alternative was already noticed by Wallerstein (1974, 1979, 1987) who viewed it as a dichotomy: *world-economy – world-empire.* Note that according to Wallerstein these are considered precisely as alternatives, and not two stages of social evolution.

> In this respect the examples of the Ancient Greek and especially Maya and Yoruba 'peer polities' are instructive (see Bondarenko 2005b: 7–8). The system of Greek *poleis* never transformed to an empire and remained heterarchic even in the time of the Delian League (see Golubtsova 1983). The case of the Maya and Yoruba interpolity networks is instructive even more so, as they, though consisted of societies organized along predominantly homoarchic lines, nevertheless did not transform to integrated empires too, notwithstanding domination of these or those polities within the networks in definite historical periods (see, *e.g.,* Beliaev 2000a; Beliaev and Pakin 2009; Martin and Grube 2000; Kochakova 1968, 1986; Smith 1988).

Thus, as one would expect, we agree with Wallerstein whole-heartedly at this point. However, we also find here a certain oversimplification. In general, we would like to stress that we are dealing here with a particular case of a much more general set of evolutionary alternatives.

The development of a politically uncentralized interpolity network became an effective alternative to the development of a single polity long before the rise of the first empires. As an example, we could mention the interpolity communication network of the Mesopotamian civil-temple communities of the first half of the 3 millennium BC which sustained a much higher level of technological development than that of the politically unified Egyptian state, contemporary to it. Note that the intercommunal communication networks already constitute an effective evolutionary alternative to the chiefdom. For example, the sociopolitical system of the Apa Tanis should be better described as an intercommunal network of a few communities (incidentally, in turn acting as a core for another wider network including the neighboring less developed polities [chiefdoms and sovereign communities] – see Führer-Haimendorf 1962).

We also do not find it productive to describe this alternative type of cultural integration as a world-economy. The point is that such a designation tends to downplay the political and cultural dimension of such systems.

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[7] For our understanding of the World-System and the world-system approach see, *e.g.*, Bondarenko 2009; Grinin and Korotayev 2009b.

Take for example, the Classical Greek *inter-polis* system. The level of complexity of many Greek *poleis* was rather low even in comparison with a complex chiefdom. However, they were parts of a much larger and much more complex entity constituted by numerous economic, political and cultural links and shared political and cultural norms. The economic links no doubt played some role within this system. But links of other types were not less important. Take, *e.g.,* the norm according to which the *inter-poleis* wars stopped during the Olympic Games, which guaranteed the secure passage of people, and consequently the circulation of enormous quantities of energy, matter and information within the territory far exceeding the one of an average complex chiefdom. The existence of the *inter-poleis* communication network made it possible, say, for a person born in one *polis* to go to get his education in another *polis* and to establish his school in a third. The existence of this system reduced the destructiveness of *inter-poleis* warfare for a long time. It was a basis on which it was possible to undertake important collective actions (which turned out to be essential at the age of the Greek-Persian wars). As a result, the *polis* with a level of complexity lower than the one of the complex chiefdom, turned out to be part of a system whose complexity was quite comparable with that of the state (and not only the early one).

The same can be said about the intersocietal communication network of Medieval Europe (comparing its complexity in this case with an average world-empire). Note that in both cases some parts of the respective systems could be treated as elements of wider world-economies. On the other hand, not all the parts of such communication networks were quite integrated economically. This shows that the world-economies were not the only possible type of politically decentralized intersocietal networks. Actually, in both cases we are dealing with the politically decentralized civilization, which for most of human history over the last few millennia constituted the most effective alternative to the world-empire. Of course, many of such civilizations could be treated as parts of larger world-economies. Wallerstein suggests that in the age of complex societies only the world-economies and world-empires ('historical systems', *i.e.* the largest units of social evolution) could be treated as units of social evolution in general. Yet we believe that both politically centralized and decentralized civilizations should also be treated as such quite productively.[8] One should stress again the importance of the cultural dimension of such systems. Of course, the exchange of bulk goods was important. But exchange of information was also important. Note that the successful development of science both in Classical Greece and Medieval Europe became only possible

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[8] As well as 'world-ideologies', 'world-politics' (see Grinin and Korotayev 2009b: 19) and similar formations that we have designated as 'spatial-and-temporal societies groupings' (Grinin 1997–2001, 1998; Grinin and Korotayev 2009b: 190).

through an intensive intersocietal information exchange between the constituent societies of respective civilizations, whereas the development of science in Europe affected, to a significant extent, the evolution of the Modern World-System.

It is important to stress that the intersocietal communication networks could appear among much less complex societies (Wallerstein has denoted them as ‘mini-systems’ without actually studying them, for a recent review of the research on the archaic intersocietal networks see Chase-Dunn and Grimes 1995; Chase-Dunn and Hall 1993, 1994, 1995, 1997; see also Grinin and Korotayev 2009b: Introduction). Already it seems possible to speak about a communication network covering most of aboriginal Australia.[9] Again we come here across a similar phenomenon – a considerable degree of cultural complexity (complex forms of rituals, mythology, arts, and dance well comparable with the ones of early agriculturists) observed among populations with an apparently rather simple political organization. This could largely be explained by the fact that relatively simple Australian local groups were parts of a much more complex whole: a huge intersocietal communication network that apparently covered most of Australia (*e.g.,* Bakhta and Senyuta 1972; Artemova 1987).

Thus, it is possible to contrast societies that followed the pathway of political centralization and ‘authoritarianization’ with cultures that further elaborated and perfected democratic communal backgrounds and corresponding self-government institutions. However, such a culture as the Benin Kingdom of the 13th–19th centuries can make the picture of sociopolitical evolution even more versatile. In particular, it reveals that not only heterarchical but also homoarchical societies can reach a very high (incomparably higher than that of complex chiefdoms) level of sociocultural complexity and political centralization still never transforming to a state during the whole long period of existence. The Benin evidence also testifies that local community's autonomy is not a guarantee of complex society's advancement along the hierarchical pathway. We have suggested elsewhere to define this form of sociopolitical organization as ‘megacommunity’ (see, *e.g.,* Bondarenko 1994; 1995a: 276–284; 1995b, 1996, 1998c; 2000a: 106–117; 2001: 230–263; 2004a, 2005a; 2006: 64–88, 96–107). Its structure may be depicted in the shape of four concentric circles forming an upset cone. These ‘circles’ are as follows: the extended family, extended-family community (in which familial ties were supplemented by those of neighbor ones), chiefdom, and finally, the broadest circle that included all the three narrower ones, that is the megacommunity as such (the Benin Kingdom as a whole). The specific characteristic of megacommunity is its ability to

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[9] It was furthermore so, as not only intercultural communication but also primitive economic specialization and exchange could be observed within it (see, *e.g.*, Butinov 1960: 113, 119; Mulvaney and Kamminga 1999: 28–31; see also Christian 2004: 197).

organize a complex, 'many-tier' society predominantly on the basis of transformed kinship principle within rather vast territories.

Besides the 13th – 19th centuries Benin Kingdom, megacommunities in precolonial Africa can be recognized, for instance, in the Bamum Kingdom of the late 16th – 19th centuries in present-day Cameroon which as a whole represented an extension up to the supercomplex level of the lineage principles and organization forms, so the society acquired the shape of 'maximal lineage' (Tardits 1980). Analogously, in some other traditional kingdoms on the territory of that post-colonial state 'the monarchical system... is... in no way a totally unique and singular form of organization but displays a virtually identical structure to that of the lineage groups' (Koloss 1992: 42). Outside Africa megacommunities (although not obligatorily of the Benin, that is based on the kin-oriented local community, type) may be recognized, for example, in the Indian societies of the late 1st millennium BC – first centuries AD. Naturally, differing in many respects from the Benin pattern, they nevertheless fit the main distinctive feature of megacommunity as a non-state social type: Integration of a supercomplex (exceeding the complex chiefdom level) society on the community basis and the whole society's encompassment from the local level upwards. In particular, Samozvantsev (2001) describes those societies as permeated by communal orders notwithstanding the difference in sociopolitical organization forms. 'The principle of communality', he argues, was the most important factor of social organization in India during that period (see also Leljukhin 2001, 2004). In the south of India this situation lasted much longer, till the time of the Vijayanagara Empire – the mid-14th century when the region finally saw '...the greater centralization of political power and the resultant concentration of resources in the royal bureaucracy…' (Palat 1987: 170). A number of other examples of supercomplex societies in which 'the supracommunity political structure was shaped according to the community type' is provided by the 1st millennium AD Southeast Asian societies, like Funan and possibly Dvaravati (Rebrikova 1987: 159–163; see, however, Mudar 1999). The specificity of the megacommunity becomes especially apparent in its comparison with the 'galaxy-like' states studied by Tambiah in Southeast Asia (Tambiah 1977, 1985). Like these states, a megacommunity has the political and ritual center – the capital which is the residence of the sacralized ruler – and the near, middle, and remote circles of periphery round it. However, notwithstanding its seeming centripetality, a megacommunity culture's true focus is the community, not the center, as in those Southeast Asian cases. As heterarchic non-kin-ties-based megacommunities, or civil megacommunities, one can consider societies of the *polis* type (Bondarenko 1997: 13–14, 48–49; 1998b, 2000b; 2001: 259–263; 2004b; 2006: 92–96; Shtyrbul 2006: 123–135).

Still, another evident alternative to the state seems to be represented by the supercomplex chiefdoms created by some nomads of Eurasia – the number of the structural levels within such chiefdoms appear to be equal, or even to exceed those within the average state, but they have an entirely different type of political organization and political leadership; besides, this type of political entities do not appear to have been ever created by agriculturists (*e.g.,* Kradin 1992: 146–152; 1996, 2000a, 2000b). This is also confirmed by the history of Scythia. Being similar to supercomplex chiefdoms and an analogue to the early state (see Grinin 2007g: 187–188), it was transforming to an early state more and more obviously in the course of the Scythians' sedentarization. The growth of trade in bread, particularly with Bosphorus, contributed significantly to the development of statehood and consolidation of royal power (see Grakov 1971: 38).

Besides the megacommunity and nomadic supercomplex chiefdoms, the Indus, or Harappa civilization that exceeded considerably in size such pristine civilzations as Egyptian and Mesopotamian, can serve as an example at this point. According to Possehl, this civilization was an example of ancient sociocultural complexity without archaic state form of political organization, what testifies that ancient civilizations, vary in form and organization to a much greater degree than traditional unilinear evolutionary schemes can reflect (Possehl 1998: 291). Definitely, the variability of sociopolitical forms and alternativity of state formation process is demonstrated not only by ancient civilizations but also by different other complex societies of different historical periods.

Societies with thoroughly elaborated rigid cast system can also be a homoarchic alternative to the homoarchic (by definition see Claessen and Skalník 1978: 533–596, 637–650; Claessen *et al.* 2008: 260; see also Claessen 2008: 13; Bondarenko 2008: 20–21, 32–33 [note 7]) early state (see, *e.g.,* Quigley 1999: 114–169; Kobishchanov 2000: 64).

So, alternativity characterizes not only two basic macrogroups of human associations, *i.e.* homoarchical and heterarchical societies. Alternativity does exist within each of them, too. In particular, within the upper range of complexity and integrativity of the sociopolitical organization the state (at least in the preindustrial world) 'competes' with not only heterarchical systems of institutions (*e.g.,* with *polis)* but also with some forms of sociopolitical organization not less homoarchical than the state.

Among numerous factors capable to influence the nature of this or that society, the family and community type characteristic of it seems to deserve notice. The distinction in the correlation of kin and neighborhood (territorial) lines is in its turn connected with the dominant type of community (as a universal substratum social institution). A cross-cultural research conducted earlier (Bondarenko and Korotayev 1999, 2000b) has generally corroborated the initial hypothesis (Bondarenko 1997: 13–14; 1998b: 198–199) that the extended-family community in which vertical social ties and non-democratic value system are usually vividly expressed, given the shape of kinship relations (elder – younger), is more characteristic of homoarchical societies.[10] Heterarchical societies appear to be more frequently associated with the territorial communities consisting of nuclear families in which social ties are horizontal and apprehended as neighborhood ties among those equal in rights (Korotayev and Tsereteli 2001; Korotayev 2003b).[11]

In the course of our cross-cultural research in the community forms, another factor important for determining societies' homoarchization *vs.* heterarchization was revealed. It appeared that probability of a democratic (heterarchical) sociopolitical organization development is higher in cultures where monogamous rather polygynous families dominate (Korotayev and Bondarenko 2000, 2001; Korotayev 2003a).

