IV. LOOKING FROM THE PAST INTO THE FUTURE

11 Technological Dimension of Big History and the Cybernetic Revolution*

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Abstract

The present paper analyzes the evolution of technology from the beginning of the human history. A new paradigm to analyze the causes and trends of the global evolution is introduced. We also describe the direction of technological transformations, discuss and explain the present and forthcoming technological changes.

Our analysis of technological evolution mainly focuses on the second half of the 20th century. We present a detailed analysis of the latest technological revolution which we denote as 'Cybernetic', and give some forecasts about its development up to the end of the 21st century. It is shown that the development of various self-regulating systems will be the main trend of this revolution. We argue that the technological transition of the final phase of the Cybernetic Revolution will start in medicine, which is to be the keystone of technological convergence forming the system of MANBRIC-technologies (based on medicine, additive, nano-, bio-, robotic, IT and cognitive technologies). Today we are at the threshold of post-human revolution, the era of an intensive impact on the human body. The authors consider the directions of this revolution such as considerable life extension, organ replacement, BCIs, robotics, genome editing, etc. It is very important to understand the mechanisms of technological development and to measure the possible risks arising from them.

Keywords: *production revolutions, technological evolution, self-regulating systems, MANBRIC-technologies.*

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Introduction. Between Human and Post-Human Revolutions

For centuries, technological changes were among the most fundamental drivers of social development, providing demographic growth and cultural progress. There is much information about the latest technological achievements appearing every day. However, for most of the human history the matter was different. For centuries and even millennia transformations have been undistinguished (Anuchin 1923; Lurie *et al.* 1939; Semyonov 1968; Chernousov *et al.* 2005; Belkind *et al*. 1956; Boas 1911; Kosven 1953; Kremkova 1936; Osipov 1959; Virginsky and Khoteenkov 1993; Sheypak 2009).

That is why it is very important to observe technological development comprehensively, where it becomes especially evident that, according to Fernand Braudel (1985), 'in reality, everything rested upon the very broad back of material life; when material life expanded, everything moved ahead'.

Technologies have been playing a significant role in the history of humankind from the very origin of *Homo sapiens*. Numerous facts show that already after 50,000 BP technologies were developed in various fields: from hunting and cooking to primitive painting. Achievements in such fields as agriculture, building, transportation, and many other human achievements could not have emerged without certain technologies. Thus, one can argue that *technologies play a very important role in Big History.* They played a special role in collective learning which is defined as the sixth threshold of increasing complexity. This *Homo Sapiens*' achievement which happened at the beginning of the Upper Paleolithic was probably one of the most important events in human history, and sometimes is termed as the *Human revolution* (*e.g.*, Shea 2006).[1] Today we are at the threshold of another important transition which is often called 'post-human revolution', which could bring quite radical changes to society and even transform the human biological nature.

1. Technological Dimension of Big History

Three production revolutions – three Big History thresholds

The whole historical progress can be divided into four big periods which we denote as four **production principles**[2]:

1. Hunter-Gatherer;[3]

2. Craft-Agrarian;

[1] Sometimes we denote it as the Upper Paleolithic Revolution.

[2] See Grinin 2006a, 2006b, 2007a, 2007b, 2012; Grinin L. and Grinin A. 2013; Grinin A. and Grinin L. 2015.

[3] It lasted till the 12^{th} mil. BP.

3. Trade-Industrial;

4. Scientific-Cybernetic.

Each production principle starts with a major technological breakthrough which we denote as Production revolution. There were three such revolutions:

1) the Agrarian or Neolithic Revolution (12,000–10,000 – 5,500–3,000 BP);

2) the Industrial Revolution (the last third of the 15th – the first third of the 19th centuries);

3) the newest Cybernetic one (1950 – the 2060/2070s).

In respect of Big History these revolutions are tightly related to the main Big History thresholds (the Agricultural Threshold; Modern Revolution Threshold; and the Cybernetic Revolution is related to the Future Ninth Threshold[4]).

Production revolutions are technological breakthroughs which change the whole structure of society and the way of life. Each production revolution has its own cycle consisting of three phases: two innovative phases and between them – a modernization phase (see Tables 1, 2; Fig. 1).

At *the initial innovative phase* a new productive sector emerges. *The modernization phase* is a long period of distribution and development of innovations. It is a period of progressive innovations when the conditions gradually emerge for the final innovative breakthrough. At *the final innovative phase* new innovations dramatically spread and improve for the new production principle, which, at this time, attains full strength.

***The Agrarian Revolution** was a great breakthrough from hunter-gatherer production principle to farming.* Its **initial phase** was a transition from hunting and gathering to primitive hoe agriculture and animal husbandry (that took place around 12,000–9,000 BP). The **final phase** was a transition to intensive agriculture (with large-scale irrigation and plowing) which started around 5,500 years ago (for more details see Grinin 2007a; Grinin A. and Grinin L. 2015; Grinin L. and Grinin A. 2016). These changes are also presented in Table 1.

Table 1. The phases of the Agrarian Revolution

Phases	Type	Name	Dates	Changes
Initial	Innovative	Manual agriculture	12,000–9,000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Middle	Modernization	Diffusion of agriculture	9,000–5,500 BP	Emergence of new domesticated plants and animals, development of complex agriculture, emergence of a complete set of agricultural instruments
Final	Innovative	Irrigated and plow agriculture	5,500–3,500 BP	Transition to irrigative or plow agriculture without irrigation

[4] A number of Big History research connect this threshold with the so-called singularity.

The Industrial Revolution *was a great breakthrough from craft-agrarian production principle to machine industry, marked by intentional search for and use of scientific and technological innovations in the production process.*

Its **initial phase** started in the last third of the 15^{th} and 16^{th} centuries with the development of shipping, technology and mechanization based on the watermill as well as with a 'more organic' division of labor. The **final phase** was the well-known breakthrough of the 18^{th} and 19^{th} centuries with the introduction of various machines and steam energy (for more details about Industrial Revolution see Grinin 2007b; Grinin A. and Grinin L. 2015; Grinin L. and Grinin A. 2016; Grinin and Korotayev 2015). These changes are presented in Table 2.

