Ecological Modelling 221 (2010) 1702–1709

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

On the reasons of hyperbolic growth in the biological and human world systems

B.M. Dolgonosov*

Institute of Water Problems, Russian Academy of Sciences, Gubkina 3, Moscow 119991, Russia

ARTICLE INFO

Article history:
Received 29 November 2009
Received in revised form 30 March 2010
Accepted 31 March 2010
Available online 29 April 2010

Keywords:
Macroevolution
Human population
Biodiversity
Genetic
Neural and external memory types
Knowledge accumulation
Hyperbolic growth

ABSTRACT

Macroevolution of the biological and human world systems in the aspect of time-dependence of their sizes is studied. These systems are considered as 'civilizations', which are defined here in a generalized sense as the systems having memory and producing knowledge (vital information) necessary for survival. Sizes of three types of memory – genetic, neural, and external – are estimated. Dominating one of them leads to the development of an appropriate type of civilization. The rise and development of the genetic memory was accompanied with the formation of the biota (which can be tractable as a biological civilization) and a hyperbolic growth of its biodiversity. The prevailing development of the neural memory in one of the taxa of biota led to the rise of the human civilization and to a hyperbolic growth of its population. The development of the external memory will probably lead to the extraction of a taxon (probably, a pool of countries) from the human world community, with a hyperbolic growth of the taxon's memory and fund of knowledge but without a pronounced growth of its population.

1. Introduction

Demographic data show that, at least several tens of thousands of years, almost up to the end of XX century, human population growth followed a hyperbolic law (von Foerster et al., 1960; von Hoerner, 1975). Moreover, it appears that a similar hyperbolic law is also inherent in the diversity of different taxa in the biological world system, indicated by the growth of the number of families and genera in the marine and continental biota (separately and as a whole) during the Phanerozoic (Markov and Korotayev, 2007, 2008, 2009; Grinin et al., 2009). The similarity of growth laws suggests that in both cases there is a universal mechanism bringing such different systems to the same regime of growth. In the cited works on biodiversity, the hyperbolic growth law is associated with an increase in life span of taxa (families or genera; data on species are not reliable). However, life span itself depends on the fit of taxa to ambient conditions and therefore is determined by the content of valuable information accumulated in genomes. Finally, it turns out that there are informational reasons for inducing the biodiversity growth. Similar reasons are responsible for the hyperbolic growth of human population; this growth is a result of the accumulation of valuable information in the genetic memory and, in a much more rapidly way, in the neural one (Dolgonosov and Naidenov, 2006; Dolgonosov, 2009). Thus, it can be hypothesized that similar informational mechanisms regulate sizes of both world systems – the number of humans and the number of taxa in the biota.

In the literature there is another interpretation of the hyperbolic growth of human population (Kremer, 1993; Cohen, 1995; Kapitza, 1996; Johansen and Sornette, 2001; Podlazov, 2004; Tsirel, 2004). Kapitza (1996) looks the reason of the hyperbolic growth in the pair interactions with information exchange between people. Kremer (1993), in one of his models, proceeds from the assumption that the rate of technological progress is proportional to population size and to the current technological level meaning this level as the amount of available resources. Supposing that population size follows the technological level (proportionally to it), Kremer comes to the hyperbolic law. A similar model is developed by Podlazov (2004), though his model considers vital technologies instead of the amount of resources. A generalization of these models is given in the series of works (Korotayev, 2005, 2006, 2007; Korotayev and Khaltourina, 2006; Korotayev et al., 2006a, 2006b).

From the informational viewpoint, civilization represents a system having memory and producing knowledge necessary for survival. In spite of that this definition seems counterintuitive and controversial to common definitions of civilization, this is not so. One of the main philosophers on the concept of civilization – Albert Schweitzer – outlined the idea that there are dual opinions within society; one regarding civilization as purely material and another, as both ethical and material (Tariq, 2009). Schweitzer (1923) defined civilization, saying: "It is the sum total of all progress made by man in every sphere of action and from every point of view in so far as the progress helps towards the spiritual perfecting of individuals as the progress of all progress". Meanwhile, both mate-

* Tel.: +7 499 7833861; fax: +7 499 1355415.
E-mail address: borismd@aqua.laser.ru.

0304-3800/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2010.03.028

rial and ethical can be consolidated in the concept of knowledge, and such a consolidation is quite natural because knowledge can be both about material objects and processes and about ethical norms assisting the spiritual perfecting of individuals. Therefore, the definition of civilization as a system producing knowledge includes common notions and even broadens them embracing not only the humanity but also the biota. Thus, this understanding of civilization is suited for systems of any origin, because the presence of memory equipped with a processor for extracting valuable information from incoming signals is a feature of not only humans but every biological species. In this connection, the question rises how memory type influences the type of civilization.

Along with the genetic and neural memory, there is an external memory. The first two types of memory are an internal property of the biological units constituting civilization. The external memory is inherent in the human civilization, where this memory type is realized in the form of different external carriers of information: physical samples, books, films, computer carriers, etc. The genetic memory dominates in the biota providing accumulation of valuable information and its inheritance. Thus, the biota demonstrates the above-mentioned attributes of civilization that allows it to be named the biological one. The human civilization, grown from it, had used advantages of the neural memory (primarily, speed of processing information), whose size on a definite stage of the phylogenesis achieved the size of genetic memory and then surpassed it providing an accelerated development of this phyletic branch. The further evolution of the humanity had led to a gradual development of the external memory, which became dominant in our time due to the fast perfection of computer carriers.

