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The Cybernetic Revolution and the Forthcoming Epoch of Self-Regulating Systems

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The Cybernetic Revolution and the Forthcoming Epoch of Self-Regulating Systems. Moscow: Moscow branch of Uchitel Publishing House, 2016. – 216 pp.
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The monograph presents the ideas about the main changes that occurred in the development of technologies from the emergence of *Homo sapiens* till present time and outlines the prospects of their development in the next 30–60 years and in some respect until the end of the twenty-first century.

What determines the transition of a society from one level of development to another? One of the most fundamental causes is the global technological transformations. Among all major technological breakthroughs in history the most important are three production revolutions: 1) the Agrarian Revolution; 2) the Industrial Revolution; and 3) the Cybernetic one. The book introduces the theory of production revolutions which is a new valuable explanatory paradigm that analyzes causes and trends of dramatic shifts in historical process. The authors describe the course of technological transformations in history and demonstrate a possible application of the theory to explain the present and forthcoming technological changes. They analyze the technological shifts which took place in the second half of the twentieth and early twenty-first centuries and forecast the main shifts in the next half a century. On this basis the authors present a detailed analysis of the latest production revolution which is denoted as ‘Cybernetic’. They make some predictions about its development in the nearest five decades and up to the end of the twenty-first century and show that the development of various self-regulating systems will be the main trend of this revolution. The authors argue that the transition to the starting final phase of the Cybernetic Revolution (in the 2030–2040s) will first occur in the field of medicine (in some its innovative branches). In future we will deal with the started convergence of innovative technologies which will form the system of MANBRIC-technologies (*i.e.* the technological paradigm based on medicine, additive, nano- and bio- technologies, robotics, IT and cognitive technologies). The monograph gives an outline of the future breakthroughs in medicine and some other technologies (between the 2010s and 2070s).

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Contents

Introduction

Between Human and Post-Human Revolutions or What Future is Awaiting Us?

In the modern world an individual deals with different technologies and products of scientific and technological progress and becomes more and more dependent on them, spending considerable time to understand changes and to keep up with progress. In general, the entire human history especially in the last few centuries is the history of victories and triumph of science, technology, and information technologies. Moreover, the humankind being a father of technology at the same time became more and more dependent on it. Today technologies penetrate almost every aspect of our life: private, family and intimate, as well as our mentality. But even more serious transformations are awaiting us in the future when devices and technologies are introduced into the human body and consciousness thus putting strain on all our biological (nervous, physical, and intellectual) adaptive capacities. Today they give a serious thought to seemingly strange ideas about whether mobile phones, computers, and organizers can become a part of our body and brain. In fact, technology has become one of the most powerful forces of development.

The changes occurring within the society are very often caused by technological transformations. That is why the issues of technological development appeal to our contemporaries. So it is extremely important to reveal some regularity in the history of technological development, and make an effort to anticipate at least the coming transformations in technologies and in the society. But, unfortunately, there are quite a few researches which in a systemic and consistent way describe the technological development and can explain in scientific terms why and how the technological revolutions occur. Besides, there are also quite a few works that present a consistent forecast of technological development proceeding from the discovered developmental trends.

Our study is devoted to the history of development of engineering and technology, to the analysis of their current state and reflections about their future. In this book we pay attention to the main technological revolutions in the history of human society, both to those already completed and to the future ones, as well as to the transformations in society and consciousness they have already brought and will cause in the future.

In the 1950s and 1960s the world (first of all, the developed countries) witnessed the largest technological revolution which continues until the present. At the end of the twentieth century the achievements of this revolution especially in the field of information technologies have become widely spread in the most countries of the world. This revolution is variously termed (scientific-technological, information, *etc*.). However, we denote this revolution as the *Cybernetic Revolution* since cybernetics is the science about information and its transformations in the process of regulating various complex systems. The current revolution has dramatically changed the information processing as well as promoted a breakthrough in the regulation of complex processes in a wide range of natural and artificial systems that have become a part of production process (and in the future it is likely to trigger such a breakthrough to the full scale by creating an essentially new environment, *i.e.* a world of self-regulating systems).

The Cybernetic Revolution is the third largest production revolution in the history of humankind following the Agrarian (Neolithic) and Industrial ones; yet, it has not finished yet. In this volume we discuss the revolutionary changes which the world will face in the coming six–seven decades within the ongoing Cybernetic Revolution. The coming phase of the Cybernetic Revolution will change the quality of our life by enhancing the impact on human body. There will also appear technologies that will allow different systems to function in a necessary regime without direct human intervention (*i.e.* these systems will become autonomous and self-regulated). The capability to maintain the given parameters in self-supporting (autonomous, self-regulated) regime will involve the control of production and information that has already become possible in various spheres during the decades of the Cybernetic Revolution, as well as control of a number of technological, social, natural, and especially biological processes (as well as in the human body).

Earlier they used to connect the emergence of *Homo sapiens* with new technologies (arguing that labour transformed apes into humans, while the labour implied first of all the ‘production’ of stone tools). Now it is clear that it was the result of a range of reasons which changed human genetics, though the material factors (such as the way of life and natural environment) also enormously contributed to this process. The transition to *Homo sapiens* is termed the *Human revolution* (*e.g.,* Mellars and Stringer 1989), yet we would better denote it as *Proto*-production revolution with account of its impact on the society since it triggered quite a rapid development of technology proper (what is more, technology developed in different spheres including also the primitive painting).

Today we are at the threshold of the Post-human revolution. Perhaps, it will be less dramatic than the transhumanists and other adherents of practical immortality imagine it in a wish to part with the biological body. But anyway we are speaking about considerable extension of life, increasingly common replacement of organs and cells of the human body with non-biological materials, introducing of electronic and other (nano-, *etc.*) elements into the human body for rehabilitation or improvement of individual functionality, and systematic influence on genome. On the whole, quite dramatic changes are upcoming.

Thus, figuratively speaking, our research lies at the intersection of Human (or Upper Paleolithic) revolution and the new 'post-human' revolution whose consequences are unclear in many respects but which will obviously start the era of an intensive impact on human body.

Between Technological Optimism and Reasonable Caution

In our book basing on the studies of the whole previous technological development we try to outline the direction and logic of further technological progress, as well as to describe the future which is already knocking at our door. In the chapters devoted to current and future changes we will pay much attention to the analysis of the features that will manifest in technologies and to what we can expect from them. But we would not like the reader to think that the authors estimate every change described in the book only in a positive and optimistic way.

Futurologists can be divided into impetuous optimists, alarmist, and careful optimists, the latter calling to think in advance of the negative consequences without disregarding progress. We belong to the third category and think that we should not be afraid of the future. However, one can hardly expect that the future will be definitely better than the present, and moreover, in every aspect. The stakes are always high.

Indeed, the achievements being a solution to problems can also cause them and even at a larger scale, thus, contributing to the increasing dependence. Besides, in the future there will appear many problems resulting from the change of the habitual way of life.

It is difficult and actually senseless to try to impede progress. However, there is always a question of what one should consider as a progress at every particular epoch and what the costs are. Anyway, it is better not to rush into changes with vague consequences. When treading new ground, it is better to be careful than to rush. Science, innovations, and changes rapidly drive a lot of new legal, moral, and economic problems and cause sharp disputes, conflicts, trade wars, and phobias. The public consciousness definitely lags behind. The uncontrollable technological progress can be compared with the Roc, the legendary bird from the Arabian Nights that quickly carries the humankind but demands human sacrifice. Are we ready for it? Meanwhile, what we are ready to sacrifice for the sake of progress is one of the most important issues.

One may ask: why discuss the dangers today if they are still longshot? The thing is that future can turn out quite unexpected and even terrible. Thus, one should anticipate and think of it in advance. Anyway, it is necessary to speak about it since there are numerous threats whose number increases in a geometric progression due to the accelerating changes, the same way as a higher speed increases the likelihood of an accident (see also the final part of Appendix 2).

The development usually starts with euphoria from implementation of new tools or knowledge and only much later there comes an understanding of pressing problems which they bring, and finally, the restrictive measures are taken on their application to reduce the revealed negative consequences. However, it is much better to change this sequence and even to find legal and appropriate restrictions before implementation.

In Anticipation of Dramatic Changes in Evolution and Human Nature

Many researchers suppose that we have been moving towards some quite considerable transformations and that in the next decades, human civilization will experience dramatic changes. Some speak about approaching the singularity point as a certain unprecedented level of development (yet singularity is a mathematical notion and not social or evolutionary one), after which a new phase of development of human and nature will start[1] (here we should especially point out Raymond Kurzweil's works, *e.g.*: Kurzweil 2005, which we can evaluate as a boundless technological optimism lacking sufficient scientific grounding). And this perception of dramatic changes is quite natural. We also believe that in the 2030–2040s the world will enter an epoch of significant and even dramatic changes. However, contrary to other researchers, we argue that this will be an expected result of previous

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[1] For more details about views on singularity see Grinin L. and Grinin A. 2015: 11; see also: Tsirel 2014; see the comment in Appendix 2 in connection with the citation in Dyakonov 1999: 348.

development of society and especially of technologies. Thus, the driving forces of the future changes are by no means mysterious or unique. And still there are many disturbing things… One should realize that these changes in human development not only provide new opportunities, but also conceal serious risks which must be anticipated.

In the end of the twentieth and early twenty-first centuries there will be widely spread an idea of a possible or even inevitable transition of humankind to a new biological form in the near future. What does it mean and what consequences will it have? Is it possible to change this line or does it realize any exceptionally challenging evolutionary trends? It is extremely difficult to answer these questions especially since they are inherently ideologized and turned into a kind of religion whose main postulate is the future immortality of every individual.

In brief, today the focus is on the increasing opportunities of changing the human nature. Consequently, the question is what is the human nature itself and to what extent can it be modified? We think that Francis Fukuyama has thoroughly analyzed this issue in his *Our Post-human Future* (Fukuyama 2002) and thus, there is no need to consider it in our research. In his opinion, *human nature is a set of behaviors and properties typical for a human as a species and arising from genetic backgrounds, but not factors of environment* (Fukuyama 2002). However, he often expressed the idea that human rights can be derived from the biological nature to prove the advantages of democratic political regimes over others. We find this approach rather disputable.

We would also like to emphasize that fifteen years have passed since Fukuyama wrote his book and today the issue is much more pressing. There exist different philosophic approaches concerning humans as a social species, but today the topical matter is the human biological nature not in philosophical terms but in a concrete medical and biological sense. The emergence of artificial organs and cells has already brought about the issue of human material and biological nature, namely: what matter will a future human be made of – natural biological or artificially made biological substance or will it be a non-biological being at all? How will humans reproduce? How will the brain and consciousness operate? Any change will dramatically alter human fundamental institutions including morals and interpersonal relations. Indeed, what will become of morals and what will it be if the matter concerns the change in the biological nature? Morals and human relations do not exist separately from technologies, all the more from human physiology and, and in a broader sense, from the biological basis. It is a result of complex sociobiological evolution, and morals can disappear after losing its material biopsychic shell.

From Human to Cyborg?

Already at the end of the last century it became clear that the opportunities to influence human genotype can generate a lot of complicated and dramatic social, political, ethic, and legal problems in the future. One should note that bioethics became a response to these future (and already emerging) dangers. Of course, this society's response has no serious implications, but after all it was meaningful. Fukuyama gives a rather detailed list of the dangers. In particular, he mentions the increasing opportunities to regulate human behavior (here he emphasizes that neuromediators made it possible already in the end of the last century), the emergence of genetic castes, classes or social strata since changing of genetic qualities can heavily depend on parents' wealth; otherwise, a more egalitarian society in terms of genetics will appear (in case of obligatory correction).[2] In fact, the attempt to improve human moral nature by means of genetic modifications seems rather dangerous. In this context the reduced diversity can significantly weaken society and its ability to respond to challenges.

However, so far we have hardly touched new and to some extent more serious threats that have recently appeared. Let us consider some of them.

It has already been mentioned that the pace of scientific and technological progress generally continues to speed up. The historical process is also gearing up while neither individual, nor public consciousness is able to keep up with it. This brings heavy collisions and frustrations, and moreover, it arouses a quite reasonable alarm about our future, and it is not about social, but about physiological and biological future since the number of people increases who wish to refuse it and to put the brain and consciousness into an abiotic immortal body (made of iron, plastic or other material). Will humans turn into cyborgs, as a result of the rapidly developing directions of bionanotechnology and cognitive sciences? It is not an idle or innocent matter at all, especially with the account of the increasing number of prophets of 'avatarization'[3] who bravely (and without thinking) appeal to discard the perishable biological body.

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[2] These fears have not decreased since then; on the contrary, the number of opponents of genetic modifications has grown, and their arguments became more convincing. At the same time it seems that the practical modification of human embryos has already started. Thus, in April 2015 China declared about the conducted work on modification of the human embryo (Field 2015).

[3] Avatar is the term used in Hinduism philosophy to denote the terrestrial embodiments of God (especially Vishnu). Respectively this term is used by some supporters of coming human immortali-

How much truth is there? Actually, on the one hand, medicine has been moving in this direction for many decades and it has learnt to make false teeth, connective tissues, bodies, to replace sense organs with devices, and to create life support systems (hearts, lungs, kidneys, *etc*.), not to mention the production of artificial preparations (drugs) causing reactions similar to those resulting from the activity of endocrine glands, impulses of the brain or work of internals. Currently, bioprinters have been actively developed and they can create these or those organs; there are also neural interfaces (or brain–computer interfaces) permitting to operate some facilities, devices and equipment 'by force of thought' through biological currents and microelectronics (see more details in Chs. 3 and 6). Undoubtedly, the opportunities for creating organs, tissues and fractions from artificial non-biological materials will considerably increase in the future. All this contributes to the transformation of the human body into a kind of cyborg. Besides, this increases a certain oncoming traffic of technologies in terms of rapprochement of people and artificial smart systems, in particular in the construction of humanoids. These robots will be employed not only as workers, but also in very close or even intimate contacts with people (*e.g*., they can be used for sexual services, or as companions, *etc*.). Then the borders between the human and artificial anthropomorphous systems are likely to dissolve.[4] Besides, modern information technologies already create a virtual environment where it becomes more difficult to distinguish reality from illusion; to say nothing of use of modern bio, cognitive and robotic technologies for military purposes.

But, on the other hand, any simplified ideas of human body and, all the more, brain and consciousness are extremely dangerous (similar to the dangerous use of brain at the level of electronic device). Millions of years of biological evolution have made all constituents of biological organisms and their functions optimal, interconnected, and sensitive to changes at any part of the body so that any interference with physiology, and all the more, the brain, has to be thought over many times to prevent possible damage. Even the slightest knowledge of biology makes it clear that human brain cannot work without

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ty to determine the transformation of the human spirit (brain and consciousness) into the new (non-biological) body.

[4] Let us note that the production of sexual robots (generally 'female', so far) has already started. There were also statements that by the middle of the century such contacts between humans and robots will become commonplace. Not without reason a campaign for their prohibition has been initiated (see Griffin 2015). However, so far these requirements come from the feminists who are concerned with such a detraction of the female role, but we agree with them. It is better to forbid or to take under control this situation in advance, because if businessmen have a chance, sex robots for any sexual orientation might appear.

body since its main function is to accept signals from the body and to transfer them. Thus, any ideas that consciousness can be somehow 'transplanted' are a rough and ignorant imagination. Therefore, the process of cyborgization can never go too far, it will always remain 'supplementary' for the biological component of organism and it can considerably improve quality of life as well as to prolong it.

Today the scientists learn to create artificial biological tissues and bodies by means of stem cells or other biotechnologies. We suppose that this way of 'repairing' our body will be more promising. For example, at present, we know some cases when a person was replaced heart six times (and once a kidney) during his life. This is a multi-millionaire David Rockefeller Sr. who has undergone the last operation on heart transplantation at the age of 99. But now only a multi-millionaire can afford it (and nevertheless, he is really lucky). However, in the future it will be possible 'to repair' many people by means of laboratory-grown organs. But, undoubtedly, this biological interference into human body has both physiological and social restrictions. The interference with human genetics can also cause serious problems, especially if used for creation of individuals with superhuman potential, for example, for sports records. Nowadays, as we know, sports organizations fight against using medical and pharmaceutical achievements for gaining advantages. In this context, it would be better to avoid the emergence of genetic control over athletes, but still there exists such an opportunity. Thus, hopefully it will become possible to prevent reckless interference with human body regardless of its motives: whether it is aspiration for scientific fame or profit or realization of the superman ideology. While welcoming the scientific and technological progress, we consider that we should preserve our biological heritage that has been created over millions of years.

The Structure of the Book

In **the first chapter** of the monograph the authors describe the main technological changes. The description covers almost the entire period of social evolution starting from the emergence of *Homo sapiens* up to the mid-twentieth century when the Cybernetic Revolution began. We did not point out every considerable invention or separate innovations in detail instead we made an attempt to show the general process of changes and to explain how and why technological epochs succeeded each other.

In **the second chapter** we describe the main characteristics of the Cybernetic Revolution, which we already can observe, yet they will be implemented in mature and mass forms only in the future. Of utmost importance is the fact that the self-regulating systems will become the major part of technological process. That is the reason why we denote the final (forthcoming) phase of the Cybernetic Revolution as the epoch of self-regulating systems. The self-regulating systems are systems which can regulate themselves by means of the embedded programs and smart components, responding in a pre-programmed and intelligent way to the feedback from the environment as well as operate independently in a wide range of situations, having opportunities for choosing optimum regimes in the context of certain goals and tasks. These are systems that operate with minimal to zero human intervention. In the second chapter we also discuss the logic of the Cybernetic Revolution, which gives us opportunity to forecast the duration of the intermediate and final phases of the Cybernetic Revolution as well as explain why medicine is to become the breakthrough sphere in the beginning of the final phase of the Cybernetic Revolution.

The third and the subsequent chapters of our research are devoted to the forecasts about the intermediate and final phases of the Cybernetic Revolution in the next 30–60 years, with respect to some fields the forecasts are given until the end of the twenty-first century. We study the development of those directions which in our opinion are most likely to trigger the future technological breakthrough, namely, medicine, additive (3D-printers), nano-, bio-, robotics, information, and cognitive technologies which we unite under the designation of MANBRIC-technologies. Altogether these areas will start the epoch of self-regulating systems which will provide unprecedented opportunities and also cause new unprecedented problems. One should note that the technological development heading for self-regulating systems correlates with the general evolutionary advance towards an increasing level of self-regulation within systems, especially animate and social ones. And it gives additional relevance to the subject of our monograph. The **third chapter** is devoted to the development of medicine. The **fourth** and **fifth chapters** consider the advances and future transformations of biotechnologies and nanotechnologies. The **six chapter** describes opportunities provided by others technologies, namely, robotics, additive and cognitive technologies, transportation, energetic *etc*.

The book also comprises **three Appendices** related to the first chapter. In the **first Appendix** some issues of the theory of historical process are considered (the notion itself as well as the procedure of periodization of historical process). In **Appendix 2** the authors present some tabular and graphic interpretations of the technological aspect of historical process (production principles and production revolutions analyzed by the authors) and some issues connected with accelerating historical process. **Appendix 3** establishes a close correlation between production principle cycles and Kondratieff cycles, the latter being the repeated fluctuations of important economic variables with a characteristic period of about 40–60 years.

We hope that our research will be interesting for those who study the issues of technological development, its role in historical process and societal advance and also for those who would like to learn more about the future development of technologies and society.

Acknowledgment

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Chapter 1

Global Technological Transformations: Theory and History

For many millennia humans have improved their tools as well as developed economic patterns, technologies, storage techniques, exchange practice and transportation means. In the history of technologies especially during the last two centuries there have occurred many significant breakthroughs while the production has been modernized over and over again. Nowadays, we quite often learn about new achievements in engineering and technologies. But for the most part of human history the matter was different. For centuries and even millennia the transformations would pass undistinguished (Anuchin 1923; Lurie *et al.* 1939; Semenov 1968; Chernousov *et al.* 2005; Belkind *et al.* 1956; see also: Boas 1911; Kosven 1953; Kremkova 1936; Osipov 1959; Virginsky and Khoteenkov 1993; Sheypak 2009). Many technologies would appear rather conservative. However, even for the ancient epochs the technological changes were among the most fundamental drivers of development and complication of societies, of demographic growth and cultural progress.

On this large scale it becomes especially evident that, using Fernand Braudel's words (1985), 'in reality, everything rested upon the very broad back of material life; when material life expanded, everything moved ahead.' That is why the distinguishing of the greatest technological revolutions also allows setting a periodization of historical process in general. In the course of time such transformations became powerful, multidimensional, and sometimes even revolutionary. However, a relevant dominance of technology can be recognized only within very large time spans and strict limits. Meanwhile, in the human history one can distinguish only three most dramatic revolutions which are the thresholds of the respective four technological epochs (or production principles). They are: 1) the Agrarian Revolution; 2) the Industrial Revolution; and 3) the Cybernetic Revolution. In what follows we will discuss them in detail.

1. The Production Principles and Production Revolutions

1.1. Periodization of historical process

According to the theory that we elaborate, the historical process can be subdivided more effectively into four major stages or four formations. The transition from any of these formations to another means a change of all basic characteristics of the respective system. However, in addition to this principal basis of periodization (that determines the number of periods and their characteristics), we need an additional basis that will help us to work out an elaborated chronology.

As such an additional basis we have proposed the notion of *production principle* (*e.g.*, Grinin 2007a, 2007b; 2012a: ch. 1; 2013; Grinin A. and Grinin L. 2015; Grinin L. and Grinin A. 2013a) that describes the major qualitative developmental stages of the world productive forces.

Below we suggested a model of periodization of historical process based on our theory of historical process. It is important to state the following reservation: this periodization can only be applied to world historical process and to a considerable (but not to the full) degree to the evolution of World System (interpreting it after the manner of Andre Gunder Frank [Frank 1990, 1993; Frank and Gills 1993; Korotayev and Grinin 2006; Grinin and Korotayev 2006, 2009]). Thus, our periodization refers only to macroevolutionary processes, and therefore can be directly applied to the histories of particular countries and societies only by means of special and rather complicated methodological procedures. Its task is to define a scale for measurement of processes of the humankind's development (or at least of the evolution of World System) and to mark possibilities for intersocietal comparison.

For more details about the procedure of periodization as well as about the concept of historical process see Appendix 1. In Appendix 2 we also demonstrate the possibilities of mathematical modeling of temporal processes and temporal cycles in historical development.

We single out four *production principles*:

1. **Hunter-gatherer.**
2. **Craft-agrarian.**
3. **Trade-industrial.**
4. **Scientific-cybernetic.**

Though the qualitative transformations in some spheres of life are closely connected with changes in other ones (and, thus, no factors can be considered as absolutely dominant), some spheres can be considered as more significant with respect to their influence; so changes within them are more likely to affect other spheres than the other way round.[1] The production principle belongs to such spheres due to the following reasons:

1. Significant changes in the production basis lead to more surpluses produced and to a rapid population growth. And together these processes lead to changes in all other spheres of life. Meanwhile, the transition to new social relations, new religious forms, *etc.* is not as directly correlated with demographic changes as are the transformations of production principle.

2. Though a significant surplus can be explained by some other factors (natural abundance, successful trade or war), such exceptional conditions cannot be reproduced, whereas new productive forces can be reproduced and diffused, and thus, they appear in many societies.

3. Production technologies are implemented by the whole society (and what is especially important, by the lower social strata), whereas culture, politics, law, and even religion are systems developed by their participants (usually the elites).

The change in production principles is connected with production revolutions. The starting point of such revolutions can be regarded as a convenient and natural point to establish the chronology of changing patterns.

1.2. The Production Revolutions

Three production revolutions. Let us emphasize again: among large technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian Revolution (the Neolithic Revolution); 2) the Industrial Revolution, and 3) the Cybernetic Revolution. From our point of view, each revolution initiates a new stage of development of the world productive forces as well as a transition to a new stage of historical process.

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[1] Of course, we do not mean continuous and regular influence but rather a qualitative breakthrough. If after a breakthrough within a more fundamental sphere other spheres do not catch up with it, the development within the former slows down.

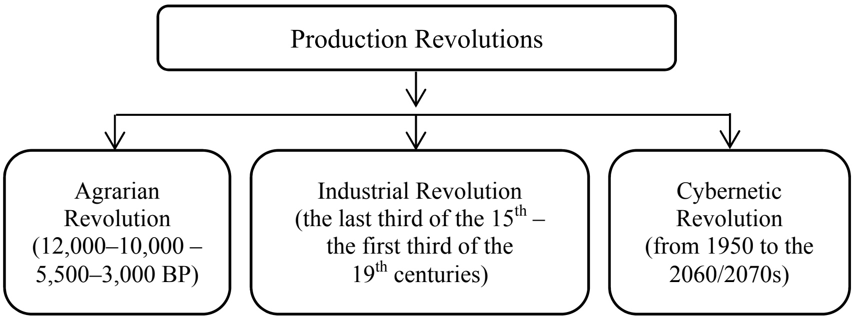

Fig. 1. Production revolutions in historical process

1. *The Agrarian Revolution* was *a great transition from foraging subsistence pattern, that is from getting food by collecting what is available in nature (through hunting, gathering, and fishing) to farming.* Its outcome was the transition to systemic food production and basing on it to a complex social labour division. This revolution was also associated with the emergence of new source of energy (animal power) and materials.

2. *The Industrial Revolution* was *a stupendous transition from the craft-agrarian production principle to a new pattern* which implied that the main production was concentrated in industry and performed by machines and mechanisms. The significance of this revolution consists not only in the manual labor being replaced by the machine production, but also in the substitution of biological energy for water and steam power. This meant a regular implementation of scientific and technological achievements in production and a constant strife for innovations. The Industrial Revolution introduced labor-saving in a broad sense (physical labour as well as account, control, management, exchange, credit, and information transfer).

3. *The Cybernetic Revolution* was *a great transition from the trade-industrial production principle to the production and service sector based on the implementation of self-regulating systems.* The first phase of this revolution started in the 1950s and 1960s and brought the development of powerful information technologies, the emergence of new materials and sources of energy, as well as the distribution of automation. Between the 2030s and 2070s the final phase of this revolution will unfold which will dramatically increase the opportunities of control over some helpful technical, biological, ecological, and even social systems

which will be transformed into independently working self-regulating systems. It is the human organism that will become one of the main subjects of the Cybernetic Revolution. Due to dramatic breakthroughs in medicine there will appear opportunities to radically increase the life expectancy and expand the range of possible modifications of human biological nature.

Literature review on production revolutions. The above-mentioned technological thresholds in the history of societies have been long attracting academic community. The Industrial Revolution became the object of an extensive research in the nineteenth and early twentieth centuries both within Marxist framework and within the non-Marxist paradigms (see, *e.g*., Engels 1955 [1845]; Marx 1960 [1867]; Plekhanov 1956 [1895]; Labriola 1986 [1896]; Toynbee 1927 [1884]; 1956 [1884]; Mantoux 1929). The first ideas on the Agrarian (Neolithic) revolution were introduced by Gordon Childe in the 1930s and between the 1940s and 1950s he developed the theory of the Neolithic revolution (Childe 1934, 1944, 1948). From the 1940s there was observed an increasing interest in the analysis of the impact of production on the historical development and historical process in general; meanwhile, the originating technological society received both optimistic and pessimistic assessments. The interest became even more acute after it was perceived that the world had entered the Cybernetic Revolution (which in the 1950s and 1980s was denoted by different terms; thus, within some approach it was called the scientific and technological revolution following John Bernal [1965]). It is not surprising then that in the 1960s and 1980s the increasing interest in production revolutions found its expression in numerous works including the publications of such postindustrial economists as Daniel Bell (1973, 1978, 1990), Alvin Toffler (1980, 1985, 1990; Toffler A. and Toffler H. 1995), Tom Stonier (1983), Alain Touraine (1974; 1983), Herman Kahn (1983), and to a lesser extent in other scholars' works (Drucker 1995, 1996; Thurow 1996; see also Dizard 1982; Martin 1981; Castells 1996), not to mention the philosophers of technology (Ellul 1964, 1975, 1982, 1984; Mumford 1966; *etc*.; see also Inozemtsev 1999).

Much has been written about each of the three production revolutions (see, *e.g.*, Allen 2009, 2011; Bellwood 2004; Benson and Lloyd 1983; Bernal 1965; Cauvin 2000; Cipolla 1976; Clark 2007; Cohen

1977; Cowan and Watson 1992; Dietz 1927; Goldstone 2009; Harris and Hillman 1989; Henderson 1961; Huang 2002; Ingold 1980; Knowles 1937; Lieberman 1972; Mokyr 1985, 1990, 1993, 1999, 2010; Mokyr and Foth 2010; More 2000; North 1981; Philipson 1962; Phyllys 1965; Pomeranz 2000; Reed 1977; Rindos 1984; Sabo 1979; Shnirelman 1989, 2012a, 2012b; Smith 1976; Stearns 1993, 1998; Sylvester and Klotz 1983). However, there is a surprisingly small number of studies concerning these revolutions as recurrent phenomena, each representing an extremely important landmark in the history of humankind. We have developed a theory of production revolutions within the framework of the general theory of the world historical process (Grinin 2007a, 2007b, 2012a; Grinin L. and Grinin A. 2013b, 2015).