However, besides social factors (including those mentioned above), a set of phenomena stemming from the fact that political culture is a reflection of a society's general culture type, is also important for determining its evolutionary pathway. The general culture type that varies from one civilization to another defines the trends and limits of sociocultural evolution. Though culture itself forms under the influence of different factors (sociohistorical, natural, *etc.*) the significance of the general culture type for the sociopolitical organization is not at all reduced to the so-called ‘ideological factor’ (Bondarenko and Korotayev 2000c; Claessen 2000). It influences crucially the essence of political culture characteristic for a given society, ‘most probably revealing itself as fully as economic, religious, artistic potential from the very beginning’ (Zubov 1991: 59). In its turn, political culture determines human vision of the ideal sociopolitical model which correspondingly, may be different in various cultures. This way political culture forms the background for the development of character, types and forms of complex political organization emergence, including the enrolling of this process along either the homoarchical or heterarchical evolutionary pathways. But real, ‘non-ideal’ social institutions are results of conscious activities (social creativity) of people to no small degree, though people are frequently not capable to realize completely global sociopolitical outcomes of their deeds aimed at realization of personal goals. People create in the social sphere (as well as in other spheres) in correspondence with the value systems they adopt within their cultures in the process of socialization. They apprehend these norms as the most natural, the only true ones.

Hence, it is evident that the general culture type is intrinsically connected with its respective modal personality type. In their turn, the fundamental characteristics of modal personality types are transmitted by means of socialization practices

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[10] This appears to be especially relevant for those societies where extended families are dominated not by groups of brothers, but by individual ‘fathers’ (see, *e.g.*, Bromley 1981: 202–210).

[11] Note that among not only humans but other primates too the role of kin relations is greater in homoarchically organized associations (Thierry 1990; Butovskaya and Feinberg 1993: 25–90; Butovskaya 1993, 2000; Butovskaya, Korotayev, and Kazankov 2000).

which correspond to the value system generally accepted in a given society and can influence significantly its political evolution (see Irons 1979: 9–10, 33–35; Ionov 1992: 112–129; Bondarenko and Korotayev 2000a: 309–312; Korotayev and Bondarenko 2000, 2001; Korotayev 2003a; Grinin 2007g: 85) though scholars usually tend to stress the opposite influence, *i.e.* the influence of political systems on socialization processes and personality types.

The ecological factor is also important for determination of the pathway which this or that society follows (Bondarenko 1998b, 2000b; Korotayev 2003c; Korotayev, Klimenko, and Prusakov 2007; Grinin and Korotayev 2009b). Not only natural environment but the sociohistorical one as well should be included into the notion of 'ecology' in this case. The environment also contributes a lot to the defining of a society's evolutionary potential, creating limits to its advancement along the homoarchical or heterarchical axes. For example, there is no predestined inevitability of transition from the simple to complex society (Tainter 1990: 38; Lozny 2000) or from the early state to mature one (Claessen and van de Velde 1987: 20ff.*;* Grinin 2007f).

Let us discuss now the implications of the approach discussed above for the study of the state formation processes and 'politogenesis' in general. The tendency to see historical rules always and everywhere the same results in gross perversion of historical reality. For example, concurrent political processes are declared consecutive stages of the formation of the state. Besides, the features of already mature state are illegitimately attributed to its early forms and in consequence of this it becomes impossible to find any 'normal' early state practically anywhere (for details see Grinin 2007f).

The notion of 'politogenesis' was elaborated in the late 1970s and 80s by Kubbel' (*e.g.,* 1988b). However, Kubbel', as well as many others using this notion today, equalized politogenesis to state formation exclusively (*Ibid.:* 3). This approach resulted from the dominant that time and still very wide-spread now, although out-of-date, unilinear ideas that: a) all non-state forms are pre-state by definition; b) the development of political institutions and forms led directly to state formation; c) any even the least developed state is naturally more complex than any non-state society; d) political relations appear with the rise of state only. However, it is impossible to reduce politogenesis to state formation at least because, as we have seen above, complex non-state societies, too developed to be called pre-state, existed alongside with states. Hence, it is necessary to ascertain substitution of a wider process of various complex political institutions and systems formation, that is of politogenesis, with a narrower (and later) one – of state formation. Meanwhile, as Lewis have fairly noted, there exist huge riches of organizational variety of non-state societies worldwide (Lewis 1981: 206). To avoid these stretches and errors, we have developed new approaches to the conception of politogenesis (see Bondarenko and Korotayev 2000a; Bondarenko *et al.* 2002; Korotayev *et al.* 2000; Korotayev and Bondarenko 2000; Korotayev, Kradin, and Lynsha 2000; Grinin 2003, 2004c, 2007e, 2007f, 2007g; Grinin and Korotayev 2006).

We suggest defining the term 'politogenesis' as the process of singling out of the political sphere in a society and formation of the political system as partially independent; as the process of rising of specific forms of power organisation in a society connected with concentration of power and political activity (both internal and external) in the hands of definite (including functional) groups or layers. In other words, it is possible to define politogenesis as the process of formation of complex political organisation of any type, what looks more well-grounded in the etymological respect: in ancient Greece the word politeia *meant a political order of any type, not just the state.*

In the English-language (and obviously Western in general) anthropology the notion of politogenesis is absent as political anthropologists regard that of *state formation process*[12] as sufficient. However, it would be very much desirable to distinguish these notions: politogenesis should be recognized as a broader one that describes the genesis of a complex society's political subsystem while state formation process should be seen as a politogenesis' specific type that leads just to the rise of statehood. That is why it would be productive if 'politogenesis' were added to the Western political anthropology's thesaurus (on this point see Bondarenko and Korotayev 2000a; Bondarenko *et al.* 2002: 66–67; Grinin and Korotayev 2009a: 56–57).

In the result of state formation administrative, violent, and legal methods applied by new types of military and civil professional administrators begin to play an ever-growing part. Clearly, state formation is 'younger' than politogenesis. Like politogenesis singles out of the general process of social (in the broader sense) development, state formation process separates from politogenesis at its definite stage. It is worth noting that as a rule, state formation demands larger territories, more population and resources for its start than other politogenetic processes that lead to the rise of the middle-range polities like simple chiefdoms and their analogues (see Grinin 2007g, 2009). Gradually state formation process becomes the leading and then dominant direction of politogenesis. Due to this one can get the impression that politogenesis is just the process of the rise of the state as a political institution. However, this im-

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[12] Such capacious notions as *complex society*, *sociocultural complexity* and so forth, however, do not solve the problem completely. The lack of such division is rather strange, as far as the notion of *political system* has firmly established itself in the English-language literature at least after publication of *African Political Systems* in 1940 (Fortes and Evans-Pritchard 1987 [1940]). The very conception of political system and *classification of political system types* are well-elaborated (for details see Skalnik 1991). Probably it is explainable by the fact that, as Skalnik and others (see *Ibid.*) point out, basically the whole variety of political systems was rigidly, mechanically and non-dialectically divided into two major ideal types: stateless (acephalous) and state, what has resulted in complete ignorance of the possibility of distinguishing complex systems evolution without state formation.

pression is completely wrong. The state formation process is not just younger than politogenesis. Even after the first state's appearance the directions of politogenesis have never been reduced to the only – statehood – line. To the contrary, these lines were multiple, and at first that of statehood was an exception to the rule among them remaining a rare case long after its appearance.

One more point is important for understanding of the correlation between politogenesis and state formation process. Cycles of states' centralization and decentralization that were among the most significant historical processes in Antiquity and the Middle Ages (see, *e.g.,* Nefedov 2007; Turchin 2007; Korotayev, Komarova, and Khaltourina 2007; Grinin 2007j), can be interpreted in some cases as trends, opposite to state formation and as instances of non-state politogenesis (Grinin 2007g). Indeed, the collapse of vast states (especially immature) into small parts resulted not infrequently in the rise of polities of the type that cannot be regarded as state because of those polities' small size, their administrative apparatus' weakness and uncertainty of sovereignty. For example, in pre-Hispanic Mexico and the Andes the debris of the early states are classified by different scholars either as chiefdoms or as 'small states', 'city-states' (see Chabal *et al.* 2004: 50). If the differences between the politogenesis and state formation processes are taken into account, the solution to the problem can be seen in another point: politogenesis has given rise to different political forms but in the course of time evolution usually returned to the road of state formation.

Therefore, the evolutionary pathway, within which the features of the state familiar to us are guessed retrospectively, is only one of the possible 'branches' of the politogenesis. But since later most alternative sociopolitical structures were destroyed by states, absorbed into states, or transformed to states,[13] it might be reasonable to recognize retrospectively the 'state' branch of the politogenesis as 'general' and the alternative pathways as 'lateral'.

This, however, does not deny the fact that the alternative sociopolitical structures mentioned above cannot be adequately described as pre-state formations, that they are quite comparable with early states by range of their functions and level of their structural complexity. Therefore, it seems possible to designate them as *state analogues* (for details see Grinin 1997, 2000a, 2000b, 2002b, 2002c, 2003, 2004a, 2004b, 2004c, 2006a, 2006b, 2006c, 2006d, 2007a, 2007d, 2007e, 2007f, 2007g, 2007h, 2008, 2009). The term *state analogue* underlines both typological and functional resemblance of such forms to the state and differences in structure. The introduction of this term makes it possible to describe the process of politogenesis more adequately.

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[13] However, such transformations could only happen when certain conditions were present. For example, this could happen as a result of the influence of neighboring state systems.

In the present article the analogue to the early state is defined as the *category that covers different forms of complex non-state societies comparable with the early state (but as a rule do not surpass the typical early state level) in size, socio-cultural and/or political complexity, the level of functional differentiation and the scale of the problems and tasks the societies face which, however, do not have at least one of the features enumerated in the early state definition.*

The following types of analogues have been singled out by us (for details see Grinin 2003, 2006c, 2007a, 2007d, 2007g, 2007h, 2007i, 2009; Grinin and Korotayev 2009b: Essay 5):

1. Some self-governed city and temple communities and territories (including settlement territories or colonies like Iceland of the 10th – 13th centuries) with population from several to tens of thousands.

2. Some large tribal unions with rather strong power of the supreme ruler (the 'king' and so forth) with population of tens of thousands (even hundred thousands or more in some cases). An example is given by some Germanic tribal unions of the Migration period.

3. Large tribal unions and confederations in which the 'royal' power was absent (had never been established or had been abolished) but the processes of social and functional differentiation were well noticeable and even surpassed the pace of political development. Examples of such tribal unions without royal power one can find among the Saxes and some Gallic peoples. The number of people they integrated usually amounted tens of thousand and even hundreds thousands in some cases.

4. Nomads' state-like polities, large and militarily strong, that look like large states (*e.g.,* Scythia or the Xsiungnu empire).

5. Many complex chiefdoms (especially very large), as they are not inferior to small and even middle states in size and complexity (for instance, the Hawaiian chiefdoms population was from thirty to one hundred thousand people [Johnson and Earle 2000: 246]).