Table 2. The phases of the Industrial Revolution

Phases	Type	Name of the phase	Dates	Changes
Initial	Innovative	Manufacturing	the last third of the 15^{th} – 16^{th} centuries	Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization
Middle	Modernization	Diffusion of industrial enterprises	the 17^{th} – early 18^{th} centuries	Formation of complex industrial sector and capitalist economy, increase in mechanization and division of labor
Final	Innovative	Machinery	1730 – the 1830s	Formation of sectors with the machine cycle of production using steam energy

The Cybernetic Revolution *is a great breakthrough from industrial production to the production and services based on self-regulating systems.*

Its **initial phase** dates back to the 1950–1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. We assume that the **final phase** will begin in the nearest decades, *i.e.,* in the 2030s or a bit later, and will last until the 2070s.

We denote the initial phase of the Cybernetic Revolution as **a scientific-information** one, and the final one – as **a phase of self-regulating systems**. Today we are in its modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous phase (*e.g.*, computers, Internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough. *We suppose that the final phase of the Cybernetic Revolution will lead to the emergence of various self-regulating systems* (see below).

The scheme of the Cybernetic Revolution is presented in Fig. 1.

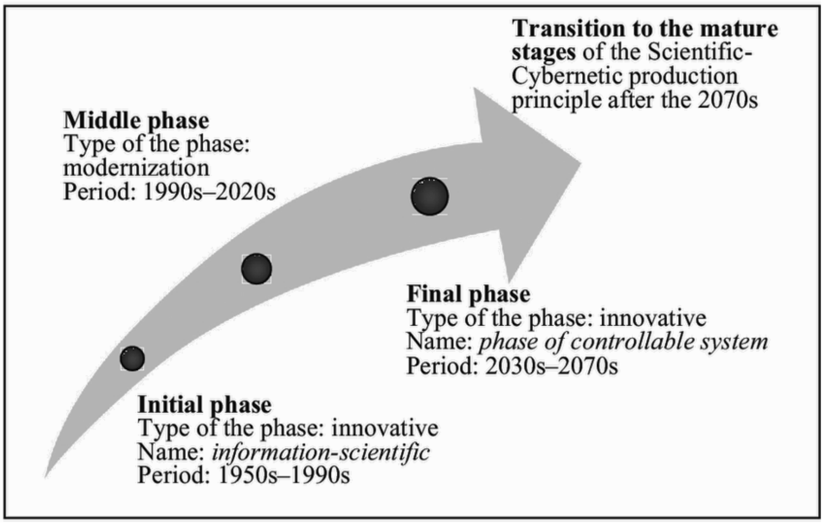

Fig. 1. The phases of the Cybernetic Revolution

Each phase of Big History is accompanied by the emergence of new evolutionary mechanisms. In particular, certain preconditions and preadaptations can be already detected within its previous phase. The same refers to the development of productive forces. Within previous production principle there appear some prerequisites of technologies, which flourish during the next production principle. For example, many mechanisms, engines and machines emerged within the Craft-Agrarian production principle, especially during its last centuries (the 12th – 14th centuries). But for Production revolution to start, there should occur some technological changes. Thus, the Industrial Production Revolution began at the end of the 15th century and lasted until 1830.

Cybernetic Revolution, self-regulation and artificial intelligence in terms of Big History

The theory of production revolutions proceeds from the assumption that the essence of these revolutions can be clearly observed only during their final phase. *The most important thing about the final phase of Cybernetic revolution will be a wide use of self-regulation in different technological and bio-socio-technological systems.* The analysis of such systems can be based on cybernetics which is a transdisciplinary approach for exploring complex regulatory systems via the processes of receiving, transformation and transfer of information (see, *e.g.*, Wiener 1948; Beer 1959; Von Foerster and Zopf 1962; Umpleby and Dent 1999).

The most important characteristics and trends of Cybernetic Revolution are the following:

1. The increasing amount of information and growing complexity;
2. Consistent development of the system's abilities to the regulation and self-regulation;
3. Mass use of artificial materials with new properties;
4. Application and control of systems and processes of various nature including living material and new levels of organization of matter (including different nanoparticles as building blocks);
5. Miniaturization and microtization as a trend of the constantly decreasing mechanisms, electronic devices, implants, *etc.*;
6. Ubiquitous resource and energy saving;
7. Individualization as one of the most important technological trends;
8. Implementation of smart technologies and a trend towards humanization of their functions (use of the human language, voice, movements, *etc.*);
9. Control over human behavior and activity to eliminate the negative influence of the so-called human factor.

Some of these trends coincide wholly or partially with the perceptions of artificial intelligence and its future development (though this concept is quite vague and difficult to define). But other trends cannot be included into the concept of artificial intelligence (for more details see below).

Self-regulation can be defined as a system's ability to preserve stability and basic parameters within changing environment. Self-regulation as a broad concept incorporates various aspects of maintaining stable state of a system at all phases of Big History and especially at the biological and social ones. Self-regulation is of great importance for Big History since it is one of the most developed levels of growing complexity (see Grinin 2016).

Self-regulation has already revealed at the early phases of Big History, in fact, with the emergence of the first systems (*e.g.,* the first stars). The emergence of life is tightly connected with self-regulating systems.

In the course of chemical evolution chemical substances gradually became more complex until some of them got the ability for self-regulation. For example, lipids, which are able to change their form when interacting with water, while retaining its chemical structure. One of the most important features of living organisms is an existence of a code molecule. RNA is considered as the first self-replicating molecule.

The further formation of complex systems, such as DNA, proteins, enzymes, *etc.*, required the creation of a complex system of regulation. The more complicated the system became, the more complicated was its regulation. In order to overcome the entropy, systems sought to isolate themselves from direct contacts with the environment, forming protective (insulating) shells. Presumably that is how the first coacervates were formed, and later – the cells. A cell became the main self-regulating living system due to which many organisms were formed in the process of evolution. Biological systems demonstrate the complexity growing up to the level of self-regulation within evolution. Due to collective learning human society has also developed into a complex self-regulating system. Within the next decades the technological complexity is supposed to rapidly increase thus promoting the ability for self-regulation.

At present there are already many self-regulating systems around us, for example, self-driving cars, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suitable mode and detect critical situations. The genetic engineering is also worth mentioning since it is used for the creation or changing biological and physiological self-regulating systems.