What is a production revolution, its characteristics and phases. *The production revolution can be defined as a radical turn in the world productive forces connected with the transition to a new principle of management not only in technologies but in the relations between society and nature. The difference of a production revolution from various technical overturns is that it involves not only some separate essential branches but the economy on the whole. And finally, the new trends of management become dominant. Such an overturn introduces some fundamentally new renewable or long inexhaustible resources in the economical circulation, and these resources spread widely enough within most territories. The labor productivity and/or land carrying capacity (the yield of useful product per unit of area) increase by orders of magnitude which is also manifested in the creation of several orders greater volume of production and in the demographic revolution (or the change of the demographic reproduction type).*

As a result, the most powerful impetus for qualitative reorganization of the whole social structure is generated. Although the production revolution originates in one or a few places, it signifies a turn of the *world* productive forces, and represents a long lasting process gradually involving more and more societies and territories. As a result a) the involved societies become progressive in technological, economical, demographical, cultural and often military aspects; b) the engagement into new production system becomes a rule.

Each production revolution has its own cycle. We can speak about three phases, including two innovative phases and between them – a modernization phase of expansion of a new production principle, that is a long period of distribution and diffusion of innovations.

Thus, the cycle of each production revolution looks as follows: *the initial innovative phase* (the emergence of a new revolutionary productive sector) – *the modernization phase* (distribution, synthesis and improvement of new technologies) – *the final innovative phase* (improving the potentials of new technologies up to the mature characteristics). See also Fig. 2.

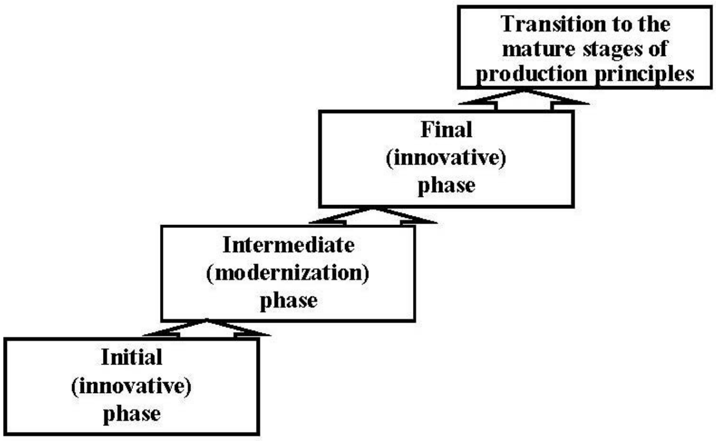

Fig. 2. A cycle of a production revolution (phases and characteristics)

At *the initial innovative phase* a new revolutionary productive sector emerges. The primary system for a new production principle emerges and for a long time it co-exists with former technologies. *The modernization phase* is a long period of distribution and development of innovations. It is a period of progressive innovations when the conditions gradually emerge for the final innovative breakthrough. At *the final innovative phase* a new wave of innovations dramatically expands and improves opportunities for the new production principle, which thus, attain full strength. As the final phase of the production revolution unfolds, the 'essence' of the production principle, its opportunities and limitations are revealed, as well as the geographical borders of its expansion via merging with new states.

The production revolutions also bring about:

1. The development of fundamentally new resources.
2. A vigorous growth of production output and population.
3. Substantial complications to society.

(For more details see Grinin 2006b, 2007a, 2012a; Grinin L. and Grinin A. 2013a; about the Industrial Revolution see Grinin and Korotayev 2015a).

Each innovative phase of a production revolution represents a major breakthrough in production. During the first innovative phase the hotbeds of new production principle are formed; the sectors concentrating the principally new production elements grow in strength. Then the qualitatively new elements diffuse to other societies and territories during the modernization phase. In countries with the most promising production and adequate social conditions, the transition to the second innovative phase of production revolution occurs marking the flourishing of the new production principle. Now the underdeveloped societies catch up with the production revolution and become more actively involved in it. Thus, we observe a certain rhythm of alternating qualitative and quantitative aspects. Moreover, we identify certain regularities in the phases of production revolutions. These regularities imply that within every production revolution each of its three phases plays functionally the same role. Besides, we revealed an important ratio between the duration of phases which we found to *remain approximately the same within the framework of each cycle* (see Appendix 2 for more details). This ratio allows defining some regularities which can be employed in forecasting. In Chapter 2 we discuss these regularities basing on the correlations between phases of production revolutions and employ them to forecast the peculiarities of the final phase of the Cybernetic Revolution.

Further we offer a general scheme of two innovative phases of a production revolution according to our theory.

The Agrarian Revolution was a great breakthrough from the hunter-gatherer production principle to farming. Its *initial innovative phase* was the transition to primitive hoe agriculture and animal husbandry (12,000–9,000 BP) while the final phase brought the transition to intensive agriculture (especially to irrigation [5300–3700 BP] or non-irrigation plough one). These changes are also presented in Table 1.

Table 1. The phases of the Agrarian Revolution

Phases	Type	Name	Dates	Changes
Initial	Innovative	Manual farming	12,000–9,000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Intermediate	Modernization	Distribution 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 plough agriculture	5,500–3,500 BP	Transition to irrigative or non-irrigated plow agriculture

The Industrial Revolution was a great breakthrough from the 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* starts in the fifteenth and sixteenth centuries with a vigorous development of seafaring and trade, mechanization on the basis of water engine, the deepening division of labor (Durkheim 1997 [1893]) and other processes. The *final phase* was the industrial breakthrough in the eighteenth century and the first third of the nineteenth century which is associated with introduction of various machines and steam energy (for more details about the Industrial Revolution see Grinin 2007a; Grinin and Korotayev 2015a). These changes are presented in Table 2.

Table 2. The phases of the Industrial Revolution

Phases	Type	Name of the phase	Dates	Changes
1	2	3	4	5
Initial	Innovative	Manufacturing	15th – 16th centuries	Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization

1	2	3	4	5
Intermediate	Modernization	Primary industry	17th – early 18th centuries	Formation of a complex industrial sector and capitalist economy, increasing mechanization and division of labor
Final	Innovative	Machinery	1730–1830s	Formation of sectors with the machine production cycle with steam energy

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

Its *initial* phase, which we call the *scientific-information epoch*, dates to the period between 1950s and 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 start in the nearest decades, that is in the 2030s or a bit later, and will last until the 2070s. This forthcoming phase can be called the *epoch of self-regulating systems* since the major point lies in the creation of self-controlled systems or systems indirectly controlled either via other systems or by means of point impact and corrections. As a result there will be much more opportunities to eliminate a direct human interference upon various natural, social, and production processes whose control is impossible or quite limited at present. The drivers of the final phase of the Cybernetic Revolution will be medical technologies, additive manufacturing (3D printers), nano- and bio- technologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulated production. We can denote this complex as MANBRIC-technologies.[2] As it was mentioned above, with respect to the sixth technological paradigm there is a widely used idea connected with the notion of NBIC-convergence[3] (see Lynch 2004; Bainbridge and Roco 2005; Dator 2006; Kovalchuk 2011; Akayev 2012). There are also

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[2] The order of the letters in the acronym does not reflect our understanding of the relative importance of the areas included in the complex. For example, biotechnologies will be more important than nanotechnologies, let alone additive manufacturing. The order is determined simply by the convenience of pronunciation.

[3] Nano-Bio-Info-Cognitive.

some researchers (*e.g.*, Jotterand 2008) who see another set of technological directions in this role – GRAIN (Genomics, Robotics, Artificial Intelligence, and Nano-technology). However, we believe that this set will be larger. And medical technologies will be its integrating part (see the next chapters for more details).

So now we are at the 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 stage (*e.g.*, computers, internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough.

The scheme of the Cybernetic Revolution is presented in Fig. 3.

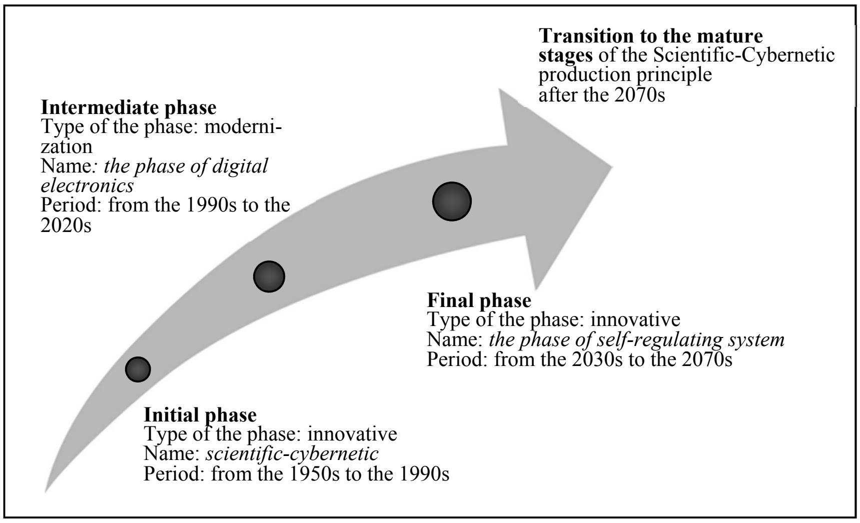

Fig. 3. The phases of the Cybernetic Revolution

1.3. Production principles

Phases of production principals. We believe that the production revolution can be regarded as an integral part of the production principle and as its first 'half' after which the development of mature relations occurs. This approach demonstrates in a rather explicit way the main 'intrigue' of the cyclical pattern of historical formations. During their first period we mostly observe dramatic changes in production, whereas in the second half we deal with especially profound changes in political and social relations, public consciousness and other spheres. Within these periods, on the one hand, political-judicial and sociocultural relations catch up with the more advanced productive forces, and, on the other hand, they create a new level which gives impetus to the formation of a new production principle.

However, the cycle of production principle can be also represented in a conventional three-phase fashion: *formation, maturity,* and *decline*. Yet, in a certain sense it appears more convenient to describe it in six phases which demonstrate the additional rhythm of change of qualitative and quantitative characteristics. This cycle looks as follows:

1. The first phase – 'transitional' – is *the start of production revolution and the formation of a new production principle*. The latter emerges in one or a few places, although in rather undeveloped, incomplete, and imperfect forms.
2. The second phase is *the stage of initial modernization*. It is associated with a wider diffusion of new production forms as well as with reinforcement and vigorous expansion of a new production principle.
3. The third phase is *the final stage of a production revolution.* The production principle obtains mature characteristics.
4. The fourth phase is *the stage of maturity and expansion of a production principle*. It is connected with diffusing new technologies to most regions and production spheres. The production principle acquires its mature forms and this leads to important changes in social-economic sphere.
5. The fifth phase implies *an absolute dominance of a production principle.* It brings an intensification of production and the full realization of the potential of the principle.
6. The sixth phase is *the stage of non-system phenomena* or *a preparatory phase* (for the transition to a new production principle). Intensification leads to the emergence of non-system elements (for the given production principle) which prepare the formation of a new production principle (when under favorable conditions these elements can form a system thus, triggering the transition to a new production principle in some societies and launching a new cycle).

The correlation between phases of production principles and phases of production revolutions is spelled out in Fig. 4.

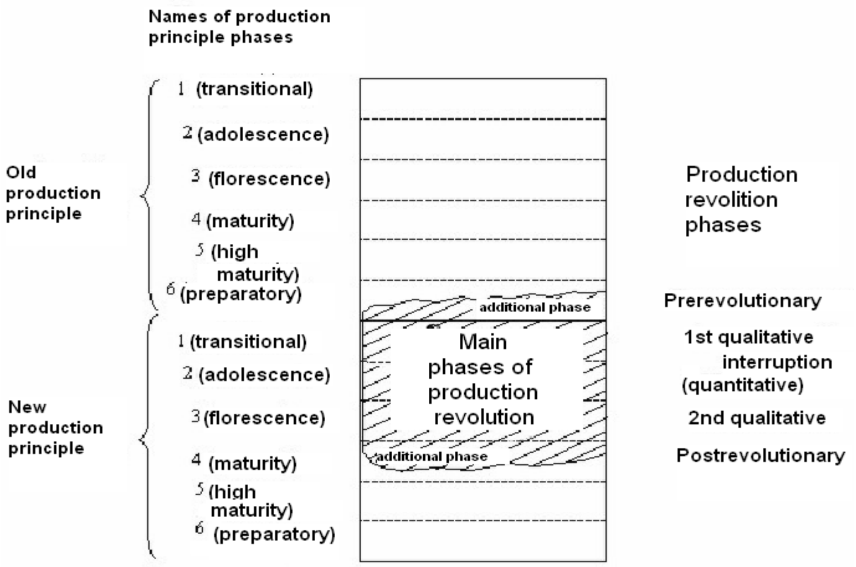

Fig. 4. The correlation between phases of production principles and phases of production revolutions

Explication:
/ / / / – temporal volume of production revolution
—— – borders between production principles

2. The Development of Historical Process in the Light of the Theory of Production Revolutions

2.1. When did historical process start?

Now let us describe our chronology of production principles, production revolutions, and their phases. We start from the period about 40,000–50,000 years ago (but to facilitate our calculations we proceed from the date of 40,000 years ago), that is, since the emergence of the first indisputable indications of truly human culture and society.

Note that this date is not identical with the modern dating of the emergence of Homo sapiens sapiens (100,000–200,000 years ago). Although the recent discoveries have shifted the date of the Homo sapiens sapiens formation back in time to 100–200 thousand years ago (see, *e.g.*, Bar-Yosef 2002; Bar-Yosef and Vandermeersch 1993; Culotta 1999;

Gibbons 1997; Holden 1998; Kaufman 1999; Klima 2003: 206; Lambert 1991; Marks 1993; Pääbo 1995; Shea 2007; Stringer 1990; White *et al.* 2003; Zhdanko 1999; see also Atkinson *et al.* 2009; Derevyanko 2011; Grinin 2009b; Kazankov 2012; Markov 2011a, 2011b, 2012; Mellars 2006), the landmark of 40,000–50,000 years ago still retains its major significance. This is the point after which we can definitely speak about humans of modern cultural type, in particular, about the presence of developed languages and 'distinctly human' culture (Bar-Yosef and Vandermeersch 1993: 94). And although there are suggestions that developed languages appeared well before 40–50 thousand years ago, still these suggestions remain hypothetical. Most researchers suppose that the dependence on language appeared not earlier than 40,000 years ago (see Holden 1998: 1455); meanwhile, as Richard Klein maintains, 'everybody would accept that 40,000 years ago language is everywhere' (*Ibid.*). Klein, a paleoanthropologist from Stanford University, has offered a theory explaining this gap between the origin of anatomically modern Homo sapiens and delayed emergence of language and cultural artifacts: the modern mind is the result of a dramatic genetic change. He dates this change to around 50,000 years ago, pointing out that the rise of cultural artifacts comes after that date, as does the spread of modern humans from Africa (see Zimmer 2003: 41 ff.). So the period from 50,000 to 40,000 years ago is the origin of social evolution in the narrow sense.

Thus, the anthropogenesis had actively unfolded until the defined period. We agree with some scholars' idea to consider the period of anthropogenesis as a pre-history which can hardly be included into the history in its proper sense (Roginsky 1977; see also: Boriskovsky 1980: 171–173; Rumyantsev 1987: 19). Nevertheless, some new evidence can change this view since some traces of the symbolic thinking and proto-art had existed in Africa long before the Upper Paleolithic (see, *e.g.*, Henshilwood *et al.* 2011). From time to time there appears information about sensational discoveries. Thus, in November 2006 Associate Professor Sheila Coulson, from the University of Oslo, announced the discovery of an artifact which is 70,000 years old and which points to the cult of a giant snake. This artifact is an evidence of the mankind's oldest known ritual. They used to think that human mind had developed to the level of group rituals only by 40,000 years ago. However, in the mountain cave in the Kalahari Desert in Botswana the archeologists found a human-size stone figure of a python (Steiger 2007).

Meanwhile, to understand the reason to choose this landmark one should take into consideration that any periodization must have a certain conceptual and formal unity at its basis. In particular, we believe that it is possible to speak about social evolution in its proper sense only after the social forces became the basic driving forces for the development of human communities. We suppose that in the era of anthropogenesis one should include not only the long period of time when our apelike ancestors (Ingold 2002: 8) were gradually obtaining an anatomic resemblance to modern human beings (*i.e.*, approximately till 100–200 thousand years ago), but the subsequent rather long (lasting for many thousands of years) period when those creatures anatomically similar to us were turning into *Homo sapiens sapiens,* that is became humans in intellectual, social, mental, and language terms. Of course, during this second phase of anthropogenesis the role of social forces in the general balance of driving forces was much larger than it used to be during the first phase. However, we believe that in general, during the whole process of anthropogenesis the driving forces were primarily biological, and only to a rather small degree were they social. Of course, it was a long-lasting process and one cannot point out a definite moment when a dramatic change occurred (and it is quite probable there was not radical turn in a literal sense). Nevertheless, we believe that after the above-mentioned landmark of 40,000−50,000 years ago the social component of the evolutionary driving forces became dominant.[4] We also believe that for the same reasons it is not possible to speak about humankind as a set of societies before this time. Thus, the notions serving the basis for our periodization – *formations of historical process* and *production principles* – cannot be applied to the periods prior to 40,000–50,000 years ago. Thus, our periodization starts from the most significant production revolution in human history; what is more, humans themselves are, undoubtedly, part of the productive forces.[5]

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[4] Yet in some important aspects the biological adaptation and anthropological transformation continued for quite a long time even after this threshold (see, *e.g*., Alexeev 1984: 345–346; 1986: 137–145; Yaryghin *et al.* 1999, vol. 2: 165).

[5] Or, using the title of Paul Mellars and Chris Stringer's book, such a radical turn can be called 'the Human Revolution' (see Mellars and Stringer 1989).

2.2. The first formation of historical process. The hunter-gatherer production principle

Due to the paucity of information on the first pattern it appears reasonable to connect the phases of the hunter-gatherer production principle with the qualitative landmarks in human adaptation to nature and its acquisition. Indeed, during this period the community size, tools, economic modes, lifestyles – that is, virtually everything – depended almost exclusively on the natural environment. If we correlate the phases with the major changes in environment, it appears possible to connect them with an absolute chronology on the panhuman scale. This appears especially reasonable since according to the proposed theory some elements of the natural environment (within a theoretical model) should be included in the productive forces, and the more natural factors are included, the weaker is the technological component (see Grinin 2003a, 2009b).

The *first* phase may be related to the 'Upper Paleolithic' Revolution (about it see Mellars and Stringer 1989; Marks 1993; Bar-Yosef 2002; Shea 2007) and the formation of social productive forces (no matter how primitive they were at that time [for details see Grinin, Korotayev, and Markov 2012]). Already for this period more than a hundred types of tools are known (Boriskovsky 1980: 180; see also Tattersall 2008: 150–158; 2012: 166–173).

The *second* phase (approximately and very conventionally, from 30,000 to 23,000 [20,000] BP) led to the final elimination of the so called residue contradiction of anthropogenesis: between biological and social regulators of human activities. This phase is associated with a wide diffusion of humans, their settlement in new places, including peopling of Siberia (Doluhanov 1979: 108) and, possibly, the New World (Zubov 1963: 50; Sergeeva 1983). Yet, the dates are very scattered (Mochanov 1977: 254; Sergeeva 1983; Berezkin 2007a, 2007b, 2013).[6]

The *third* phase lasted till 18,000–16,000 BP. This was the period of the maximum spread of glaciers (referred to as the glacial maximum).[7] And though this was not the first glaciation, this time humans had a sufficient level of productive forces and sociality so that some groups managed to survive and even flourish under those severe conditions. Con-

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[6] The genetic data dates this period to 25–15 thousand years ago (Goebel *et al.* 2008). Still the settlement of America was a complicated and long-lasting process.

[7] During the last glacial epoch, Würm III. The glacial maximum was observed about 20,000–17,000 BP when temperatures dropped by 5 degrees (Velichko 1989: 13–15).

siderable changes took place with respect to variety and number of tools (Chubarov 1991: 94). This was precisely the time when there occurred a fast change of types of stone tools; for example, in France (Grigoriev 1969: 213), in the Levant (18,000 BP) the microliths appeared (Doluhanov 1979: 93). During this phase, as well as the subsequent *fourth* phase – *c.* 17,000–14,000 (18,000–15,000) BP – the level of adaptation to the changing natural environment significantly increased. In some places that had avoided glaciation, an intensive gathering developed (Hall 1986: 201; Harlan 1986: 200; Fainberg 1986: 185). During that period one also observes the development of proto-crafts including sewing and weaving, making clothing, and basketry (see Dyatchin 2001: 37).

The *fifth* phase – from 14,000 to 11,000 (15,000–12,000) BP, that is the late Paleolithic and the early Mesolithic (Fainberg 1986: 130) – may be related to the end of glaciation and climate warming (Yasamanov 1985: 202–204; Koronovskij and Yakushova 1991: 404–406). This warming together with the consequent change in the landscape decreased the number of large mammals. That is why the transition to individual hunting was observed (Markov 1979: 51; Childe 1949: 40). The technical means (bows, spear-throwers, traps, nets, harpoons, new types of axes, *etc.*) were developed to support the autonomous reproduction of smaller groups and even individual families (Markov 1979: 51; Prido 1979: 69; Avdusin 1989: 47). Fishing in rivers and lakes was developed and acquired major importance (Matyushin 1972). There developed the following types of stone arrowheads: leaf-shaped, fluted, hollow-base, and winged arrowheads. The bone and wood arrowheads would have an indented and later barbed and tanged shape (Semenov 1968: 323, 324).

The *sixth* phase (*c.* 12,000–10,000 BP) was also connected with continuing climatic warming and environmental changes culminating in the transition to the Holocene (see, *e.g.*, Hotinskij 1989: 39, 43; Wymer 1982 [and in archaeological terms – to the Neolithic in connection with considerable progress in stone industries Semenov 1968; Monghite 1973; Avdusin 1989; Yanin 2006]). This period evidenced a large number of important innovations that, in general, opened the way to the new, craft-agrarian, production principle (see, *e.g.*, Mellaart 1975). Of peculiar interest are the harvest-gathering practices that were a potentially more progressive development of the craft-agrarian mode since such gathering can be very productive (see, *e.g.*, Antonov 1982: 129; Shnirelman 1989: 295–296; 2012a; Lips 1956; Lamberg-Karlovsky and Sabloff 1979).

Leaping ahead, we would like to explain the quantitative proportions we have detected between the periods of the hunter-gatherer production principle which we present below (see Tables 1–4 in Appendix 2). We have empirically determined certain correlations between the duration of the stages (phases) recurring within each production principle. But to what extent are these proportions relevant to the hunter-gatherer production principle, if for the identification of the beginning of its periods we involve some exogenous factors of nature and climate changes?

In fact, since the climate changes could have occurred at any other time these proportions are random to some extent. However, in general they are not random at all and moreover, are endogenously reasonable, since each described successive cyclic change requires more or less definite time. This perfectly explains why the lengths of the given processes-stages correlate between each other in certain proportions. Second, though with respect to society the climate changes can be considered as external (and therefore, random) factor, the diversity of macroevolutionary lines significantly neutralizes such randomness. The idea following from the rule of the necessary diversity maintains that the larger is the diversity, the higher is the probability of the emergence of required randomness at the right moment and at the right place. The same way a person staking on more than one event at once secures himself from accidents, and so, figuratively speaking, evolution with greater variability can accomplish a breakthrough if not in one place then in another. That is why, although the proportions in the correlation between the stages of hunter-gatherer production principle can slightly shift, they will remain almost the same since the qualitative changes, if unprepared, prevent excessive suitable cases. Meanwhile, if such a shift lags behind when a society appears ready ('overmature') for changes necessary for a qualitative breakthrough even less suitable situations will work. In particular, let us repeat that along with periods of maximal cooling in some regions (which was on the whole random with respect to social macroevolution at a certain point), there were highly specialized gatherers in other territories and that was consistent for social evolution. Consequently, the most important breakthroughs could have followed the same pattern already from the period of 18,000 years ago and it was likely to have slightly accelerated the start of the Agrarian Revolution, but, most probably, would have delayed its transition to the second phase.

2.3. The second formation of historical process. The craft-agrarian production principle

Whatever plants were cultivated, the independent invention of agriculture always took place in special natural environments (with respect to South-East Asia see, *e.g.*, Deopik 1977: 15). Correspondingly, the development of cereal production could only occur in certain natural and climate environments (Gulyaev 1972: 50–51; Shnirelman 1989: 273; 2012a; Mellaart 1982: 128; Harris and Hillman 1989; Masson 1967: 12; Lamberg-Karlovsky and Sabloff 1979). The cultivation of cereals is supposed to have started somewhere in the Middle East: in the hills of Palestine (Mellaart 1975, 1982), in the Upper Euphrates area (Alexeev 1984: 418; Hall 1986: 202), or Egypt (Harlan 1986: 200). The beginning of the Agricultural Revolution is dated within the interval from 12,000 to 9,000 BP, though in some cases the traces of the first cultivated plants or bones of domesticated animals are even of a more ancient age of 14,000–15,000 years. Thus, in a rather conventional way it appears possible to maintain that the *first* phase of the craft-agrarian production principle continued approximately within the interval from 10,500 to 7,500 BP (between the ninth and sixth millennia BCE [as the reader remembers we regard the first phase of the craft-agrarian principle as simultaneously the initial innovative phase of the Agrarian Revolution]). This period ends with the formation of the West Asian agricultural region, and on the whole one may speak about the formation of the World-System during this period, also including its first cities (about cities see Lamberg-Karlovsky and Sabloff 1979; Masson 1989).

The *second* phase can be conventionally dated to 8,000–5,000 BP (from the sixth to the mid-to-late fourth millennia BCE), that is up to the formation of a unified state in Egypt and the development of a sophisticated irrigation economy in this country. It includes the formation of new agricultural centers, diffusion of domesticated animals from West Asia to other regions. There developed the husbandry of sheep, goats and the first draught animals (Shnirelman 2012b; Meadows *et al.* 2007; see also Gupta 2004; Zeder and Hesse 2000). The active interchange of achievements (domesticates and their varieties, technologies, *etc.*) is observed. The first copper artefacts and tools in Egypt and Mesopotamia (and in Syria) date to this period (starting from the fifth millennium BCE) (Tylecote 1976: 9). According to Childe the so-called urban revolution took place at that time (Childe 1952: ch. 7; see also Lamberg-Karlovsky and Sabloff 1979; Masson 1980; 1989: 33–41; Oppenheim 1968; see also Adams 1981; Pollock 2001: 45; Bernbeck and Pollock 2005: 17; Zablotska 1989: 34–38; Bondarenko 2006: 50; Mellaart 1975; Wenke 1990: 326–330; Turnbaugh *et al.* 1993: 464–465; Harris 1997: 146; Schultz and Lavenda 1998: 214–215; Balter 2006).[8]

During the *third* phase, from 5000 to 3500 (5300–3700) BP, that is from 3000 to 1500 BCE, farming developed along with animal husbandry, crafts and trade which differentiated into separate branches of economy (as the readers remember the third phase of the craft-agrarian principle we regard simultaneously as the final innovative phase of the Agrarian Revolution). Though, according to our theory, crafts did not determine the development of the Agrarian Revolution, it appears necessary to note that, according to Chubarov's data, at the end of the second phase and beginning of the third one a very wide diffusion of major innovations (wheel, plough, pottery wheel, harness [yoke], and bronze metallurgy, *etc.*) was observed (Chubarov 1991; about plough see also in McNeill 1963: 24–25; Kramer 1965; about bronze metallurgy see Tylecote 1976: 9). This was the period when the first states, and later empires, rose in the Middle East. Urbanization also expanded reaching new regions. This period ended with a major economic, agrotechnical, and craft upsurge in Egypt at the beginning of the New Kingdom (Vinogradov 2000).

The *fourth* phase (from 3500 to 2200 [3700–2500] BP, or 1500–200 BCE) is the period when systems of intensive (including non-irrigated plough) farming were developed in many parts of the world. We observe an unprecedented flourishing of crafts, cities, and trade, as well as the formation of new civilizations and other processes indicating that the new production principle was approaching its maturity. This phase lasted till the formation of new vast world empires from Rome in the West to China in the East, which later led to major changes in productive forces and other social spheres.

The *fifth* phase (from the late third century BCE to the early ninth century CE) was the period of the most complete development of the

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[8] The formation of productive economies in Central Andes and Mesoamerica started in the seventh and sixth millennia BCE (see Berezkin 2007b; 2013: 17; see also Dillehay *et al.* 2010; Quilter *et al.* 1991; Vega-Centeno 2010).

productive forces of the craft-agrarian economy, the period of flourishing and disintegration of the ancient civilizations and formation of civilizations of a new type (Arab, European, *etc*.).