Some of these analogues never became states. Others transformed to it but at an already rather high development level; so they transformed directly to large (not small or middle in size) states. We have described in detail elsewhere two basically different models of transition to the state (see *e.g.,* Grinin 2007f, 2007h, 2007i, 2009; Grinin and Korotayev 2009a, 2009b). One of those models is represented just by cases, in which states formed 'vertically' *i.e.* direct transition from pre-state to state societies took place. Most often this transition resulted in small states appearance, as it happened, for example, with the Betsileo of Madagascar in the 17th century (Kottak 1980; Claessen 2000, 2004; see also Orlova 1984: 178–179). Many such instances can be found in Ancient Greece where compelled resettlement from several small settlements to one for the sake of defense from military actions or from pirates was spread very widely and got the name of synoecism (see Gluskina 1983: 36; Frolov 1986: 44; Andreev 1979: 20–21).[14] However, there could be cases of large states' vertical formation.[15]

Thus, in order to find solutions to a certain range of political anthropology problems it is necessary to consider the genesis of early state in the general context of socioevolutionary processes coeval with it. This could make it possible to appreciate more exactly the correlation between general evolution and state formation processes. For example, it seems evident that the early state formation is finally connected with general changes caused by the transition from the foraging to food production. This generally resulted in the growth of sociocultural complexity. This led to the appearance of the objective needs in new methods of organization of societies and new forms of contacts between them. But in different societies it was expressed in different ways. So, over long periods of time, the growth of sociostructural complexity, the exploitation of neighbors, development of commerce, property inequality and private ownership, growth of the role of religious cults and corporations *etc.* could serve as alternatives to purely administrative and political decisions of above-mentioned problems. And in these terms, the early state is only one of forms of new organization of the society and intersociety relations, although later it became almost universal due to quite objective evolutionary reasons.

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[14] Note, however, that even for those who recognize the *polis* socio-political model as a form of the early state the attribution as states of these or those historical incarnations of the *polis* model remains discussable (see, *e.g.,* Berent 2000c; Grinin 2007f: 67–118; Korotayev, Kradin, and Lynsha 2000; see also the discussion in *Social Evolution & History* journal in 2004–2006, *vide stricto*: van der Vliet 1987, 2005; Grinin 2004a, Berent 2006). See also note 6.

[15] Probably this is just what happened to the Zulu who in a short time created (first under Dingiswayo and than under his successor Shaka) in the south of Africa in the early 19th century a very large power out of separate small chiefdoms. Note, by the way, that high degree of supracommunity institutions hierarchization and significant degree of the institutionalized hierarchy's stability were characteristic of this mighty polity (see, *e.g.,* Gluckman 1987 [1940]; Ritter 1955).

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Abstract

The article deals with important theoretical problems of social evolution. In the authors' opinion, a number of general evolutionary ideas, principles and conclusions formulated in the article may be significant for the study of not only social evolution but also of evolution as such.

The authors' basic ideas and principles are as follows: Evolutionary alternatives can be found for any level of social complexity. Different social and political forms coexisted and competed with each other for a long time and for some specific ecological and social niches the lines, models and variants lateral in the retrospect could turn out more competitive and adequate than those that became dominant later. The statements about an unavoidable result of evolution can be considered as true only in the most general sense (and given some conditions are observed). The point is that an evolutionary result usually is an outcome of long-lasting competition between different forms, their destruction, transformations, social selection, adaptation to various ecological milieus, *etc.* Thus such a result could be not inevitable for each and every particular society.

These ideas are concretized and proved at different levels including that of pre-state societies (the characteristic features of chiefdoms on the one hand and their analogues and alternatives on the other are compared). The notions of heterarchy and homoarchy as labels for ideal models of rigidly (invariably) and non-rigidly (in multiple ways), ranged social structures respectively, are also scrutinized. The authors argue that it can be possible to postulate heterarchic and homoarchic evolutionary trajectories that embrace all cultures throughout whole human history.

Special attention is paid to an analysis of the models of politogenesis in the course of which alternative models of transition to complex societies form. This idea resists the outdated representation about the transition from non-state to state societies as direct and unilinear. The authors show that this transition was multilinear, they introduce the notion of the early state analogues and propose their classification. The early state analogues are represented by them as complex non-state societies, comparable with early states in size, socio-cultural and/or political complexity, functional differentiation level, *etc.,* that, however, do not have some features typical of the early state.

8

Evolution of Nested Networks in the Prehistoric U.S. Southwest: A Comparative World-Systems Approach[*]

Christopher Chase-Dunn

Place-centric interaction networks are arguably the best way to bound human systemic processes because approaches that attempt to define regions or areas based on attributes necessarily assume homogenous characteristics, whereas interaction itself often produces differences rather than similarities (Chase-Dunn and Jorgenson 2003). The culture area approach that has become institutionalized in the study of the pre-Columbian Americas is impossible to avoid (as below), but the point needs to be made that important interactions occur across the boundaries of the designated regions and interaction within regions produces differences as well as similarities. Networks are the best way to bound systems, but since all actors interact with their neighbors, a place-centric (or object-centric) approach that estimates the fall-off of interactional significance is also required.

The comparative world-systems approach has adapted the concepts used to study the modern system for the purpose of using world-systems as the unit of analysis in the explanation of human social evolution. Nested networks are used to bound systemic interaction because different kinds of interaction (exchange of bulk goods, fighting and allying, long-distance trade and information flows) have different spatial scales. Core/periphery relations are of great interest but the existence of core/periphery hierarchy is not presumed. Rather the question of exploitation and domination needs to be asked at each of the network levels. Some systems may be based primarily on equal interdependence or equal contests, while others will display hierarchy and power-dependence relations. It should not be assumed that earlier systems are similar to the modern global system in this regard. Rather it should be a question for research on each system.

The comparative world-systems claim that whole systems must be the unit of analysis for explaining much of social change is mainly sustained by

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[*] An earlier version was presented at the workshop on 'Analyzing Complex Macrosystems as Dynamic Networks' at the Santa Fe Institute, April 29–30, 2004.

the hypothesis of 'semiperipheral development'. Without looking at intersocietal relations it is impossible to see this phenomenon.

Studies of premodern interaction networks have found a pattern of **pulsation** in which networks expand and contract over time, with an occasion vast new expansion that integrates larger and larger territories. Recent waves of globalization in the nineteenth and twentieth centuries are a continuation of this phenomenon. And another observation from comparing systems is that all systems that have hierarchies exhibit a pattern of the **rise and fall** of powerful polities. The modern rise and fall of hegemonic core states is thus analytically similar to the rise and fall of empires and the rise and fall of paramount chiefdoms.

Chase-Dunn and Hall (1997) propose an explanation of human social evolution that combines transformations of systemic logic across rather different modes of accumulation with an underlying 'iteration model' that posits causal relations among population growth, intensification, population pressure, migration, circumscription, conflict and hierarchy formation and technological change. It is an interaction model because the outcomes (hierarchy formation and technological development) have a positive effect on population growth, and so the model predicts a spiral of world-system expansions.

A number of important exogenous variable affect the iteration model. Climate change is mainly an exogenous variable, though local climate may have also been impacted by societies in the past, and is quite certainly being impacted in the present. Geographical conditions can facilitate or hinder the emergence of larger polities. Zoological and botanical capital can speed up processes of technological development by providing species that are easily domesticated by humans. And natural capital scarcity can also slow down technological change.

The long-distance diffusion of domesticated crops and animals, and of technological ideas from distant systems can have huge consequences for a local world-system without signifying a systemic integration of the two systems. Systemic integration requires two-way and regularized (frequent) interactions. Very intermittent incursions or pandemic diseases can impact upon a system from without. These possibilities of exogenous impacts on local and regional systems need to be taken into account in order to fairly test the iteration model and transformations of the modes of accumulation as explanations of human social change.

It does not make sense to ask **how many** world-systems there were in prehistoric North America if we accept the group-centric approach to bounding world-systems mentioned above. If every group interacts with neighboring peoples then there are no major breaks in interaction across space. Thus there were as many 'systemic wholes' as there were groups because each group had a somewhat different set of interactions.

Of course this is not to say that there were not differential densities of interaction. Natural barriers such as deserts, high mountains, and large bodies of water increased the costs of communication and transportation. But ethnographic and archaeological evidence reveals that most of these geographical 'barriers' did not eliminate interaction. In California travel across the High Sierra was closed by deep snow in the winter. But when the snow thawed regularized trade across this high range resumed. Natural barriers do affect interaction densities, but in most cases they do not eliminate systemic interaction.

The suggestion that 'culture areas' – the culturally similar regions designated by anthropologists (*e.g.,* California, the Pacific Northwest, the Southwest, *etc.*[1]) – can be equated with world-systems is fallacious from the group-centric point of view because important interactions frequently occurred across the boundaries of these culture areas. Nevertheless it is convenient to follow Stephen Kowalewski's (1996) lead in discussing how the world-systems in these traditional culture areas were similar or different from one another. The literature on trade networks by archaeologists is usually organized into discussions of these culture areas, but there has been more and more study of trade interactions between the different culture areas.[2] This section discusses the U.S. Southwest and those recent adjacent to it that may have been in systemic interaction with the Southwest. Chase-Dunn and Hall (1998) also examine the other described the world-system aspects of the other 'culture areas' in that part of North America that became the United States.

Humans came across the Aleutian land bridge at least thirteen thousand years ago. An encampment of hunter-gatherers near Monte Verde, Chile, complete with chunks of Mastodon meat, has been firmly dated at 12 500 BP (10 500 BCE). The land route was difficult to pass before about 12 000 years ago because of the large Pleistocene glaciers. But it is possible that maritime-adapted peoples moved along the coasts. Most archaeologists discount the possibility of early voyaging across the open ocean.

In the region that became the United States so-called Paleo-Indian used large distinctively fluted stone spear points known as Clovis points[3] over

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[1] The culture areas for which there are volumes of the Smithsonian *Handbook of North American Indians* are: Arctic, Subarctic, Northwest Coast, California, Southwest (2 volumes), Great Basin, Plateau, Plains, Southeast, and Northeast.

[2] Multiscalar and multitemporal spatial analyses have been applied to the Southeast and the Midwest by the studies contained in Nassaney and Sassaman (1995) and this approach has been applied in several of the essays included in Neitzel (1999).

[3] The first Clovis points found near Clovis, New Mexico, have been dated as 11 200 BP (9200 BCE).

a wide region of North America. Archaeologists think that the peoples who lived during the epoch they call ‘Paleo-Indian’ (usually from 10 000 BCE to 8 000 BCE) were small groups of big game hunting nomads who ranged over wide territories. In the case of the Paleo-Indian archaeologists disagree about whether or not there was trade among groups. Many Clovis points have been found that are made of stone that came great distances. But since it is thought that the nomadic Paleo-Indian ranged widely, it is possible that they procured the materials directly from quarries rather than trading for them.

The general model of social evolution that has most often been applied to North America is that groups migrated to fill the land, then population increased, and trade and complexity emerged. This general sequence is implied in the periodizations that archaeologists have developed to characterize the cultures for which they find evidence in North America. In every region the Paleo-Indian period was followed by the Archaic, a period in which groups became more diversified hunter-gatherers, restricted their migrations to smaller regions and developed distinctive regional lithic styles. Sometimes distinctions are made between the Lower and Upper Archaic. The Archaic lasted longer in some regions than in others. After the Archaic, the periodization terms differ from region to region. The general picture is one of increasing population density, the development of more complex societies in each region and increasing trade within and between regions. But this general model becomes more complicated when we look more closely. The trends toward greater population density, complexity and trade were broken by cyclical processes of the rise and fall of hierarchies and complexity, changes in the patterns of interaction within and between regions and important differences in the timing and nature of social change across regions.

The notion of widely nomadic populations becoming gradually more sedentary is related to the problem of cultural differences, social identities and territoriality. Archaeologists note that stylistic differences among groups became more pronounced as nomadic circuits became smaller and sedentism developed. This is interpreted as the formation of local cultural identities by which people distinguished their own communities from those of their neighbors.[4] The wide circles of year nomadic treks of the Paleo-Indians with their continentally similar Clovis spear-points were replaced by smaller regional and intersecting circles of migration by groups hunting smaller game species and using regionally distinct projectile points. Thus the spatial nature of nomadic ‘settle-

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[4] Ericson and Baugh (1993) and Baugh and Ericson (1994) helpfully summarize the archaeological evidence and interpretations of the relationship between changing trade networks and the rise and fall of societal complexity in North America.

ment systems' shrank toward the eventual development of sedentism. A system of moving people to resources was replaced by a system of moving resources to people through trade networks. At first the trade networks were small, but over time they grew larger. It is this latter process of trade network expansion that brought small regional systems into greater interaction with distant peoples. This is analogous to the sequence of network expansions in waves that occurred in Afroeurasia since the emergence of sedentism that began twelve thousand years ago in the Levant.