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends should produce a cluster of technological innovations*. The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. In our opinion, *the general driver of this cluster will be medicine, which can connect additive technology, nanotechnology, biotechnology, robotics, information and cognitive technologies. We denote this technological cluster as a MANBRIC-complex (an acronym for the included technologies).*[5]

Fig. 2 shows the citation frequency of MANBRIC-technologies in scientific publications and relations between the technologies forming the complex. The thickness of line demonstrates the intensity of interactions while the direction of arrows shows the sphere of application of technologies.

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[5] Namely: **M**edicine, **A**dditive, **N**ano, **B**io, **R**obotic, **I**nformation, and **C**ognitive technologies. For the convenience of pronunciation the technologies are listed not in order of priority.

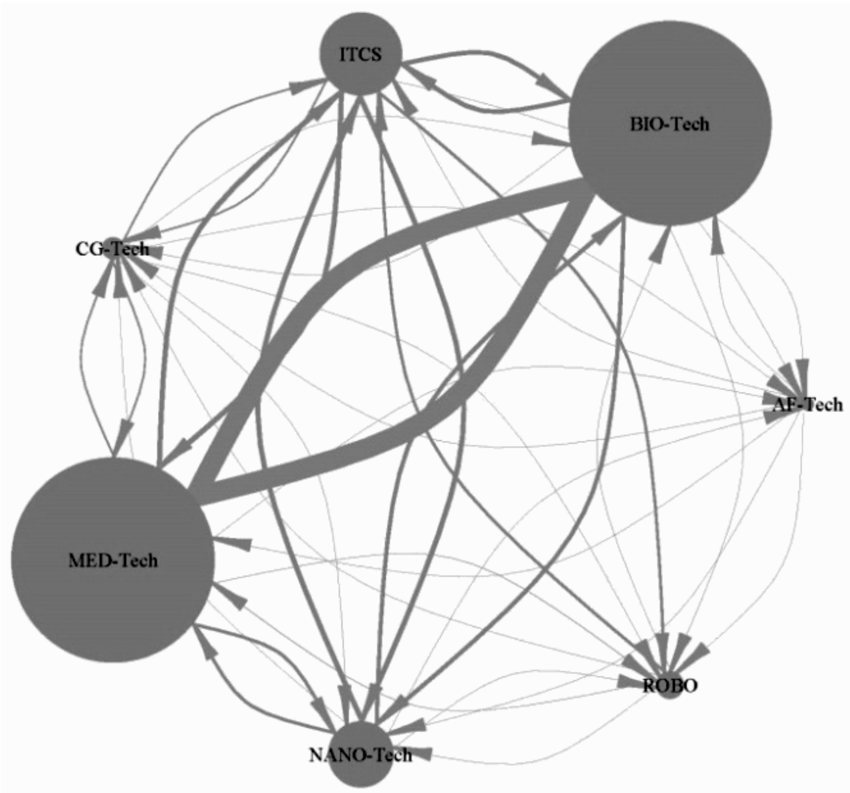

Fig. 2. The relationship between citation frequency in scientific publications and the technologies forming MANBRIC, according to the Web of Science, 2010–2015

As one can see from this figure, medicine and biotechnologies are most closely related. There is also distinguished a separate direction of biomedicine (Pankhurst *et al.* 2003; Gupta A. and Gupta M. 2005).

The development of MANBRIC-complex can be examined, for example, via the analysis of patent applications in medicine, pharmaceuticals, and biotechnologies which also demonstrate *convergening growth rates* (Grinin L., Grinin A., and Korotayev 2016).[6]

[6] See also Appendix to Ch. 9 in Grinin L. and Grinin A. 2015 at URL: https://www.socionauki.ru/book/files/ot_rubil_do_nano/online_version/9_chapter_appendix/266p.php.

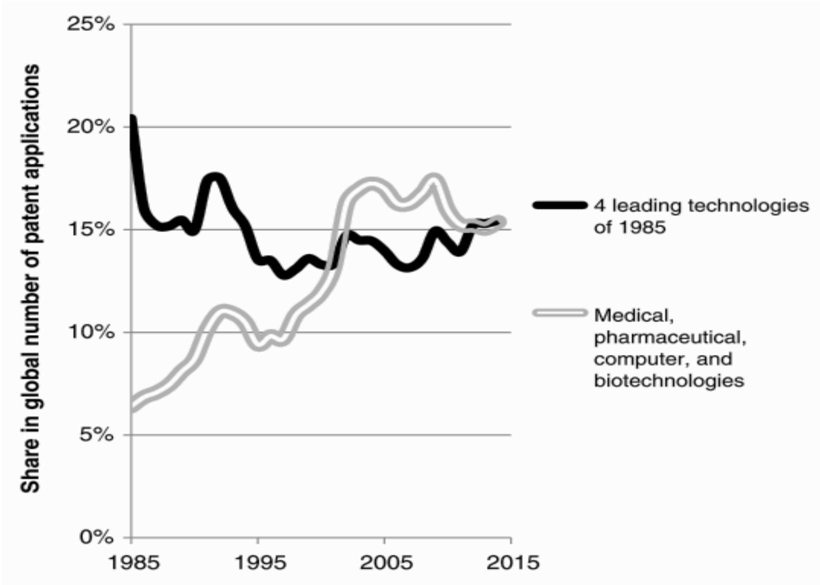

Fig. 3. Dynamics of the global combined share of four technologies with the highest share of patent applications in 1985 (electrical machinery, measurement, machine tools, and other special machines) in comparison with the dynamics of the global combined share of patent applications in four top categories (medical, pharmaceutical, computer, and biotechnologies), 1985–2014

Source: WIPO IP Statistics Data Center 2016.

The important question is in what sphere will the final phase of the Cybernetic Revolution start? First of all, one should remember that the 'breakthrough' sphere is usually quite narrow as it happened during the Industrial Revolution (when the breakthrough occurred in a specific field – cotton industry). In a similar way, given the general vector of scientific achievements and taking into account that a future breakthrough area should be commercially attractive, we think that the final phase (the one of self-regulating systems) of the Cybernetic revolution will begin in one of the recent branches of medicine. It probably has already formed (such as biomedicine or nanomedicine) or it can form as a result of the uptake of other innovative technologies into medicine.