At the beginning of the *sixth* phase (from the ninth century till the first third of the fifteenth century) one could observe important changes in the production and other spheres in the Arab-Islamic world and China; in particular, in the second half of the first century BC a wide international trade network from the East African Coast to South-East Asia and China was developed in the Indian Ocean basin (Bentley 1996, Chew 2014, 2016; Boussac *et al*. 2016). Later the urban and economic growth started in Europe, which had finally created first industrial centers of and preconditions for the Industrial Revolution (see also Grinin and Korotayev 2013).

2.4. The third formation of historical process. The trade-industrial production principle

The first phase of the trade-industrial production principle (as the reader remembers it means respectively the beginning of the initial phase of the Industrial Revolution) may be dated to the period from the second third of the fifteenth century to the late sixteenth century. This phase includes those types of activities that were both more open to innovations and capable of accumulating more surplus (trade [Mantoux 1929; Bernal 1965; Cameron 1989; see also Acemoglu *et al*. 2005] and colonial activities [Baks 1986], which had become more and more interwoven after the start of the sixteenth century). Besides, at that time, primitive industries (but still industries) developed in certain fields. It is during that period when according to Wallerstein (1974, 1987) the capitalist world-economy originated.

It is worth to mention the viewpoint according to which along with the Industrial Revolution of the eighteenth century, there had also been an earlier industrial revolution (or even industrial revolutions). This technological upswing that took place in Europe between 1100 and 1600 was noticed long ago – back in the 1930s – starting with the work of Lewis Mumford (1934), Marc Bloch (1935), Eleanora Carus-Wilson (1941) and was actively studied by economic historians in around 1950–1980 (Lilley 1976; Forbes 1956; Armytage 1961; Gille 1969; White 1978; Gimpel 1992; see also Hill 1955; Johnson 1955; Bernal 1965;

Braudel 1973; Islamov and Freidzon 1986: 84; Gurevich 1969: 68; Dmitriev 1992: 140–141; Hoot 2010; see Lucas 2005 for more details). This period also quite rightly considered as the time of scientific breakthrough, or rather a number of revolutionary breakthroughs in such areas as mathematics, astronomy, geography, cartography, etc. (see, *e.g.*, Singer 1941; Goldstone 2009). Still it appears that in the last two decades the idea of marking out Early Modern Period (the end of the fifteenth – eighteenth centuries) has attracted a number of supporters. However, all these scholars do not associate Early Modern Period with an earlier industrial revolution.

Our view is that the idea of the early industrial revolution in the explanatory terms is very useful, but it requires its own conceptual development in the direction that allows treating this early revolution not so much as a separate isolated phenomenon, but as the initial phase of the Industrial Revolution (or the innovations that occurred in the last phase of the Craft-agrarian production principle). Very schematically, this approach may be outlined as follows.

The period between 1100 and 1450 may be regarded as a preparatory period of the Industrial Revolution with quite a vivid manifestation of early capitalist relations and forms of production in some regions of Europe (Northern Italy, Southern Germany, the Netherlands, Southern France [see, *e.g*., Pirenne 1920–1932; Wallerstein 1974; Postan 1987; Milskaya and Rutenburg 1993; Lucas 2005]).

The period from the late fifteenth century to the end of the sixteenth century is the initial phase of the Industrial Revolution, associated with the development of navigation, engineering and mechanization on the basis of watermill, spreading and improving of different machines, the development of division of labor. At this time, in different parts of Europe, there are significant breakthroughs in different directions, which by the end of the period are synthesized into the general Western Europe system (Johnson 1955; Braudel 1973; Wallerstein 1974; Barg 1991; Yastrebitskaya 1993; Davies 1996). Changes in one country tended to produce substantial impact on the economy and the lives of others – through the spread of innovations, through the publication of special technical books, through the movement of technical experts to different countries, through the introduction of various advances and innovations by kings and emperors to their realms, etc. Thus, we find impressive achievements in the field of mechanization in mining operations in Southern Germany and Bohemia; major contributions to the development of navigation, geographical discoveries and world trade accomplished by the Spanish and Portuguese, but also by the British; significant developments of technologies of manufacturing in Italian and Flemish cities; significant shifts in agriculture in Northern France and the Netherlands; important scientific and mathematical discoveries made by scientists in Italy, France, Poland, England; new financial technologies developed in Italy (Barone 1993; Davies 1996, 2001; Collins and Taylor 2006; Goldstone 2009, 2012; Ferguson 2011; Porter 2012). But all of this, anyway, quickly became the common heritage of Europe.

The period from the early seventeenth century to the first third of the eighteenth century is the middle phase, when one could observe the formation of a complex industrial sector and the capitalist economy, the increased mechanization and the deepening division of labor. This is the age of trade leadership of the Dutch, the successor to the hegemony of Spain and Portugal. The Netherlands created an unprecedented industry of shipbuilding, mechanized port facilities and fishing (Boxer 1965; Jones 1996; de Vries and van der Woude 1997; Rietbergen 2002; Israel 1995; Allen 2009). But the seventeenth century is a century of very large changes in military technology and science, engineering; whereas as a result of wars and other processes the Netherlands lost its leadership, which was gradually moving to Britain (Rayner 1964; Boxer 1965; Snooks 1997; Jones 1996; de Vries and van der Woude 1997; Rietbergen 2002). So during this phase of the Industrial Revolution (and new production principle) new sectors of industry had become dominant in some countries (in the first place in the Netherlands and England).

Finally, the period between 1730 and 1830 may be identified as the final phase of the Industrial Revolution, which was accompanied by the creation of the sectors with the machine cycle of production and the use of steam power. Supplanting handwork with machines took place in cotton textile production that developed in England (Mantoux 1929; Berlanstein 1992; Mokyr 1993, 1999; Griffin 2010). Watt's steam engine started to be used in the 1760s and 1770s. A new powerful industry – machine production – had developed. The industrial breakthrough was more or less finalized in England in the 1830s. Although Britain was here clearly the leader, but we also observe in this period a number of important processes that can be identified as pan-European (including the development of military technology, trade, science, pan-European commercial and industrial crisis of the second half of the eighteenth century, the beginning of the demographic revolution – see below). In this concept, we clearly see in the Industrial Revolution the result of the collective achievements of different societies of Europe, a sort of relay-race of achievements. The successes of industrialization were evident in a number of countries by that time and it was also accompanied by significant demographic transformations (Armengaud 1976; Minghinton 1976: 85–89).

The *fourth* phase (from the 1830s to the late nineteenth century) is the period of the victory of machine production and its powerful diffusion. The *fifth* phase took place in the late nineteenth century − the early twentieth century up to the world economic crisis of the late 1920s and 1930s. During that period huge changes took place. The chemical industries experienced vigorous development, a breakthrough was observed in steel production, the extensive use of electricity (together with oil) gradually began to replace coal. Electrical engines changed both the factories and everyday life. The development of the internal combustion engine led to the wide diffusion of automobiles. The *sixth* phase continued till the mid-twentieth century. A vigorous intensification of production and the introduction of scientific methods of its organization took place during this period. There was an unprecedented development of standardization and enlargement of production units. Signs of the forthcoming Cybernetic Revolution became more and more evident.

We have established a close correlation between production principle cycles and Kondratieff cycles. About this correlation with respect to the Industrial and Scientific-Cybernetic production principles see Appendix 3.

2.5. The fourth formation of historical process. The scientific-cybernetic production principle and the Cybernetic Revolution

The scientific-cybernetic production principle is only at its beginning (see Fig. 3); only its first phase has been finished and the second phase has just started. Hence, all the calculations of the forthcoming phases' lengths are highly hypothetical. These calculations are presented in Tables 1 and 2 (see Appendix 2).

The *first* phase of the scientific-cybernetic production principle took place between the 1950s and mid-1990s, when a vigorous development of information technologies and the start of real economic globalization were observed. It is also connected with the transition to scientific methods of production and circulation management. As the reader should remember, the first phase of a production principle corresponds to the initial phase of a production revolution. Especially important changes took place in information technologies. In addition, this production revolution had a few other directions: in energy technologies, in synthetic materials production, automation, space exploration, and agriculture. However, its main results are still forthcoming.

The *production revolution* that began in the 1950s and continues up to the present is sometimes called the 'scientific-technical' revolution (*e.g.*, Bernal 1965; Benson and Lloyd 1983). However, in any case it would be more appropriate to call it the Cybernetic Revolution since its main changes will imply rapid increasing opportunities to control various processes by means of creating self-regulated autonomous systems or through the impact on the key parameters and elements that are able to launch a necessary process, *etc.* (see our explanations about the name of this revolution and its connection with scientific field Cybernetics also in the next chapter).

The *second* phase of the scientific-cybernetic production principle (= the intermediate phase of the Cybernetic Revolution, see Fig. 3) began in the mid-1990s in conjunction with the development and wide diffusion of user-friendly computers, communication technologies, cell phones and so on. Medicine and biotechnologies have also made great advance (see Chs. 3–4) as well as some other innovative fields (see Chs. 5–6). This phase has been going on up to the present.

The *third* phase may begin approximately between the 2030s and 2040s. It will mean the beginning of the final phase of the Cybernetic Revolution that in our view may become the epoch of '*self-regulating system*' (see below in the following chapters), that is, the vast expansion of opportunities to purposefully influence and direct various natural and production processes. There is a great number of various suppositions concerning changes of that kind, they are dealt with by intellectuals in different fields starting from scientists and philosophers to fantasists (see *e.g.*, Fukuyama 2002; Sterling 2005; de Grey 2008). But as we will show below, the final phase of this revolution may start in the sphere of medicine and will be connected with its innovative branches; thus, this will lead to serious modification of human organism and, perhaps, of its biological nature.

For the expected lengths of the *fourth*, *fifth*, and *sixth* phases of the scientific-cybernetic production principle see Table 1 in Appendix 2. In general, it may end by the end of this century, or by the beginning of the next one (for more details see Grinin 2006b).

The next chapter is devoted to the analysis of the main features and characteristics of the Cybernetic Revolution while the subsequent chapters discuss the main innovative branches and directions of it.

Chapter 2

The Characteristics and the Logic of the Cybernetic Revolution. MANBRIC-Technologies

1. Characteristics of the Cybernetic Revolution

Below we enumerate the most important characteristics and trends of the Cybernetic Revolution and its technologies. Today one can observe them, yet they will be implemented in mature and mass forms only in the future. These features are closely interconnected and corroborate each other.

1.1. The main features of the Cybernetic Revolution

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

1. The increasing amounts of information and complication of information processing (including the capacity of the systems for independent communication and interaction).
2. Sustainably developing system of regulation and self-regulation.
3. Mass use of artificial materials with previously lacking properties.
4. Qualitatively growing controllability a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic level and usage of tiny particles as building blocks).
5. Miniaturization and microtization[1] as a trend of a constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*
6. Resource and energy saving in every sphere.
7. Individualization/personalization as one of the most important technological trends.
8. Implementation of smart technologies and the humanization of their functions (use of common language, voice, *etc.*).
9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[2]

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[1] See: http://www.igi-global.com/dictionary/microtization/18587.

[2] For example, to control human attention to prevent accidents (*e.g.*, in transport) as well as to prevent human beings from using means of high-risk in unlawful or disease state (*e.g.*, not allow driving a motor vehicle while under the influence of alcohol or drugs).

The characteristics of technologies of the Cybernetic Revolution:

1. The transformation and analysis of information as an essential part of technologies.

2. The increasing connection between technological systems and environment.

3. A trend towards autonomation and automation of control along with an increasing controllability and self-regulation of systems.

4. The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies) as well as ability to *choose optimal regimes for certain goals and tasks*.

5. A large-scale synthesis of materials and characteristics of the systems of different nature (*e.g.*, of animate and inanimate nature).

6. The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system.[3]

7. The self-regulating systems (see below) will become the major part of technological process. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution can be called *the epoch of self-regulating systems* (see below).

Various directions of development should generate a systemic cluster of innovations.[4]

1.2. Why do we denote the latest production revolution as 'Cybernetic'?

The theory of production revolutions proceeds from the assumption that the essence of these revolutions can be most clearly observed only during the final phase. One can retrospectively outline the future features in initial and intermediate phases which do not form a clear system yet. Thus, the designation given to the third production revolution is based

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[3] During the Industrial Epoch these elements existed separately: technologies were preserved on paper or in engineers' minds. At present, thanks to informational and other technologies the technological constituent fulfils the managing function. And this facilitates the transition to the epoch of self-regulating systems.

[4] Thus, for example, the resource and energy saving can be carried out via choosing optimal modes by the autonomous systems that fulfil specific goals and tasks and *vice versa*, the choice of an optimum mode will depend on the level of energy and materials consumption, and a consumer's budget. Or, the opportunities of self-regulation will allow choosing a particular decision for the variety of individual tasks, orders and requests (*e.g.*, with 3D printers and choosing of an individual program as the optimal one).

on our forecasts concerning its final phase. We suppose that *the most important thing about this phase will be a wide implementation of* ***the principle of self-regulation and self-controlling in different technological systems*** *which as a result will transform into self-regulating systems. At the same time the new-type systems will combine the characteristics of living matter with technological principles.* We denote this revolution as 'Cybernetic' since it will lead to a wide spread of self-regulating systems. We base our analysis of such systems on the ideas from cybernetics which is a theory of control over different complex regulated systems based on communication (*i.e.* of receiving, transformation and transfer of information) (see, *e.g.*, Wiener 1948; Ashby 1956; Beer 1959, 1994; Foerster and Zopf 1962; Umpleby and Dent 1999; Tesler 2004).

Cybernetics can also be defined as a study of general laws of receiving, storage, and transfer of information in complex controllable systems. Its main principles are quite suitable for the description of self-regulating and self-controlling systems.[5] In any case the notions of regulation and information are considered as the most important ones for cybernetics, as it is impossible to control anything without transforming information. Within the Cybernetic Revolution, the technologies connected with information processing and more complex systems of control become of utmost importance. That is the reason why it makes sense to consider changing information technologies as the initial phase of the Cybernetic Revolution since information technologies underlie the transition to regulating technologies. Regulation and self-regulation (as the highest form of regulation) within systems are also the most important categories in cybernetics.

1.3. What are self-regulating systems?

Thus, *the main characteristic of the Cybernetic Revolution is the emergence and wide spread of systems of peculiar type: of controllable systems (in some respect they can be denoted as self-contained systems, i.e. systems which are able to operate independently), and the systems of higher level – self-regulating ones.*

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[5] In the present work by self-controlling systems we mean not only self-controlling machines and self-controlling processes but a wider range of systems with high level of self-regulation as well as technologies of biological, techno-biological and other nature which are and will be implemented in medicine, genetic engineering, robotics and other branches and spheres. Different self-regulating systems will be also used for regulation of human behavior in different situations.

Let us explain. *Controllable (self-contained) systems are based on* ***the principle of controllability****, this means a higher level of control which is not a direct human control but a control via some inanimate system or subsystem of control (technical or of some other kind). In fact such kind of regulated systems should have a greater autonomy.* Just as even a primitive machine differs from a mechanical appliance, so the control by the autonomous systems differs from human control or control by means of primitive appliances. The highest level of controllability will be denoted as *self-regulation.*

Self-regulation and self-regulating systems. Self-regulating systems are systems that by means of the embedded programs and smart (and other) components can regulate themselves, responding in a preprogrammed and intelligent way to the feedback from the environment[6] as well as operate independently (or suggest alternatives) in a wide range of variations, having opportunities for *choosing optimum regimes in the context of certain goals and tasks*. These are systems that operate with minimal to zero human intervention.

On the whole, this refers to the type of regulation via technologies allowing the systems: a) to work most of the time without human controlling interference; b) to have more opportunities to independently respond to changes and to make operative decisions (and in future responsible decisions as well); c) to self-regulate and to self-adjust. In other words, these specific technologies allow the required processes to proceed autonomously, intervening only in the case of unexpected deviations from the predetermined parameters or in the case of some important reset of the parameters (of course, it is necessary to provide the signal about changing parameters and a message inquiring the permission for some changes, or a number of possible options will be provided). Let us emphasize that this refers not only to technical but also to biological, compound or some other types of systems.

Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Moreover, there emerge self-driving electric vehicles (for more details see Chapter 6). 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 suit-

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[6] The connection with the environment and the 'selection' of this or that 'decision' by the system on the basis of environment changes are also the most important ideas in cybernetics.

able mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (like robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and resources consumption. Human life will become organized to a greater extent by such self-regulating systems (*e.g*., via health monitoring, regulation or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, *etc*.). As a result, the opportunity to control various natural, social, and industrial production processes without direct human intervention (which is impossible or extremely limited at present) will increase.

Nowadays, there are a number of so-called 'smart' technologies and things which in a proper and rather flexible way respond to external impacts. The simple but very illustrative example here can be mattress or pillows which take (or remember) the form of body (head) of a user; another example is chameleon sunglasses which change the intensity of sun protection depending on the brightness of the sunlight. However, these technologies as well as some automatic systems like auto-open doors, auto-switch light, *etc.* apply only some elements of self-regulation. Within self-regulating systems, the processes of identification, memorizing and selection of regime should operate on a much larger scale; it will often be the choice within the framework of uncertain opportunities. One can say that 'smart' technologies with elements of self-regulation have the reaction amplitude within the predetermined range. For example, a temperature regulator (connected through WiFi to Internet) which memorizes the climatic habits of an individual in a given period of time, has a rather small amplitude of preferences. Whereas for self-regulating systems, the amount of variations is largely unlimited, such a system is capable of choosing a proper action model in any combination within the framework of its opportunities.

Let us consider the navigator. There are usually several ways to reach destination, but since navigators can get direction from every point a navigator is supposed to lead the driver to the destination from any place. The number of routes to reach the destination is not limited (since even when there are several possible routes, the number of variations grows). Here the degree of self-regulation can be considered high, though the device itself is not too complicated.

1.4. The main directions of the Cybernetic Revolution

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends will produce a system cluster of innovations as is often the case with the innovative phases of production revolutions*. Thus, as for the forecasts for the final phase of the Cybernetic Revolution in our opinion *the general drivers of the final phase of the Cybernetic Revolution will be medicine,* additive (3D printers), *nano- and bio technologies, robotics, IT, cognitive sciences,* which together will form *a sophisticated system of self-regulating production.* We denote this complex as **MANBRIC-technologies** (about the order of the letters in the acronym see also Note 2 in the previous chapter).

Another point is in what sphere will the final phase of the Cybernetic Revolution start? Which one will be the first? First of all, one should remember that the ‘breaking through’ sphere will be narrow as it happened during the Industrial Revolution (when the breakthrough occurred in a narrow field – cotton industry). In a similar way, we assume that the Cybernetic Revolution will start first in a certain area. Given the general vector of scientific achievements and technological development and taking into account that the future breakthrough area should be highly attractive in commercial terms and have a large market, we anticipate that the final phase (the one of self-regulating systems) of this revolution will begin in one of the new branches of medicine or its associated field. However, the development will follow the path of spreading the self-regulating systems into different new fields, their integration and development of the complex of MANBRIC-technologies.

Our assumption that the first field will be a new branch in medicine is based: a) on the analysis of the latest achievements in technologies; b) on a number of observed demographic and economic trends favorable for the rise of medicine (see in Ch. 3); c) on the regularities discovered within the theory of production revolutions which we analyze in the following section.

2. The Logic of the Production Revolution: The Analysis of Utility and Correlations between the Phases

The significance of the theory of production principles and production revolutions consists in the fact that they allow a more detailed and fruitful description of the evolution of production and technological development as well as provide the means to forecast the unfolding of the Cybernetic Revolution and of the scientific-cybernetic production principle. These instruments prove the scientific nature of this theory. Our forecast is based on the identified regularities in the phases of production revolutions. This section will define these regularities and the way they can be employed in forecasting.

Let us remind that the fundamental idea of the proposed conception of production revolutions is that *within every production revolution each of its three phases plays functionally the same role while the ratio between the duration of phases within the framework of each cycle remains approximately the same* (see Appendix 2 for more details). Thus, on the basis of the regularities identified within the Agrarian and Industrial Revolutions, one can make assumptions about the following points:

– *First*, about the duration of the intermediate (modernization) phase of the Cybernetic Revolution;

– *Second*, about the beginning and approximate duration of the final phase of the revolution;

– *Third*, about the sectors and directions that will be affected by the new technological breakthrough.

Therefore, the theory of production revolutions provides a methodological approach to ground our forecasts about the future technological shifts within the Cybernetic Revolution. Let us remind the reader that the initial phase of the Cybernetic Revolution has already completed (it lasted from 1950 to the early 1990s) and the modernization one is approximately half way through its development (it started in the 1990s and presumably will last till the end of the 2020–2030s). So we can compare the forecasts of the theory concerning each phase of production revolution with the present-day reality, and we can also infer the role that technologies will play in the final phase of the Cybernetic Revolution.

To give a better explanation to such a methodology, we formulate a number of functional and processual relations between the initial and final phases of a production revolution, between the initial and intermediate phases, and between the intermediate and final phases of the production revolutions. Knowing the algorithm of how the processes manifested in the initial phase of the production revolution can be transformed at the intermediate and final phases, we provide forecasts of the Cybernetic Revolution development for the upcoming decades proceeding from the study of its initial and uncompleted middle phase.

2.1. The peculiarities of the initial phase: Amalgamation of non-system tendencies into a system and the development of new ones

The *initial phase* of the production revolution is marked by the following peculiarities:

1. *A number of trends and innovations that used to be non-systemic within the previous production principle get a systemic character.* The non-systemic character means that within the previous production principle these phenomena did not play a crucial role and did not result from its main characteristics, whereas within a new production principle the role of these characteristics significantly increases. This can be exemplified by automatization which was developed to a certain extent within industrial production long before the Cybernetic Revolution. One of the main characteristics of the industrial production principle is that production is carried out by machines operated by humans who use their sense organs, power, and qualification. At the same time, some operations were performed without human intervention, in other words automatically. But the automatization of processes was not essential and it was not a necessary characteristic of the industrial production principle but its extra bonus. In the early twentieth century, automatization started to vigorously develop (*e.g.*, in electrical engineering for the prevention of accidents, in engines for convenient control, *etc.*). But still it had no decisive importance as it was not generally used for the automatization of technological processes.

Therefore, in that period automatization can be regarded as a hyper-development of such essential phenomenon as mechanization. Besides, in the first half of the twentieth century, automatization was not the leading trend of the industrial production principle. On the contrary, the leadership belonged to the processes of the latest division of labor including the wide distribution of assembly-flow production (a constant intensifying division of labor is an essential and transparent characteristic of the industrial production principle, strikingly manifested already in manufactures). The development of automatization in the second half of the twentieth century is quite a different matter. It became the most important characteristic of the scientific-cybernetic production principle (at its initial stages), finding new forms of application and implementation in releasing human costs in controlling over process (especially in Information and Communications Technologies [ICT]).

Thus, *the initial phase of production revolution develops to the highest degree the non-system elements of the previous period.* In this respect, automatization succeeded mechanization (see, *e.g.*, Lilley 1966; Philipson 1962; Bernal 1965); similar as the chemistry of synthetic materials was sequential to organic chemistry (Zvorykin *et al.* 1962); and as the Green Revolution in agriculture was sequent to agronomy (Thirtle *et al*. 2003). The development of radio and television technologies continued the trend of new means of information transfer which had emerged earlier. Such continuity can conceal the intensity of the transition from one epoch to another. So it is not surprising that in the 1950s and 1970s the scientific and technological development was considered as the continuation of the Industrial Revolution, and at best it was defined as a new industrial revolution (scientific and technological revolution [Bernal 1965]). However, this super-development possessed some qualitative characteristics which we will describe below.

2. *The former non-system characteristics together with newly emerging ones now merge into a unified system manifesting a new production principle.* Automatization, chemical synthesis of materials, a powerful development of non-computer electronics and means of communication, the emergence of various engines, a general transition to a new type of energy and fuel, the breakthrough in selection and plant protection, the discharge of a million workers previously employed in agriculture and industry and their transition to the service sector; together with a number of new directions in technology, informatics and science – all this creates a principally new situation in economy and also evidences the start of a new production revolution, namely, of the Cybernetic one.

3. *An important factor with a powerful synergistic effect is a temporal density (a cluster pattern) of formation and development of a number of directions which, to a greater or lesser extent, is typical of a new produc-*

tion principle. Such directions in the 1950s and 1960s were the nuclear power industry, space exploration and usage of space frequencies for communication and other purposes, deep-sea exploration, information and computer technologies, multiplying equipment, laser technologies, and other areas (*e.g.*, genetics, medicine and biotechnology).

4. *However, these innovative spheres can have different destinies*: some of them get peculiar and important development in the second half of the initial phase and at the intermediate phase; while other trends will develop less intensively. Some can turn (at least, temporally) into dead-ends. Thus, at present the atomic energy industry faces severe constraints due to environmental problems, the hopes to master thermonuclear energy fell short of expectations while deep-sea exploration (except for shelf sea) still remains exotic. At the same time, the development of ICT has become the leading trend.

5. *The change of the leading sector in the course of production revolution.* The leading role of some peculiar characteristics and sectors of a new production principle becomes especially obvious by the end of its initial phase or during the modernization phase (as in the case with ICT). These sectors need some time to reach maturity and acquire a systemic character. *Thus, during these two first phases of production revolution there is a constant alteration of leading branches and sectors as well as the formation of new sectors.* One of the branches of a new production principle starts to dominate over the others for quite a long period of time (from the end of the initial phase till the intermediate phase). This branch becomes the key phenomenon of the production revolution and its driving force. *But later its role as a driving force decreases.* For example, the wool industry (the most important branch of the initial phase of the Industrial Revolution) appeared to be unimportant in the final phase when it was replaced by the cotton industry.[7] So one can make an assumption that at the final phase of the Cybernetic Revolution the ICTs will hardly remain the most important sphere. They can make (and most likely will do) a breakthrough triggered by new advanced technologies but this will happen after the start of the final phase of this revolution. Later, in the course of the final phase of the Cybernetic Revolution (approximately in the 2040–2050s) one can expect a new qualitative breakthrough in ICTs. For example, one can assume that sooner

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[7] Animal husbandry which developed at the modernization phase of the Agrarian Revolution did not become the leading direction of the final phase of this revolution.

or later serious changes will inevitably occur in programming. At present this process is labor-intensive and slow. It will most likely develop in the direction of simplification and robotization of some elements of programming and especially in implementation of programs. In other words, machine programming will largely substitute human programmers and 'the self-programming' trend will advance.

6. *Already at the initial phase there emerge prototype sectors which will become the leading ones at the final phase. But at the initial phase they do not play the leading role* (see more details about future leading sector below).

2.2. The characteristics of the intermediate (modernization) phase: accumulation of innovations and search for a breakthrough point

1. *The large scale of already existing tendencies and formation of new ones.* On the one hand, at this phase many processes develop (to a varying degree) that have been formed at the initial phase of production revolution. On the other hand, at the modernization phase we can trace the roots of those forms which will turn leading at the final phase of production revolution. Therefore, it is important to distinguish between the trends which have already turned mature and the tendencies which are only being formed, as well as to understand which of them will increase and which of them will be of less importance, become stable or later will decrease.

2. *The expanded development. The necessity of profound social and political changes.* The expansion of new technologies is especially noticeable in the first half of the modernization phase. In its second half this expansion undergoes certain saturation and slows down and thus, increases innovation activities. There appears an anticipation of something important. But the decisive component for the formation of a new system is still lacking. Besides, this gap can be manifested in the absence not only of basic technological innovations but also of the social conditions for its implementation. One of the most important characteristics of the modernization phase is that *during this period some profound changes or even breakthroughs in social and political relations should occur*. With respect to the Industrial Revolution, the period between the seventeenth and eighteenth centuries was the time of social revolutions in Great Britain, the Netherlands, the USA, and France which

had changed the world. It was also the time of changes in the world policy: The Thirty Years' War (1618–1648) and the subsequent Piece of Westphalia laid the foundations for international relations for a long time. Globalization and the period which we denoted as the epoch of new coalitions (Grinin 2009a, 2012b; Grinin and Korotayev 2010b, 2015) will significantly change the world and this process is already underway.

3. *The idea of a decisive component*. During the modernization phase opportunities and improvements accumulate which will contribute to the start of the final phase of the revolution. All components should be ready for this start. However, we emphasize that innovations can form a new system only after the key component emerges. At the same time the reconstruction of the relationships within the production system in general will be considerable.