The Southwest

Most of the research on the Southwest that explicitly uses world-systems concepts has focused on relations among societies within the Southwest (*e.g.,* Upham 1982; Spielmann 1991a, 1991b, 1991c; Baugh 1991; Wilcox 1991; McGuire 1992, 1996), but there has also been an important literature on the relationship between the Southwest and Mesoamerica (discussed below). The term 'Pueblo' is the generic word that Spanish colonizers applied to sedentary horticulturists found in what is now New Mexico and Arizona. These groups had only a few traits in common: they built adobe villages with a central plaza and ceremonial structures, and they grew corn, beans, and squash. In historical times (*i.e.* after the arrival of Spanish colonists) there was no overarching unity among the Pueblo peoples, and warfare occasionally occurred between different Pueblo villages. The people who occupied these villages spoke languages from at least three different major linguistic stocks.

There are several culture areas within the Southwest. The main centers that developed political complexity about 1100 years ago were the Hohokam in Arizona, the Anasazi Chacoan polities and a few centuries later, Paquime (Casas Grandes) in Northern Chihuahua about 200 kilometers south of Chaco Canyon (see Fig. 1). Other important archaeologically known cultures in the region are Mogollon and Mimbres.

The ancestors of the historically known Pueblo Indians were the Anasazi – the 'people of old'. The Anasazi culture emerged from 900 CE to 1150. Several large centers were built in this period. At Chaco Canyon a very large center emerged in the tenth and eleventh centuries with perhaps more than 10 000 people living in the Chaco core (Vivian 1990). The Chaco culture, recognizable by distinctive pottery and architecture, spread widely in New Mexico and Arizona through the establishment of many 'Chaco outliers'.

After 1200 Chaco Canyon was nearly abandoned as the region endured a fifty-year drought. Kintigh (1994: 138) notes that at the turn of the thirteenth century there was a renewed aggregation of living units into large communities and abandonment of smaller settlements. This suggests the reestablishment of a regional system. This second wave of complexity also collapsed. All this is reminiscent of the cycling, or rise and fall of chiefdoms that Anderson (1994) describes for the prehistoric Southeast.

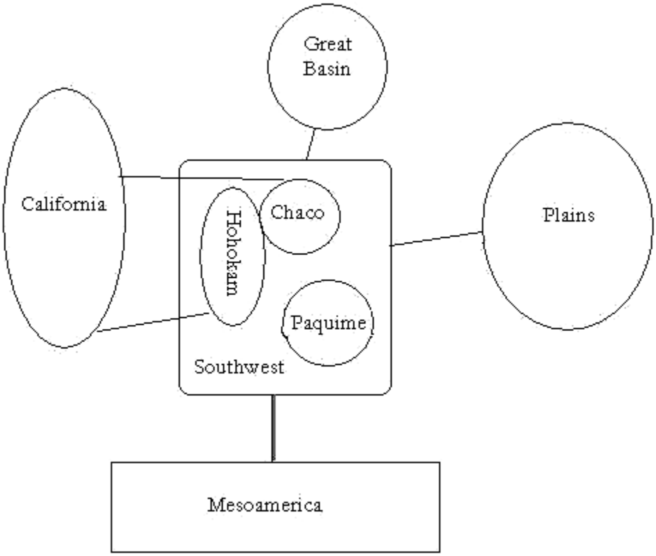

Fig. 1. Southwestern macroregion and adjacent regions

Stephen Lekson (1999) has formulated an explanation for the rise and fall sequence of the Southwest that focuses on the significance of what he calls the ‘Chaco Meridian’. Lekson sees immense significance in the geographical aspects of the great straight roads that radiated from the ritual center of Chaco Canyon. He notes that after the decline of Chaco the next large central place to emerge in the region, the so-called Aztec Ruin on the Salmon River, is directly to the north of Chaco and that one of the ritual roads goes north from Chaco in the direction of the Aztec Ruin. And after the decline of Aztec a new, larger central place emerged that we know as Paquime (Casas Grandes) in a region that allowed for the building of an elaborate canal-based irrigation system.

Lekson makes much of the observation that Casas Grandes, though 200 kilometers to the south of Chaco, is also exactly on the Chaco Meridian. Lekson's explanation focuses on a hypothetical religious elite that adapted to successive drought crises by moving its center of operation first directly north, and then directly south of its original cult center.

David Wilcox's (1999) interpretation of the hegemonic rise and falls in the Southwest posits a system of competing polities that succeed one another rather than the adaptation of a single cultural group that moves its center of operation. It is, of course, possible that newly emergent groups tried to appropriate the spiritual power and legitimacy of earlier dynasties. This phenomenon is well known from state-based systems. So it is possible that Wilcox's scenario can also account for the phenomenon of the Chaco Meridian.

The debate over the nature of Southwestern complex polities is reminiscent of similar controversies about Mississippian complex chiefdoms. Wilcox points out that chiefdoms may be organized either around a single sacred chief who symbolizes the apex of a polity or they may take a different form that he calls ‘group-oriented’ that is organized around a council of chiefs. Few examples of elite burials are found in the Southwest (though this may partly be a consequence of the existence of cremation rituals). Wilcox contends that the polity that emerged at Chaco Canyon started out as a ritual theocracy in which an ethnic group of rainmakers migrated to the canyon, perhaps at the invitation of the horticulturalists who already lived there. This group of ritual specialists constituted a theocratic polity at first and the cult of the Great House was established in the Chaco outliers to organize the collection of food and raw materials. A new center was established at Aztec Ruin, but Wilcox believes that this outlier became an independent and competing polity. He sees the emergence of Chaco as stimulating secondary chiefdom formation in adjacent areas and the emergence of ‘peer polities’ that constitute a system of competing and allying polities. Wilcox contends that institutionalized coercion eventually became a more important feature of the Chacoan system. He cites evidence of mass burials and cannibalism in the period just before the Chaco collapse. He characterizes the transition from theocracy to institutionalized coercion as the emergence of a tributary state. He thinks that the Chacoan hegemonic state conquered Chuska to the east in order to gain control of timber resources.

But while Wilcox sees the Chacoan phenomenon as involving a core/periphery hierarchy based on tribute-gathering, his characterization of the Hohokam phenomenon in Arizona is quite different. Hohokam settlements emerged in the context of the building of a large system for irrigating maize horticulture in the Phoenix basis and adjacent regions. The big Hohokam capital was a Snaketown. One of the main signatures of the Hohokam religion was the circular ball court used in fertility rituals. The largest of these ball courts was at Snaketown. Wilcox claims the centrality of Snaketown was completely a matter of ‘ritual suzerainty’ and that there was no coercive element in the relationship between Snaketown and the Hohokam outliers.

Kowalewski's (1996) comparison of the Southwest with other US culture areas describes a radical core/periphery identity separation that emerged between closed corporate Pueblo communities of horticulturalists and the more nomadic foragers and raiders that lived around them. The Pueblo peoples live in defensible towns, often atop mesas (flat-topped mountains), where they were able to protect their stores of corn from nomadic raiders. And the dramatic Anasazi cliff dwellings (*e.g.*, Mesa Verde) have obvious defensive advantages.

But Feinman, Nicholas and Upham (1996), in their explicitly world-systemic comparison of Mesoamerica and the Southwest (which ignores the issue of the interaction between these two macroregions), characterize the Southwest as a region in which networks were open and permeable, without strong boundaries between societies. The contrast with Kowalewski's portrayal is vivid. Perhaps the earlier system was open, while the bounded Pueblo communities emerged after the Spanish invasion or after nomads obtained horses. But the existence of the Anasazi cliff dwellings, built hundreds of years before the arrival of Spaniards and horses, looks functionally quite similar to the mesa communities of historically known Pueblos. It is a lot of trouble to build houses into a cliff and carry water up from below. Defense against raiders would be a likely explanation. Defensive communities and conflictive relations are often associated with strong cultural boundaries between the conflicting groups.

In her discussion of Plains/Pueblo interactions Katherine Spielmann (1991a, 1991b) delineates two ways in which exchange between what had heretofore been relatively autonomous groups might have developed into systemic exchange (core-periphery differentiation in world-system terms).[5] The first, which she favors, is **mutualism**, in which sedentary horticulturalists engage in systematic exchange with nomadic hunters in such a way that the total caloric intake over the necessary variety of food types mutually benefits both groups. The second, favored by Wilcox (1991) and Baugh (1991), is **buffering** in which sedentary agriculturists use exchange with nomadic hunters to supplement food supplies during periods of scarcity.

The issue of pacific *vs.* conflictive relations between horticulturalists and foragers has been raised in many other contexts. Gregg's (1988) discussion of the expansion of gardening into Europe portrays a symbiotic relationship between farmers and foragers who exchanged complementary goods. Spielmann's (1991b) rendering of this relationship in the Southwest also favors a symbiotic interpretation in which complementary surpluses were exchanged between Pueblos and nomadic foragers. Baugh (1991) uses world-systems concepts to

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[5] Other sources on Plains – Pueblo interaction are Baugh (1984), Habicht-Mauche (1991), Spielmann (1989), Wilcox (1984), Wilcox and Masse (1981).

analyze this same relationship. Both he and Wilcox (1991) see elements of a core/periphery hierarchy in which the sedentary groups (Pueblos) were benefiting more than the nomadic foragers from the interaction.

One hypothesis that stems from the iteration model of world-systems evolution (Chase-Dunn and Hall 1997: ch. 6) is that all systems go through cycles of increase and decrease in the level of conflict among societies. Farmer/forager interactions are more likely to be symbiotic under conditions of low population pressure, but when ecological degradation, climate change or population growth raises the costs of production, conflict among societies is likely to increase. It is during these periods that new institutional solutions are more likely to be invented and implemented. But if new hierarchies or new technologies are not employed, conflict will reduce the population and a period of relative peace will return.

Randall McGuire's (1996) study of core/periphery relations in the Hohokam interaction sphere reveals evidence of the rise of a culturally innovative center near what is now Phoenix, Arizona. Several different surrounding peripheral regions adopted styles from this core. McGuire demonstrates the dangers of applying assumptions based on the modern world-system to stateless systems. He finds that the peripheral Hohokam regions did not culturally converge, but rather they become more different from one another as climate changed and they interacted with other distant core regions. Of course the hypothesis of convergence among peripheral regions is also contradicted for the modern world-system because peripheral areas often experience quite different developmental paths.

Little is known archaeologically about nomad – nomad relations in the Southwest. Some of the nomadic groups may have been recent arrivals (Wilcox 1991). Baugh (1991) and Wilcox (1991) suggest that trade among nomadic foragers was an alternative to centralization in stabilizing volatile food supplies. The arrival of Spaniards (from 1530s on) vastly disrupted intergroup relations (see Hall 1989). The alliances that some of the nomadic groups made with the Spanish (*e.g.*, the Comanches) may have had prehistoric analogues in which nomadic groups allied with particular Pueblo core societies to provide protection against other nomadic groups, and possibly to serve as allies in disputes among Pueblo societies.

The nested network approach to bounding world-systems is helpful for understanding the ways in which precontact North American societies were linked to one another and the relevance of these links for processes of development. As with state-based systems, bulk goods, political-military interactions, prestige goods networks and information networks formed a set of nested nets of increasing spatial scale. Some of the earliest explicit usage of world-systems concepts by archaeologists (Whitecotton and Pailes 1986; Weigand *et al.* 1977) were arguments that the Southwest constituted a periphery of the Mesoamerican world-system.