It is important that in the nearest decades not only the developed but also developing countries will face the problems of population ageing, shortage of labor resources and the necessity to support a growing number of elderly people. The progress in medicine can contribute to the extension of working age (as well as to the general increase of the average life expectancy) of elderly people and to more active involvement of disabled people into labor activities. *Thus, elderly people and people with disabilities could more and more subsist for themselves.*

At present medicine is closely related to biotechnologies (see Fig. 2) through pharmaceuticals, gene technologies, new materials, *etc*. The distinctive feature of modern medical science is its 'bio-related trends' – a wide use of approaches based on the methods of molecular and cell biology.

Nowadays medicine is highly computerized especially in the field of diagnostics, various automatic control systems have been developed; for example, for the control of breathing, nutrient supply to specific organs, blood pressure, control over the functioning of some internal organs, *etc.*

Medicine (supported by both government and private funding) has been a major influence on GDP.

Taking into consideration the anticipated faster growth rates of GDP in the developing countries and a rapid formation of the middle class there, one can suppose that in general, health care spending will increase significantly. For example, in Germany a number of health care personnel constitute 22 % of the total number of employed people while the share of automobile industry is only 2.3 % (Nefiodow L. and Nefiodow S. 2014).

We have no opportunity to describe the whole range of MANBRIC-technologies with the equal attention. So in this paper we will focus on the most important spheres.

2. Future Technologies

Big History, technologies, and rules of evolution

When considering the issue of future technologies in terms of Big History, one should emphasize that the growing technological complexity is connected with some other aspects of Big History. Elsewhere we formulated a number of evolutionary rules, which can be applied for the analysis of different Big History directions (*e.g.*, Grinin, Markov, and Korotayev 2008, 2009; Grinin 2014, 2016; Grinin, Markov, and Korotayev 2017).

Among these evolutionary rules we single out three rules which are of particular importance for the development of technologies.

Rule 1. **Evolution occurs only in a small part of a system**

According to data obtained from Planck observatory, the Universe is composed of 5 % of ordinary (baryonic) matter, 24 % of dark matter, and 70 % of dark energy. Thus, the most bulk of our Universe is occupied by dark matter and energy which can hardly evolve. In living organisms, for example, an estimated percentage of the non-coding DNA reaches 98 %. In social evolution, according to some sources, the number of innovators in a society is about 3–5 %. The same is in evolution of technology, for example, only a small number of startup projects appear successful.

Rule 2. **Evolutionary block assemblage**

In evolution, there emerge some basic and more complex components which assemble in various combinations. In this sense, evolution is similar to construction, where ready-made units are used to build new creations. Thus, in cosmic evolution atoms are universal components for the formation of molecules while chemical evolution in space started with the emergence of a sufficient variety of atoms. On Earth the atoms and non-organic molecules launched the geological development, and later – the emergence of organic molecules, and eventually life. In biological evolution block assemblage principle of formation can be observed, for example, at the level of cells, tissues, and organs. Many molecules, for example, of DNA, also consist of peculiar semantic units. Similarly in social evolution religion or legal systems are often borrowed by other countries. All technologies are made according to this principle. For instance, a modern vehicle is a result of numerous technological achievements: from wheel, alloys, mechanical systems, plastic, fabrics to the onboard computer.

Rule 3. **The increasing diversity**

Variety is as a universal evolutionary trend. Thus, within cosmic evolution there appeared a growing number of chemical elements and molecules, as well as stars and planets. In biological evolution the number of species has been continually increasing for a long time. However, the growth cannot be constant since evolution always balances around the optimum. Thus, it is not surprising that there are periods of reverse development and reduction of the diversity (*e.g.,* during mass extinctions). In social evolution, there is a growing diversity of political forms, cultures and religions.

In the evolution of technologies the growing diversity is very impressive. From 1980 to 2014 the number of patent applications has increased ten folds.[7]

The rules given above are used as examples to demonstrate that technological development we observe nowadays is not unique. Under similar conditions and preconditions, evolution in different systems may follow the similar patterns.

[7] About the dynamics of patent application see Appendix to Grinin L. and Grinin A. 2015, 274ff. URL: https://www.socionauki.ru/book/files/ot_rubil_do_nano/online_version/9_chapter_appendix/274p.php.

Thus, based on the evolutionary rules and the theory of production principles and other aspects we give some forecasts of upcoming technological revolution.

On some future medical technologies

Constant health monitoring as a self-regulating supersystem. During the final phase of the Cybernetic Revolution a very important direction of self-regulation can develop as different health monitoring systems for early diagnosis and preventing diseases. The key compounds of such devices are biosensors and similar tiny devices. One can easily imagine that in the future they will be able to become an integral part of a human life, providing a constant scanner of an organism or a certain organ and transmitting the information to a medical center in case of potential or real threats. On the whole, medicine will develop towards increasing individualization and personification through the selection for individual therapy while the use of mass drugs and standard therapeutic technologies will be reduced.

Economy, optimization of resource consumption, and miniaturization. The achievements in medicine will make a significant contribution to *the optimization of resource consumption*, for example, due to the targeted drug delivery and minimization of interference with the organism. Hospital treatment will be less used as the operations will be more targeted, and the rehabilitation period will be minimal. More people will be treated at home since the development of remote treatment is rather probable when doctors control the indices of a patient online and can make the necessary prescriptions remotely. It could sharply decrease a cost of medical treatment which now is exorbitant one for a great number of people. Saving money (as well as resources) is one of the most important directions for the economy.

Medicine develops in the direction of growing **miniaturization.** There is a trend of constantly decreasing size of instruments to micro and nanoscale (Peercy 2000). For example, repairing heart tissue destroyed by a heart attack usually requires invasive open-heart surgery. But now researchers have developed a technique that allows using a small needle to inject a repair patch, without opening up the chest cavity (Montgomery *et al.* 2017).

The perspective direction in medicine is slowing down the ageing process. It is highly probable that human medicine will significantly increase life expectancy. Already nowadays in some countries the average life expectancy is more than 80 years. We suppose that increase of life expectancy will occur as a result of a breakthrough in medical technologies in the 2030s–2050s. In the 2050s the average life expectancy will increase by 15 years or even more.

It is quite possible that genetic methods will significantly increase life expectancy. In this respect, the study of telomeres, which were found to play an important role in cell division, seems to be promising (Slagboom, Droog, and Boomsma 1994).[8]

Transplantation. Another important branch of medicine is regeneration and transplantation of organs and tissues of a human body. At present medicine achieved great results in organ transplantation (*e.g.*, heart, lungs, liver, pancreas, and kidneys). However, human donor organs are scarce, and people who donate donor organs without special agreement are brought to criminal responsibility all over the world.