4. *The emergence of a decisive innovation in the new field.* Basing on our analysis of production revolutions we can deduce that the decisive innovation will hardly appear within the most important economic sector. (Just as irrigated agriculture failed to become the most important sector of agriculture in pre-state barbarian societies while the cotton industry was not the most important industrial sector in the first half of the eighteenth century.) Moreover, within this field there should appear certain conditions including high commercial profitability and attraction which will provide a steady demand for a long period of time. Nevertheless, the emergence of the decisive innovation can remain underestimated for some time.

The decisive innovation for the final phase of the Cybernetic Revolution to start can emerge in some fields of bio- or nanomedicine (or another new branch of medicine). This can be a series of innovations which will make the growing number of innovations into a qualitatively new system. It is quite possible that such a breakthrough will associate with the invention of successful methods to fight cancer since this disease differs significantly from other diseases and requires solutions at the genetic level as well as an application of fundamentally new technologies.

2.3. The peculiarities of the final phase

1. *The main characteristics of the production revolution reach maturity.* One can find all the basic characteristics of the final phase of the revolution already at its initial phase though in undifferentiated, incomplete or

undeveloped state. These characteristics of the future system show up at the intermediate phase when the production principle takes a relatively complete although undeveloped form.

Thus, one may infer about the main characteristics of the Cybernetic Revolution basing on the analysis of the initial and intermediate phases, through a focus on their features and developmental dynamics. This analysis allows singling out the most important characteristics of the Cybernetic Revolution including resource saving, miniaturization, individualization, a wider implementation of artificial and smart materials, *etc.* These characteristics already show up in our epoch but they will absolutely dominate in the next epoch.

2. S*ome of the numerous directions which developed during the initial phase will inevitably become the leading directions at the final phase.* At the same time at the initial phase they play a less significant role. Thus, while at the final phase of the Industrial Revolution the main focus was on mechanisms, machines, and replacement of manual labor by machinery, at its initial phase machinery was only a part of this new direction. In the beginning of the Industrial Revolution, the technical innovations (replacement of manual labor by machines) were of less importance and the main factor was the intensifying labor division. If one considers the Agrarian Revolution, the leading direction of manual (hoe) agriculture was the use of fertile areas with the help of manual labor (*e.g.*, with the help of a sharp stick or stone hoe). The soil fertility was natural or was achieved by burning plants. As to irrigation technologies, at the initial phase of the Agrarian Revolution they were not so widespread and were determined by the local environment. But at the final phase they came to the fore and remained leading ones during the whole period when the craft-agrarian principle dominated in production.

Therefore, the leading sector of the final phase of the Cybernetic Revolution has already formed, but it is one of those sectors which do not, as yet, play a decisive role in economy. In our opinion, medicine (or one of its new branches) will play the leading role in the unfolding final phase of the Cybernetic Revolution.

3. *The mutual integration of innovative sectors starts after the formation of the decisive innovations or their group.* This process especially intensifies at the final phase of production revolution. Innovations are mutually integrated and form a fundamentally new system. That was the case with the invention of the power spinning loom in the 1760s (which

was then constantly being improved). Before that, for two decades separate important directions (steam engines, steam energy, new types of machines, principles of management at large enterprises, establishing the institution of inventions and different technological innovations) allowed the formation of the fundamentally new sector of cotton mills. This caused a cumulative effect of rapid development of lacking innovations in the field of cotton carding (*i.e.*, the separation of cotton fibers), painting, printing, *etc.*

Thus, the breakthroughs in medicine and allied technologies will cause the 'catching up' and amalgamation of different innovations into a system which might bring about the completion of the Cybernetic Revolution.

4. One should *distinguish between the field of breakthrough and the essence of a new production system.* The field of breakthrough just initiates profound transformations. The production revolution will fully gain its logic and 'sense' or 'essence' only later when the transformations become profound and expanded. However, one can try to guess this 'meaning', 'sense' and 'essence' on the basis of the processes occurring during the initial and intermediate phases of production revolution.

Thus, the general idea of the Cybernetic Revolution can be connected with a constant and comprehensive energy, resources and materials saving which will start due to mass development of self-regulating systems at a fundamentally new level. In fact, without the breakthrough in saving there will be no growth of living standards of the world population whose number will grow at least until the 2070s (according to most forecasts, see, *e.g.*, UN Population Division 2012).

3. The Determination of the Future Sector of the Breakthrough. Why Medicine?

3.1. Characteristics of the future sector of a breakthrough area

As we have shown above one of the number of directions defined in the initial and middle phases of any production revolution becomes a breakthrough area by the beginning of its final phase. But this factor does not play a leading role in the economy until the beginning of the breakthrough.

The analysis of the actual development of production revolutions also suggests the following characteristics of the future sector:

- the commodity produced in this sector should be of prime necessity. Thus, cereal in the period of the Agrarian Revolution and cotton in the period of the Industrial Revolution were basic necessities;
- the direction of development of the sector should conform to the leading tendencies and problems in the society (irrigation agriculture could support and increase the sudden exponential population growth; the cotton industry met the needs of increasing urbanization and made use of the surplus labor force which had emerged in the agrarian sector);
- the sector can influence a significant number of spheres and integrate them (*e.g.*, in the period of the Agrarian Revolution the irrigation facilities required joint actions in society; and in the period of the Industrial Revolution the transition to machines and steam-engine in the cotton industry caused a rapid growth of economy, the reconstruction of transportation routes and trade);
- technological conservatism in this sector is relatively weak;
- the breakthrough sector should provide high profits and rely on steady demand, otherwise it will fail to attract major investments. Besides, borrowing from this sector new technologies which arose in the advanced society will face no obstacles (*e.g.*, government's ban, *etc.*) in other societies;
- the sector must have a great potential for the growth of its productivity and the need for the growth of productivity must remain high for a long time to stimulate the innovations and investments.

Let us consider these conclusions in the context of the Cybernetic Revolution. It is evident that the future breakthrough sector of the final phase of this revolution should have already developed. But which of the existing ones meets the mentioned characteristics? We argue that there will be no breakthrough, for example, in the field of green (low-carbon) energy sector (despite the fact that at present wind and solar power demonstrate high growth rates) because green power will be unable to completely replace traditional energy resources but it will coexist with it similar to hydro- and nuclear power coexist with carbon energy. We think that robotics could become the breakthrough direction if there were created robots that could perform different functions in the service sector. Not without reason the future scientific and technological progress was thought to be connected with achievements in the sphere of robotics. At present robotics finds wide application and is rapidly developing (see, *e.g.*, Makarov and Topcheev 2003; Gates 2007). But still one can hardly say that robotics will become the breakthrough direction judging by the current volume of investments in this sphere which grows slowly, and much smaller capital is invested in the biotechnology field. However, it will play a very important part in the final phase of the Cybernetic Revolution and should achieve outstanding results though somewhat later, perhaps in the middle of the final phase of the Cybernetic Revolution (for more details see Chapter 6). We consider the development of self-driving cars as a vivid sign that the future technological breakthrough will be associated with self-regulating systems. Yet, there are many legal and social obstacles hampering a wide introduction of self-driving vehicles. Thus, we consider the development of robotic vehicles as the precursor of the coming final phase of the Cybernetic Revolution but not of its beginning.

3.2. Why is medicine to become the breakthrough sphere?

On the basis of the analysis of the current situation one can conclude that the only field which meets all the requirements is medicine. That is why medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, the development of self-regulating systems will cover the most diverse areas of production, services and life.

We treat medicine in a broad sense, because for its purposes it will involve (and already actively involves) a great number of other scientific-technological branches. These are the use of robots in surgery and taking care of patients, information technologies in remote medicine, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor an organism; new materials for growing artificial organs and many other things to become a powerful sector of economy.

Let us consider in detail why medicine is to become the breakthrough sphere.

a) Medicine is unique because it inspires constant activity in the field of new high technologies.

b) The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. Many spheres (including but not limiting to biotechnologies, nanotechnologies, robotics, use of the latest ICTs and various devices, cognitive technologies, synthesis of new material) will be integrated in this field (we define this complex as MANBRIC-technologies).

c) There are far fewer social, cultural, or structural obstacles to the implementation of these technologies in medicine than in other fields (the same situation with respect to the obstacles to adoption of innovations is observed in country of invention as well as in many other countries).

d) The commercial prospects and profits of new technologies in this sphere are huge since people are always ready to pay for them.

e) Some important demographic and global trends with growing urgency. Let us examine them.

First. A rapid growth of the world middle class and of the population education level, especially in the developing countries (NIC 2012) is anticipated by the 2030s. Besides, poverty and illiteracy will be reduced in the peripheral countries. As a result, the focus will shift from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc*. Thus, there is a huge potential for the development of medicine.

Second and the most important. In the nearest decades not only the developed but also many developing countries will face population ageing (see Figs 5, 6), shortage of labor resources and the necessity to support a growing number of elderly people. Moreover, in the remaining period of the modernization phase of the Cybernetic Revolution (until the 2030s) the increasing life expectancy will be the largest in developing and medium-developed countries where life expectancy is significantly lower than in developed countries.[8] By 2030, the number of people aged 65 and over in the world will amount a billion (see Fig. 5).

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[8] Simultaneously by that time, the birth rates in many developing countries will significantly decrease. Therefore, the governments in these countries will start to be concerned about the health of the national population and not with limiting population growth.

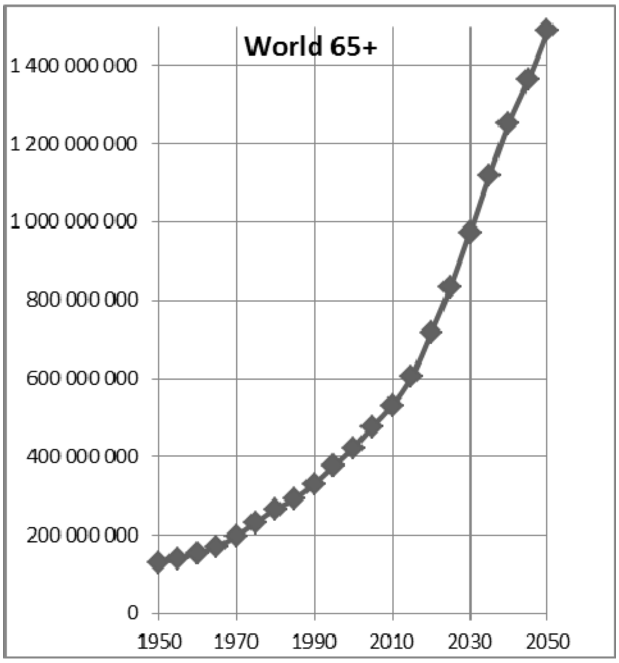

Fig. 5. Predictable increase in the number of people aged 65+, estimated for 1950–2015 and projected to 2050

Source: UN Population Division 2015; see also Grinin and Korotayev 2015b.

At present we observe the dynamics of increasing life expectancy, when the average life expectancy in some countries is more than 80 years. Fig. 6 shows the dynamics of growth rate of persons aged 80 years. By 2030s the number of people aged 80+ will be 200 million. Their growth during the final phase of the Cybernetic Revolution will generate new and new invention in medicine. Even in the case of inertial prognosis the number of persons 80+ will reach seven hundreds of millions. But in fact in the end of the final phase of the Cybernetic Revolution the number of people 80+ can increase much more.

In result of progress of ageing pension issues will become more acute (as the number of retirees per worker will increase) and at the same time a shortage of qualified labor force will increase (which is very critical in a number of countries). *Thus, we will have to solve the problem of labor force shortages and pension contributions by increasing the retirement age by 10–15 or more years.* It also refers to the adaptation of people with disabilities for their full involvement in the working process due to new technologies and achievements of medicine.

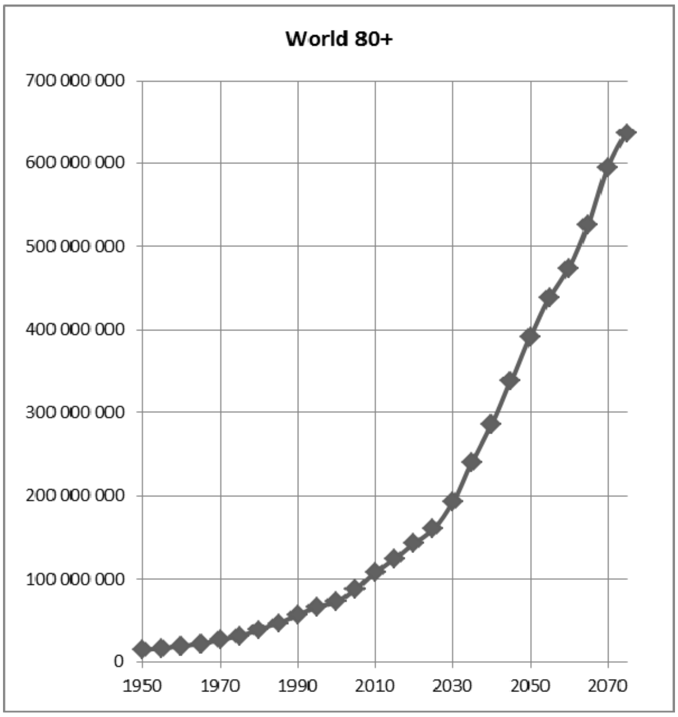

Fig. 6. Predictable increase in the number of people aged 80+, estimated for 1950–2015 and projected to 2075

Source: UN Population Division 2015; see also Grinin and Korotayev 2015b.

3.3. Medicine as a sphere of the initial technological breakthrough; the development of MANBRIC-technology complex

It is worth again remembering that the Industrial Revolution began in a rather narrow area of cotton textile manufactory and was connected with the solution of quite concrete problems – at first, liquidation of the gap between spinning and weaving, and then, after increasing weavers' productivity, searching for ways to mechanize spinning. However, the solutions for these narrow tasks caused an explosion of innovations mediated by many of the major elements of machine production (including abundant mechanisms, primitive steam-engines, the high volume of coal production, *etc.*) which gave an impulse to the development of the Industrial Revolution.

In a similar way, we assume that the Cybernetic Revolution will start first in a certain area, namely medicine.[9] By the 2030s there can appear unique opportunities for a breakthrough in medicine. However, when speaking about medicine, one should keep in mind that with respect to potential revolutionary transformations medicine is a very heterogeneous sphere. That is why the breakthrough will not occur in all spheres of medicine but in its one or two innovative fields. Perhaps, it has already formed (as biomedicine or nanomedicine) or it can form as a result of involving other innovative technologies into medicine. As for other branches of medicine, revolutionary transformations will begin there later. Moreover, some branches of medicine would be unable to transform due to their conservatism. Thus, more radical reforms will occur in these fields in the future.

In general, the breakthrough vector in medicine and associated branches can be defined as a rapid growth of *opportunities for correction or even modification of our biological nature*. In other words, it will be possible to extend opportunities to alter a human body, perhaps, to some extent, its genome; to widen sharply opportunities for minimally invasive operations instead of the modern surgical ones; to use extensively cultivated biological materials, bodies or their parts and elements for regeneration and rehabilitation of an organism, and also to make and use artificial analogues of this biological material (organs, tissues, bodies, receptors), *etc.* This will make it possible to *radically expand the opportunities to dramatically increase life expectancy and improve physiological abilities of people as well as health-related quality of life (HRQoL).* Of course, it will take a rather long period (about several decades) from the first steps in that direction (in the 2030–2040s) to their common use.

On the whole, *the drivers of the final phase of the Cybernetic Revolution will be* complex ***MANBRIC-technologies**,* namely, *medicine, additive* (3D printers), *nano- and biotechnologies, robotics, ICT, cognitive sciences.*

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[9] It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the Sixth Kondratieff Wave (Nefiodow 1996; Nefiodow and Nefiodow 2014a, 2014b). We generally support his ideas about the role of medicine (including the ideas about a new type of medicine), but it is important to point out that Nefiodow believes that it is biotechnologies that will become an integrated core of a new mode. However, we suppose that the leading role of biotechnologies will consist, first of all, in their ability to solve the major medical problems. That is why, it makes sense to speak about medicine as the core of new technological paradigm.

Chapter 3

Medicine in the Cybernetic Revolution: Medicine and Medical Technologies as a Breakthrough to the Control over Human Body

In this chapter we will concentrate on describing the current and future transformations in medicine. We will focus on those transformations that are an integral part of this complex during the starting period of the final phase of the Cybernetic Revolution. Where possible we will point out the interconnections of medicine with robotics, cognitive and information technologies.

1. Medicine at the Initial and Modernization Phases of the Cybernetic Revolution

At the initial phase of the Cybernetic Revolution (from the 1950s to the 1990s) there was a rapid growth of medicine as an increasingly important service sector. *At the same time the growing health services constituted the general process of a rapid increase in the service sector, which became the leading sector in terms of GDP in developed countries.*

During this initial phase of the Cybernetic Revolution new directions of medicine emerged while those directions that had emerged earlier reached a certain level of maturity (among them are electroencephalography, electric shock therapy, transplantology, active use of electronics, laser and new methods of diagnostics such as ultrasound, *etc.*). Substantial progress has been achieved in the sphere of child mortality reduction, infertility treatment, gerontology, psychiatry, development of contraceptive methods, and transplantation of organs and the creation of artificial organs, gender reassignment surgery, *etc.* Sport medicine, space medicine and other directions in medicine appeared during this time. On the whole, due to medicine people learned about controlling their bodies and maximizing their health.

To better understand the breakthroughs which took place in medicine during the initial phase of the Cybernetic Revolution, it makes sense to refer to the most prestigious award in the field of science. In the period from the 1930s to the 1980s the authors of discoveries in the field of vitamins, hormones, antibiotics, nervous regulation, enzymes were awarded the Nobel Prize. All of these discoveries began to be used in pharmacology. After 1958 genome researchers were awarded the Nobel Prize.

Medicine in the modernization phase. The period from the 1990s till the present represents the modernization phase of the Cybernetic Revolution.

At this phase the major direction of medicine underwent dramatic changes. In the nineteenth and twentieth centuries many fatal diseases were defeated (cholera, yellow fever, typhoid, tetanus, polio, whooping cough, measles, malaria, diphtheria, *etc.*). It would seem that fatal highly infectious diseases except for AIDS (which is widespread in African countries) have been defeated. At the initial phase of the Cybernetic Revolution the fundamental task was to increase the life expectancy. As a result, when the task was accomplished, the main concern of the last period of the initial phase and the modernization phase of the Cybernetic Revolution became the struggle against the diseases of aged people.

According to WHO, in 2012 the most frequent causes of death in the world were respiratory diseases – 6.2 million (14 per cent), ischaemic heart diseases – 7.4 million (11.1 per cent), stroke – 6.7 million (11.9 per cent), HIV/AIDS – 1.5 million (2.7 per cent) (WHO 2014).

As a result of the Cybernetic Revolution the changes in the general trend in medicine led to the emergence of new pharmaceuticals. One of the peculiarities of contemporary medical development is a constantly increasing production of drugs. For example, in the USA, from 1950 to 2000, the number of firms producing drugs increased more than seven times (Demirel and Mazzucato 2008). By 2006, the production of drugs doubled, and the total global market volume of drugs was estimated at US$ 640 billion, about half of which was accounted for in the USA (Kondratieff 2011). This field remains one of the most profitable fields with a sales profitability of 17 per cent (*Ibid.*). Every year the volume of consumed drugs increases by several percent. Over the last 15 years the revenue of the worldwide pharmaceutical market has increased more than twice.[1]

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[1] See URL: http://www.statista.com/statistics/263102/pharmaceutical-market-worldwide-revenue-since-2001/

Now medicine is closely related to biotechnologies (through pharmaceuticals, gene technologies, new materials, *etc.*). The distinctive feature of modern medical science is its 'bio-related trends' – a wide use of approaches based on the methods of molecular and cell biology. Note that the growing importance of medicine is shown in the phenomenon of medicalization. It is expressed in the fact that many aspects of human behavior (especially deviant) and psyche which have never been related to medicine, start to be described in medical terms and require medical observation and intervention (see Yudin 2008).

The process of differentiation of medicine which started many years ago in many branches has intensified. At present there are about one hundred medical branches and relative scientific disciplines. Among others, nanomedicine, biomedicine, stem cell research and generative medicine are declared as formed branches (see Strategy… 2013; Wagner *et al*. 2006; Minger 2006). It is also worth mentioning such new directions as shockwave therapy and control of cholesterol levels. The directions which emerged earlier have been actively developing, for example, those which are related to artificial fertilization, maintenance of pregnancy and obstetrics, *etc.*

At present medicine is highly computerized especially in the field of diagnostics, various automatic control systems have been developed; for example, for the control of breathing, nutrient supply to specific organs, blood pressure, control over the functioning of some internal organs, *etc.* A large range of drugs have been developed which over time decrease in price and become more available to the general public. Surgery connected with the transplantation of organs and the replacement of certain human organs by artificial organs, endoscopic surgery providing operations without incisions, and rehabilitation medicine are all developing rapidly. Surgical methods have become less invasive and require less time for rehabilitation.

The current stage is represented by the prevalence of innovations accumulated over the last decades since most of the latest technologies are based on improvements to previous discoveries and inventions. Starting with the 1980–1990s we observe considerable progress in the struggle against the most common causes of mortality – heart attacks, strokes, orphan diseases and other diseases including hereditary. Significant progress has been made in technologies for diagnosing internal organs and tissues using such methods as X-ray computed tomography, nuclear magnetic resonance introscopy, X-ray photography and others (Mirsky 2010: 19). At present the fastest developing fields of medicine (in its broad sense) are the fight against incurable diseases, implantations, reproductive medicine, gene therapy, pharmaceutics and aesthetic medicine which we will consider below.

On the whole, medicine (supported by both government and private funding) has been a major influence on GDP. The distribution of medical technologies is a very expensive process. Despite that cost, there still has been a steady increase in funds allocated to medicine by the state. Generally, its growth is comparable to the GDP growth rate. But in the developed countries spending on health care per capita is 10–20 times larger than in the developing countries. Taking into consideration the anticipated faster growth rates of GDP in the developing countries and a rapid formation of the middle class there, one can suppose that in general, spending on health care will increase significantly. Ageing of the population together with growing prosperity will lead to a situation where health care spending will outpace the general GDP growth. And this tendency is likely to increase.[2] It is not strange because in the developed countries a significant part of population is involved in medicine. For example, in Germany a number of health care personnel constitute 22 per cent of the total number of employed people while the share of automobile industry is only 2.3 per cent (Nefiodow and Nefiodow 2014). The level of medical development has significant impact on such popular development indicators as the human development index (HDI).

At the same time within the medical sphere some major innovations will reach maturity in two or three decades (some of them even earlier). At present the fastest developing fields of medicine (in its broad sense) are the fight against incurable diseases, implantations, reproductive medicine, gene therapy, pharmaceutics and aesthetic medicine which we will consider below. Medicine is closely related to biotechnologies (through pharmaceuticals, gene technologies, new materials, *etc.*). The distinctive feature of modern medical science is its 'bio-related

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[2] One can prove this by the fact that even in the periods of insignificant GDP growth, the expenses for health care increase very fast. In particular, in the OSCE countries in the period of the last crisis (2008) the growth of GDP per capita was very low – 3 per cent (correspondingly in 2007 – US$ 35,855, in 2010 – US$ 36,994), and expenses for health care per capita increased by 13 per cent (correspondingly in 2007 – US$ 3,858, in 2010 – US$ 4,364) [calculated on the basis of World Bank 2012]).

trends' – a wide use of approaches based on the methods of molecular and cell biology. There appeared new perspective directions of biomedicine (see Strategy… 2013) and nanomedicine (Wagner *et al.* 2006). Below we will consider some important trends within medicine. Note that the growing importance of medicine is shown in the phenomenon of medicalization. It is expressed in the fact that many aspects of human behavior (especially deviant) and psyche which have never been related to medicine start to be described in medical terms and require medical observation and intervention (see Yudin 2008).

Development of new pharmaceuticals. One of the criteria of medical development is a constantly increasing production of drugs. In the USA, from 1950 to 2000, the number of firms producing drugs increased more than seven times (Demirel and Mazzucato 2008). By 2006, the production of drugs doubled, and the total global market volume of drugs was estimated at US$ 640 billion, about half of which was accounted for in the USA (Kondratieff 2011). This field remains one of the most profitable fields with a sales profitability of 17 per cent (*Ibid.*). Every year the volume of consumed drugs increases by several percent. Meanwhile, along with the expansion of pharmaceutical production, its efficiency is decreasing and they only suppress symptoms but do not have a curative effect (of only 30–50 per cent). The growth of pharmaceutical production is connected with unification which leads to decreasing efficiency as even well-investigated diseases often proceed individually. The solution to this situation can be individualization of medicine due to genetic engineering.

2. Medicine on the Threshold of a Great Breakthrough

2.1. Two decades before the start of the final phase of the Cybernetic Revolution

As we predict within the medical sphere some major innovations will reach maturity in two or three decades (some of them even earlier). Below we will consider some important trends of medicine.

The development of aesthetic medicine. At present aesthetic and cosmetic medicines are vigorously developing and their main task is to correct defects or alterations which concern the person and improve attractiveness (eliminate wrinkles, provide attractive rejuvenation, different types of face lift, liposuction, body shaping, transplant hair, wide spread of already proven technologies, *etc.*). According to *Forbes*, the global cosmetic surgical and aesthetic medical market amounts to 180 billion dollars (Zhokhova 2011).

One of the highest achievements of plastic surgery is the face transplantation. The first full face transplant was performed in France in 2005 on a woman who was mauled by her dog. Recently, details of the most extensive face transplant performed in March 2012 were presented. The doctors from the University of Maryland Medical Center gave a new face including jaw, teeth and tongue to 37-year old Richard Norris.

During the next two decades cosmetic and aesthetic medicines are supposed to rapidly develop (though it can cause rather serious psychological problems including those connected with individual's self-identification). This will be achieved through the emergence of new technologies, as well as the living standard growth in the developing countries. Along with the new technologies there will be a wide spread of already proven technologies (*e.g.*, diverse types of face lift, liposuction, body shaping, *etc.*). The wealthier a society, the more money people spend on health and beauty. Taking into account the growth of the world middle class, this direction and all types of aesthetic medicine are expected to develop rapidly. Once the new technologies based on the achievements of medicine and genetic engineering have been established, aesthetic medicine will be able to become the correction medicine of the future, whose most important task will be to correct birth defects and acquired defects.

Systemic problems of the Pharmaceutical industry. As we have already mentioned, at present the pharmaceutical industry has made considerable progress.

For example, we observe a rapid development of so called generics which are the drugs whose patent protection on the production is no longer valid. It is supposed that the global market of generics will double in the period from 2010 to 2018 and will reach US$ 230 billion. One can explain such a rapid growth by the fact that the vigorously growing economies of developing countries, like India and China, actively enter this market. Such growth is typical of the modernization phase of the production revolution as well as an opposite tendency which will be described below. In the securities market pharmaceutics also shows rapid growth (Williams 2014).

However, the number of serious systemic problems in pharmaceutics is increasing. In particular, in the recent decade there is a reduction in the amount of officially approved biopharmaceuticals protected by patent. On the other hand, a number of clinical trials of drugs steadily increase (Woollett 2012). Despite the rapid growth of capitalization at the markets of bio-technological (pharmaceutical) corporations in 2013–2015 which resembles a rapid growth of capitalization of IT corporations in the 1990s, the innovation process is slowing down. Many observers note that the expenditures on the new drug development are reduced because corporations have to spend from 1.5 to 3 billion dollars for new drug development and the drug development together with testing takes from 10 to 17 years. Therefore, the number of principally new drugs is not only increasing but on the contrary, decreasing; there are no breakthrough inventions (*e.g.*, Saigitov 2015; Martyushev-Poklad 2015). One of the important reasons of reducing production of biostimulators is strengthening control over their production. And most likely the problem of accelerated production of safe drugs will aggravate in the nearest decades; the solution of this problem can become an impetus for a breakthrough.

It is obvious that mass-market drugs have an important disadvantage: its efficiency is decreasing *and really help only some part of patients (from 30 to 50 per cent).* The growth of pharmaceutical production is connected with unification which leads to decreasing efficiency as even well-investigated diseases often proceed individually. *Prescribing faults also cause serious side effects. For example, according to some data (probably, overestimated), in the period from the late 1990s to the early 2000s, prescribing faults annually* caused more than 100,000 deaths (Null *et al.* 2003: Table 1).

The theory of production revolutions can provide a general explanation of such innovation slowdown in pharmaceutics. The main vector of the modernization phase of the Cybernetic Revolution is a wide dissemination of innovations which have already emerged (in the first stage), their modification and synthesis. Therefore, there can be fewer basic innovations in this period in certain directions than in the previous period (yet they are much more widespread). Besides, the increasing scale of the production revolution causes an intensification of the struggle between 'conservatives' and 'innovators' with respect to the implementation of innovations, for example, in the field of drug control (as well as in the field of distribution of GMOs and other innovations such as cloning, *etc.*).[3] In such situations it is rather difficult to say who is right: ‘conservatives’ or ‘innovators’. On the whole, such discussions contribute to the search for optimal paths towards progress. On the other hand, one can suppose that in the nearest decades there will be a new burst of innovations and creation of new age cures. At present we observe some attempts to find new directions in the field of pharmaceutics.