There has been a huge controversy about the importance or unimportance of links between the US Southwest and Mesoamerica (Mathien and McGuire 1986; Cobb, Maymon, and McGuire 1999). An early advocate of the importance of these linkages was Charles Dipeso (1974) who argued that the great houses at Chaco Canyon were erected as warehouses and dwellings for a small group of Toltec traders, the *pochteca.*[6] Dipeso contended that it was the withdrawal of the Toltec *pochteca* in the twelfth century that prompted the rapid decline of the Chaco Canyon polity.

That there were at least some connections between the Greater Southwest and Mesoamerica is now widely accepted. However, their importance for local development is still the subject of considerable dispute. Weigand and Harbottle (1993) continue to argue that the Southwest was a periphery of Mesoamerica based on the proven fact that turquoise from the Cerrillos Hills just south of Santa Fe was mined and exported to the states in the Valley of Mexico (where Mexico City now is). They claim that turquoise played an important role in the overall structure of trade between these two regions and that the demand for turquoise was an important factor in the rise of complex societies in the Southwest. Other features of societies in the Southwest, such ball-courts, ceremonial mounds and scarlet macaws kept as pets, also suggest influences from Mesoamerica. Striking similarities in Southwestern and Mayan mythology (spider woman, warrior twins, *etc*.) are downplayed by Cobb, Maymon and McGuire (1999). They suggest that the feather-serpent motif associated with Quetzecoatl may have been part of an ancestral mythology common to all the Native Americans. Cobb, Maymon and McGuire also contend that important large settlements in Western Mexico linked to the states of the Valley of Mexico are relatively recent phenomenon, and that before that the huge region of northern Mexico was inhabited only by nomadic foragers.

Late Mississippian chiefdoms such as that at Etowah in Georgia have been found to have produced iconography that employs design elements and symbolic content that is strikingly similar to the icons of Mesoamerican states (*e.g.,* Anderson 1994: 83). Archaeologists refer to the cultural complex that produced this iconography as the 'Southern Cult' (Galloway 1989). Most archaeologists

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[6] In the Aztec empire *pochteca* were important agents of the king who were sent on distant missions to trade and to obtain political and military intelligence. It is thought that earlier Mesoamerican states such as the Toltecs also had long-distance specialists of this kind. The most plausible explanation for Kaminaljuju, a city in Guatemala built in the style of Teotihuacan (in the valley of Mexico), is that trader priests converted the local Mayans to the Mexican religion.

contend that influences from Mesoamerica were unimportant to the processes of development that occurred in the Southwest and other areas of what is now the United States. Some argue that these cultural resemblances are due to parallel evolution, not interaction (*e.g.,* Fagan 1991).

The evidence of turquoise sourcing shows that there was definitely trade between highland Mesoamerica and the Southwest. Certainly there was down-the-line trade, but there could have also been at least a few long-distance trade expeditions undertaken by *pochteca* from the Mexican highlands or from Western Mexico. It is hard to imagine how down-the-line trade could have transmitted the ideologies behind the iconographs of the Southern Cult, though the predominant consensus among both Southwestern and Southeastern archaeologists (*e.g.,* Cobb, Maymon and McGuire 1999) is that direct influence was slight. The predominant opinion among archaeologists after a several decades of dispute is that local and regional processes were much more important determinants of development in the Southwest and the Southeast than were the long-distance connections with Mesoamerica.

The Plains

The Plains Indians are best known in the ethnographic literature for large bands of horsemen who hunted buffalo and made war. But horses were introduced by Spaniards in the sixteenth century and rapidly adopted by nomadic groups on the Plains. The coming of the horse had a revolutionary effect on the societies of the Plains because of increased mobility and increased efficiency of the hunt. Groups that formerly needed to disperse to find food could now come together to form larger polities and alliances. These developments had important affects on adjacent regions where peoples both adopted plains features and organized to defend against the military power of the Plains peoples.

But an earlier story is less well known. Contemporaneous with the emergence of the Mississippian interaction sphere was the florescence on the southern Plains of a mound-building culture that had important trade and cultural links with both the Mississippian heartland, especially Spiro, and with the Southwest (Vehik and Baugh 1994). This is known as Caddoan culture. The Caddoans built large mounds and villages and planted corn, but they were culturally somewhat different from similarly complex societies to the east and west. This cultural distinction might be interpreted as only marginal differentiation if we did not also know that the Caddoans cut themselves of from trading beyond the Plains and constructed a network centered on the Caddoan heartland (Vehik and Baugh 1994). This was an instance of a semiperipheral region turning itself into a core by means of delinking from other distant cores. Around

1200 CE Caddoan trade with the Mississippian societies collapsed. This caused societies on the eastern Plains (on the border between the Plains and the Mississippian interaction sphere) to decrease in complexity. It also created a Plains trade network centered in the Caddoan heartland that was largely separated from both the Southwest and the Mississippian networks. Later the Caddoan core declined at about the same time as the Cahokian core chiefdoms. And this was contemporaneous with declines in the Southwest. A fascinating instance of synchronous growth/decline phases of cities and empires in East and West Asia from 650 BCE to 1500 CE (Chase-Dunn, Manning and Hall 2000) suggests the possibility of similar synchronies in the growth/decline sequences in the Americas.

The Great Basin

In what are now the states of Utah, Nevada and eastern California is a region of high desert in which water does not flow to the seas, but rather into large landlocked basins. Some rather large rivers run for hundreds of miles and disappear into the sand. It is an ecologically sparse environment that is punctuated by small areas where water, game and plant life are more abundant. In addition to the lack of rainfall in most areas, the distribution of rainfall varies greatly from year to year. This ecologically coarse environment was the home of nomadic foragers, known ethnohistorically as the Paiute, the Western Shoshone and the Ute, who adapted to the desert environment by moving to where food was most available. This region was also the inspiration of the theory of social evolution known as cultural ecology that emphasizes the importance of social adaptations to the local environment. Julian Steward, a major figure in the development of cultural ecology (1938, 1955), did important ethnographic surveys in which he charted population densities across the entire Great Basin region and analyzed why there were important organizational and cultural differences among the ethnohistorically known groups in this large region. The ecological constraints on human societies are dramatic in the basin and range geography studied by Stewart.

As the debate about whether or not the Southwest was a periphery of Mesoamerica has raged, there has been an analogous controversy over whether or not the Great Basin was a periphery to the Southwest. The early peoples who moved into the Great Basin occupied the few locations where there were good supplies of game and food plants. Subsequent population growth and more recent arrivals led groups to occupy more marginal regions. What emerged was a mosaic of social structures that mapped the ecological geography almost perfectly. The desert mosaic was composed of small settled groups near isolated food resources (*e.g.,* near rivers and lakes) surrounded by more nomadic groups who were following the yearly variation in food availability. This desert mosaic was impinged upon by outside influences from California, the Plains and the Southwest, but despite these factors and changes in climate, the basic mosaic pattern still existed when the Euroamericans came to explore this region in the 1840s.

Southwestern-type village-living horticulturalists and pot-makers, called the Fremont culture, emerged in the southern Great Basin in about 400 CE. Upham (1992) has argued that Great Basin peoples alternated back and forth from settled *versus* nomadic strategies depending on climatic, ecological and interactional shifts. Trade networks that are visible in the potsherd evidence (broken pieces of pots with distinctive designs) indicate that the settled groups used trade networks to insure against local food shortages (McDonald 1994). Between 1250 and 1350 CE the Fremont peoples abandoned the Great Basin, probably because of the droughts of the Little Ice Age. It was this same climatic change that probably caused the abandonment of the Anasazi regions on the Colorado plateau to the south. New groups of people, presumably the ancestors of the Shoshoni, may have moved into the region at this time (Madsen and Rhode 1994).

Julian Steward's (1938) analysis shows that the local sedentary core groups developed religious rituals, collective property rights, and political organization at the village level, whereas their more nomadic neighbors existed primarily with only family-level organization. Steward does not discuss the interactions among these groups. Indeed he claims that there was little trade and little interaction. But the groups occupying prime sites would have needed to protect their resources from intruders. They developed political organization to regulate internal access, but also to protect from external appropriation. Steward argues that warfare was not an important emphasis for any of these groups, except those few who adopted some of the cultural trappings from neighboring societies on the Great Plains. Nevertheless the development of bounded territories and the enforcement of legitimate claims to resources by means of coercion – even if only yelling and stone-throwing – represented an institutional response to a core/periphery differentiation in which some groups needed to protect their ecological resources from other groups.

As for the peripheral peoples, their culture, as Steward (1938) says, was primarily ‘gastric’ – focused on food. In order to not starve they needed to cache enough food to survive through the winter. The key food for this purpose was the nut from the cone of the Pinion pine. These were available for harvest in the fall. Pinion nut crops varied greatly from location to location and from year to year, and when they were plentiful in one location there was usually enough for all those who had the ability to harvest and process them. This set of characteristics was not propitious for the development of property rights, and so groups did not try to control particular Pinion stands.

This was a rather elemental form of a local core/periphery structure. There was no core/periphery hierarchy in which core societies exploited the labor or resources of peripheral societies. What the core societies did was to protect their assets from potential peripheral intruders. And for their part the peripheral peoples were disorganized by the ecological circumstances, in which ‘optimal foraging strategy’ dictated that they remain spread out in very small groups. Thus when hunger gripped them they had not the ability to attack the stores of the core societies. Rather they simply starved.

Contrary to Steward's claim that Great Basin peoples did not trade, there is ample archaeological evidence that they did participate in long distance trade networks.

Bennyhoff and Hughes (1987) show that an olivella shell-based trade network that linked the Western Great Basin to the coast of Northern California expanded from 2000 BCE to 200 BCE and then contracted from 200 BCE to 700 CE and then expanded again from 700 CE to 1500 CE. After 1500 CE there was a major expansion within California based on a different kind of shells (clam disk beads), but this network did not extend into the Great Basin. Hughes (1994) shows that two cave dwellings in the Western Great Basin that are rather close to one another, were parts of very different obsidian exchange networks, but were linked into the same shell network. This cautions us against assuming that all sorts of trade items fit into the same exchange networks.

California

This section considers the whole California culture area in comparative perspective. In California only a few societies had clans and moieties,[7] and there were no hierarchical kinship systems. In the area of Northern California that was studied by Chase-Dunn and Mann (1998; see also Chase-Dunn and Hall 1997: ch. 7) the largest polity was the tribelet, a very small unit consisting of a few villages. Larger political entities did not exist except in the San Joaquin Valley (Yokuts) and in Santa Barbara (Chumash). Though California has been characterized as a culture area based on social structural and artifactual similarities, there were enormous differences within California as well. Linguistic differences are the most obvious. Linguists contend that six major linguistic stocks were present in indigenous California. Whereas clay pots were not

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[7] Moieties are kinship groups organized as dualities. For example, the people of each village are divided into two kin-based groups.

used by most of the indigenous peoples of California, the Western Mono, Paiute and some of the Yokuts peoples made pottery in southeastern California. The only maize horticulturalists in California lived along the Colorado River on the border between California and Arizona, although nearly all groups in California planted small amounts of tobacco.

We have already mentioned the studies of trade linkages between California and the Great Basin. These show that the expansion and contraction of trade networks is a feature of intersocietal relations even when the constituent societies are very egalitarian. Shell and shell artifacts from the Pacific were traded with the Southwest. Wilcox (1999) emphasizes the notion that the Chumash traded abalone shell and shell fishhooks with the Chacoans.

Interaction Nets over the Long Run

Rather than a simple model of interaction nets getting larger, the sequence found in several North American regions shows a more complicated pattern. The 'settlement systems' of nomads were spatially huge as they ranged over great territories. As population density increased these nomadic ranges became smaller until the transition to sedentism emerged. The first sedentary societies had very small interaction nets, but these got larger and then smaller again, and then once again larger. This is network pulsation.