Medicine and biotechnology will provide an opportunity to design different artificial organs, such as skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, the lungs, pancreas, bladder, ovaries. Many of them are already designed today. Even new organs or combinations are possible. There is already an opportunity of tissue engineering. In laboratories scientists cultivate new cells to replace injured bone or cartilage. For example, recently, the soft artificial heart was created from silicone using a 3D-printing, lost-wax casting technique; it weighs 390 grams and has a volume of 679 cm^3. This artificial heart has a right and a left ventricle, just like a real human heart, though they are not separated by a septum but by an additional chamber. This chamber is in- and deflated by pressurized air and is required to pump fluid from the blood chambers, thus replacing the muscle contraction of the human heart (Cohrs, Petrou, and Loepfe *et al.* 2017).

This technology has the potential to develop cell therapy and methods of tissue regeneration.

One can expect that opportunity to 'deceive' the immune suppression will be one of the main breakthroughs in the field of regeneration and transplantion of organs and tissues.

Changing human reproductive capabilities is an especially important field of medicine. The number of incurable diseases causing infertility decreases. Nevertheless, the only opportunity for some patients is to use *in vitro* fertilization. Besides, due to the development of medicine there increases a number of women who want to have children after their reproductive age is over (*e.g.*, at present, it is possible to grow an embryo outside the woman's body).

The future of biotechnology

One can suppose that at the very first stage of Cybernetic Revolution biotechnology, as an independent direction, will play a less important role than medicine. It will be rather an important component of medical technologies, pro-

[8] In 2009, Elizabeth H. Blackburn, Carol W. Greider and Jack Szostak were awarded the Nobel Prize for the discovery of how chromosomes are protected by telomeres and the enzyme telomerase from terminal underreplication.

viding breakthroughs in treatment of diseases or monitoring of organism functions. Genetic engineering will play important role in different spheres of biotechnologies (see below).

Gene modification. On the basis of the genetic data the most appropriate treatment will be adapted for individual patients, and if it is necessary the defective genes will be corrected. Presumably, first gene therapy will manifest itself in sport medicine as enormous investments are made in it and the best minds are engaged in this field.

When choosing the appearance of a future child (color of eyes, skin, *etc.*) gene therapy can be used. In future it might be possible that babies will be born almost by order, these will be 'the perfect babies' (Fukuyama 2002).[9] In other words, parents will choose desirable features of a child before his/her birth.

Achievements in self-regulation. The level of controllability will increase considerably within a number of important systems connected with biotechnologies. Thus, probably, while transforming an organism, scientists will insert not a separate useful gene (Simon, Priefer, and Pühler 1983), but a whole set of necessary genes which will operate depending on environmental conditions. Such characteristics will be extremely important in the case of climate changes which are quite probable. It will become possible to choose the most optimal varieties of seeds for a unique combination of weather conditions and territory. Consequently, huge databases of such plant varieties and variations will be created. It is quite possible that in the future the whole process of getting a transgenic plant will take place without human participation, thus, it will become self-regulating.

It is possible to assume that by the end of the final phase of the Cybernetic Revolution the agricultural biotechnologies will be already developed to a degree that the modified products will be able to response even to the smallest fluctuations of local conditions. In other words, it will be possible for farmers to select individual fodder and drugs by means of programs and to order them via the Internet. Even an individual will be able to invent a houseplant hybrid suitable for the interior and to order its production and delivery.

The same refers to domestic animals: it will be possible to breed animals with peculiar characteristics within separate breeds of animals (or even by the individual order). It is probable that the selection of animals on the basis of genetic engineering will also develop in the direction of decreasing human participation.

[9] It is difficult to say how 'perfect' they will be and what kind of problems will appear as a result of these technologies. *E.g.*, the possibility to predict the baby's gender resulted in gender imbalance in China. As a result, there are a disproportionate number of boys. Thus, we agree with Francis Fukuyama, who believes that the future achievements of the 'biotechnology revolution' should be accepted with great prudence (Fukuyama 2002).

Creation of new materials. In the 1940–1970s, one of the main directions was the development of industrial production of already known substances (*e.g.*, vitamins) or their analogues; however, during the same period there appeared the elements which did not exist in natural environment (*e.g.*, Humalog, which is a widely applied synthetic analogue of human insulin [Woollett 2012]). This sequence reminds the history of development of chemistry: at first people learned to produce the known substances, and then the artificial materials.

Due to biotechnologies many new materials are produced, for example, bioplastics. The main advantage of this material is that unlike ordinary plastics it is biodegradable. Thus, the main goal of bioplastics production is preserving the environment, reducing the production of goods from non-renewable resources and cutting the discharging of carbon dioxide into the atmosphere. This is an important step to the creation of self-cleaning ecological systems in the future and also to the preservation of the environment.

The increase and cheapening of food production is a global challenge for the humankind taking into account that the population number will continue to increase for several more decades (first of all in the poor and poorest countries, especially in Africa), perhaps, reaching nine or more billion people (see UN Population… 2012). Biotechnologies can make a huge contribution to the solution of the problem.

The solution of urban and some environmental problems

Biotechnologies are successfully used for cleaning up oil spills, in wastewater treatment, *etc.* According to the Organization for Economic Cooperation and Development (OECD), the potential market for bioremediation, that is, the use of living microorganisms to degrade the environmental contaminants (including plants for soil purification), amounts tens of billions of dollars. Thus, important changes will certainly take place in the employment of biotechnologies for the solution of environmental problems. Here it is possible to assume that biotechnologies will be intruded first of all into the urban ecology. It is necessary to consider that in the coming decades the urban population will increase by 40–50 % (see, *e.g.*, NIC 2012). Among the problems which can be potentially solved by means of the development of biotechnologies, there are those related to water cleaning, recycling of waste, liquidation of stray animals (it will be promoted by introducing genes for sterility or something of that nature). Already today the micro-organisms for water cleaning are applied; with their help we also get bio-gas from waste recovery. But in the future these and similar problems will be solved due to the development of self-regulating systems that will make it possible to solve a number of technical and scientific problems.

But the problem of ecological self-regulating systems, naturally, is not limited by the cities; it has to be extended to the cleaning of reservoirs and other ecosystems. The creation of ecological self-regulating systems will considerably reduce expenses and free huge territories occupied by waste deposits, as well as allow breeding fish in self-cleaning reservoirs.