Obviously, in the work of pharmaceutical firms such an important characteristic of the Cybernetic Revolution as individualization lacks. It is quite obvious since the considerable expenses for the development of new drugs require huge market for their distribution.

However, there are some precursors of the strategy changing towards individualization. For example, let us consider Christopher Wasden and Brian Williams' model. Pointing to such difficulties as lower reimbursement rates, diminished pools of venture capital, the advent of personalized care and a growing demand for improved patient outcomes, they consider them as a precursor to a hurricane that will batter unprepared companies and fundamentally change how healthcare is delivered and evaluated (Wasden and Williams 2012: 2).

These representatives of innovative business offer a new model in pharmaceutical and medical business which is named ‘Owning the disease: A new transformational business model for healthcare’. Their suggestions are based on the experience of IT companies and they propose to turn to consumer-centric disease solutions rather than the traditional R&D department approaches (*Ibid.*).

The basic idea of this model is to combine the opportunity to solve the tasks and problems related to diagnostics and treatment of a certain disease. In other words, the patient gets the full range of services to solve health problems connected with the real (or potential) disease.

> Medical technology companies are changing their focus in three important ways, shifting from selling features to providing solutions; from focusing on silos to a broader systems approach; and from generating profits by increasing volume to winning by delivering greater value. In turn, these strategies are transforming the fundamental business model of medical device manufacturers, resulting in them taking a more comprehensive approach to

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[3] Here one can make an analogy with a situation in the seventeenth and eighteenth centuries when different craft restrictions stood in the way of technological progress (and the technological progress bypassed these restrictions). That is why one can suppose that a brand new breakthrough can follow a different pattern.

> their business that compels them to seek to 'own' the diseases or conditions their products are intended to treat. Owning the disease should not be confused with disease management, the early iterations of which evolved during the heyday of managed care but which lacked the connectivity and incentives to effectively understand, monitor, influence, and change patient behavior, as well as support care coordination or overcome the cultural divide between payers and providers (Wasden and Williams 2012: 7).

This approach takes account of such important tendencies of the forthcoming Cybernetic Revolution (which have been mentioned above) as resources saving (according to the authors of the project, the systemic approach allows reducing expenses) and individualization. The clients of medical companies insist on a personalized approach and on the correlation between the payment for treatment and its results but not the number of manipulations. As the company will be paid for the results of the treatment and not for the treatment process, it will be interested in avoiding the treatment and searching for the prevention measures and optimal solutions.

The authors of this work believe that the company which will be able to create a platform for 'mastering the disease', will have many strategic advantages over the competitors.

However, the conservatism of the present pharmaceutical and medical institutions and huge financial interests of very influential forces behind them will certainly obstruct such a transition.

The struggle against incurable diseases, as it was said, is the most important direction of medicine. According to WHO, in 2008 the most frequent causes of death were lower respiratory diseases (11.3 per cent), diarrheal diseases (8.2 per cent), HIV/AIDS (7.8 per cent). Meanwhile, in developed countries the most frequent causes of death are coronary artery disease (12–15 per cent), stroke and other cerebrovascular diseases (8.7 per cent), trachea cancer, bronchus cancer, lung cancer (5.9 per cent). In general, mortality from cancer in developed countries reaches the same level of mortality with coronary artery disease.

With the rapid ageing of population the potential danger of age-related diseases will increase. The present tendency is that with growing life expectancy cancer diseases take first place among diseases. Therefore, the most significant task of medicine will be the struggle against cancer and other age-related diseases. In the nineteenth and twentieth centuries many fatal diseases were defeated (cholera, yellow fever, typhoid, tetanus, polio, whooping cough, measles, malaria, diphtheria, *etc.*). It would seem that fatal highly infectious diseases except for AIDS (which is widespread in African countries) have been defeated. However, at present in many developing countries with tropical climate a multitude of people die from infectious diseases and fevers. Nowadays incurable diseases are the challenge for humanity. It is not surprising that big awards are provided for solutions to these problems.

In the context of the struggle against cancer there are some positive changes connected with the possibility of early diagnosis and increasing percentage of cured people (see below) but the situation has not changed dramatically. It is possible that cancer will not be defeated by the 2030s. Apparently, cancer treatment requires considerable changes. If we defeat this disease, there will appear a strong impetus for a breakthrough in medicine and its transition to a completely new level.

Movement towards self-regulating systems and minimization of interference. We observe the growing controllability of systems in different branches of medicine. Some of them have already reached the stage of real self-regulation. For example, life support systems or artificial organs. Other systems are moving towards self-regulation and they are intrinsically linked to the minimization of traumatization of a patient. For example, in surgery a lot of flexible instruments are used allowing the doctor to be able to perform surgery on the most inaccessible parts of human body with minimal incision. These operations are conducted with the help of endoscopes and video cameras transmitting an enlarged image on the monitor. In order to solve the problem of hand tremor special robots are used to substitute for human hands. Operating such a device, a surgeon controls the smallest movements of the instrument (including the laser, or ultrasound). One can anticipate that in the nearest future a lot of operations will be conducted without human surgeon's participation.

Robots in surgery. Surgical robots is a rapidly developing sector. Robots-surgeons are classified as: assistance functions robots, telesurgical instruments, navigation system, robots for precise positioning, robots for specific surgery tasks (Taylor 1997).

The surgical operations involving robots' participation have a lot of advantages. The surgical robot DaVinci is mostly widespread.

It is a big machine which is equipped with flexible ‘hands’ – manipulators with a set of surgical tools. A very small incision is made to the patient, therefore surgical operations are not so painful and demand the smaller period of recovery. Robots allow to use all the latest tele-video systems which help doctors to see clearly the operation process much enlarged and in color. The doctor watches the monitor and controls the robot, sitting in the other part of the surgery (in future he can also be in any other city or even country), the assistant watches the robot and the patient. For the purpose of watching the surgery process in full detail HD 3D screens are installed for the patients. Surgeries involving robots' participation are becoming very popular, for example, the medical companies in the USA use the billboards for attracting more clients to these painless fast procedures (Pinkerton 2013).

However, along with the advantages, surgical robots cause serious fears. The doctors from Rush University Medical Center, the University of Illinois and the Massachusetts Institute of Technology provided the data according to which the strong increase in the cases of injuries and fatalities after the operations performed by the robots is observed, from 13.3 cases per 100,000 surgical operations in 2004 to 50 cases in 2012 (*Ibid.*). FDA registered an increase of 34 per cent of the deaths from surgical operations involving robots in 2013, relative to the previous year (*Ibid.*). In 2013 Massachusetts health officials sent an advisory to the state's hospitals urging caution, ‘As with any new technology, care should be taken that protocols are in place to ensure appropriate patient selection and the full explanation of risks and benefits for all surgical options’ (*Ibid.*). The cost of surgical operations involving robots is higher as compared to the ordinary types of surgery and in the USA varies from US$ 30,000 to 50,000. The price of Da Vinci starts from one million dollars. However, in view of significant economy at a recovery stage, it is possible to predict that clinics will prefer to buy robots for the long-term economy and customer engagement (*Ibid.*). Substantial savings can be realized on the skilled work of surgeons. Many clinics may not have the leading surgeons; they will be able to use services of online surgical operations conducted by the leading experts hands.

2.2. Once more about premises for a breakthrough

In the third paragraph of the previous chapter we summed up the reasons according to which the breakthrough in the beginning of the final phase of the Cybernetic Revolution will start in some innovative branches of medicine. Successful conditions for this will entail major investments in medicine: increase in the number of well-off and educated people in the developing countries and middle-aged and elderly people in the World (who particularly are willing to actively spend money on medicine), as well as strengthening of the need for extra labor force and interest of the state in improving the working capacity of elderly people. In other words, the conditions to give an impetus to business, science, and state in order to provide a breakthrough in the field of medicine can be unique and *the formation of such unique opportunities is necessary for the beginning of a new phase of the Revolution!*

One more prerequisite for the beginning of the final phase of the Cybernetic Revolution in the 2030s will become remote medical care which will be well developed by this time and due to which there will also be a leveling of conditions for patients. It means that the quality of medical care services will not be so highly dependent on the qualifications of medical personnel in a particular medical care unit. Even now we are witnessing this process, thus we can say that it will be very strong in the nearest decades and in the beginning of the final phase of the Cybernetic Revolution.

3. The Shifts during the Final Phase of the Cybernetic Revolution

3.1. The developing characteristics of the Cybernetic Revolution

Preliminary ideas about the forthcoming changes in medicine. As we have already mentioned the transition to the final phase of the Cybernetic Revolution will begin in some field of new medicine (which could be closely related to some other innovative technologies) and then step by step will affect other fields. In particular these revolutionary changes will be connected with the formation of systems for monitoring health, supporting the organism and treatment will be performed mainly by the autonomous systems which will be able to function regularly and constantly.

Nowadays the boundary between medical diagnosis and treatment already becomes more and more imperceptible. Diagnostics is a constant necessary measure for disease controlling and drug dosage. During the final phase of the Cybernetic Revolution there will start a breakthrough in medicine. It will be connected with the formation of systems for monitoring health, supporting the organism and treatment will be performed mainly by the autonomous systems which will be able to function regularly and constantly. Besides, due to opportunities of remote medical care, there will also be a leveling of conditions for patients. It means that the quality of services will not be so highly dependent on the qualifications of medical personnel in a particular medical care unit.

A breakthrough in the field of struggle against incurable diseases will occur but the most important – in the field of improving the quality of life and extending the working age. Medicine will also develop in the direction of: a) prevention and propedeutics of diseases; b) controlling the processes of life and elimination of irregularities; and c) maximal account of individual characteristics.

Self-regulation and controllability of systems is manifested in many branches of medicine. Self-regulation will manifest in the fact that treatment, operations and further rehabilitation will be under a fuller control of self-regulating systems. In the future it will be possible to provide certain treatments through special devices, systems, robots, *etc.* It is one of the most important directions which will be realized during the 2030–2050s.

Meanwhile, the emergence of robots also shows the transition to self-regulating systems. The scientists from the Oslo University in Norway by means of 3D-printing invented the self-learning robots which also have 3D printers in their structure and are capable to print the necessary detail (Howell O'Neill 2014). The RoboEarth project is very interesting: it is the Internet for robots in which they record all their operations and can address it if the necessary operation is absent in the installed program. It is the beginning of the collective intelligence of robots (Waibel *et al.* 2011).

Another manifestation of self-regulation will consist in the technological and automated control of processes of human organs (through necessary albuminous compounds, cells, antibodies, activization of immune system, *etc.*). In other words, treatment will become more targeted.[4] The drug delivery systems will change dramatically. Nanotechnology, particularly nanotubes, will probably play the key role in it.

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[4] One of the contemporary optogenetic technologies provides a good example as well as a general idea of how this can work. The essence of the technology is that the DNA fragment which codes for special membrane proteins is integrated into the genome. These light-activated proteins (from the light-source implanted in the brain tissue or through transosseous luminescence) can create an ion flow inside the cell and thus lead to its activation (Saigitov 2015).

The radical transformations in medicine will dramatically change the position of a doctor. Which technological innovations will cause such transformations?

At present the tests for important indices can be made without doctors by means of special devices and testers (see, *e.g.*, below the paragraph about the antibodies). On the basis of the test results one can define the norm and abnormalities. According to *Scientific American,* there will appear stamp-size medical devices which, if you apply them to a wound, will carry out the blood test and determine which medicines should be used and then will inject them (Rybalkina 2005: 46). In order to remotely control the patients, the company Applied Digital Solutions developed the device 'Digital Angel' equipped with the self-rechargeable energy. This tiny biochip measures the biological parameters of the body. It is unlikely that such devices will appear in the very near future. Nevertheless, the emergence of such forecasts is quite remarkable as they show the movement towards the development of self-regulating systems.

Due to such technologies a number of functions of a doctor can be performed by the patients. Perhaps, in the near future diagnostics will be transferred to mobile devices on the basis of biochips which do not require the specialists' participation. Already now the centers of the best practice (Centers of Excellence) are developing, *i.e.* the places from where the leading doctors will be performing the operations and consulting the colleagues online (Binder *et al.* 2004). Thus, the profession of a doctor in its current form can lose a number of its present attributes. At present such a metamorphosis occurs in service sector (such as photo service, type setting and page makeup, design, selection of interior, purchase of tourist vouchers, selection of routes, *etc.*). Of course, the profession of a doctor will exist but the number of doctors probably will not grow and in the end of the final phase of the Cybernetic Revolution its number will even decrease. If there is a necessity to increase the number of doctors, it will be difficult to make a technological breakthrough because of problems of training and the costs. Such systems as health monitoring system described below will also affect the positions of a doctor.

Improving the accuracy of treatment is a very important direction which can transform the treatment of diseases into a controllable process. One method that will become accurate is drug delivery to target cells. Here nanotubes, which we will consider in the section on nanotechnologies, will probably play the key role. Other methods include affecting the immune system, correction for genetic disorders, change of the technology of surgical procedures towards less harmful manipulations, *etc.*

Constant health monitoring as a self-regulating supersystem. Nowadays the boundary between medical diagnosis and treatment already becomes more and more imperceptible. Diagnostics is a constant necessary measure for disease controlling and drug dosage. During the final phase of the Cybernetic Revolution there will start a breakthrough in all fields of medical care. Thus, very important direction of self-regulation can be associated with the development of the health monitoring system that will allow early diagnosis and preventing diseases. The key compounds of such devices are biosensors.

Biosensors are a good example of self-regulating systems and development of individualization. These are electronic registering devices which use biological material such as enzymes, cells and antibodies. Biosensors are able to transform biological energy into electric one. At present they are actively used in medicine for different analyses: determination of metabolites and hormone levels, *etc*. Also biosensors are already used which allow controlling the changes in organism during surgery. An example of biosensors used at home is the glucometer, a device used to define the glucose concentration in blood. Biosensors are also used in measuring physical activity. They are applied in production to measure different parameters: the proportions of mixture, concentration of toxins, poisonous gases, *etc.* There is the development of biosensors and nanorobots which, for example, can monitor the spread of viruses in the blood online (Cavalcanti *et al.* 2008).

One can easily imagine that in the future biosensors will be able to become an integral part of human life fulfilling the function of a constant scanner of the organism or of certain organs and even transmitting the information about it to medical centers in case of potential threats or serious deterioration in the state of health. Built-in sensors will allow for controlling and regulating all vital processes, as well as prompting the time of drug intake and their dosage, time of physical activities and required exercises with the account of different circumstances, and recommending the most appropriate diet, *etc.* For sportsmen biosensors are already the instruments of control of their physiological indicators for calculation of physical activities level and probably their capabilities will increase. During surgeries, the biosensors will control necessary parameters and will prompt the surgeon regarding further actions. These programs giving particular recommendations for individuals will become a reality. At the same time, smart computer systems will be able to monitor significant fluctuations of indicators and give recommendations about short- and long-term living habits.

What will these innovations bring: will the consequences be good or bad? Of course, people's free agency will be restricted as sometimes it is more difficult to resist machines than human wishes. At the same time, certain imperatives with respect to health will be formed. In fact, everybody will have his own electronic nurse (just like the children of ancient Greek prosperous citizens had teachers from among the slaves, and the children of nobility of landowners had the teacher from among the servants). By the way, it can be especially important for controlling children and nursing sick people who stay at home. If there emerge some relatively cheap multifunctional robots able to flexibly react to changes then the life of people will become much more comfortable (but in that case their independence will decrease).

Respectively, such mini-systems can be integrated into a large system which monitors a large number of people, for example in medical centers, therapeutic facilities, hotels, *etc.* We have already mentioned the decreasing number of hospitals, and such monitoring and remote online access can significantly relieve hospitals. One can imagine that such systems will be able to detect potentially dangerous situations and quickly respond to critical situations. That is a good example of prognostics and prevention of problems. We suppose that it will take much time to create such systems. Besides, there are complicated ethical and legal problems as regards to such monitoring as there always exists the danger that a watching ‘Big Brother’ will take advantage of this.

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

Medicine heads for increasing *miniaturization (as one of the economy).* We think that with respect to medicine we can use the term 'miniaturization' in two senses. The first meaning is a trend of constantly decreasing size of instruments to micro and nano size (Peercy 2000). The second one is a trend of constantly decreasing the zone of medical intervention on human organism. For instance, during surgery contact is focused only on the target epidermis layers. For example, some eye operations with the use of laser are aimed at removing tissues only a few microns thick. Such operations require no subsequent rehabilitation.

Growing life expectancy and features of the Cybernetic Revolution. In the 2030–2050s, probably, there will be a breakthrough in increasing the life expectancy. Perhaps, it will increase up to 15 years. The increase of life expectancy and especially preserving the quality of life and the individuals' activity for as long as possible in the context of the abovementioned characteristics of the Cybernetic Revolution means a further development of self-regulating systems, individualization, selection of optimum regimes, huge energy saving (including emotional) and unique experience and world perception. Every person gains invaluable life experience during his lifetime. One can also note that it is an opportunity to preserve the previous generations' experience at the expense of the personal experience of long-livers and personal contact of their descendants with them. It is especially important under the conditions of rapid technological development and as a result the rejection of experience and knowledge accumulated by generation previous generations that one could observe already during the several.

3.2. The forecasts of the development of some medical technologies

Artificial antibodies and growing opportunities to use the immune system. There will never be any universal drug against all diseases. But strengthening the immune system is one of the universal directions which can transform this situation and help the struggle against different diseases. There is a special instrument of the human immune system – antibodies.

Antibodies are the molecules synthesized to fight against certain cells of foreign origin – antigens. The damage done by antigen usually leads to the destruction of foreign organisms and to recovery. Specific antibodies are produced for each antigen. They are produced by special immune cells – lymphocytes, which accumulate and circulate in the blood over the period of a lifetime. Thus, everyone has his own protective system based on the 'history of diseases'. It is one of the most important directions of development of *individualization*.[5] Medicine is always connected with a patient's individuality. However, in the twentieth century there was a tendency towards mass medicine (connected with mass vaccination, preventive examinations, *etc.*). At present there are some signs of transition from mass medicine to personal/individual medicine (in particular, in aesthetic medicine), which is related to the general tendency of the Cybernetic Revolution towards individualization. But individualization to an even greater extent will be manifested when based on the unique characteristics of the organism, one of which is the immune system. Artificial antibodies can strengthen the tendency towards the individualization of medicine.

Scientists have repeatedly attempted to produce artificial antibodies. Various methods were used, the most widespread method was isolating antibodies from the blood of animals but the degree of purification remained low. In 1970, Cesar Milstein and Georges Köhler found the method of producing the antibodies of a certain type, that is of monoclonal antibodies. In 1984, they were awarded the Nobel Prize for this discovery. By injecting the antigens into a mouse and by isolating the antibodies from its spleen, the scientists managed to get separate antibodies which were cloned by forming multiple copies of themselves. However, such cells could exist for a short period, and only via their hybridization with the cancer cells there were produced long-lived self-cloning antibodies – hybridomas. Nowadays a focus of much medical research is into the production of antibodies by other means (Schirhagl *et al.* 2012) and also the creation of chemoreceptors (Dickert *et al.*

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[5] Here the notion of individualization refers not to every antibody but to the artificial antibodies specifically created by each individual organism.

2001). Antibodies have already become widely used in pregnancy tests, in the diagnostics of many diseases, in laboratory experiments.

We suppose that during the final phase of the Cybernetic Revolution there will be considerable progress in the creation of artificial antibodies and their acceptance by the organism. There is no doubt that progress in this field will lead to a breakthrough in medicine. The formation of artificial antibodies will play an important role in the prevention and treatment of many serious diseases, they will prevent the rejection of transplanted organs, *etc.* This will help make controlling the course of a disease easier and will help in suppressing the disease and defeating the disease if it is possible. Progress towards the creation and acceptance level of artificial antibodies will mean a significant growth of *opportunities to control processes previously inaccessible for controllable interference and appearing of self-regulating systems for regulation of such interference.*

Control of programmed cell death (*apoptosis*) is one of the promising methods to defeat serious diseases including cancer. The researches into this field have been carried out from the 1960s. They show that some cells often die in strict compliance with the predetermined plan. Thus, the microscopic worm nematode's embryo consists of 1090 cells before hatching but later some of them die and there remain only 959 cells in the adult worm organism (Raff 1998; Ridley 1996). The mechanism of apoptosis is associated with the activity of signaling molecules and special receptors which receive the signal, launch the processes of morphological and biochemical changes, and as a result lead to the cell death.

An opportunity to trigger the self-destruction of the cells provoking the diseases can make the struggle against diseases controllable. Besides, it provides a rapid recovery without long period of rehabilitation which is necessary after surgical intervention, chemotherapy or radiation treatment (it is the example of economy of energy and time for a patient). Also switching off the mechanism of cell self-destruction will help to save an organism from some diseases and, probably, to control the process of ageing. We suppose that during the final phase of the Cybernetic Revolution medicine will be able to make progress in this direction and in the mature stages of the scientific-cybernetic principle of production to control it. In this case similar to the artificial antibodies and the systems of immune production (see about it below) the movement towards creation of self-regulating systems will occur on the basis of the influence on the key elements of these subsystems of the organism in order to select the optimal regime in the context of certain goals and tasks. So in some cases it will be possible to evoke the death of unwanted cells deliberately and in other cases to block the mechanism of death of necessary cells.

Breakthroughs in the field of control of human body. Transplantation: on the way to biotechnical systems of the highest level. Another important direction of medicine is connected with the regeneration and transplantation of organs and parts of the human body. At present such operations are already performed, for example, heart, lungs, liver, pancreas, and kidneys are now transplanted. However, human donor organs are scarce, and people who distribute donor organs without special agreement are brought to criminal responsibility all over the world. The solution to the problem of shortage of organs is carried out in different directions:

1. Use of a part of a donor organ and growing a new organ using stem cells.
2. The possibility of xenotransplantation (transplantation of animal organs into humans).
3. The development of different organ substitution technologies such as 3D printers (the most promising direction).

Besides, in medicine scientists already use or work to design different artificial organs: skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, lungs, pancreas, bladder, ovaries. Even combination of the abovementioned opportunities is rather possible. There is already an opportunity of tissue engineering. In laboratories they cultivate healthy skin or cartilage cells to replace injured bone or cartilage.[6] The potential of this technology is the formation of cell therapy and methods to regenerate tissues.

A breakthrough in medicine has become the development of artificial cornea by the scientists of Stanford University (USA). Such a great achievement became possible due to joint researches in the field of chemistry, nanotechnologies, biology and medicine (which are typical of complex technologies of the Cybernetic Revolution).

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[6] Having grown a sufficient number of cells, these cells are implanted in the developed materials on the basis of polysaccharides and special substrates which control this growth. The growth conditions of the cells in these structures are very similar to their natural environment.

We can forecast that the finding of the opportunity to 'deceive' the mechanism of immune suppression of foreign cells will be the breakthrough in the field of regenerating and transplanting organs and tissues (see above). Already some steps have been made in this direction. Here one can also point to the opportunity to control processes by affecting the key elements of initial subsystem of human organism, in this case switching off the most vigilant systems of immune protection (just like anesthesia during a surgical procedure). The important event was when Japanese scientists discovered a way to reprogram the functions of cells. For example, the skin cells were reprogrammed and substituted for the damaged cells of an eye. Such kind of cells are not rejected, so this direction is exceptionally promising (Kostina 2013).

Neural interfaces and cyborgization. How far can it proceed? As we point out in the Introduction 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 breakthrough in the field of 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. People with disabilities can make the most of the development of medicine and cyborgization as they will be able to significantly compensate their drawbacks.

A popular word 'cyborg' (short for 'cybernetic organism') derives from the word 'cybernetic'.[7] At present the term cyborg is 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.

Neural interfaces provide new opportunities for the partial cyborgization of disabilities. The technologies creating the interaction between an

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[7] The term 'cyborg' was introduced by Clynes and Kline in connection with their theory of the expansion of human capabilities to survive in space. They wrote in their article introducing the notion of 'cyborgs': 'Altering man's bodily functions to meet the requirements of extraterrestrial environments would be more logical than providing an earthly environment for him in space ... Artifact-organism systems which would extend man's unconscious, self-regulatory controls are one possibility' (Clynes and Kline 1960: 26).

individual's nervous system and external devices are called neural interfaces (Brain-Computer Interface). They implement the interaction between brain and computer systems that can be realized via electrode contact with head skin or via electrodes implanted into brain. The implementation of neural interfaces is already wide-spread. They have developed neural interfaces that allow prosthetic devices to be moved via brain signals. Today, there have been developed scanning techniques to study brain signals. This gives an opportunity to reproduce any brain response.

At present there already exist devices which allow paralyzed people to speak, write and even work at the computer as, for example, in the case of the famous astrophysicist, Stephen Hawking. The neurosurgeons from the University of Pittsburgh School of Medicine performed a miracle when they implanted a chip in Tim Hemmes's brain. Being paralyzed, he can move a bionic prosthesis with his mind. The prosthesis has a special computer which conducts the neural impulses from the brain to the specified action (Pylyshyn 2003). Global media actively discussed the news about the attaching of the electrical prosthesis by Italian and Swedish surgeons to a 22 year old drummer Robin Ekestam who lost his arm as a result of cancer. We will continue the discussion on neural interfaces in Chapter 6 below.

Thus, we should be aware of the fact that these technological achievements actually mean not only the formation of a new direction in medicine, but also the moving towards *cyborgization* of a human being and the creation of transcybernetic systems (that is the systems combining elements of different nature). 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, 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.

However, we think it to be just pure a fantasy 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 (see Introduction; the well-known ideas about such future for humankind are presented by Kurzweil [1999]; see also in Rybalkina 2005: 333). This will never come true. People who propose such solutions, for example, to replace supposedly less lasting and comfortable biological material by the technological inventions (such as replacement of haematocytes by billions of nanorobots, *etc.*) in their forecasts try to use the outdated logic that was widespread several decades ago in science fiction or scary stories: the replacement of biological organisms with technical ones. The modern logic of scientific and technological progress including the latest achievements in bioengineering shows the movement towards the synthesis of biological forms and technical solutions into a unified system. Technical achievements can hardly replace the biological mechanisms which have been selected for many millions of years. On the contrary, we should follow the path of 'repair', improvement, the development of self-regulation and support of biological mechanisms via some technical solutions.

The human brain is very tightly connected with the body and sensory organs, most of its functions are based on the control of the body that does not imply its full-fledged work outside its biological foundation. The opportunities of science and medicine to replace worn organs will increase but the biological foundations of a human will always exist and must prevail. If one can help the human body by different means including methods of activization of immune system, opportunities of genetics, the methods of blocking or decelerating the process of ageing, *etc.* it is much more reasonable to preserve the human biological foundation. In any case, in the nearest decades in the process of cyborgization quite radical breakthroughs are possible, but nevertheless the process of cyborgization will not go too far.

Improvement of individuals' natural abilities. It is important to note that at present all these technologies aim at restoring individual's lost functions. It does not exclude the future possibility that this direction will provide opportunity to move towards improvement of natural and intellectual abilities beyond the natural bounds. However, in fact this can hardly happen by the end of the twenty-first century. Probably, the process will be similar to the process in the field of plastic surgery which was first created for the repair of damaged tissues but then it became the beauty industry.

Gene therapy is an advanced means of correction of an organism. Gene therapy constitutes a separate direction in modern medicine. A significant contribution to its development has been made by the Human Genome Project, whose aim is to determine the sequence of human DNA (Brown 2000; Stein 2004). However, the path from defining the structure of the genome to understanding its functions is long and this scientific discipline is at the very beginning of its development. The leading countries spend billions of dollars on the researches in the field of gene therapy.

Gene therapy combines a whole range of characteristics of the Cybernetic Revolution including expanding opportunities for *choosing optimum regimes in the context of certain goals and tasks*. Historically gene therapy was aimed at treating hereditary genetic disorders. But at present gene therapy is already considered as a potentially universal approach to the treatment of a wide range of diseases from genetic to infectious ones.

There are two approaches to gene therapy: *fetal gene therapy* when foreign DNA is introduced into the zygote (fertilized egg) or a germ at the early stage of development; thus, it is expected that introduced material will be inherited. The second approach is *somatic gene therapy* when the genetic material is introduced only in somatic (that is non-germinal) cells and it is not transferred to sex cells.

There is another approach – activization of organism's own genes for the sake of full or partial overcoming the impact of the mutated gene. The striking example of such approach is the usage of hydroxyurea for the activation of the synthesis of fetal hemoglobin in patients with sickle-cell anemia and thalassemia.

Gene therapy can become the example of individualization of the technologies and targeted influence on the processes. On the basis of the genetic data the most appropriate treatment will be adapted for individual patients, and if it is necessary the defective genes will be corrected. In addition, the actuation of necessary genes and gene silencing (if necessary) are quite possible. Presumably, gene therapy will manifest itself first of all in sports medicine as, first, it can become a new tool in the attempts of the pharmaceutical companies to avoid the control of anti-doping committee and, second, inherent potentialities become insufficient for achieving the best results in big-time sports.