The early Paleo-Indians were explorers and colonizers of land that was yet uninhabited. They chased herds of big game, and they also tended to concentrate in areas that had greater amounts of game and other foods (Anderson 1994). As has been the case in other colonization sequences (*e.g.*, the Pacific), the first arrivals probably took the best locations and then tried to hang on to them. Population density was so low at first that there were plenty of good new locations, and so interactions among groups were mainly friendly. But as the best locations became utilized and the megafauna became scarce, more competition emerged. Some groups developed seasonal migration rounds in particular territories and tried to defend the best camping sites against new arrivals. The small bands always needed to gather with other bands seasonally to trade and exchange marriage partners. But the sizes of these seasonal gatherings were limited by the availability of food stocks at the meeting place.

A kind of territoriality emerged among nomads, but it was probably not well institutionalized. We do not know whether or not the Paleo-Indian pioneers brought with them a cultural apparatus for claiming and defending collective territory. The Polynesian pioneers of the Pacific brought with them an ancestral culture that included the concepts of *mana* and *tapu*[8] that were the basis

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[8] *Mana* is the powers of the universe as controlled and directed by the sacred chiefs. *Kapu* refers to the prohibitions (taboos) that protect sacredness. These important elements of ancestral Polyne-

of sacred chiefdoms. The Polynesians temporarily abandoned ceremony and hierarchy and to become egalitarian hunter-gatherers when they landed on islands populated by large and delicious flightless megabirds (*e.g.,* New Zealand). But when the birds were all eaten, the Polynesians reconstructed class societies and territoriality using the linguistic and ideological equipment that was embedded in their ancestral culture.

Very likely the immigrants to North America did not have such a hierarchical cultural heritage because the Asian societies from whence they came had not yet developed ideas and kin relations appropriate to the symbolization of the linkage between place and blood. This means that the original American pioneers had to invent these institutions as they came to need them.

The Paleo-Indian interaction networks were large, especially for exchanging fine and useful objects such as Clovis points and exotic lithic blanks. Cultural styles were widely shared across macroregions. And the territories exploited by human groups were huge, though the numbers of people in each macroband were small. As bands became somewhat less mobile they developed more differentiated tool-kits depending in part on the nature of the territories they inhabited, but also as a way of symbolizing alliances with friends and differences with foes.

The question of systemic *versus* conjunctural or intermittent relations among macro-regions in prehistoric North America remains. The consensus among archaeologists is that the patterns of network development, complexity and hierarchy seen in the Southwest were predominantly endogenously caused, though exogenous impacts from climate change obviously were important. The notion that Toltec *pochtecas* from Mesoamerica were major players in the emergence of large polities in the southwest has been largely dismissed and no direct evidence in support of this idea has been found. The idea that the export of turquoise to the South had an important impact on developments in the Southwest is plausible, but the mechanisms by which this may have worked have not been investigated. Did the mining and trading of turquoise play an important role in the development of the Chacoan polity? The turquoise trade constitutes a prestige good connection with Mesoamerica, but how important was it in terms of volume and what role did it play in Southwestern social change? These questions have not been answered by those who point to the turquoise connection as evidence that the Southwest was a periphery of Mesoamerica.

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sian culture can be seen throughout the regions of the Pacific that became inhabited by Polynesians.

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Abstract

This paper uses a nested interaction networks approach to interpret patterns of social evolution in the late prehistoric U.S. Southwest in comparative and world historical perspective.

9

Conceptions of a Global Brain: An Historical Review

Francis Heylighen

Introduction

There is little doubt that the most important technological, economic and social development of the past two decades is the emergence of a global computer-based communication network. This network has been growing at an explosive rate, affecting – directly or indirectly – ever more aspects of the daily lives of the people on this planet. A general trend is that the information network becomes ever more global, more encompassing, more tightly linked to the individuals and groups that use it, and more intelligent in the way it supports them. The web does not just passively provide information, it now also actively alerts people to information that is likely to interest them, gives them personal recommendations, and incites them to collaborate with like-minded others. To support this, the web increasingly builds on the knowledge and intelligence of all its users collectively, thanks to 'Web 2.0' technologies such as wikis (Heylighen 2007a), social networks, tagging, collaborative filtering, and online markets. It appears as if the net is turning into a nervous system for humanity.

The *Global Brain* is a metaphor for this emerging, collectively intelligent network that is formed by the people of this planet together with the computers, knowledge bases, and communication links that connect them (Mayer-Kress and Barczys 1995). This network is an immensely complex, self-organizing system (Heylighen 2007b). It not only processes information, but can also be seen to play the role of a brain: making decisions, solving problems, learning new connections, and discovering new ideas. No individual, organization or machine is in control of this system: its knowledge and intelligence are distributed over all its components. They emerge from the collective interactions between all the human and machine subsystems. Such a system may be able to tackle current and emerging global problems that have eluded more traditional approaches (*Idem* 2004). Yet, at the same time it will create new technological and social challenges that are still difficult to imagine.

Although these developments seem very modern, the underlying visions of knowledge and society have deep roots, going back to Antiquity, and developed in particular during the 19th and 20th centuries. The present paper wishes to review the main conceptual developments in an approximately historical order.

The global brain is a complex and multifaceted idea, which has been proposed independently under many different names and guises. I will try to classify the major contributions according to their guiding metaphor or source of inspiration. This results in three major categories, that I will label as *organicist*, *encyclopedist* and *emergentist*, depending on whether they see the global brain as a social organism, a universal knowledge system, or an emergent level of consciousness. I will conclude by sketching an approach that attempts to integrate the preceding conceptualizations, using evolutionary and cybernetic theories to go beyond metaphors and build a scientific model that can be operationalized and applied to practical problems.

Organicism: Society as a Living System

The idea of society as being similar in many respects to an organism or living system is an old notion. In this metaphor, organizations or institutions play the role of organs, each performing its particular function in keeping the system alive. For example, industrial plants extract energy and building blocks from raw materials, just like the digestive system, while roads, railways and waterways transport these products from one part of the system to another one, just like the arteries and veins. This metaphor can be traced back at least as far as Aristotle (Stock 1993). In the 19th century, it was a major inspiration for the founding fathers of sociology, such as Comte, Durkheim and particularly Spencer.

The British philosopher Herbert Spencer based his *Principles of Sociology* 1876–1896 (Spencer 1969) on the postulate that ‘society is an organism’, pointing out the many analogies between structures and functions, while emphasizing the internal processes of integration and differentiation (division of labor):

> A social organism is like an individual organism in these essential traits: that it grows; that while growing it becomes more complex; that while becoming more complex, its parts acquire increasing mutual dependence; that its life is immense in length compared with the lives of its component units; that in both cases there is increasing integration accompanied by increasing heterogeneity.

However, according to Spencer this analogy does not extend to the mental functions:

> ...the discreteness of a social organism ... does prevent that differentiation by which one part becomes an organ of feeling and thought, while other parts become insensitive. High animals [on the other hand] ... are distinguished ... by complex and well integrated nervous systems. ...Hence, then, a cardinal difference in the two kinds of organisms. In the one, consciousness is concentrated in a small part of the aggregate. In the other, it is diffused throughout the aggregate.

He went on to note that the consciousness or nervous system of society is reflected in its democratic institutions and government, but, lacking the concept of a global information network, fell short of uncovering any brain-like structure.

After its popularity around the beginning of the 20th century, organicism (and the ensuing structural-functionalism) has lost most of its appeal to sociologists. The idea that society forms an integrated, self-maintaining whole, where every individual or group performs its function, has often been used to justify a status quo, and thus counter any protest against the ruling classes. For example, the Roman consul Menenius Agrippa appeased the Plebeians by arguing that the hands should not rebel against the other organs because otherwise the entire body would be destroyed (Bukharin 1925). Since Marx, sociologists and political scientists have been more interested in how society can be changed, and how the oppressed can be liberated. This entails a focus on the unavoidable conflicts and competition within society, in contrast to the organicist approach, which emphasizes synergy and cooperation. The organicist view is not just rejected on the left by Marxists, but on the right by advocates of ‘laissez-faire’ economics, who abhor the idea of individuals as merely little cells subordinated to a collective, which they see as a justification for totalitarian systems such as those created by Mao, Hitler or Stalin (although a more up-to-date view comes to the opposite conclusion, namely that a more ‘organic’ society would increase individual freedom and diversity [Heylighen 2007c]).

Outside of sociology, the organicist view has regained popularity with a deeper understanding of living systems and the growing awareness of the world as an interdependent whole. Space travel has made an important contribution to this shift of perspective: while we can see society only from the inside, and therefore tend to focus on the differences and oppositions between its parts, satellites and astronauts brought back pictures of the Earth viewed from the outside, thus focusing our attention on the coherence of the whole. The futurologist and systems theorist Joël de Rosnay has turned this perspective into a conceptual tool which he called ‘the macroscope’ as it allows us to see the larger wholes – as a complement to the microscope that focuses on the smaller parts. He used this tool to examine the flows of matter, energy, and information that govern the global organism (de Rosnay 1979).

The biologist Gregory Stock (1993) wrote a popular account of the process where individuals are increasingly tied to others through technology, forming a global superorganism, which he calls *Metaman*. Like Spencer, he emphasizes the analogy between on-going social, economic and technical progress and biological development, comparing for example the growth of railway or communication networks with the growth of networks of arteries or nerves. A more systematic investigation of the correspondences between organisms and social systems can be found in the *Living Systems Theory* of James Grier Miller (1978), which analyses the abstract functions, such as processing resources and information, protecting itself, learning, making decisions, that any ‘living system’, be it biological or social, must perform.

A different level of application of the organicist perspective is the *Gaia* hypothesis, according to which the planet Earth itself is a living organism (Lovelock 1995). This organism would be able to regulate its own essential variables, such as temperature and composition of the atmosphere. While popularized by James Lovelock in the 1970s, the underlying intuition is much older as well, as illustrated by the following quotation from the romantic author Edgar Allan Poe, where he observes that an intelligent global superorganism might not be aware of us, just as we are not aware of it:

> I love to regard [the rocks, waters, forests... of the Earth] as the colossal members of one vast animate and sentient whole – a whole ... whose life is eternity; whose thought is that of a God; whose enjoyment is knowledge; whose destinies are lost in immensity; whose cognizance of ourselves is akin with our own cognizance of the *animalculae* which infest the brain – a being which we, in consequence, regard as purely inanimate and material, much in the same manner as these animalculae must regard us [Island of the Fay, 1850].

Compared to the global brain as we have defined it, this ‘Gaian’ organism seems rather primitive. Moreover, as several authors have noted, humanity seems to act more like a parasite (Poe's ‘animalculae’ are what we now would call bacteria) or ‘tumor’ of the encompassing Gaian organism, because of its unsustainable growth and exploitation of the Earth's resources (Hern Warren 1993; Russell 1982). The more optimistic outlook is that this parasite would evolve into a symbiote (cf. de Rosnay 2000) and from there into an organ that helps the superorganism to make informed decisions and solve complex problems. For example, Robert Muller, a former assistant Secretary-General of the United Nations and Chancellor of the UN University, proposed that we are all cells or perceptive nervous units of the Earth, and that the UN and its network of associated multinational organizations form part of its brain (Muller 1991). But to create an intelligent system on the global level, you first need to make sure that it has access to all relevant knowledge.

Encyclopedism: A Universal Knowledge Network

The ideal of a publicly available record of all of humanity's knowledge is probably not much younger than the organicist metaphor, although it really comes to the fore only in the 18th century with the Enlightenment. An early summary can be found in the Oration (c. 1737) of the Chevalier de Ramsay, who describes one of the objectives of freemasonry as:

> ...to furnish the materials for a Universal Dictionary ... By this means the lights of all nations will be united in one single work, which will be a universal library of all that is beautiful, great, luminous, solid, and use-

> ful in all the sciences and in all noble arts. This work will augment in each century, according to the increase of knowledge (Lamoine 2002).

The most influential implementers of this idea are the French Encyclopedists, led by Diderot and d'Alembert, whose *Encyclopedia* (1751–1772), published between 1751 and 1772, spread the ideas of rational inquiry, science, and technology, thus laying the foundations for the industrial and French revolutions.