One can assume that an important direction will be the creation of self-regulating environmental systems in resort and recreational territories which will provide the best conditions for rest and business.

The breakthrough in the sphere of resource-saving

Resource and energy saving is one of the main tasks and outcomes of introduction of biotechnology. The basic opportunities with respect to resources-saving are connected with an opportunity to influence the genetic organization of living beings which at present serves the basis for the agricultural ('green') biotechnology which has already become a part of the initial phase of the Cybernetic Revolution. The breakthrough in this area is connected with *totipotency*, *i.e.* an ability of plants to form a full-fledged organism from a single cell. With the necessary gene transfer, one can make, for example, a variety of potato resistant to the Colorado beetle, or reduce the susceptibility to drought, cold and other stresses (Grinin *et al.* 2010). New agricultural technologies are of great importance for the developing countries. For example, genetically modified and pest resistant varieties of cotton plant and corn demand much smaller usage of insecticides which is more cost-effective and eco-friendly. The individualization is also noticeable in the animal genetic engineering which develops more slowly, but even now and in prospect it has an enormous value for agriculture and medicine (by means of genetic engineering it is possible to increase milk production, to improve quality of wool, *etc.*).

Biotechnology can help to solve many global issues, for example, to cheapen the production of medicines and foodstuffs including producing and making them in ecologically sound ways that can also keep or make the environment pristine, thereby considerably expanding their production. The solution to the food problem will proceed in different ways, in particular due to the mass production of food protein whose shortage is sharply perceived in many societies (at present the feed protein for animals is generally produced in this way). Even now there are results based on the production of food proteins or, for example, imitation meat. But so far such a production is too expensive. A gram of laboratorial meat costs US$ 1,000 dollars (Zagorski 2012) but this is part of the usual process from the laboratory to mass cheap production.

Artificial Intelligence, robots, nanotechnologies, additive and cognitive technologies

Self-regulating systems and Artificial Intelligence (AI). Within Big History the period after a new threshold is sometimes anticipated as a period of rapid development and even predominance of artificial intelligence. We agree that the future investigations in the fields of Big History and evolution are closely associated with the development of Artificial Intelligence. Thus, it turns out to be important to define similarities and differences between self-regulating systems and AI.

On the one hand, the notion of 'self-regulating systems' correlates rather closely with Artificial Intelligence which has become a subject of intensive research in the recent decades (see*, e.g.*, Poole, Mackworth, and Goebel 1998; Russell *et al.* 2003; Hutter 2005; Luger 2005; Neapolitan and Jiang 2012; Keller and Heiko 2014; Hengstler, Enkel, and Duelli 2016). 'Intelligent' machine is often defined as the one that takes actions that maximize its chance of success at some goal (*e.g.*, Russell *et al.* 2003). Of course, such a machine can be also considered as a self-regulating system. The notion of Artificial Intelligence is usually connected with machines, IT-technologies, robots, and sometimes equated with technical intelligence (Zhang *et al.* 2016).

On the other hand, *the notion of 'self-regulating systems' is wider than the notion 'artificial intelligence'* since the former includes various self-regulating systems that can function independently, but can hardly be regarded as Artificial Intelligence. For example, biotechnological systems designed to neutralize pollution, or the ones connected with human physiology (*e.g.*, artificial immunity on the basis of artificial antibodies, or systems based on the use of various other proteins or viruses, or genetic engineering technologies that are able to control certain physiological processes and so on). In addition we expect the emergence of self-regulating systems of mixed nature – for example, biochemiotechnical. One should also note that they can function within more complex systems, like a human organism. As examples of such self-regulating systems one may mention artificial organs grown in laboratories and incorporating a number of biosensors and other technical elements. Thus, any AI can be regarded as a self-regulating system, but not all self-regulating systems can be associated with AI.

Robots and self-driving cars in the future. The opportunities of using robots are undoubtedly vast. In particular, only these devices can help to solve the problem of care of growing numbers of elderly people and to some extent the associated problem of labor shortage. In general, there is no doubt that robots will play a significant role in the transition to self-regulating systems. We assume that in the 2020s certain although not revolutionary achievements in this area will occur, in the 2030–2040s we will witness a much more significant rise in robotics, but an explosive development of robots will happen a bit later in the 2050–2060s. By this time it is also possible to expect the creation of really 'smart' robots. We believe that in the next two decades robotics will develop rapidly in the service sector. At present there are many publications on how robots may replace humans in many fields. We agree that the changes in this sphere will be enormous yet, they will take several decades to occur.

In future robotic servants may replace household chores as well as perform some complicated tasks, for example, they will be more and more involved into investigation of space bodies and other tasks that can be dangerous for humans (military, rescue, space activities, *etc.*). Hardly all of them will be anthropomorphous; their design will be most likely defined by functions. However, universal robots are also likely to emerge.

Robots will play a very important role in medicine, for example in surgery and in the sphere of social nursing care. The number and variety of surgical robots grow every year. According to some forecasts, surgical robotics market will grow up to US$ 28.8 billion by 2020.[10] Surgical robotic systems are a combination of equipment, accessories, software, and services, which help doctors to perform minimally-invasive surgeries including gynecological, cardiac, neurological, and orthopedic ones. Robotic systems allow surgeons to automate the surgical procedure, improve efficacy and precision during the procedure, and minimizing post-surgical complications.

Robotic systems will continue to be used extensively in transportation, in particular they will also be used in the development of self-driving vehicles. The latter might be especially important. Taking into account the above-described ‘meaning’ of the Cybernetic Revolution (as a revolution of self-regulating systems), the breakthrough will most probably occur in the direction of autonomous transport. Vehicles and other transport systems will become self-driving and will use the electric vehicle technologies. Even today, there are attempts of realizing this opportunity. A vivid example here is Tesla's self-driving cars. But other groups of companies also announced their self-driving cars. For example, ‘Mercedes-Benz’ has presented the concept of driverless car (della Cava 2015). *Google* works to create such a car by 2020 (see Muoio 2015), but it already tests the Toyota self-driving car in California (and arranges joint projects with *Ford*). Just as in 1997 the computer defeated the world chess champion, recently self-driving car has beaten the racing driver at speeds over 200 kilometers per hour. Some researchers even work to understand how to make self-driving cars become capable of making moral and ethical decisions just like humans do. Any decision that involves risk of harm to a human or even an animal is considered to be an ethical decision. It also includes quite rare situations when a collision is unavoidable, but a decision can be made as to which obstacle to collide with. Researchers believe that by algorithms it is possible to make self-driving car decide whether to use a sophisticated algorithm or a simple rule such as ‘always stay in the lane’ (Sütfeld *et al.* 2017).