When choosing the appearance of a future child (color of eyes, skin, *etc.*) gene therapy can be used. In future it might be possible that babies will be born almost by order, these will be ‘the perfect babies’ (Fukuyama 2002 with cite McGee 1997).[8] In other words, that means that parents will choose desirable features of a child before his birth. So, the geneticists will probably find 'the genes' of such qualities as nobility, aggression or self-assessment and even intelligence and due to this there will be created an 'improved' baby. Such genetic improvement will remind the improvement of face and body by plastic surgery methods. In other words, it will be impossible to make a genius or a champion of any child but it is not excluded that it will be possible to improve his potentialities. Just like at present it is possible to improve the sports and intellectual potentialities via pedagogical technologies and certain conditions. Such improvement to a certain extent will remind the situation of agricultural biotechnology.

Presumably, first gene therapy will manifest itself in sport medicine as enormous investments are made in it and the best minds are engaged in this field (*e.g.*, the average annual salary of a physician in sports medicine is about US$ 200,000). Second, it can become a new method in the struggle of pharmaceutical companies against anti-doping committee. Third, increasing of sportsmen abilities is in great demand in professional sport as innate potentialities are no longer enough to set the record.

Changing human reproductive capabilities is an especially important field of medicine. The number of incurable diseases causing infertility decreases. Nevertheless, the only opportunity for such patients is to use *in vitro* fertilization. Besides, due to the development of medicine there increases a number of women who want to have children after their reproductive age is over (*e.g.*, Annegret Raunigk, a 65-year-old woman from Germany gave birth to quadruplets [McKie 2015]). One should mention the technologies of growing an embryo outside the woman's body. The transplantation of reproductive organs becomes possible.[9] The scientists are developing the artificial womb which can be transplanted to a woman with the damaged womb or even to a man that will radically change the concept of sex (McKie 2002) and will cause new ethical problems. Artificial womb experiments have been success-

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

[9] See http://www.theguardian.com/science/2014/oct/04/woman-gives-birth-womb-transplant-medical-first.

fully conducted in Italy where artificial womb was grown and transplanted to a woman. In our opinion as a result of the final phase of the Cybernetic Revolution the number of the experiments with artificial fertilization will increase and growing of embryo outside the woman's body will become the reality.

The perspective direction in medicine is slowing down the ageing process. It was very difficult to find the scientific foundation of ageing process but finally it probably became tangible after the invention of the genetic structure of special bodies of the cells which are necessary for division – telomeres. It appeared that every time after the duplication of chromosomes a number of telomeres at its ends decrease. That is one of the reasons why cells are getting old and die when an organism reaches certain age. Perhaps, that is why our bodies get older, though hot debates among the scientists about this issue still take place (Slagboom *et al.* 1994). In 2009, Elizabeth H. Blackburn, Carol W. Greider and Jack Szostak were awarded the Nobel Prize in Physiology or Medicine for the discovery of the way chromosomes are protected by telomeres and the enzyme telomerase from terminal underreplication. It is probable that genetic methods can significantly increase life expectancy. On the processes determining ageing and opportunities to 'fight' ageing also see the monograph by Aubrey de Grey and Michael Rae *Ending Aging: The Rejuvenation Breakthroughs That Could Reverse Human Aging in Our Lifetime*.

Chapter 4

Biotechnologies in the Cybernetic Revolution: Biotechnologies and Creation of Self-Regulating Systems

Biotechnology is a broad and multifaceted notion. Until the 1970s the term 'biotechnology' was used mainly for the description of some technological processes in food industry and agriculture. After in vitro-cultured recombinant DNA and cell cultures started to be used in laboratories, biotechnology started to associate with genetic engineering, and at present these two concepts are often used as synonyms. Now, there are known several dozens of definitions of biotechnology (see, *e.g.*, Blinov 2003). There are also official international definitions, for example: 'Biotechnology represents a complex sphere of activity in which new methods of modern biotechnology are connected with the established practice of traditional biotechnical procedures. The basis of this growing knowledge-intensive industry is made by the complex of methods giving a chance to the person to change purposefully the structure of deoxyribonucleic acid (DNA), or genetic material, plants, animals and microorganisms as a result of receiving useful products and technologies' (the UN 1992: ch. 16). We interpret *biotechnology as a range of scientific and industrial methods of producing various stuff by means of using live organisms and biological processes.*

The main directions in modern biotechnology are the biotechnology of food, agriculture, products for industrial and household use, pharmaceuticals and other medical preparations, environment protection against pollution, *etc.*

1. History of Biotechnology before the Start of the Cybernetic Revolution

In spite of the fact that biotechnology is a rather new branch, the period of 'traditional' microbiological production goes back to the Stone Age: yeast bread, yoghurt, beer, wine, and vinegar have been used since ancient times. The first scientific foundations of biotechnology were set by

Louis Pasteur who discovered fermentation. At the end of the nineteenth and the beginning of the twentieth centuries the microbiological knowledge which found increasing practical application was actively accumulated. In 1917, the Hungarian engineer Károly Ereky introduced the term ‘biotechnology’.

Some scholars (Glick and Pasternak 2002) mark the following periods in the development of biotechnology: 1) until 1917 it was the period of ‘conventional’ microbiological production; 2) from 1917 to 1973 – the period of laying scientific foundations for modern biotechnology. In addition, this period is subdivided into two intervals: from 1917 to 1940 is in a way an ‘incubatory’ sub-period when biotechnologies were already actively employed, but generally played no significant role in industry and economy; and from 1940 to 1970 biotechnology already became a noticeable branch of industry; 3) from 1970 to the present is the period of the modern biotechnology, implementation of scientific research results in biotechnological production.

This periodization fits well our concept of the Cybernetic Revolution. Actually, starting from the 1940s and until the 1970s one can speak about a rapid development of biotechnologies within the scientific and information phase of the Cybernetic Revolution. They started to most powerfully develop from the 1970s on the basis of the Cybernetic Revolution.

Biotechnology appeared at the last stages of the industrial production principle along with many other innovative branches. In the late nineteenth and early twentieth centuries there appeared biofertilizers and biological preparations for pest control and combatting plant diseases, production experiments in bioconversion (Volova 1999). There was established the production of acetone, butanol, antibiotics, organic acids, vitamins, feed proteins, *etc.* with the help of microorganisms (Yegorova and Samuilova 1987).

The 1930s and 1940s were marked by the formation of a background for the transition to the Cybernetic Revolution. At that time there started industrial production of some vitamins, for example, vitamin C. The production of preparations by means of biotechnological methods increased. The first mass biotechnological production was the production of penicillin which started in 1943. The World War revealed an urgent necessity to organize mass production of cheap drugs, provision and vitamins.

2. The Initial Phase of the Cybernetic Revolution

2.1. Biotechnology becomes an essential branch of industry

According to our concept, the Cybernetic Revolution (its scientific and information phase) started in the 1950s when *a number of trends that used to be non-systemic in relation to the previous production principle obtained a systemic character*. During this period, biotechnology finally became a rapidly growing industrial sector affecting the whole economy. The biotechnological products were widely implemented. In the first decades after World War II a large-scale production of amino acids, unicellular feed proteins (from oil and paper-pulp industry waste), steroids was organized, and cell culture of animals and plants was mastered. Already from the late 1940s they started organizing mass production of antibiotics which found extensive use not only in medical industry, but also in agriculture for treatment of animals and plants, as bioadditives in fodders. Some highly effective forms of antibiotics were created with the help of mutations. The intact cells of microorganisms began to be widely used for receiving medical substances of the steroid type, large-scale production of vaccines was organized (Volova 1999). The production of pharmaceuticals became a successful and also very profitable business; therefore, capitals and scientific forces flowed there. The quantity of medical supplies received via biotechnological method or the so-called 'red biotechnology' began to increase steadily. Let us emphasize that biotechnology became a powerful support for agriculture, as it provides the production of fodder, additives, vitamins, and fertilizers, as well as the protection against pests. By means of biotechnology people also receive biofertilizers, amino acids, organic acids, alternative energy sources, and utilize biological waste. The industrial biotechnological production became possible also due to a wide implementation of automated processes. As noted above, automation is one of the main characteristics of the initial and intermediate phases of the Cybernetic Revolution.

2.2. Fundamental breakthroughs in biotechnologies

The breakthroughs in biotechnologies are connected, first of all, with achievements in the study of transferring hereditary information. In 1953, James Watson and Francis Crick defined the structure of the DNA molecule. It laid the foundation for understanding the role of genetic information and basic opportunities of the purposeful transfer of genes from one organism to another. It opened enormous prospects, perhaps, surpassing the most courageous fantasies, like the ones presented by Herbert Wells in his novel 'The Island of Doctor Moreau'. The further discoveries connected with genome were abundant. But, naturally, it took decades for the discoveries to find their industrial implementation.

The period from the 1970s to the 1990s (the end of the initial and transition to the intermediate phase of the Cybernetic Revolution) were also marked by a tidal wave of advances in understanding of molecular biology.

We will list some of them:

– 1973 – Herbert Boyer and Stanley Cohen laid the foundation of the recombinant DNA technology;

– 1975 – George Köhler and Cesar Milstein developed the technology of getting monoclonal antibodies;

– 1978 – the Genentech Company produced human insulin received by means of E. coli (colibacillus);

– 1981 – the first automatic synthesizers of DNA hit the market;

– 1982 – the first vaccine for animals received by the recombinant DNA technology is permitted in Europe;

– 1983 – hybrid Ti-plasmids are applied for the transformation of plants;

– 1988 – the method of polymerase chain reaction (PCR) is invented.

As a result of the mentioned and other findings the genetic engineering becomes a powerful branch of biotechnology. The qualitatively new level of development of biotechnologies from the 1970s meant that within the frame of the Cybernetic Revolution they already outgrew the opportunities provided by the industrial production principle and started to develop on a new basis. During the last decades of the initial phase of the Cybernetic Revolution (from the 1970s to the early 1990s) biotechnology became already quite a significant industrial branch making a considerable contribution to agriculture (both plant growing, and cattle breeding including veterinary science), food and chemical industry, pharmaceuticals and medicine.

3. Biotechnology at the Modernization Phase of the Cybernetic Revolution

The period from the 1990s to the 2000s was marked by a powerful advance in biotechnology as a branch of industry.

Biotechnologies become a rapidly growing sector in which many countries started to invest significant funds. The company Ernst & Young (EY) which over 30 years has been analyzing the biotechnological market recorded a sharp rise of biotechnological industry in 2000. In the period from 2000 till 2005 the global revenue in the field of biotechnologies doubled and reached US$ 50 billion. And in 2013 in the USA, Europe, Canada, and Australia the revenue in the field of biotechnologies was about US$ 100 billion (Glen *et al.* 2013). From 2008 most investments in biotechnologies were made in R&D that is in innovations.

During this period the directions connected with genetic modification that developed in the previous phase became stronger. Organisms are cloned and a number of diseases are treated by means of genetic modifications. Along with production of medicines, bioadditives to feeding-stuffs, *etc*., the production of GMO became a very significant agricultural segment; increasing energy prices caused a rapid growth of biofuel production (which includes GM foods).

No wonder that biotechnologies are considered as the most promising branch which can become the engine of a new innovative breakthrough.

The significance of biotechnologies is proved by a wide use of their achievements in different fields. For example, it can be widely applied in food industry as well as in chemical production (in particular, production of polysaccharides, biodegradable polymers, biocatalysis, and also creation of new materials, for example, bioplastics), energetics, agriculture, municipal service (*e.g.*, in waste recycling), the branches connected with long storage of production, medicine and pharmacology, nanotechnologies, cosmetology, military branch are connected with biotechnology. At last, biotechnologies become common for people who use bioadditives and vitamins, special products in a diet, use certain type of cosmetic products, *etc.*

Biotechnologies contribute to the development of biosensors. A biosensor can be generally defined as a device consisting of a biological recognition system, often called a bioreceptor, and a transducer (Ferrari 2006). Different biological materials such as enzymes, cells and antibodies are used in biosensors (Vo-Dinh *et al.* 2001; Rusmini *et al.* 2007). Biosensors are able to transform biological energy into electric one. Thus, biosensor technology combines the achievements in biology and modern microelectronics and it seems to be of utmost importance for combining technical and biological elements for the future self-regulating systems into a single system. There are different types of biosensors. Some of them are devices measuring a limited number of parameters (*e.g.*, blood glucose level); others monitor several parameters at once. At present they are used in many fields including measurement of environmental pollutants. They are especially useful for analyses in medicine, for example, to determine metabolites or hormone levels (see also above about health monitoring in the future). Biosensors enable to control various changes in organism during surgery. An example of home-use biosensors are blood glucose meters. Biosensors are also used to measure physical activity. For sportsmen biosensors are already instruments to monitor their physiological parameters. Hundreds and even thousands of biosensors can be combined in biochips. Biochip is a miniature device, essentially the entire laboratory which can perform thousands of simultaneous biochemical reactions. Biochips help to carry out quick analysis of a large number of biological parameters for different purposes, including diagnosis of cancer, infections, and intoxications (Fung *et al.* 2001). The combination of biochips and nanorobots seems rather promising with respect to the online monitoring of the spread of viruses in blood (Cavalcanti *et al.* 2008).

The prospects of biotechnologies are great. So far they are closely connected with microbiology, and microorganisms are everywhere, and thus, the sphere of application of biotechnologies seems boundless (from space needs to production and processing of mineral resources). Finally, biotechnologies will become one of the main spheres where the final phase of the Cybernetic Revolution and the consecutive epochs will unfold (in the 2030s and 2070s).

4. The Characteristics of the Cybernetic Revolution in the Development and Application of Biotechnologies

Advancing on the way to self-regulating systems. Already in the 1970s, computers were applied for the automation of biotechnological production. Computers rather quickly ceased to play a secondary role and have become the basis of automation (Zudin *et al.* 1987). Thus, the emergence of such journal as *Computers and Automation* edited by Edmund C. Berkeley was no coincidence in 1961. Lots of devices for biotechnology, especially for DNA processing, were designed with the help of microprocessors. In the modernization phase of the Cybernetic Revolution, a powerful development of ICTs and software has raised the automation in biotechnological production and scientific researches to a new level.

In particular, in course of time factories producing biotechnological products demanded a lesser human participation. This substantially cheapens mass production of medicine and agricultural goods making them more available.

The software for the needs of genetic engineering has been rapidly improved. It is the one of many examples of convergence of different directions within the Cybernetic Revolution. Today experts, without leaving the computer, can select a necessary gene, model its embedding and behavior at transformation. There are devices for automatic purification, cleaning of DNA and division into necessary fragments, transfer of a gene, *etc.* The sequenators (the devices for dividing a chain of nucleic acids into nucleotides and composing them) which used to occupy an impressive part of laboratories today are produced in the form of USB flash drivers and serve an example of miniaturization as well.[1]

It is extremely important that at present we can already speak about implementation of the principles of self-regulation at the genome level. In particular, together with a useful gene, for example, of salt-tolerance in plants (Grinin, Kholodova, and Kuznetsov 2010) scientists build in special genes-controllers – the promotors which launch the necessary gene only under certain conditions (a high concentration of salt in the soil). Thus, there emerges a self-regulating biological system (without direct human participation but controlled by people), which has not existed before and which, however, works in a proper way. In brief, we observe a prototype of autonomous and self-regulating biological systems which, thanks to biotechnologies, will be widely and actively used in the future in almost all spheres of life.

In biotechnologies self-regulation is also widely employed at the level of a cell. For example, the feedback strategies of a substratum and

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[1] See about Oxford Nanopore Technologies. URL: https://www.nanoporetech.com/products-services/minion-mki.

enzyme are used, known as the operon model which brought François Jacob and Jacques Monod the Nobel Prize in 1965.

The achievements of contemporary genetic science and technology demonstrate opportunities of creation of self-regulating biological (and ecological) systems of a rather high level in the future. Already today the genetic modification can change a whole population. Thus, the method of distributing genes via 'decoy' individuals is widely spread. For example, infertile mosquitoes were massively introduced into the wild population. Such an ineffective crossing led to the reduction in a number of insects (Tkachuk 2011; Benedict and Robinson 2003).

Synthesis of new materials. In the 1940s and 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 stuff which does 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 artificial materials.

Due to biotechnologies many new materials are produced, for example, bioplastics. The main advantage of this material is that unlike ordinary plastic many bioplastics are designed to be biodegradable. Thus, the bioplastics production contributes to preserving environment by reducing the production of goods from non-renewable resources and cutting the discharge of carbon dioxide into the atmosphere. This is an important step to the creation of self-cleaning ecological systems and preservation of environment. The range of bioplastic products is already very large. From 2000 to 2008, the world consumption of compostable plastics made of starch, sugar and cellulose increased by 600 per cent (Ceresana Research 2011). However, the production of oil-free plastic amounts only one per cent so far. The experts consider that by 2020, the production of bioplastics will make 3.5–5 million tons, but, unfortunately, it will be only about 2 per cent of total production of plastics (Leshina 2012). Despite difficulties, biotechnology brings hope for more non-polluting and renewable production which in the long-term will allow saving resources.

Individualization in biotechnologies. Genetic engineering appears to be an especially bright example of individualization which is one of the main characteristics of the Cybernetic Revolution. Individualization in biotechnologies is associated, first of all, with opportunities to change genome and to get new properties of an organism. In fact, in future each individual's identity will be taken into account with respect to the life style, health control, improvement of work of an organism, *etc.* (Perhaps, individualization in biotechnologies will be applied not only to human organism, but for example, to pets – dogs, cats, *etc.*).

Another example of individualization in biotechnology is cloning. Cloning by itself is a very widespread phenomenon in nature. One of the first experiments on cloning was performed by Georgy Lopashov in 1948. He proved that if the cell nucleus of the other species is put into the ovule, the set of genes of an embryo will be the same as of an organism whose cell nucleus is used. Numerous experiments showed that if the nucleus of an adult cell is used, an embryo will be nonviable. The experiments on frogs proved that the cells which are not yet specialized can be used in cloning. Thus, the stem (immature) cells came into use in cloning (Gurdon and Colman 1999). Since then scientists have managed to clone pigs, sheep, cows, dogs and other animals. But these experiments were less successful.

There is full and partial cloning of organisms. Of course, cloning of a whole organism is of greatest interest for public, besides it provokes largest disputes on the need and acceptability of such researches. However, despite famous experiments, especially with Dolly the sheep, cloning will hardly develop in the near future due to serious biological obstacles. It is necessary to point that the results of cloning are strongly exaggerated because of the aspiration for sensation. Dolly the sheep grew old twice quicker than the congeners. As a result, the animal was euthanised. Thousands of experiments were conducted with different animals, including more than a hundred anthropoids, but the positive result has not been achieved so far.

The therapeutic cloning provides much more ample opportunities for development and introduction at the level of commercial production. This type of cloning is described in more detail in the section on medicine.

Resource and energy saving is one of the main tasks and outcomes of introduction of biotechnology. The basic opportunities with respect to resources saving are connected with possible influence on 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* which is an ability of plants to form a full-fledged organism from a single cell. With the necessary gene transfer, one can make, for example, a variety of potato resistant to Colorado beetle, or reduce the susceptibility to drought, cold and other stresses (Grinin, Kholodova, and Kuznetsov 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 and thus such modified plants appear to be more cost-effective and eco-friendly. The individualization is also noticeable in the animal genetic engineering which develops more slowly, but even today has an enormous value for agriculture and medicine (*e.g.*, by means of genetic engineering it is possible to increase milk production, to improve quality of wool, *etc.*).

The increase and cheapening of food production is a global challenge for the humankind taking into account that the population number will continue to increase for several decades (first of all in the poor and poorest countries, in particular in Africa), and reach, perhaps, nine or more billion people (see UN Population Division 2012). Biotechnologies can make a huge contribution to the solution of the problem. Already today biotechnologies has made much with respect to the increase of the overall food production due to the increasing yield, resistance of plants to stresses, adaptation to local conditions through the creation of new genetically modified organisms and improvement of already existing GMOs, production of a significant amount of artificial nutrients, in particular, proteins.

The agricultural ('green') biotechnology which has already been involved the initial phase of the Cybernetic Revolution is based on the technology of genetic modification (see, *e.g.*, Borlaug 2001).[2] GMOs allowed significant reducing of expenses, increasing crop capacity, economies on the refusal from long selection. One of the most widespread and widely discussed methods of genetic transformation is the transition of gene of resistance to chemical herbicide under the trade name

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[2] About successes of the Green Revolution in different countries see Wik *et al.* 2008; Pingali 2012.

Roundup (Williams *et al.* 2000; Richard *et al.* 2005). As a result when treated with Roundup, genetically modified plants remain intact but weeds are killed.

Despite various sanctions, the overall production of GMOs is quickly growing in crop farming. Since 2010 the GMO farming area in developing countries surpassed that one in developed countries (Clive 2011). The analysis of the world economic effect of using biotechnological cultures shows the increasing profit thanks to two sources. The first one is the reduction of production expenses (to 50 per cent) and the opportunity to get large crops on the same agricultural areas. The second one is a considerable increase of harvest (in case of removal of restrictions on distribution of GMO World GDP could grow by US$ 200 billion [Kamionskaya 2011]).

The problems connected with GMOs, real and imaginary, demand a special consideration. However, in comparison with the problem of hunger or malnutrition they seem less important. No doubt, that such production will increase (especially the production of biofuel) as it is the only way to solve food problems. The biotechnological production gives cheaper food-stuff, increases productivity in territories which used to be unsuitable for the cultivation of crops. New properties of farm animals and plants considerably save time and expenditures inevitable in the case of long selection.

In general, as it was already mentioned, the achievements in genetic engineering will become one of the most breakthrough directions of the future revolution.

Biofuel. Biotechnology can help to produce rather cheap alternative energy sources. One can hardly say that biofuel is something new in the history of mankind as firewood, brushwood, *etc.* have been used from ancient times. But now it is extremely important to note that it is a renewable resource, whose overall production has become large notably thanks to biotechnologies. Now its global production amounts to over100 million tons (mainly, in the USA, Europe and Brazil). Today biofuel makes 10 per cent of all energy output; however, by 2035 its application will probably grow by more than ten times. However, the majority of biomass for biofuel (80 per cent) is from forestry residues (Kopetz 2013). Meanwhile, the aspiration to maintain the ecological balance of the planet and to reduce wood use can strongly affect this source of alternative energy.

5. Forecasts of Development of Biotechnologies at the Final Phase of the Cybernetic Revolution

5.1. The introduction of new technologies at the modernization phase of production revolutions

The modernization phase of a production revolution is characterized by two major trends: 1) the extensive distribution of new technologies with resulting simultaneous improvements; 2) increasing social tensions and even struggle for necessary changes in some spheres of social life due to the introduction of these technologies. In order for the final phase of a production revolution to begin, the development of technologies during the modernization phase has to achieve a rather large variety and 'density'. Taking into account that biotechnologies are innovative branches, any country which wants to be the leader in this field will have to develop them anyway. Let us point out that international documents accepted by the UN Conference on the environment and development (Rio de Janeiro, June 3–14, 1992) placed their highest hopes on biotechnologies.

Therefore, on the one hand, we will observe a wide diffusion of biotechnologies in our everyday lives: in nutrition, various nutritional supplements, and influence on our body (through various branches of medicine, in particular via cosmetic and individualized treatment of body as, for example, body-builders do), *etc*. There must quickly develop the branches which have already become a reality (*e.g.*, the cultivation of genetically modified plants, affecting the productivity of domestic animals, production of biofuel), as well as the technologies which are less spread today, in particular in the development of biomaterials. On the other hand, such a wide implementation of biotechnologies, undoubtedly, will intensify public, diplomatic and economic resistance to the change of traditions, national features, real or imaginary harm. The movement against cloning, GMOs, computer selection, *etc.* has been already spreading in different countries. Such a reaction is quite natural, legitimate and in many respects useful though it may happen that conservatism will suppress the progress. Just within the framework of this struggle and collisions, they may make the decisions which become important in the long term and will promote achieving some balance as well as give an impetus to the development (let us remember that the ban on the importing of cotton fabrics in England served as a trigger for the development of its own cotton industry which became a cradle for the Industrial Revolution [Mantoux 1929; Allen 2009; Grinin and Korotayev 2015]).

5.2. The beginning of the final phase of the Cybernetic Revolution and the development of the scientific-cybernetic production principle

Now, proceeding from the current trends and general logic of the development of the Cybernetic Revolution, it becomes possible to set out *the future developmental milestones in biotechnology* at the final phase of the Cybernetic Revolution (in the 2030s and 2070s). As already mentioned, it can start in a rather narrow sphere, from which the innovations will start distributing and gradually penetrate the new areas.

Certainly, it is very difficult to anticipate the direction and time of concrete discoveries. In spite of a widespread idea about biotechnological revolution in the near future we suppose that at the very first stage biotechnology as an independent direction will play a less important role than medicine. It will be rather an important component of medical technologies, providing breakthroughs in the area of treatment of diseases and regulation or monitoring the organism functions. But, probably, the adoption of biotechnological achievements will make it possible to help an organism successfully overcome certain diseases.

The achievement of self-regulation within a system without human intervention. The level of controllability will increase considerably within a number of important systems connected with biotechnologies. Thus, probably, while transforming an organism, they will insert not a separate useful gene (Simon *et al.* 1983), but a whole set of necessary genes which will operate depending on environmental conditions. Such characteristics will be extremely important in the case of climate changes which are quite probable. It will become possible to choose the most optimal varieties of seeds and seedling for a unique combination of weather conditions and territory (the sort of imitation of evolutionary selection via automatic search in databases). Consequently, huge databases of such plant varieties and variations will be created. It is quite possible that in the future the whole process of getting a transgenic plant will proceed without human participation, and thus, it will become self-regulated.

It is possible to assume that by the end of the phase of self-regulating systems (and perhaps, even earlier, *e.g.*, by the 2050s) the agricultural biotechnologies will be already developed to a degree that the very adaptiveness of modified products will allow for a response even to the smallest fluctuations of local conditions. In other words, it will be possible to order producers or collectors to create varieties of plants for individual greenhouses, hotbeds or plots. Farmers will be able to select individual fodder and drugs by means of programs and to order them via the Internet. Also people will be able to invent a houseplant hybrid suitable for their individual interior and to order its production and delivery. Thus, individualization will reach a new level.

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

The solution of urban and some environmental problems. Undoubtedly, some important changes will occur in using biotechnologies for the solution of environmental problems. Here it is possible to assume that biotechnologies will be intruded first of all in the urban ecology. It is necessary to consider that in the coming decades the urban population will increase by 40–50 per cent (see, *e.g.*, NIC 2012). With the pace of development quickening in poor countries the problems of unsanitary conditions, incidences of disease, *etc*. will become very acute. And since different diseases can quickly spread worldwide, the problems of some countries will become problems for all countries. Among the problems which can be potentially solved by means of the development of biotechnologies, 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 kind). Already today the microorganisms for water cleaning are employed; with their help we also get bio-gas from waste recovery. But in the future these and similar problems will be solved through the development of self-regulating systems that will make it possible to solve a number of technological and scientific problems.

Thus, just as in the late nineteenth and early twentieth centuries people coped with mass infections by means of biotechnologies, in the middle of the twenty-first century, the latest biotechnologies, perhaps, will help to solve the most vexing urban problems since at least two thirds of the population will live in cities. But the problem of ecological self-regulating systems, naturally, is not limited by cities; it has to be extended to the cleaning of reservoirs and other ecosystems. The creation of ecological self-regulating systems will considerably reduce expenses and free huge territories occupied by waste deposits, as well as allow breeding fish in self-cleaning reservoirs.

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

The breakthrough in resource saving. Biotechnology can help to solve many global issues, for example, to cheapen the production of medicines and foodstuffs including producing and making them in ecologically sound ways that can also keep or make the environment pristine, thereby considerably expanding their production. The solution to global food crises will come in different ways, in particular due to the mass production of food protein whose shortage is 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 this production is too expensive. Now a gram of laboratorial meat costs 1000 dollars (Zagorski 2012), but this is part of the usual process from the laboratory to mass cheap production.

The synthesis of new materials. The creation of self-regulated and self-operated systems by means of biotechnologies, in particular through genetic manipulations, opens an important direction in the field of new materials with desirable properties (*e.g.*, genetic material). At present genetic engineering is able to create not only certain genes but also entire genomes and even chromosomes. The artificial chromosomes can be inserted and add some new genes absent in the organism (Dymond *et al.* 2011). It potentially allows making substitutes for the natural process feedstock, for example, leather. The respective projects are already developed. For example, the Modern Meadow Company aims at making a revolution in clothing industry by growing leather and other types of animal skin in the laboratories (Zagorski 2012).