Yet by the end of the 19th century, knowledge had grown so much that it no longer seemed possible to publish it in a single volume or collection. The Belgian Paul Otlet, the founding father of documentation (or what is now called 'information science'), therefore set out to tackle the practical problem of collecting and organizing the world's knowledge. He designed a structured system of documents containing texts or images connected by links (Boyd Rayward 1994), and founded the still active *Union of International Organizations* (Judge 2001) to help collect this knowledge. By 1935, Otlet had developed a conception of a global brain that seems eerily prescient of the World Wide Web:

> Man would no longer need documentation if he were assimilated into a being that has become omniscient, in the manner of God himself. To a less ultimate degree, a machinery would be created [that would register from a distance] everything in the universe, and everything of man, as it was being produced. This would establish the moving image of the world, its memory, its true duplicate. From a distance, anyone would be able to read a passage, magnified and restricted to the desired subject, which would be projected on an individual screen. Thus, anyone from his armchair would be able to contemplate creation, as a whole or in some of its parts (Otlet 1935: 390–391, my translation).

At about the same time, the British author H. G. Wells, who is best known for his science fiction novels, envisaged a *world brain* (Boyd Rayward 1999; Wells 1938), which he defined as 'the idea of a permanent world encyclopaedia':

> As the core of such an institution would be a world synthesis of bibliography and documentation with the indexed archives of the world. A great number of workers would be engaged perpetually in perfecting this index of human knowledge and keeping it up to date. ... There is no practical obstacle whatever now to the creation ... of a complete planetary memory ... accessible to every individual. ... [It] will supply the humanity of the days before us, with a common understanding and the conception of a common purpose and of a commonweal such as now we hardly dare dream of. And its creation is a way to world peace ... dissolving human conflict into unity (Wells 1938).

Neither Otlet nor Wells had as yet a clear idea of the kind of technology needed to create such a knowledge system, although they speculated about future uses of filing systems, microfilm and telephone to store, retrieve and transmit information world-wide. The American Vannevar Bush (1945) is generally credited with inventing the idea of *hypermedia* – that is chunks of information connected by associative links that can be called up automatically. Bush's vision adds little to the one of Otlet though (Boyd Rayward 1994), and his conceived ‘memex’ merely augments individual memory rather than integrating the knowledge of humankind. In the 1960's, Douglas Englebart, the computer pioneer who invented such ubiquitous interface elements like the mouse and windows, was also the first to implement a true hypertext. For him too, the primary motivation was to augment human intellect (Englebart 1963) in the face of the growing complexity of knowledge, although he focused beyond the individual to the organization, and what he later called ‘collective IQ’.

In the 1970s, Theodore Nelson, who coined the words ‘hypertext’ and ‘hypermedia’, was probably the first to envisage a computer system for publishing and linking documents on the global level (Nelson 1983). His *Xanadu* system, however, never got further than a grand, inspiring vision, illustrated by a few rudimentary prototypes. The more pragmatic approach of the British scientist Tim Berners-Lee provided the foundation for the *World-Wide Web* in 1991 (Berners-Lee 2000). His primary innovation was to combine a simplified format for hypertext documents (HTML) with a universal scheme for locating documents on the Internet (URL). Thus, documents on different computers could be linked directly – depending on their subject matter rather than on their geographical location. The resulting web is truly *distributed* over the world, and therefore much more robust, open, and democratic than the centralized systems envisaged before (Boyd Rayward 1999).

The ease and freedom with which web documents can be created and linked, however, led to an anarchic proliferation of websites, many of which are poorly structured and with low quality information. This makes it difficult to find the specific information one is looking for. Therefore, Berners-Lee and others have started developing the next stage of the *semantic web* (Berners-Lee 2000), in which knowledge would be organized according to formal categorization schemes or ‘ontologies’, thus in a way going back to Otlet's bibliographic indexing methods. This would allow asking the web concrete questions, such as ‘which birds cannot fly?’, ‘on what date did Richard Nixon marry?’, or ‘which plumbers specialized in bathrooms work within a 10 mile radius of my home?’, and getting precise answers without having to wade through dozens of potentially relevant web pages. In practice, however, the semantic web seems to be much more complex to implement than initially foreseen, mostly because it is very difficult to subdivide the infinitely flexible world of phenomena into a system of strict, formal categories about which all users can agree (Hepp 2007), and which can be understood by computer programs that lack human experience.

Much faster progress has been made by adapting the more traditional encyclopedia paradigm to the Internet. The Wikipedia project, started in 2001 by

Jimmy Wales and Larry Sanger, has efficiently harnessed web technologies to develop the largest encyclopedia ever, by soliciting the contributions from millions of users worldwide (Voss 2005). By 2010, over 3 million articles covering virtually every subject were freely available in the English version of this web encyclopedia, while (smaller) versions existed in over 200 other languages and dialects. Moreover, the typical Wikipedia article offers much more information, in the form of details, cross-references, quotations, bibliographic references, photos, *etc*. than an article in a traditional encyclopedia. Finally, this information is continuously being expanded, improved and updated. In that sense, Wikipedia is approaching the ideal of a ‘world memory’ envisaged by Otlet and Wells, but this is still far from an active, autonomous ‘global brain’.

Emergentism: A Higher Level of Consciousness

Although most authors have addressed the global brain from a scientific or technological perspective, some have focused on its spiritual aspects. Similar to many mystical traditions, the global brain idea points towards the achievement of a state of higher consciousness (the Buddhist's *Nirvana*), in which the individual loses its separate, subjective being and merges with humanity and perhaps even the world as a whole. Religious people might view this state of holistic consciousness as a union with God, the Tao, or what Emerson called the ‘Oversoul’. Humanists might see it as the creation, by humanity itself, of an entity with God-like powers of cognition (cf. the preceding Otlet quote).

The best-known author to develop this argument is the French paleontologist and Jesuit priest Pierre Teilhard de Chardin, who combined his knowledge of evolution and theology into a mystical and poetic vision of future evolutionary integration (Teilhard de Chardin 1955). According to Teilhard's *law of complexity-consciousness*, evolution is accompanied by increases in both complexity and consciousness, characterized by a growing number of connections between components. Thus, the human brain with its billions of neurons and synapses is the most complex and most conscious biological system. But evolution in the biosphere is followed by the emergence of the *noosphere*, the global network of thoughts, information and communication, and it is here that spiritual union will be achieved:

> No one can deny that ... a world network of economic and psychic affiliations is being woven at ever increasing speed which envelops and constantly penetrates more deeply within each of us. With every day that passes it becomes a little more impossible for us to act or think otherwise than collectively (Teilhard de Chardin 1969).
>
> We are faced with a harmonized collectivity of consciousness, the equivalent of a sort of super-consciousness. The idea is that of

> the earth becoming enclosed in a single thinking envelope, so as to form, functionally, no more than a single vast grain of thought on the cosmic scale... (Teilhard de Chardin 1955)

Not surprisingly, Teilhard's unorthodox views were suppressed by the Vatican. His major works were only published after his death in 1955 by the Belgian theologian Max Wildiers, who further developed some of Teilhard's ideas on the evolution of mind, focusing on the role of technology in the noosphere.

Inspired by Timothy Leary, the guru of the psychedelic age, and Herbert Kahn, the technology forecaster, the American futurist Jerome Glenn explored the connection between technological development and expansion of consciousness (Glenn 1989). He proposed that as we develop ever more sophisticated methods for sensing and processing information, the technology to support these processes and the enhanced human consciousness will gradually merge, forming a continuum, which he called *Conscious-Technology*. This will produce a much higher level of intelligence and awareness, or what mystics call ‘enlightenment’.

Peter Russell (1982), a British physicist interested in Eastern religions, proposed a simpler and more up-to-date conception of Teilhard's emergentist philosophy, and coined the expression ‘global brain’ to describe it. After using Miller's living systems theory (Miller 1978) to point out the similarities between global society and an organism, Russell focused on the mental development of this superorganism, emphasizing consciousness-raising techniques like meditation that might help people worldwide to achieve a deeper synergy. Russell's ‘New Age’ vision was brought into the Internet age by the German complexity theorist Gottfried Mayer-Kress (Mayer-Kress and Barczys 1995). Mayer-Kress noted that complex systems tend to undergo a phase transition to an emergent level of organization once their number of components reaches a certain large number (10 billion neurons in the brain, almost 10 billion people on earth), and once the communications between those components reach a certain degree of speed and intensity, as supported by the Internet and teleconferencing.

Although intuitively attractive, this emergentist perspective leaves a fundamental issue unanswered: precisely how and why will a new level of organization emerge? The numerical argument advanced by Russell and Mayer-Kress, while seemingly science-based, is in fact not more than a coarse analogy. For example, at present the consensus seems to be that the human brain contains 100 rather than 10 billion neurons, invalidating any argumentation that the world's population will soon reach a ‘brain-like’ level. To understand global integration, we need a more in-depth, qualitative understanding of the evolution of emergent levels.

Evolutionary Cybernetics: Towards an Integrated Theory

While most conceptions of the global brain are based on some kind of progressive evolution towards higher levels of complexity, intelligence and integration, this assumption receives surprisingly little support from the theory of evolution itself. The traditional (neo-)Darwinist theory emphasizes the gradual, erratic, and non-directed character of variation and natural selection, and the struggle for existence between selfish organisms or genes. It is only in the last two decades that biologists have started to focus on the ‘major transitions’ in evolution, such as the emergence of multicellular organisms out of single cells, or societies out of individuals – studying the specific circumstances in which components can turn from selfish, competing individuals to cooperating members of a collective (Maynard Smith and Szathmáry 1995).

The general consensus seems to be that, while such transitions have happened, they are rare and difficult to achieve, because they require sophisticated control mechanisms to protect the cooperative from being exploited by ‘free riders’, *i.e.* components that profit from the efforts of others without investing anything in return (Heylighen and Campbell 1995). Humans in particular are intrinsically ambivalent, vacillating between altruism and solidarity on the one hand, and selfishness and competition on the other. The conclusion is that humanity cannot as yet be viewed as a superorganism, and that there remain fundamental obstacles on the road to an eventual global integration. Evolutionary biology thus tends to side with the conflict model of present-day sociology, questioning the organicist and emergentist perspectives. Yet, it ignores the role of shared knowledge and communication technologies emphasized by the encyclopedist perspective, which – at least in Wells's utopian view – would seem to allow overcoming conflicts.

Cybernetics is the discipline that studies levels of organization in complex systems, with the emphasis on communication, control and knowledge (Heylighen and Joslyn 2001). Traditionally, though, it was limited to modelling existing forms of organization, whether biological, social or technical, neglecting the issue of how this organization had arisen. The new approach of *evolutionary cybernetics* (Heylighen 2007c) integrates the Darwinian logic of variation and selection with the cybernetic analysis of emergent levels. It is thus eminently suited to model the evolution of a global brain-like system.

This approach was originated by the Russian-American computer scientist Valentin Turchin, in his book entitled *The Phenomenon of Science* (Turchin 1977), as a tribute to Teilhard's (1955) ‘The Phenomenon of Man’. Turchin's most important contribution is the concept of *metasystem transition:* the evolution of a higher level of control and cognition. In analogy with the emergence of multicellular organisms, Turchin predicted that humans would be integrated into a global *superbeing*, communicating through the direct connection of their nervous systems. The aforementioned systems scientist de Rosnay independently arrived at a similar conception of an evolutionary process that recursively generates higher levels of complexity, producing a *planetary brain* for the *cybiont,* or global cybernetic organism (de Rosnay 2000). Joined by the systems scientist Cliff Joslyn in 1989 and by myself in 1990, Turchin founded the Principia Cybernetica Project (Heylighen 2000), an international organization that uses the Internet to collaboratively develop an evolutionary-cybernetic knowledge network. This added the encyclopedist perspective to Turchin's synthesis of emergentist and organicist approaches.