However, the development of such systems as self-regulating systems is an important forerunner of the forthcoming start of the final phase of the Cyber-

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[10] URL: https://www.alliedmarketresearch.com/surgical-robotics-market?surgical-robotics-market.

netic Revolution (in the 2030s). The self-driving electric vehicles with a new accumulator together with roads allowing free recharge can become a powerful source of technological development during the final phase of the Cybernetic Revolution.

The future of nanotechnology

Nanotechnologies have become one of the most popular technologies of modern times and they have many prospects.[11] First of all, different nanocoatings will rapidly develop. Nanocoatings are used in different fields: industry, aircraft building, and electronics. The components of nanoelectronics, photonics, neuroelectronic interfaces and nanoelectromechanical systems are also promising. They will allow further micronization of devices. We believe that self-regulating technologies (*e.g.*, self-cleaning coatings which regulate the temperature) will gain a widespread use. Similar technologies have already been created.

For example, recently in the University of Central Florida a flexible anti-reflection film on smartphones and tablets was made. It makes the screen bright and sharp as well as scratch resistant and self-cleaning. The film contains tiny uniform dimples, each about 100 nanometers in diameter (about one one-thousandth of the width of a human hair) (Guanjun Tan *et al.* 2017).

In future, the nanotechnologies will provide excellent opportunities for the self-assemblage of nanoelements and nanodevices. It will become possible to make a transition to controlled self-assemblage of nanosystems, creation of three-dimensional networks, nanorobots, *etc*. One may also speak about the use of molecular devices, atomic design. There are rather attractive prospects in the development of nanomechanics, nanomachinery, and nanorobotics. Long ago there started to develop the idea of creation of computers that process and store information through not special condition of environment (magnetic, electric, and optical) but through nanotechnologies, for example, via silicone (the main material in the production of semi-conductor devices) chips replaced by carbon nanotubes. In this case a bit of information can be written in the form of a cluster, for example, of 100 atoms. This would reduce their size several-fold and at the same time increase quick response. Quantum technologies (*e.g.*, the creation of quantum computer) will be one of the most important technological breakthroughs in this context. It is very difficult to predict which path the development of information technologies will follow, but one can assume that as a result of the completion of the Cybernetic revolution, the information capacity will increase by an order of magnitude.

[11] See Appendix to Grinin L. and Grinin A. 2015, p. 288ff. URL: https://www.socionauki.ru/book/files/ot_rubil_do_nano/online_version/10_chapter_appendix/288p.php.

The future of 3D-printers

The opportunities provided by 3D-printers are great: from building to cooking, from a house workshop to museums, from medicine to children toys, from training models to design. At present, 3D-printing is used in aircraft construction and rocket engineering to produce individual elements, for example, support stand for an aircraft engine (see, *e.g.*, Turichin 2015). And just because they are used in such high-technology spheres their development needs considerable investments.

In fact, 3D-printers constitute a universal house workshop or a universal production or, construction factory. And in the future they will acquire new functions and incorporate new subsystems.

Additive 3D-printing (*i.e.*, merging (fusing) of materials and creation of certain objects) is a very promising direction. Thus, in future 3D-printers will help to produce any material needed, even the biological one. Great opportunities are especially associated with the opportunities to grow human organs and tissues, including through the usage of patient's own tissues. Soon it will suffice to have a sketch and to make (to 'print', 'fuse') any detail at home or in a 3D-printing center. It will also be possible to organize a small single-piece production. Engineers could also develop simple 3D-food printers which can print, for example, candies or pizza.

Undoubtedly, the development of additive technologies will be connected with other directions of MANBRIC-complex, for example, with robotics (additive technologies will be used to create robots, and at the same time the robots themselves will use additive technologies in their activities).[12]

Cognitive technologies. Neural interfaces or brain-computer interfaces (BCI). A brain-computer interface (BCI) is a direct communication pathway between brain and an external device. This technology implements the interaction between brain and computer systems that can be realized via electrode contact with head skin or via electrodes implanted into brain. The implementation of neural interfaces is already wide-spread, for example, in artificial visual systems or bionics. The most notable device is the cochlear implant, which has been implanted in more than 220,000 people worldwide.

In three or four decades, disabled people will get another chance in life. BCIs may improve rehabilitation for people with strokes, head trauma, and other disorders. At present there already exist devices which allow paralyzed peo-

[12] *E.g.*, the Stormram 4, as the robot is named, is made from 3D-printed plastic and is driven by air pressure. This robot can be used in an MRI scanner. Carrying out a biopsy (removing a piece of tissue) during a breast cancer scan in an MRI significantly increases accuracy. The Stormram 4 is a stimulus for the entire diagnostic phase of breast cancer; the accurate needle control, effectively real-time MRI scanning and a single, thin-needle biopsy enable quicker and more accurate diagnoses to be made (University of Twente 2017).

ple to speak, write and even work at the computer as, for example, in the case of the famous astrophysicist, Stephen Hawking.

Those who can afford it and want to increase their abilities will be able to replace their body parts by bionic ones.

Also in three or four decades, small scalp electrodes will make remote brain control possible. So people will be able to turn TV on only by thinking about it. In the future neural interfaces can be applied not only in medicine, but also in daily pursuits, for example to control condition of a driver's or an operator's brain and in case of falling asleep to awake him automatically. In general the achievements in cognitive science are already in use and their application will increase even more in the areas which move towards self-regulating systems – from medicine to robotics, from cybernetics to problems of artificial intelligence, and, of course, for the military purposes. However, serious technical and social difficulties can hamper the development of this direction (see below). After surpassing these constraints, the development of neural interfaces will promptly reach a new level.