Let us consider the macroevolution of civilization under the domination of a definite memory type and what happens when the dominant changes. A key role pertains here to the compression of the incoming information in its processing into knowledge.

2. Compression of information

Each type of memory is provided with a processor, which transforms an unconditional (primary) information R, perceived through signals from the outer world, into a conditional (useful, valuable, vital) information q that represents knowledge (Fig. 1). As measures of the quantities R and q, we can take the memory sizes needed for storing the corresponding information. The primary, unconditional information requires too large memory size to store it completely and, moreover, cannot be used directly, without a definite processing for the extraction of useful information. This processing results in a compression of information. Generally, the degree of compression depends on data structure and algorithms employed (Salomon, 2007). A higher compression can be made using the algorithms that allow loss of insignificant information. If the data have a fractal structure characterized by a selfsimilarity, or scaling (that is typical for the primary information, for example in the form of time series – see: Pavlov and Anishchenko, 2007), the compression algorithms can conserve the scaling providing a power law compression of the form $q \sim R^{\varepsilon}$, where $0 < \varepsilon < 1$. Compression of information in the course of biological evolution is many orders of magnitude due to the action of molecular mechanisms of memory formation along with the natural selection directed towards improvement of the genetic and neural processors. Such a high compression means that in the mentioned power law the exponent ε holds very small, close to zero. From the differential form $dq \sim dR/R^{1-\varepsilon}$ of the power law it follows that at $\varepsilon \to 0$ we have $dq \sim dR/R$ and after integration we come to the logarithmic law $q \sim \ln R$.

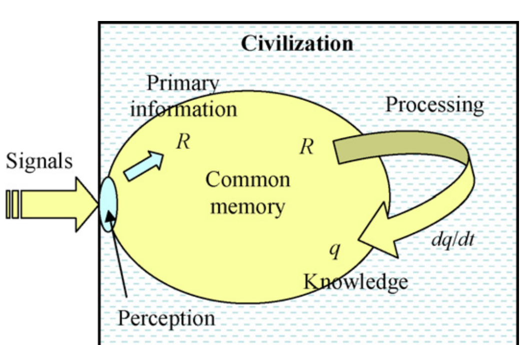

Fig. 1. Schematic of knowledge production.

A similar conclusion was made in a descriptive manner by Korogodin and Korogodina (2000). Following their views, the quantity q should be considered as the length of the system coding program, and R, as a measure of the system complexity. The measure of complexity is understood as the number of binary code digits (i.e. bits) required for describing the system (on a selected level of organization), and the coding information content is measured in the number of bits specifying the system construction program (on the same level of organization). The authors assert that the complexity increases much faster than the system coding information content. Moreover, if the system construction program is created following the dichotomy principle, the system coding information content will increase logarithmically with its complexity in accordance to the above-mentioned result.

In statistical physics, such a logarithmic compression occurs in the transition from a microscopic description considering each of the unimaginable number of microstates of the system to a macroscopic description using a finite, mostly not large, set of macro-variables. This corresponds to the concept of statistical ensemble of microstates at a given macrostate characterized by definite values of macro-variables such as temperature, pressure, volume, particles number, etc. In this transition, the compression of information is given by the entropy $S(X) = k \ln W(X)$, where X is a set of essential macro-variables, W is the statistical weight, or the number of microstates at a fixed X (Zubarev et al., 1996), k is the Boltzmann constant. In our terms, W represents the amount of primary information R, and S represents the amount of valuable one q, i.e. knowledge.

Thus, the logarithmic law of information compression is a result of the extraction of valuable information and can be written in the form $q = q_c \ln(R/R_0)$, where q_c is a constant depending, in general, on the memory type. Inverting this formula in $R = R_0 \exp(q/q_c)$, we can conclude that at $q \to 0$ the memory size R tends from above to R_0. Hence, R_0 can be considered as the minimum memory size necessary for starting the knowledge accumulation process. Actually, valuable information must be saved somewhere, and hence at least one memory element must be present.

Notice that, if there is a dominant memory type, the knowledge size q can be measured in the units of q_c and the primary information R, in the units of R_0, i.e. formally we can set $q_c = 1$ and $R_0 = 1$, and then the information compression law takes the form $q = \ln R$. This law can be interpreted as follows: at a knowledge level of q civilization is capable to recognize primary information from the outer world in the amount of $R = e^q$, i.e. figuratively speaking, the scope of civilization broadens exponentially with knowledge.

As stated above, common memory of civilization contains primary information and knowledge. The former is accumulated only partially as much as the available memory size allows. A sufficiently developed civilization has a good amount of knowledge, $q \gg 1$, and owing to $R = e^q \gg q$ must have a much greater reserve of the primary information destined to be processed into knowledge. In other words, a prevailing part of memory of any type will be filled with raw, partially processed information.