In 1996, I came in contact with the American mathematician Ben Goertzel, who had been developing algorithms for an intelligent computer system at the global level (Goertzel 2001). Together, we founded the *Global Brain Group* to discuss these issues, being joined by most of the active researchers in the domain, including Turchin, de Rosnay, Stock, Russell, and Mayer-Kress. The present paper was in part inspired by the first workshop organized by this group in 2001. The group is still active via its mailing list for discussion, GBRAIN-L.[1]

None of these researchers had tackled the problem of free riders though. In collaboration with the evolutionary social scientist Donald T. Campbell (Heylighen and Campbell 1995), I had proposed a preliminary solution, arguing that shared knowledge or culture can function like a control mechanism to thwart free riders, and that its spread will be facilitated by global communication technology. This argument builds on the mechanism that Boyd and Richerson (2001) call 'conformist pressure': in groups of closely communicating or mutually imitating individuals, the majority tends to impose its views (beliefs, ideas, morals) on the minority. A free rider typically constitutes a minority of one, and will therefore undergo a very strong pressure to conform to the rules of behavior adopted by the majority. The result is that the group as a whole will follow the same rules. Group selection will then make sure that the groups whose rules best promote cooperation will outcompete others groups. Thus, cooperative cultures will thrive at the expense of less cooperative ones, leading to the evolution of increasingly cooperative groups. And as communication extends ever more widely across the globe, cooperation will expand to larger and larger groups too.

A more general version of this mechanism was proposed by the Australian evolutionist John Stewart (2000). He argued that any system, whether an individual, institution or shared culture, that manages to establish control over a group – even if for initially selfish purposes – will eventually evolve into an efficient 'manager' that suppresses selfish abuses, because it is in its own interest to have the group function cooperatively. For example, a warlord may take control of a community initially just to exploit it, but then discover that in

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[1] See: http://pcp.vub.ac.be/GBRAIN-L.html

order not to be pushed aside by rival warlords he should make sure that his community thrives, by creating institutions that protect it from attack, internal conflict, and exploitation by free riders. As a result of such mechanisms, selfish abuse will be held in check not only by the pressure to conform, but by an increasingly sophisticated system of controlling agents and structures, including the police, the government, the legal system, the market, *etc*. A similar conclusion was reached by the American author Robert Wright (2000), who examined the historical role of different technologies and institutions, such as writing, money and law, in turning the 'zero-sum' competition between individuals into 'positive-sum' cooperation. As a result of these processes, evolution produces ever wider and deeper synergy, up to the global level.

None of these evolutionary mechanisms as yet provides a concrete model for the role of the Internet. It is here that the cybernetic perspective is most useful. Turchin's sequence of metasystem transitions (Turchin 1977) not only describes the social integration of individuals, but the stepwise complexification of the nervous system. In 1996 I argued that the Internet is undergoing similar transitions to a higher level of intelligence (Heylighen and Bollen 1996). At the same time, in collaboration with my PhD student Johan Bollen I designed concrete algorithms that would allow the web to become a learning and 'thinking' system. The core idea is that frequently used sequences of hyperlinks are reinforced and eventually collapsed into a single link, similar to the 'Hebbian' strengthening of synapses in the brain. The result is that the web learns from its users what they – collectively and individually – need, anticipating their questions, and thus minimizing their effort in finding answers (*Idem* 2002). As such, the web would turn into an intelligent, adaptive, self-organizing system of shared knowledge, structured in a much more flexible and intuitive way than the formal classification schemes conceived by Berners-Lee and others.

Unlike material resources, knowledge and information do not diminish by being shared with others (economists call this property 'non-rivalry') (Heylighen 2007a). Since the learning web would make this sharing effortless and free, this enables a positive-sum interaction in which everyone gains by making their individual knowledge and experience available to others. This provides a continuing incentive for further cognitive integration. The web plays here the role of a shared memory that collects, organizes and makes available the collective wisdom (Heylighen 1999). It achieves this without demanding anything from its users or contributors beyond what they would have had to invest if they were working on their own – thus removing any incentive for free-riding. On the contrary, contributing to the web (*e.g.*, by writing a blog entry, publishing your photos, or uploading a program) is likely to benefit you personally, as it helps you to get an enhanced reputation, feedback, suggestions, additions, and improvements to your work made by others (*Idem* 2007a). More generally, by participating in the web you may profit from the *wisdom of* *crowds* (Surowiecki 2005) or *collective intelligence* (Lévy 1997) exhibited by all the people on the Internet.

Collective intelligence is efficiently supported by the self-organizing mechanism of *stigmergy* (Heylighen 2007a, 2007b): individual actions leave marks or 'traces' in a shared medium (here the web); these signals stimulate further actions by the same or different individuals, so that the activity can build further on its own results. In this way, a variety of independent actions is coordinated into a coherent stream of activity. Moreover, the process is amplified by positive feedback: the more results are stored in the medium, the more material there is to stimulate further improvement. The most impressive example of such a stigmergically-coordinated activity is Wikipedia, the web encyclopedia that is collectively being written by millions of independent contributors (Voss 2005). The website here functions as the medium that registers all the traces of individual activity into an immense collective memory, while constantly stimulating its users to further improve, correct or complete the record. The same stigmergic dynamics can be found in a variety of other successful 'Web 2.0' systems for the public sharing of information, including the development of open-source software, communities, blogs, wikis and folksonomies. The development of such 'creative commons' appears like a promising public alternative to the traditional, commercial approach based on intellectual property (Heylighen 2007a).

Conclusion

It is intuitively attractive to see humanity together with its shared knowledge stores and communication channels as an intelligent, organism-like system. Many thinkers have therefore developed a conception of such a 'global brain'. This way of thinking has further gained in popularity with globalization and the explosive growth of the Internet. Yet, if we wish to use this perspective to understand the future development of society and technology, we need to go beyond metaphor, and propose concrete mechanisms and models (Heylighen and Bollen 1996). This paper has reviewed the main conceptual strands available to build such an integrated theory.

Historically, I distinguished three approaches: *organicist*, *encyclopedist* and *emergentist*. While each of these conceptions provides an inspiring metaphor for understanding and guiding social development, each also has major shortcomings. The organicist perspective, by ignoring conflicts and competition and by studying the way things are rather than how they might be or ought to be, tends to promote a status quo. The encyclopedist view, while inherently progressive, relies too much on rational planning and organization, and tends to ignore not only the potential for conflict, but the intrinsic difficulty of unifying and centralizing something as context-dependent, complex and changeful as the world's knowledge. The emergentist perspective, while emphasizing the potential for self-organization and radical evolutionary innovation, seems to suffer from wishful thinking, assuming that we just need to more communicate, become conscious, or use technology to see a global brain miraculously emerge.

I have argued that these shortcomings can be overcome by integrating two existing theoretical frameworks: evolutionary theory and cybernetics. Biological evolution points us to the intrinsic sources of conflict, and how these have been overcome by evolving synergetic systems and control mechanisms against free riders. Cybernetics shows us how systems and control are organized in levels, and based on knowledge and communication. Evolutionary cybernetics introduces the concept of metasystem transition: the self-organization of individual components into a positive-sum system that functions at a higher level of intelligence and consciousness. More specific models associated with cybernetics, such as neural networks, distributed knowledge systems and stigmergy, help us to design concrete technologies that could support such a collective intelligence. The World Wide Web, finally, provides an extremely flexible and powerful platform for implementing and testing such technologies at the global level.

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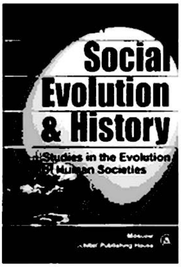
Abstract

The 'global brain' is a metaphor for the intelligent network formed by the people of this planet together with the knowledge and communication technologies that connect them together. The different approaches leading up to this conception, by authors such as Spencer, Otlet, Wells, Teilhard, Russell, and Turchin, are reviewed in their historical order. The contributions are classified in three major approaches: organicism, which sees society or the planet as a living system; encyclopedism, which aims to develop a universal knowledge network; and emergentism, which anticipates the evolution of a suprahuman level of consciousness. The shortcomings of each perspective lead us to propose an integrated approach, based on evolutionary cybernetics. Its selectionist logic allows us to analyse the process whereby initially selfish individuals self-organize into a synergetic system functioning at a higher level of intelligence, making use of an advanced version of the World Wide Web.

Notes

Social Evolution & History: Studies in the Evolution of Human Societies



Social Evolution & History (SEH) is a semiannual international journal that serves the needs of all scholars seeking an understanding of how human societies developed in the past and continue to develop in the present. The Journal has been published since 2002. *Social Evolution & History* acts as a forum for debate about key issues and concepts in the field, challenging and re-examining the boundaries of the search. As well as original research articles, the journal includes critical notes and a book review section. It publishes researches on the basis of its originality, importance, interdisciplinary interest.

The Journal's aim is to contribute to the integration of such fields of knowledge as anthropology, history, sociology, and also philosophy and theory of history. Such integration has been lacking until now, though its necessity has long been felt acutely by the academic community. In the current situation of continuously increasing knowledge and professional endeavor, any attempt to introduce new methods of integrating facts with social theory, and to establish interdisciplinary links, would appear to be especially valuable.

The Journal *SEH* seems to be almost the only one dedicated to the issues of social evolution. Already in the very first issue we pointed out that while dozens of journals dealing with organic evolution have the words 'Biological Evolution' in their titles, hardly a journal exists in the whole world which includes 'Social Evolution' in its title. This alone seems to be a compelling reason to establish a new journal specifically devoted to social evolution in title and contents.

The significance of studies in cultural and social evolution is rather evident. Currently one can observe an increasing interest to the problems of evolution in general and cultural evolution in particular. Moreover, the problems of inter-evolutionary and cross-evolutionary research also have great importance. Over the whole period of existence of our journal, we constantly appeal to the issues of evolution.

The study of evolution is considered to be one of the priority and productive directions of interdisciplinary research where representatives of natural and exact sciences as well as of the humanities can find contact points. Thus, the special issue of the Journal under the general title *Analyses of Cultural*

Evolution (2009, vol. 8, No 2, Guest Editor Herbert Barry III) publishes contributions revealing a wide range of topics under investigation: from universal problems of evolution up to the analysis of individual evolutionary laws in the development of society and culture.

The Journal *Social Evolution & History* from the very beginning has set a goal to meet the needs of those seeking to understand how human societies developed in the past and continue to develop in the present.

All information can be found at *SEH'* homepage http://www.socionauki.ru/journal/seh_en

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tems, 2002), 'Cybernetics and second order cybernetics' (*Encyclopedia of Physical Science & Technology,* 2001), 'Collective Intelligence and its Implementation on the Web' (*Computational & Mathematical Organization Theory,* 1999), and 'The World-Wide Web as a Super-Brain' (*Cybernetics and Systems' 96,* 1996). Homepage: http://pespmc1.vub.ac.be/HEYL.html

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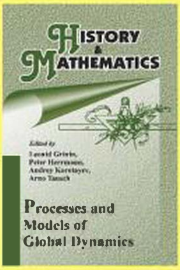

HISTORY & MATHEMATICS: Processes and Models of Global Dynamics

Edited by Leonid Grinin, Peter Herrmann, Andrey Korotayev, and Arno Tausch. – Volgograd: 'Uchitel' Publishing House, 2010.

This issue is the third collective monograph in the series of History & Mathematics almanacs and it is subtitled Processes and Models of Global Dynamics. The contributions to the almanac present a qualitative and quantitative analysis of global historical, political, economic and demographic processes, as well as their mathematical models. This issue of the almanac consists of two main sections: (I) Analyses of the World Systems and Global Processes, and (II) Models of Economic and Demographic Processes.

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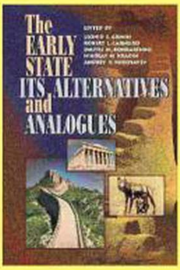

THE EARLY STATE, ITS ALTERNATIVES AND ANALOGUES

Edited by Leonid E. Grinin, Robert L. Carneiro, Dmitri M. Bondarenko, Nikolay N. Kradin, and Andrey V. Korotayev. – 'Uchitel' Publishing House, 2004.

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