Some ideas on other future technologies. Smart devices. Everyday technologies become more self-regulating, complicated, and more intelligent. Their names speak for themselves. The word 'smart' is used as a prefix for many devices. Today smartphones have become ubiquitous, while smartwatches are becoming popular, people watch smart TV, and in schools they use smart boards. Here are just a few examples of smart things: smart kettle, smart swimsuit, smart stroller, smart cup, smart rope, smart T-shirt which tracks your posture, smart cane with GPS for elderly people, smart bottle which automatically tracks hydration and temperature, smart highway with nanocoating which changes its color according to the weather and warns drivers of potential risk. There is also developed a concept of a smart city with smart traffic signs and traffic light signals, as well as smart cars. This will also allow time and resource saving. Exoskeleton will allow people to perform hard work with fewer efforts. We assume that this trend will continue and thus, in three or four decades most of everyday devices will be smart. An absolute majority of them will be connected to the smartphone and Internet. One can predict that we will live in smart homes with smart kitchens, while a smart climate control system will maintain the required temperature 24 hours a day.

Mobile phone as an integrating device. The key feature of the future technologies is that most of them will be integrated with mobile phone or similar devices. A mobile phone will be a universal control panel and analytical center. It will collect all data from smart technological devices, for example: how many meters one walks, how many calories one consumes, how many hours one sleeps, how much money one spends, how many hours one plays basketball and how many points one scores. The mobile phone will become a powerful means of control not only over an individual, but over pets and children. For example, a smart bracelet that monitors a child's clean hands and signals if the child takes, for example, unwashed fruit. At any time parents can check the purity of their child's hands using a special smartphone application.

Thus, the important future technological trend is the development of virtual reality through different devices especially mobile phone or in another form of such integrative device (as it is known there are different ideas on this future forms, *e.g.*, glasses). It is quite probable that such devices will be able to adopt the functions and become a new type of sensory organ and source of information for people. Thus, special glasses will allow connecting vision and hearing with the high resolution virtual reality devices. In the future, virtual reality may be not only seen but also felt. A small band with a device on the arm is already designed which will enable users touch the object in virtual reality.

Conclusion. Will the Development of the Cybernetic Revolution Proceed in the Direction of Cyborgization?

There is no doubt that future development within Big History and evolutionary paradigms is connected with the development of intelligence and transformation of intellectual creatures. As to the direction and speed of this transformation there are many points of view, including those (which we do not share) that AI will be able to unite billions of people's minds into a new system (Kurzweil 2000) or that humans will soon become immortal (see below). On the other hand, the development of medicine and self-regulating systems, which will constitute the nucleus of changes in the final phase of the Cybernetic Revolution, will undoubtedly lead to the increasing interference in human body. In this context, we would like to conclude the paper by the reflections about the ways this interference in human body can change the human biological nature and transform a human into a cyborg. A very popular word 'cyborg' (short for 'cybernetic organism') derives from the word 'cybernetic'. Cyborg is defined as a theoretical or fictional being with both organic and biomechatronic parts.[13]

The term 'cyborg' often applied to an organism that has restored function or enhanced abilities due to the integration of some artificial component or technology that relies on some sort of feedback. It is obviously that many achievements in medicine will impel our civilization to the state in which more and more humans can become partial cyborgs. Thus, we are following the path of development of self-regulating systems of a new type which will be constituted by the elements of different origin: biological and artificial. All that we have written about artificial organs and tissues will contribute to the break-

[13] The term was coined in 1960 by Manfred Clynes and Nathan S. Kline (Halacy 1965).

through in the field of both production of absolutely new materials which will expand the implementation of non-biological elements in the human body. Thus, the Cybernetic Revolution is closely connected with the process that can be designated as cyborgization. We should be aware of the fact that this actually means not only the formation of a new direction in medicine, but also the movement towards the *cyborgization* of a human being. Of course, this can cause a certain and quite reasonable anxiety. On the other hand, expanding the opportunities for not just a long but also an active life is hardly possible without significant support for the sensory organs and other parts of the body which weaken as a result of ageing and other reasons. Finally, glasses or contact lenses, artificial teeth, tooth fillings, bones, aerophones, artificial blood vessels, mitral valves, *etc.* allow hundreds of millions of people to live and work and these people still remain humans. The same is true with respect to more complex systems and functions. Thus, people with disabilities can benefit from the development of medicine and cyborgization as they will be able to significantly compensate their drawbacks. However, we suppose that the idea that someday the human body will be fully replaced by non-biological material and only the brain or the organs which support the senses will remain is just fantasy. This will never come true (the well-known ideas about such future for humankind are presented by Kurzweil [1999]). People who propose such solutions, for example, to replace supposedly less lasting and comfortable biological material by the technological inventions (such as replacement of haematocytes by billions of nanorobots, *etc.*) in their forecasts try to use the outdated logic that was widespread several decades ago in science fiction or scary stories: the replacement of biological organisms with technical ones. The modern logic of scientific and technological progress including the latest achievements in bioengineering shows the shift towards the synthesis of biological forms and technical solutions into a unified system. Still there are numerous obstacles here. Let us take, for example, the above-mentioned possible opportunities for brain control which may be hampered by the immune rejection first of all. Second, many nanostructures, for example, nanopipes, which had been predicted a bright future appeared very toxic for human body (Kotov *et al.* 2009). Third, the implantation of external devices leads to traumatization of the whole organism despite all serious attempts to reduce this impact. Another problem is the different electric conductance of biological material and of a technical device, though there is certain progress in the solution of this problem (Abidian and Martin 2009). But even if we solve these problems we will still need some powerful software capable to handle brain signals.

Technical achievements can hardly replace the biological mechanisms which have been selected for many millions of years. On the contrary, we should follow the path of 'repair', improvement, the development of self-regulation and support of biological mechanisms via some technical solutions.

The human brain is very tightly connected with the body and sensory organs, most of its functions are based on the control of the body that does not imply its full-fledged work outside its biological foundation. The opportunities of science and medicine to replace worn organs will increase but the biological foundations of a human will always exist and must prevail. If one can help the human body by different means including methods of activization of immune system, opportunities of genetics, the methods of blocking or decelerating the process of ageing, *etc.*, it is much more reasonable to preserve the human biological foundation. In any case, in the nearest decades in the process of cyborgization quite radical breakthroughs are possible, but nevertheless the process of cyborgization will not go too far. Thus, we believe that in the next hundred years the human lifestyle and biological nature will experience crucial changes which can become a turning point in the transition to the post-human society. However, these changes, no matter how profound they are, will be very far from the images drawn by modern wishful-thinking scientists.

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