The process of creation of biotechnological genuine leather will include several stages. At first scientists will select millions of cells from donor animals. It can be both cattle and exotic animal species who are often killed only because of skin. Then these cells will be multiplied in bioreactors. At the following stage the cells will be mingled in one mass which will be formed in layers by means of the 3D bio-printer. The skin cells will create collagen fibers while the ‘meat’ cells will form a real soft tissue. This process will take some weeks after which soft and fat tissues can be used in food production. Despite the exoticism and queerness of the above-described method, it is actually very similar to the process of production of artificial furs which made it possible to solve the problem of warm clothes.

Chapter 5

Nanotechnologies as the Way to Mastering the Microworld

1. Definition and the History of the Field

Definition and scale. The humankind has been using nanomaterials for a long time whereas the ideas of nanotechnologies have appeared quite recently. Now with the current knowledge about nanoparticles one can explain the peculiar properties of the well-known materials created in ancient times such as various enamels, painting materials, damask steel, *etc*.

Nanotechnology is a widely used concept which can be conventionally defined as *an interdisciplinary field of applied science and technology which develops practical methods and research*, *analysis and synthesis*, *and also methods of production of nanomaterials by a controlled manipulation of separate atoms and molecules*. The broad range of topics covered by nanotechnologies makes it problematic not only to define them, but also to classify nanoproducts (to specify the latter a special group within European Commission was created).

Now the Technical Committee ISO/TC 229 defines the nanotechnologies as follows (ISO 2005):

– knowledge and control of processes, as a rule, on the nanometer scale, including the scale of less than 100 nm in one or more measurements;

– use of properties of the objects and materials on the nanometer scale which differ from the properties of free atoms or molecules, for the creation of more perfect materials, devices, and systems realizing these properties.

Thus, the main point in nanotechnologies is control of matter on a scale smaller than 1 micrometer, normally between 1–100 nanometers (to 100 nanometers in one measurement; one nanometer is equal to one milliard share of the meter, or 10^{-9} m).

Why did nanoparticles become so popular? At this level the fundamental property of matter clearly shows up, that is realization of antipodal properties in its various systems. For example, at the macrolevel gold is a conductor, but at the nanolevel it is an insulator. The particles of some substances sizing from 1 to 100 nanometers show very good catalytical and adsorptive properties, while other materials show wonderful optical properties. At the nanolevel the relation between the surface and volume changes, and thus, the properties of matter change. In nature there exist nanosystems capable to get organized in special structures, gaining new properties, for example, the biopolymers (proteins, nucleic acids).

The peculiarity of nanoscience consists in the fact that it deals with atoms − compound particles of matter (a nanometer equals to a conditional construction of ten atoms of hydrogen built in a row). Now scientists already can operate with separate atoms and merge them in blocks. In other words, in prospect, it will be unnecessary to saw a tree to receive a toothpick, theoretically, it will be possible to force atoms to ‘construct’ it. Such an approach opens fantastic opportunities for creation of new materials with desirable properties. The prospects of this field were announced by the Nobel laureate Richard Feynman in the report ‘There's Plenty of Room at the Bottom’, presented in 1959 at the California Institute of Technology at the annual meeting of the American Physical Society. The scientist assumed that it would become possible to mechanically move single atoms by means of a manipulator; at least, this process will not contradict the known physical laws. Feynman offered a way of atom-by-atom assembly of objects that would allow reducing expenses and saving energy in production. This direction was actively supported by scientific community and the era of discovery of nanocomposite materials began. At present, various ingenious means and forces are applied as such nuclear manipulators, but the solution to the problem has not been found yet.

2. Nanotechnologies as an Outcome of the Cybernetic Revolution. The Origin of the Discipline and Field of Research

As it has been already mentioned, the first practical steps in nanotechnologies, as well as the ideological interpretation of the field, were made in the 1950s (and the term, according to some scholars, was introduced in 1974 by the Japanese physicist Norio Taniguchi). In other words, nanotechnologies appeared to be the result of the Cybernetic Revolution. However, for quite a long time they remained in the background of other important results. Practical interest in nanotechnologies rapidly grew at the end of the initial phase of the Cybernetic Revolution, in the 1980s, with the publication of Eric Drexler's books *Engines of Creation: The Coming Era of Nanotechnology and Nano-Systems: Molecular Machinery, and Computation* (1987; see also Drexler 1992). However, the term became widespread when caught-up by mass media. With the beginning of 'the nanotechnological race', the word 'nano' frequently appears on television and in print. It meant that nanotechnologies started to be considered as a strategic branch of the future hegemony (together with others: biotechnologies, green power industry, *etc.*). Its ultimate task is to win the market of industrial production of new, important and highly sought technologies. The country which will succeed it can ensure its own economic growth and development for many years.

The race of nanotechnologies began at the US suggestion which launched the competition. During President Clinton's governance there started the development of the first program of the US National Science Foundation for studying the problems of nanotechnology. Explaining interest in the development of nanotechnologies, Clinton, in particular, declared, 'I earmark 500 million dollars in the current fiscal year (2001. – *L.G., A.G.*) for the state nanotechnology initiative, which will enable us to create new materials in the future (surpassing in characteristics the ones we have today thousands of times), to download all data in the Congress Library on a tiny device, to diagnose cancer in a few affected cells and to achieve other amazing results. The initiative being offered is for at least twenty years and promises to lead to important practical results' (see also Lane and Kalil 2007).

Almost at the same time at the request of the government a similar program was launched in Japan. A series of projects directed at development of nanodevices was planned, and the Angstrom Technology Project with financing of 185 million dollars became the most significant among them. For ten years 80 firms participated in its realization. The Western European countries also joined the race and conduct researches in nanotechnologies within appropriate national programs. In Germany, nanotechnologic researches are generally supported by the Ministry for Education, Science, Research, and Technology. In Great Britain the management of this direction is realized by The Engineering and Physical Sciences Research Council, and also by the National Physical Laboratory. The first specialized journals *Nanotechnology* and *Nanobiology* appeared. In France the developmental strategy of nanotechnologies is defined by the National Center for Scientific Researches. In Russia the Russian Corporation of Nanotechnologies or Rusnano was founded; in 2014 its nanoproduction amounted to US$ 1 billion. There appeared the club of nanotechnologists which has united scientists and industrialists from various branches. More and more attention nanotechnologies get in China, South Korea, many other states, including Russia whose starting positions are supposed to be rather good in this area (Dementiev 2008).

Now nanotechnology is one of the most intensively developing branches of economy.

3. The Development of Nanotechnologies in the Course of the Cybernetic Revolution

The characteristics and opportunities of nanotechnologies correlate with the concept of the Cybernetic Revolution, which is not surprising since they originated within this revolution and besides, will play more and more important role in the process of its development. The stages of development of nanotechnologies even better fit the periodization of the Cybernetic Revolution, than biotechnologies and medicine.

1. The initial phase of the Cybernetic Revolution (from the 1950s to the early 1990s) was the period of formation of the field. Conditionally speaking, concerning nanotechnologies this is the period starting from 1959 when Richard Feynman presented the idea about constructing new materials from nanoparticles till Bill Clinton's initiative in 2000. This period is characterized by quite numerous scientific discoveries, many of them, however, had no application at that time.

For example, in 1956 D. N. Garkunov and I. V. Kragelsky described the effect of wearlessness. They found the phenomenon of spontaneous formation of a thin copper membrane in pairs of friction between bronze and steel in aircraft parts. This membrane reduced deterioration and frictional force by ten times or more. The thickness of the membrane does not exceed 100 nanometers (the similar system functions in human joints). It exemplifies that the friction is not only a destructive process, but under certain conditions it can be self-regulating, thus opening new unknown properties. In 1968, Alfred Cho and John Arthur, the researchers from the Bell Company (USA), developed the theoretical bases of nanoprocessing of surfaces (see Rybalkina 2005: 21).

At that stage the development of nanotechnology in many respects was defined by the creation of devices of probe microscopy and devices of appropriate size. These devices are a sort of eyes and hands for the nanotechnologists. In particular, in 1981 the German physicists created a microscope which made it possible to see separate atoms, and in 1985 the American physicists created the technology allowing precise measuring particles of a nanometer diameter.

The modernization phase (the period of distribution of innovations) of the Cybernetic Revolution is the period of the formation of 'modern nanotechnology' (from the 1990s to the 2020/30s). Nanotechnologies became involved in industrial production, the nanotechnology race between countries started and many projects and whole institutes of nanotechnologies were created. The number of goods produced by means of nanotechnologies is rapidly increasing. The investments in researches increase, while nanomaterials penetrate into various spheres: engineering, medicine, transport, aerospace, and electronics, *etc*. According to the data from BCC Research (2012), the sales volume of nanotechnology products in 2009 amounted 11.67 billion dollars.

Euphoria from the opportunities provided by nanotechnologies. The analytics associate the first stage of the development of nanotechnologies (between 2000 and 2005) with the so-called 'passive nanostructures' (incremental nanotechnologies), but generally it involved production and use of nanodisperse powders. They were added in order to modify the properties of basic construction materials: metals and alloys, polymers, ceramics, and also are used in cosmetics, pharmaceuticals, *etc*. Now this is a rather primitive generation of nanomaterials already widely used in production, and they can be found in many goods. However, only few nanoprojects are applied in high-tech branches of industry.

The wide prospects provided by nanotechnologies, stirred up by certain interests and mass media, caused euphoria of forecasts the majority of which have proven wrong or will hardly come true.[1] These forecasts seem quite natural. People want the process of creation of innovations

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[1] For example, according to the forecasts of the British Trade Department, the demand for nanotechnologies will annually make more than one trillion dollars by 2015, and the number of experts engaged in this branch would increase to two million people.

and their implementation to go faster; at the same time they do not see obstacles and challenges and do not take into account the economic crises which may change plans. Thus, the volume of nanoproduction is continuously growing despite the fact that the growth rates are not so fast as it has been predicted earlier.

A number of analysts suppose that after 2020 the era of 'radical nanosystems' in the form of nanorobots will start. At this stage nanobiotechnological and nanomedical systems will develop and significantly change human life, first of all, increasing life expectancy. However, the theory of production revolutions maintains that in spite of numerous innovations appearing at the modernization phase, they will hardly make a breakthrough while many will remain of low demand at all. At the same time the discoveries which will become the basis for the breakthrough are prepared while the breakthrough itself will happen later. In the field of nanotechnologies it will most likely happen between the 2030s and 2050s. Thus, the achievements of nanotechnologies which, according to a number of researchers, will come by the 2020s (but, of course, not all of them), will actually take place one or two decades later. Nevertheless, in the coming decades the achievements already tested today in different areas will be developed.

4. What Characteristics of the Cybernetic Revolution does the Development of Nanotechnologies Manifest?

The synthesis of new materials with desirable properties. One of the major challenges for nanotechnology is to make molecules group in a necessary pattern and self-organize in order to receive new stuff or devices. The supramolecular branch of chemistry deals with this problem and explores interactions that can organize molecules in a certain way, creating new substances and materials. There are different processes of self-assembling, for example, the electrochemical anodic oxidation (anodizing) of aluminum, in particular, the one that leads to the formation of porous anodic oxidic membranes. At present within the field of nanocomposite construction they develop different technologies to produce substances with various properties, for example protective, self-cleaning, antibacterial, *etc*.

The growing self-regulation within systems. Self-organization of nanoparticles and self-organizing processes. A close connection between nanotechnologies and growing self-regulation within systems is based on the opportunity to make use of the processes of self-organization of matter, forcing molecules and atoms to be ordered in a certain spatial and structural way. The creation of new materials with desirable properties is a direct way to make systems work according to the predetermined scenarios. No wonder that nanotechnologies produce striking examples of different self-regulating systems, for example, self-cleaning nanocoatings (*i.e.*, self-cleaning mechanisms to remove bacteria from vessels or self-cleaning nanopolish products for car glass). The nanopolishes modify surface in such a way that a drop of water slides on it, collecting all the dirt, whereas on a smooth surface, on the contrary, a water drop, while slipping, leaves dirt on the surface. It is called the 'lotus effect'. The idea is borrowed from nature: the leaves of lotus are covered with the smallest wax bulges and cavities, and thus, water flows down from them, completely washing away the dirt.

Miniaturization is the phenomenon characteristic of the current technological progress. We can see that most devices, gadgets, and professional tools become smaller in size and more convenient. Miniaturization transforming into microtization is most visible in nanotechnologies. Modern processors consist of more than a billion of transistors, but nanodevices will allow increasing this number by an order of magnitude. Now there is a race to reduce the manufacturing processes for semiconductors and chips to nanometers. Some companies have already changed to 45, 32, 28 nanometer process. The Intel Company uses 32-nm process for tablet computers and smartphones, and the Qualcomm Company uses 28-nm process for manufacturing chips. The Intel Company already starts mastering 14-nm process. In the last decade the process diminished in size approximately by three times (from 90 nanometers to 32 nanometers). In the near future they strive to achieve the size of 7 or even 5 nanometers. Whether it will be successful and possible to achieve the invention of a principally new generation of computers due to such a decrease in size is not clear yet.

Nanotechnologies, energy efficiency and economy. Many nanotechnologies aim at energy saving and invention of alternative energy sources. So, the trend of small-size process technology not only increases the operating speed of electronic devices and packing density on the chip, but also reduces their energy consumption. For example, 'smart glass' for rooms is capable to react to changing illumination and environmental temperature by corresponding change in transparency and heat conduction. There are many various projects of such saving. Thus, a wide use of electronic paper could prevent deforestation. Nanotechnology also can help to solve the problems of sewage treatment.[2]

Nanotechnologies are already actively applied in agriculture, in particular, in the production of fodders which allows a considerable cutting their consumption and providing the best accessibility. In crop farming the use of nanopowders with antibacterial components provides increasing resistance to poor weather conditions and increases productivity of many food crops, for example, potatoes, crops, vegetable and fruit and berry crops.

5. Forecasts

5.1. Nanotechnologies as a breakthrough component at the final phase of the Cybernetic Revolution (in the 2030s and 2070s)

One can trace all the characteristics of the Cybernetic Revolution in the future development of nanotechnologies: the vigorous development of bionanotechnology and nanomedicine, the invention of technologies of self-regulating systems (in which nanorobots independently or as a part of more complex technology will play an important role), the production of new materials, saving of materials and energy (*e.g.,* in house due to nanomaterial for window glass; by delivering a minimum portion of medicine directly to the damaged area or even to separate cells) miniaturization, targeted actions, *etc*.

Connection with medicine: large opportunities. Despite serious progress of nanotechnologies in electronics and other branches, the real nanotechnological revolution will most likely happen at first in medicine that will give an additional impulse to the development in other areas. As a result, the breakthrough in the final phase of the Cybernetic Revolution will be provided by deep integration of medicine with biotechnologies and nanotechnologies which will bring the emergence of various technologies of self-regulating systems. We have already mentioned some directions of integration of these branches in the previous

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[2] The Chinese scientists created a system which can produce electricity by decomposition of organic substances, alongside removing organic compounds from waste water. Yanbiao Liu with colleagues developed a photocatalytic fuel cell on the basis of nanotubes which uses solar energy to destroy organic compounds in waste water and converts chemical energy into the electric one.

sections. In general the prospects of such integration are already evident. So, according to some forecasts, chimerical nanobiostructures (capable of transposing medical nanosensors, medicines and even reconstructing cells of an organism) will be created in a decade or so and in 15 years they will become everyday practice. Of course, their active use in diagnostics and developing means to acquire immunity will become an important direction in nanotechnologies. We already have examples of this process now. The Engelhardt Institute of Molecular Biology (part of the Russian Academy of Sciences) applied nanotechnologies to create a biochip allowing quick diagnosing of a number of dangerous diseases, including tuberculosis. The development of nanotechnologies to create materials imitating properties of, for example, bone tissue will be quite promising. Nanotechnologies are already implemented in such surgeries as nano neuro knitting for repair of severed optic tract, implantation of artificial limbs with high precision, cardiological surgery, *etc*.

One of the directions where huge efforts of nanotechnology are concentrated is the struggle with cancer. For example, the Institute of Cancer in the USA voted 150 million dollars for such researches.

One can suppose that cancer treatment will become possible as soon as there is found a means to better target a certain layer of cells in a necessary part of the organism. However, it is possible that cancer will be defeated without destroying cancer cells, but by means of the method to fight metastases. The work is conducted in various directions here. Perhaps, the organism will give a clue. For example, it is known that metastases do not appear in heart tissues: obviously, there are some defense mechanisms which should be discovered (Marx 2013).

There are some examples of new directions of the cancer control based on nanotechnologies. For example, the system of carcinoma treatment is being developed based on heating of nanoparticles of iron oxide which are put into the infected tissue and influenced with a magnetic field as a result of which particles heat up and destroy cells. At present, this method is passing clinical testing phases; however, the lifetime of the patients who underwent a cure considerably exceeded the time forecasted by doctors. A problem with this method is the exact injection of the iron oxide particles into the tumor cell.

At the Laboratory of Nanophotonics at Rice University in Houston, Professors Naomi Halas and Peter Nordlander invented a new class of nanoparticles with unique optical properties – nanoshells. With a diameter twenty times smaller than red blood cells (erythrocytes), they can freely move in the blood system. Special proteins, that is antibodies attacking cancer cells, are specifically attached to the surface of cartridges. Some hours later after their injection the organism is beamed with infrared light which nanoshells transform into the thermal energy. This energy destroys cancer cells, and the neighbouring healthy cells are almost not injured at that.

The important direction of research in the area of oncotherapy consists in automatic 'smart' hitting of the malignant cells by nanoparticles. The thing is that only one-millionth part of the revolutionary new substance Herceptin, used to treat a considerable number of patients with breast cancer, would target the diseased cell. To make the transportation of Herceptin more effective, a group of American scientists invented a special model of a capsule from porous silicon into which the medicine is injected and is directly delivered just to the damaged cell. Now this technology is being clinically tested. The American scholar Mark Davis discovered a special capsule which has a structure similar to sugar and therefore is not rejected and not excreted by the organism. A preparation is put into this capsule and can be stored in the organism for weeks. It is searching for a tumor moving within the blood-vascular system. Cancer cells are more acidic, than the usual, healthy cells, and, when finding such cells, the capsule opens and discharges the strong medicine. A patient with a pancreas terminal cancer, at the stage of metastasis was subjected to such cure and is still alive and even did not lose his hair after chemotherapy.

A future direction of medicine is the development of diagnostic methods that are also cost-cutting. We have already spoken about nanochips which can play an important role here. The nanorobots which will be able not only to perform medical functions, but also to control individual cellular nourishing and excrete waste products will be put into practice. Nanorobots can be used for the solution of a wide range of problems, including diagnostics and the treatment of diseases, fighting ageing, reconstruction of some parts of human body, production of various heavy-duty constructions (Mallouk and Sen 2009).

It is clear that some promising technologies which are forecasted today, will fail to become successful in the future. But there is no doubt that the use of nanomaterials, nanorobots suitable for research, and other nanotechnologies will create important backgrounds for the future era of self-regulating systems in medicine.

The connection with biotechnologies and agriculture. Other important directions of nanotechnology are research in the field of nanobiotechnologies. One can mention here the development of controlled protein synthesis technologies for receiving peptides with desirable immunogenic properties. Vector systems for the cloning of immunologically significant proteins of the causative agents of the diseases and vaccines of the new generation possessing a high activity and safety are created. Research is being conducted on creating nanoparticles for making genetically engineered proteins, the development of biochips and test systems for biological screening (Persidis 1998), immune monitoring and forecasting of dangerous and economically significant contagions of animals. Biochip technology is constantly improving and their manufacturing is cheapening (Rusmini *et al.* 2007).

It is expected that by means of nanotechnologies and use of robots the development and application of biotechnologies will significantly advance in the direction of creating self-regulating systems of farming, where agricultural operations will be for the most part performed in an autonomous mode. Many technologies will appear to promote this process. Thus, the implementation of membrane systems for cleaning, and also special biocidal coverings and silver-based materials will facilitate and increase the level of managing the farm livestock and providing them with high quality water. It is assumed that the use of nanotechnologies will allow changing technology of cultivation of lands due to the use of nanosensors, nanopesticides and a system for decentralized water purification. Nanotechnologies will make it possible to treat plants at the genetic level and allow creating high-yielding plant varieties especially resistant to unfavorable conditions (Balabanov 2010). Today there are some innovative ideas which can be further elaborated in the agriculture. In particular, there appeared microbial preparations based on associative, endophytic and symbiotic bacteria. These preparations are intended to produce and convey various enzymes and low-molecular biological active agents (nanoobjects) in plants. These can improve adaptation of plants to unfavorable environmental conditions: pollution by toxic metals, salinization, superacidity, *etc*. A fundamental approach to getting high quality seed material is essentially developed. This approach is as follows: biologically active and phytosanitary components which can increase the adaptation of seeds and plants to real negative environmental conditions are constructed in the form of multifunctional nanochips.

5.2. Various prospects of usage of nanotechnologies within the Cybernetic Revolution and at the mature stages of the scientific-cybernetic production principle

Nanotechnologies have considerable prospects. The components of nanoelectronics, photonics, neuroelectronic interfaces and nanoelectromechanical systems will be developed. Then on the basis of the achieved results we can expect advance in development of nanosystems capable to regulate self-assemblage, the creation of three-dimensional networks, nanorobots, *etc*. One can also speak about the use of molecular devices, nuclear design, *etc*. Especially alluring prospects are observed in the development of nanomechanics, nanomechanical engineering and nanorobotics.

Quite long ago there appeared an idea to store data using peculiar environmental phenomena (*e.g*., magnetic, electric, and optical), with advent of nanotechnologies it becomes possible to store information, for example, by means of replacement of silicon, the basic material in the production of semiconductor devices, or by carbon nanotubes. In this case a bit of information can be stored in the form of numerous atoms, for example, of 100 atoms. It would reduce the sizes of processors by an order of magnitude and essentially increase their operation speed. Now the number of transistors in the processor reached a billion and more. However, a few years ago the task was to create a processor with more than one trillion transistors by the 2010s (that would lead to radical increase of the ICT opportunities). Most likely, this is an unreal task to achieve even by the 2020s, before the beginning of the final phase of the Cybernetic Revolution. It is supposed that this level will be achieved later, as we are already in the process of developing this phase (this would also open new horizons for a full replacement of the information computer equipment due to a transition from using silicon to nanomaterials).

However, it is possible that the smallest computers will have an essentially new basis. According to Eric Drexler, it is nanomechanics, not nanoelectronics, can become such a base. He has developed mechanical constructions for the main components of the nanocomputer. Their main components can be pushed in and out cores interdependently locking the movements of each other (Balabanov 2010).

From special structures, such as fullerenes, nanotubes, nanocones and others, molecules can be gathered in the shape of various nanodetails – tooth wheels, rods, bearing details, rotors of molecular turbines, moving parts of manipulators, *etc*. The assembly of the finished parts into a mechanical design can be realized by using the assemblers (self-assemblers) with the biological macromolecules attached to the details capable of selective connection with each other. This idea was realized by Professor James Tour and his colleagues from Texas Rice University who in 2005 created a molecular mechanical design – the all-molecular four-wheel nanocar about 2 nanometers wide consuming light energy. It consisted of about 300 atoms and had a frame and axes. The development and creation of the nanocar took eight years. The scientists plan to create nanotransport devices, the nanotrucks, to transport molecules to conveyors in nanofactories (*Ibid.*).

Certainly, this is more like toys, than research for practical use. They remind us of the steam toys like the mechanisms created by the Greek mechanic Heronus Alexandrinus, who amazed the audience in the first century AD. They hardly had any similarity with a steam-engine. But unlike Heronus who even did not think of a practical use of steam, the current nanotechnologists are absorbed with practical application. Therefore, the creation of nanomechanical engineering is quite real, though a long-term perspective. It will most likely happen close to the end of the current century. The same refers to nanorobotics. At present, the expected designs of nanorobots and their use exist only in forecasts.

There is an opinion that in the 2030s some nanodevices will be implanted into human brain and will be able to perform the input and output of necessary signals from the brain cells and this can even make learning and getting education become unnecessary. But it causes great doubts. Even if such a cyborgization is realizable in principle, it will occur much later.

Anyway it is obvious that both nanomechanical engineering and nanorobotics will propel the development of self-regulating systems to a new level towards the formation of an industry that will design such systems (similarly, the use of cars promoted their industrial manufacturing – mechanical engineering).

Chapter 6

Robotics and Other Technologies in the Cybernetic Revolution

1. Robotics as a Direction in the Development of Self-Regulating Systems

The concept of robot is very uncertain since today computer programs, manipulators, and other mechanisms, as well as human-like autonomous devices can be called a robot. But despite such a variety, a number of the main characteristics of robots of all types can be defined. It is of special importance for us that these characteristics coincide to a large extent with the characteristics of the Cybernetic Revolution and its technologies. First of all, an ideal robot (which can move, work and solve problems depending on the situation, as well as to meaningfully communicate) is a good example of a self-regulating system. It also visually reflects concrete manifestations of the main cybernetic categories, namely: active information processing (its receiving, analysis, distribution, transformation, *etc.*), management of the whole system (and of other objects) by means of information, flexible interaction with environment, existing contours of direct, and feedback links that allow fulfilling various functions. Many definitions also emphasize the aspiration to treat robot as a self-regulating system. For example, *robot is a device capable to move independently in space, to cope with tasks of picture recognition and analysis, possessing a large mobility, able to analyze a situation by means of feedback and also to predict situations, relying on its own experience and available information* (definition by Professor Shigeru Vataat, see Nakano 1988: 26).

1.1. Robotics at the modernization phase of the Cybernetic Revolution

The initial phase of the Cybernetic Revolution convincingly showed a powerful rise of the new branch of robotics; thus, hardly anyone doubted the promising prospects of its development as well as broad implementation. Indeed, the development of robot seemed to have limitless potential. Serious futurologists predicted, for example, that in the 1980s the number of industrial robots will increase approximately by 35 per cent a year (Kahn 1982: 182). However, the growth was much more modest. The reason is that in the Western countries where large-scale industry has been excluded and the share of industry (and the number of workers) has been constantly reduced, the need for the substitution of workers has significantly decreased, and investments into the relevant research has also been reduced respectively.[1] Robotics continues to develop in such countries as Germany and Japan which in many respects have preserved their heavy industry unlike other developed countries.

In the 1990s robots continued to develop: there were improved the characteristics, software, and interface, the control became easier, *etc*. But the focus was on the development of information robots and not industrial ones (we have already spoken about the use of such robotic programs at the stock exchanges).

Apparently, the number of industrial robots will grow rather actively due to modernization of the developing countries' economies, but most probably, the industrial direction of robotics will not become breaking through at the initial stage of the final phase of the Cybernetic Revolution in the 2030s and still will gain pace a bit later.

According to the International Association of Robotics, in 2010 just over a million robots were involved in production in the world (only rather advanced machines which have at least three axes of mobility and possibility of free programming are taken into account). Every year the number of robots increases by 100,000 or even more ‘individuals’. At the same time the trend of growing number of robots shifts to Asia (*e.g.*, in 2010 26,000 devices out of 120,000). First of all, robots are used here for work under sterile conditions (in electronic and in pharmaceutical industries), product assembling and packing (Smirnova 2011). Nevertheless, a considerable number of robots are still used in automobile factories where there are from 400 to 700 robots per 10,000 workers. In comparison, in electronic industry there are 100–200 robots for the same number of workers, and there are less than 50 robots in the food industry (*Ibid*.). Robots are actively employed in logistic centers and in some other areas. Fig. 7 shows the estimations of the industrial robots shipment.

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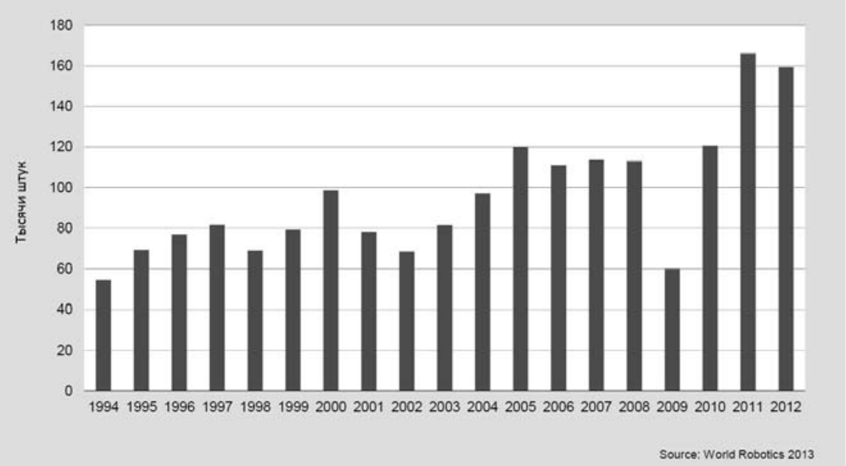
[1] Process of deindustrialization is vividly described, for example, in Martin and Schumann 1997.



Source: World Robotics 2013

Fig. 7. Estimated worldwide annual shipments of industrial robots (1994–2012) (Tsirel 2014: 365)

Of course, robots have serious advantages over humans: they work much faster and besides, their work is more qualitative, their application also reduces the level of product failures which is extremely important when releasing expensive facilities. Nevertheless, industry has not immense market for implementing robots since there are a lot of countries with cheap and young labor force.

At present, along with first-generation robots (most numerous) various second-generation robots are developed. The active work is carried out on the design of the third-generation robots with high order of intelligence, adaptation and orientation.

One should also mention military robots or robot-like facilities since today the greatest part of robots is produced for defense needs – about 45 per cent. However, it is not surprising. From their very emergence the nuclear and space industries as well as aircraft industry where such mechanisms began to be used have been primarily connected with military tasks. All this has begun even before the Cybernetic Revolution. At first there were used ordinary technical innovations for production of military automatic machines (like magnetic torpedoes or torpedoes reacting to noise). Then devices with operating subsystems appeared. In fact, modern military rockets capable of bypassing obstacles and obtaining the target, as well as drone aircrafts, or even autonomous cars present very perfect systems, and it is rather difficult to find their precise differences from robots. But today the flying robots (also called pilotless planes, or drones) start to be actively used for peaceful purposes (a rather frequent trend of technological development) for checking the power lines or delivering first-aid equipment (they can also be used as messengers), in agricultural sector, for shooting and many other purposes when inexpensive and ongoing aerial support or supervision is necessary. So far the drones of this kind are controlled by a person on the ground.

Nevertheless, the experts believe that the following step in the drone technologies will be the development of vehicles operating autonomously and this will open numerous opportunities for their use in new fields.

At present, a number of military robots have been developed: spy rectangulars (including underwater vehicles), hospital attendants, mine-clearing robot and some others. However, the majority of military robots are remote-controlled by human operators, only very few models have an opportunity to fulfill some tasks autonomously. Thus, these (as well as other) self-regulating systems after all are still closer to the operated machines, yet, they advance towards self-regulation. At the same time it is obvious that the remote control even in technical terms does not work everywhere. For example, while controlling robotic missions in deep space there is a delay in receiving a signal at the expense of vast distance (about several minutes) that is unacceptable. Therefore, people need robots operated not directly by a person, but performing behaviors or tasks with a high degree of autonomy (see Yuschenko 2015).

1.2. Robotics in medicine and nursing

We have already spoken about a successful use of robots in medicine. In our opinion, this direction will unambiguously promote the start of the Cybernetic Revolution. Now surgical robots are most widespread. Robotic surgery started to develop in the 1980s. The surgical robot *Da Vinci* was one of the first robotic systems used to aid in surgical procedures. The working prototype was designed in the late 1980s within the framework of the contract with the US army. By 2015 more than 3,000 such machines have been constructed. Since 2000, about 1,370 American clinics ordered robots whose average price is about two million dollars for a system (Beck 2013).

Robotic surgery is a rapidly developing sector. In 2000, there were performed only 1,000 robotic surgeries world-wide. In 2011 their number already grew to 360,000, in 2012 – 450,000 (Pinkerton 2013). According to the research conducted by the Columbia University from 2007 to 2010, in the US clinics from 10 to 30 per cent of surgeries were robotically-assisted (Beck 2013).

Robotically-assisted surgery has many advantages. However, along with advantages robots (including the surgical ones), cause new problems and fears since the surgeries with involvement of these systems carry a significant risk. Thus, the doctors from Rush University Medical Center, the University of Illinois and the Massachusetts Institute of Technology provided the data which show a definite increase of the number of injuries and fatalities after the operations performed by the robots, from 13.3 cases per 100,000 surgical operations in 2004 to 50 cases in 2012. FDA registered a 34-percent increase of deaths after robotically-assisted surgeries in 2013, relative to the previous year (Pinkerton 2013). Thus, medicine and robotics are only at the beginning of the way; however, this direction looks very promising.

Currently, robots are actively involved in nursing-care and medical-care. In Japan they already test robots nurses. They help patients to get out of bed, render help to stroke victims in reasserting control over their limbs (Khel 2015). *GeckoSystems* produce robotic nurses and robotic attendants that with telepresence capabilities will permit doctors and nurses to monitor and examine patients remotely as well as change bed linen and give medicine to patients. In our opinion, it is one of the most challenging directions of using robots in the future. This market is estimated to be in the hundreds billions of dollars.

1.3. Forecasts of the development of robotics

So, we believe that in the next two–three decades robotics will develop more rapidly not in industry but in other spheres. First of all, in service industry. Why? First, today it involves the major part of the working population in the developed countries. For example, in the USA its current share has reached almost 80 per cent (World Bank 2016). The similar share of people employed in the sector is observed in other developed countries, and it is rapidly increasing in all states, including China, India, and the Third World countries in general, where the least intellectual and skilled work still exists. Most migrants move to Europe to work in this very sector, while the tension towards migrants is increasing. Thus, in economic terms this is the most promising sector for labor replacement since the industrial sector has already considerably exhausted its employment opportunities (besides, manufacturing will continue to grow in the developing countries with their abundant cheap labor). Here one can also mention robot cooks and robo-waiters. Secondly, more complicated jobs and service such as, for example drivers, consultants, especially health workers will be actively robotized due to the high price of their work. But probably robots will mostly substitute medical attendants and nursing staff (*e.g.*, medical assistants, laboratory assistants, nurses, surgical assistants).

Thirdly, robotics will continue to develop in the direction of robotic housing units (such as vacuum cleaners), including the Internet of Things (IoT) network. It will obviously provide a huge market and, moreover, give opportunities to connect robots to home computer or an operating center.

Forecasts of development of robotics at the final phase of the Cybernetic Revolution. 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. Already today it is evident from the exploratory developments (though they are far from production). For example, the scientists from the Oslo University in Norway by means of 3D-printing has developed a category of self-learning and self-repairing robots which are able to take analyze the situation, and, using its integrated 3D-printer, produce a new part (Vogt 2014). This is a good example of integrated self-regulating systems. Another interesting example is the *Roboearth* project of the Internet for robots. Robots record all their operations into this remote database and can address it if the necessary operation is absent in their installed program. It is not just a self-regulating system, but to some extent it is the inchoate collective robotic intelligence (Waibel *et al.* 2011). The task of providing control over multi-robot system in the future is already set for robotics. A group of machines is able to fulfill qualitatively different tasks than one robot (Yuschenko 2015).

Also, it is not surprising that people have considerable interest in robots, as well as in any demonstrations of innovations in this sphere which draw attention and are always effective. But here one should point that although the ideas about 'smart' robots are very much important for us since they are a good example of the most important characteristic of the Cybernetic Revolution and its technologies (that is a transition to self-regulating systems), it is necessary to recognize that the forecasts about coming of such 'smart' facilities in the near future do not correspond to the real opportunities yet (just as well as the predictions of earlier researchers have not come true, see, *e.g.*, Moravec 1988).[2]

There are various assumptions of role of robotics in the near future. In 2007 Bill Gates (2007) considered that robotics was approximately in the same position as computers used to be in the 1970s when they founded the Microsoft Company together with Paul Allen and he apparently anticipated that in the 2030s robotics would become as important as ICT today. However, we consider that this prediction will not come true by the appointed time. Some firms work on these or those developments, but in general, unfortunately, there is not so much business interest in this direction yet, say, in comparison with bio- or even nanotechnologies though robotics has already a rather long history. Now the total volume of world production of robots is rather small, only several billion dollars. And even according to optimistic forecasts of the Japanese Association concerning robotics, by 2025 the turnover of the robotic branch will make only 50 billion dollars (Gates 2007), that is the volume absolutely insufficient for an economic takeover.

Therefore, there is no doubt that a bright future is awaiting for this direction. But most likely its rise will happen already during the Cybernetic Revolution on the basis of development of technologies of the future.

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.

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[2] Some authors go very far and believe that in the twenty-first century robots will have all characteristics of human mental and physical abilities. In their opinion, the twenty-first century will become the century of the post-biological world when as a result of the natural selection robots will force a human out of the pedestal of evolution and will develop under the influence of the new post-biological evolution which can exceed the rates of the biological evolution millions of times (Wadhawan 2007). In our view this looks more like a scientific fiction than scientific forecasts.

In what particular direction will robotics start to develop quickly? We believe this will be the sphere of social nursing care for the infirm and with medical care, since let us emphasize again, this is one of the main directions that will allow at least a partial solution of the problems of care for elderly persons. Also, as it has already been mentioned, the development of robotics will be connected with service industry (there will appear robots-messengers, sellers, cashiers, consultants, inspectors, *etc.*), domestic life (cleaning, cooking, other domesticities, managing a household, *etc.*) or business.[3] There is great progress in robotized electric vehicles, which are self-driven and thus, can strongly reduce the number of drivers. As we have already spoken, programming will be also robotized, and there will be actively developed the robotic systems for the tasks that can be dangerous for humans (military, rescue and space activities, *etc.*). Hardly all of them will be anthropomorphous, most likely their design will be defined by functions. However, universal robots are also likely to emerge.

2. Universalization and 3D-Printers

Universalization as a characteristic feature of the Cybernetic Revolution. Universalization is one of the most important and even surprising characteristics and trends of the Cybernetic Revolution about which we have spoken insufficiently. This vector of technological changes will incorporate maximum possible operations from different technologies and will make them widely used, and for this purpose it will constantly combine various techniques and mechanisms existing and working independently. Technologies and devices become more and more functional, incorporating previous independent technologies as subsystems. At the same time this unification can be quite unexpected and can combine with a tendency towards miniaturization and individualization. The example of this kind is the computer currently integrating at least twenty functions (from a former typewriter to video camera, from a pencil to a secretary,

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[3] There are also some exotic assumptions. For example, some researchers consider that one of the most perspective directions in development of robots is intimate services (we have already spoken about it in *Introduction*). By the way, robots already show considerable results and prospects in this sphere (Yeoman and Mars 2012). There are also apologists of this direction. In the book 'Love and Sex with Robots' David Levy (2008) assumes, for example, that by 2050 the relations between human and robot will be a universal and common phenomenon. However, it is quite possible (and it would be reasonable) that such production can be forbidden. Let us note that feminists have already begun such a campaign (see Griffin 2015).

from a tape recorder to the TV), and mobile phone. Even the Walkman has become multi-functional (though it will most likely disappear).

And what about a car? It includes so many functions now! It is a house, transport, mini-station and a concert hall simultaneously. On the basis of this universalization there developed do-it-yourselfer competences which we have already mentioned and which lead to disappearance of the number of professions. However, universalization is observed not only in electronic devices. We can trace it in the development of robotics where one of the main directions is to create multifunctional robots as well as mini-laboratories which also become more and more multifunctional.

In general the industrial production principle of the eighteenth-nineteenth centuries developed specialization; yet universal things were invented during this period as well (*e.g.*, electric motors). It should be mentioned that universalization did not clearly show up at the initial phase of the Cybernetic Revolution. On the contrary, specialization was seemingly increasing. However, the tendency came to the fore during the modernization phase of the Cybernetic Revolution and has been increasing ever since.

We believe that, first of all, this tendency has not come to maturity yet but it is likely to step forward in the final phase of the Cybernetic Revolution. Secondly, it actually leads to the emergence of complex self-regulating systems which, being multifunctional, will include a number of subsystems and technologies, yet their main element will be the system of management capable to self-regulation and self-management. Thirdly, this tendency will respectively reveal itself in various spheres. For example, we have already described health monitoring systems which will fulfil numerous functions. Besides, multifunctional robots are also most likely to appear. Fourthly, this tendency will promote the emergence of closely interconnected complex technologies.

One of the most recent trends in universalization are the 3D-printers which will probably start to compete with computers in terms of scale and scope of application. The opportunities provided by such printers are exclusively great: from building to cooking, from a house workshop to museums, from medicine to children's toys, from training models to design. These machines are actively used in such branches as aircraft construction and rocket engineering to produce individual details, for example, support stand for an aircraft engine (see, *e.g.*, Turichin 2015). And just because they are used in such spheres their development needs considerable investments.

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

These devices can exist in different sizes and use different materials (from refractory metals to paper with only exception for aluminum) and can manufacture most different objects. Three-dimensional or 3D-printer unlike the usual ones that print two-dimensional drawings, photos, *etc*. on paper gives a chance to synthesize three-dimensional information, that is to manufacture three-dimensional physical objects. With reference to 3D-printing we can also mention fusing of powder agglomeration of both polymeric elements and metal powders (we can observe here a link between printers and nanotechnologies).

Printing with a 3D-printer is a process of making of a real three dimensional solid object from a digital file, a template designed with 3D Computer Aided Design (CAD) software and saved in the STL format, and then the 3D-printer manufactures a real product by fusing layers upon layers of materials.

Fusing layers consists of a number of repeated cycles of creating three-dimensional models, applying a layer of materials on the working surface (elevator) of the printer, descending of the elevator platform by a distance equal to the thickness of a single layer and removal of waste from the surface of the working area. The cycles follow one by one continuously.

In industrial production (metallurgy and mechanical engineering) a detail is produced most often by subtraction that is a removal of the material (though casting and other methods are known), turning and drilling it, deleting superfluous material. The basis of 3D-printing is additivity, that is merging (fusing) of materials and creation of a certain construction (such technologies are called additive).[4] Due to a widespread use of 3D-printers long technological chains can be eliminated in some branches of production. It will be enough to have a sketch and to make (to ‘print’, ‘fuse’) a detail at home or in a 3D-printing center. It will also possible to organize a small single-piece production. Engineers could al-

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[4] As well as of future assemblers of Drexler (1987, see also Drexler 1992, 2013).

so develop simple food 3D-printers which can print, for example, candies or pizza.

3. Cognitive Science and Cognitive Technologies

Cognitive sciences study the nature of mental and nervous processes which control movement and many other bodily processes. Actually it is a large complex of diverse areas connected with intellectual processes, consciousness, knowledge, memory, *etc*. We refer here to such fields as cognitive neurophysiology, cognitive neuroscience, *etc*. In the previous decades many discoveries have been made which explain some mechanisms and reactions of our brain and mentality, including the work of so-called neuromediators. A considerable number of neurostimulating pharmaceuticals of a new generation have been created which are actively used in medicine nowadays. In general there appeared a new direction in pharmacology – neuropharmacology.

The key technological achievement was the development of new brain-scanning technologies (including computed tomography, *etc*.) which for the first time allowed producing multiple images of the inside of the brain and receiving direct and not indirect data of its work. Nowadays many research organizations are involved in the studies and try to create a database of neuronal cells and their types (according to the latest data, there are 90 billion neurons in human brain). This will allow advance in the interpretation of the mechanism of visual system operating by means of development of a functional classification of different types of neurons in the brain.

Neural interfaces or brain-computer interfaces (which we spoke about in Chapter 3) can become one of the breaking through directions of cognitive science and the Cybernetic Revolution in general. Let us remind that neural interfaces are technologies connecting human nervous system with external devices (usually they implement the interaction between brain and computer systems). The basic achievement of cognitive sciences is an opportunity to control artificial organs via brain signals as healthy people do it. In 1924 the German scientist Hans Berger made the first recording of human brain activity by attaching electrodes to the head (Wolpaw J. and Wolpaw E. 2012). Later electrodes were embedded directly into human brain.[5]

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[5] In 2010 there were about 35,000 people in the world with the electrode implanted into the brain (see Swaab 2014: 292–294).

After it was established that electric activity of neurons can help to operate robotic manipulators, the study of neural interfaces became even more active (Lebedev and Nicolelis 2006). Now they have managed to perform the transmission of neurons signals to devices and thus, to operate artificial limbs with a natural accuracy. We have already spoken about some of them earlier. Scientists are already adjusting the functioning of an artificial eye, ear, and heart by means of neural interfaces.

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. Among obstacles one can mention, first, the immune rejection. 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 traumatizing of the whole organism despite all serious attempts to reduce this impact (Grill *et al*. 2009). 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. At the same time it is very important to find the means to provide feedback between a device and human brain, in other words, the brain should not only emit a signal, but also receive it from the device. After exceeding these constraints, the development of neural interfaces will promptly reach a new level. But to avoid the mistakes and problems like experienced ones from the spread of computer games (but with consequences of a much larger scale), it is necessary to preliminarily prevent data abuse and influence on mentality.

4. Transportation and the Cybernetic Revolution

In the middle or end of the final phase of the Cybernetic Revolution (between the 2040s and 2060s) one can expect a mass development of some new means of transport. In recent years the improvement of electric automobiles has proceeded rather quickly which is connected with the fight against emissions of greenhouse gases, high oil price, and government financial incentives. As a result the fleet of electric cars is quickly growing. By the end of 2015 there were more than one million electric automobiles. In a number of countries electric cars already have an essential share in sales of vehicles. For example, in Norway in 2013 it accounted for 6.1 per cent and more than 10 per cent in 2015. According to the forecasts of the International Energy Agency (which we consider too optimistic), by 2020 electric cars will amount to 2 per cent of the world fleet of motor vehicles which will make 20 million cars in numerical expression (see Sidorovich 2015).

Thus, the number of sold electric vehicles is growing quickly enough, in the near future they can amount to half a million a year or more. But one should point that more than 40 per cent of such cars are hybrid vehicles that combine a conventional internal combustion engine with an electric propulsion system (Statistics… 2015). It reminds a situation with steamships in the nineteenth century when many vessels had both the steam engine and the sails. Thus, the development of electric vehicles becomes already a significant sector in car industry. However, we should keep in mind that the importance of a sector may turn illusive since it can be much written and spoken about while the actual importance is rather modest with respect to the general scales of a branch. Besides, when new systems become widely available we face problems and drawbacks which are not so easy to eliminate. And this starts to hamper the initial fast development. Perhaps, the development of electric vehicles will be limited to a certain share of the automotive market (at least, in the next two decades).

Speaking about electric vehicles, one should mention the recent research (especially in Germany) in construction of highways, on whose separate lanes it would be possible to construct something like an electricity conductor by using special materials.[6] Then electric vehicles would recharge as needed (the so-called wireless charging technology). Certainly, such roads could change modern transportation system considerably.

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[6] For example, there are projects of using solar batteries instead of pavement, or electricity will be charged from another source.

But taking into account the above-described ‘meaning’ of the Cybernetic Revolution (as a revolution of self-regulating systems), most likely, the breakthrough will happen in the direction of autonomous traffic and its management. That is transport vehicles and systems will become self-regulated and will incorporate the electric vehicle technologies. Even today there is some draft of realization of this opportunity. For example, Tesla Motors produces some models with autopilot; the German concern ‘Mercedes-Benz’ has presented the concept of the driverless car (della Cava 2015). And *Google* promises to create such a car by 2020 (see Google n.d.), but it already tests the Toyota self-driving car in California (and arranges joint projects with *Ford*). Just as in 1996 the computer defeated the world chess champion, recently self-driving car has beaten the race driver at speeds over 200 kilometers per hour. The record has been set up in Northern California – the car was faster only by 0.4 of a second (Prigg 2015). It is not clear how it will stimulate the development of driverless cars since chess competitions with computers have been little spread. However, engineers from Google especially emphasize that their new developments can make our usual daily trips much safer. Nevertheless, there are many obstacles, including legal and organizational (safety, fears and conservatism) on the way to the mass implementation of self-driving cars. It is impossible to overcome them quickly.

The spread of electric cars for the owners' private goals can be delayed since they have neither really important advances for mass users and impossible for conventional vehicles, nor can they evidently reduce the costs. Also since humans can drive cars themselves, quite few of them will be eager to pay for a robot. Thus, together with anxiety that such self-driving cars will leave millions of people without work in the near future there arise the obstacles for their mass distribution. In business terms the self-driving vehicles could dramatically change the freight transportation as well as taxi service. These self-driving cars can completely eliminate taxi drivers as a profession (Khel 2015) as well as truck drivers. But here there can emerge certain legal and social difficulties.

In any case the development of such self-regulating systems is an important forerunner of the forthcoming start of the final phase of the Cybernetic Revolution (in the 2030s). The self-driving electric vehicles with a new perfect accumulator[7] together with roads allowing free recharge can become a powerful source of technological development during the final phase of the Cybernetic Revolution and during the mature phase of the scientific-cybernetic production principle.

5. Other Technologies within the Cybernetic Revolution

The described processes must prove the idea that the final phase of the Cybernetic Revolution will be the era of a rapid development of self-regulating systems. Actually, already now we use a lot of systems of the kind, but do not take them as such. Others have not found a broad application yet like self-cleaning glasses, but soon enough they can become a part of our everyday practice. With the emergence of machines in the preceding centuries there appeared dozens of bright insights about their future application, and at the same time numerous ideas which failed to come true. And today it is difficult to define what will become a reality and what will not. But there is no doubt that the development proceeds towards the invention and wide distribution of self-regulating systems. We expect the development of such systems which will work almost independently and control important aspects of human life like today computer programs of spelling start checking your style or spelling. All this demands a deep understanding of the field of minimization as a solution to important present day and emerging problems. As already mentioned, the Cybernetic Revolution (like any production revolution) brings changes in all spheres of production and areas of life. However, these changes being part of a single large process will happen not simultaneously.

Now it makes sense to say a few words about changes in other spheres.

Specialization. Finally, there is no doubt, that the future technological changes will bring major and in many cases radical changes in the professional structure and competences of the population.

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[7] Li-Ion accumulators become cheaper quickly enough, there is progress concerning speed of recharge of accumulators. It may happen that use of graphene will become a breakthrough in production of accumulator equipment. The Spanish company *Graphenano* announced accumulators which are 77 per cent cheaper and easier than those used today and provide a driving distance of 1000 kilometers and at the same time are charged just in ten minutes (Sidorovich 2015). But one should keep in mind that such victorious reports may actually turn far less impressive or even just fancy talk.

The production revolution radically changes the specialist area of people, their professional skills (competencies) and creates a need for new professionals. The farmer and the craftsman replaced the competences of the hunter and gatherer during the Agrarian Revolution. With the emergence of metals specialists, stone working disappeared. But nevertheless, during the era of the Agrarian Revolution, changes were happening rather slowly.

Almost the whole period of the Industrial Revolution, since the sixteenth century and, at least, till the last third of the nineteenth century, passed under the banner of battles pitting the skilled craftsmen against the Leviathan of technological progress. This period is full of episodes of prohibitions on inventions, the acceptance by the representatives of factories of various constraining laws, and history of destroyers of machines, *etc*. Thus, the grounds for such bans and constraints were the most serious: product degeneration, falling of earnings, competition between the people having no necessary professional skills. However, as a result, machinery replaced manual operation, waves of technological innovations wiped out the groups of experts.

The initial (and even the intermediate) phase of the Cybernetic Revolution, especially with the spread of computers, has also led to changes in professional skills, including in the spheres of intellectual activity: typing, books publication, magazines and newspapers, translation, collection of information, library science and archiving, design, advertising, photo, cinematography, *etc*. There is not a long time from now when books in their present form will become a rarity. The emergence of ‘do-it-yourself’ technologies (a director, a publisher, an artist, a photographer, *etc*.) became an attribute of the time.

The further technological development will undermine the bases of many professions – from a doctor and teacher to a nurse and tax assessor. As we said above the robotic pilots can replace professional drivers and children and sick people could have their own electronic nurses.

On the whole, the general course of development should proceed towards the reduction of the workers in service industry sectors (both simple and more difficult types), but at the same time many new professions will be in demand. As we have already noted, the reduction of people involved in service industry will occur not least due to the development of robotics.

Power industry. During the previous production revolutions the energy source would also change. The Agrarian Revolution brought biological energy into use that was strength of animals; the Industrial one used at first water power, then it was replaced by steam power and then electricity and fuels.

An adequate energy source to start the Cybernetic Revolution, namely, electricity has already existed. The idea that a new leading energy source will become thermonuclear, hydrogen or some other new type of power has not been realized yet. There is a question: whether an adequate energy source for the final phase of the Cybernetic Revolution has to appear? The experience from the previous revolutions shows that it is not necessary at all. The transition to the irrigational intensive agriculture did not demand the obligatory use of animal draught power (for plowing) as well as the first sectors of the machine industry quite managed with the known water energy source. However later, in the end of the final phase of every production revolution and during the transition to mature stages of every production principle, new sources of energy appeared (so, the completion of the Agrarian Revolution in the rain fed zones was connected with agriculture with the use of bulls and oxen; and the completion of the Industrial Revolution – with the use of steam energy). It should be noted that in both cases it was not totally unknown energy. Steam energy was occasionally used since the seventeenth century.

Essentially new power source will not be required to start the final phase of the Cybernetic Revolution. Concerning the development of alternative (low carbon) power engineering will not play a decisive role here. However, a new energy source has to appear either during the final stage of the revolution, or a bit later. Also, most likely, it will not be absolutely new and not used previously. Most probably, thanks to technical innovations, it will become possible 'to tame' and to make sufficiently available this or that type of alternative energy (hydrogen, thermonuclear, solar; or it will be the invention of easily stored electric power which will also solve the problem with a power source for eco-friendly transport). At the mature stages of production principle changes in energy production also take place which create the base for a new production revolution (so during the maturity period of the craft-agrarian production principle the power of water acquired those properties, used for driving mechanisms, and during the maturity period of the trade-industrial production principle the electric power became such a source). But what energy will appear at the final stage of the scientific-cybernetic production principle is difficult to imagine so far.

Communications. The production revolution surely changes the ways of communication. At the beginning of the Industrial Revolution there was invented a new type of information technology which created one of the impulsive forces of communication. We mean the invention of printing. The role of the new types of communication and connection (TV and computer) became even more essential at the beginning of the Cybernetic Revolution. Thus, the initial phases of the production revolution can be caused by the emergence of new types of communication. However, it is not a prerequisite for the beginning of the final phase of a production revolution (though writing appeared on the eve of the final phase of the Agrarian Revolution, its role was not essential). New forms of communication could appear at the end of the final phase of a revolution or after it. For example, electric coupling (telegraph, telephone) was introduced after the termination of the Industrial Revolution.

Thus, in the next decades the emergence of essentially new types of communication is hardly possible. The development of communication has made great progress during the last decades and in general even surpassed the overall level of the development. Most likely, the revolutionary new types of mass communication can appear only toward the end of the twenty-first century. However the powerful progress in existing ICT is quite possible within the next three-four decades.

The development of communication via interfaces or via direct implantation of chips into human brain (thus, the communication will proceed from the source right to the brain) seems fantastic now; yet, if it succeeds it will hardly be widely implemented in the near decades (due to ethic, medical and legal restraints). Nevertheless, one can hardly ignore such opportunities and should think about restrictions beforehand since this possibility raise concerns.

On the whole we can suggest that new types of mass communications may emerge as a rather broadly implemented phenomenon not until the mid-twenty-first century but more probably by its end.

Afterword

Threats and Risks of the Future World of Self-Regulating Systems

How can we coexist with scientific and technical progress? We have completed our analysis of the history of development and of the current state of technologies as well as made some assumptions about the directions of their further development. But, of course, life will turn more diverse than any forecasts and even imaginations, and it is difficult to define what will become reality and what will not.

But nevertheless, we have no doubts that the development will head for creation of self-regulating systems. We think there is coming a heyday of the systems which will work mostly independently and at the same time more insistently controlling the most diverse aspects of human life. All this claims for a deep understanding and some activity in order to minimize the emerging problems; for example, to prevent the emergence of a new and even more supervising 'Big Brother' knowing much more about us than the 'Brother' that visibly controls all our life on the Internet today. Not only our on-line chat, but also the genealogic tree, medical history, individual peculiarities of the organism and probably, even our thoughts will become accessible soon. Who, how and for what for purpose will use this information, can hardly be ignored.

There also exist some other problems. Bill Joy (2000) describes the situation when an increasing dependence on machines will wean humans from thinking and solving problems and thus, eliminate any practical choice since all the decisions will be machine-made. Yet, Joy, probably, overestimates when writing that: 'the human race might easily permit itself to drift into a position of such dependence on the machines that it would have no practical choice but to accept all of the machines' decisions'. Possibly, Joy exaggerates that: 'Eventually a stage may be reached at which the decisions necessary to keep the system running will be so complex that human beings will be incapable of making them intelligently. At that stage the machines will be in effective control. People will not be able to just turn the machines off, because they will be so dependent on them that turning them off would amount to suicide' (Joy 2000). Nevertheless, the danger of heavy reliance on technological systems is not so speculative. And what will remain of the human 'freedom of choice' is absolutely unclear.

Besides, in the future when the systems make the most part of human mental work our mind will start to work less and thus, become weaker than the mind of the modern human; as a result, it will weaken just as the muscles of many our contemporaries who have no need in physical activity. Naturally, there will appear more systems facilitating and supporting intellectual work. Here the positive feedback will come to the fore: mind does not want to work, devices facilitate its work and the mind weakens even more. Therefore, it is not surprising if in the future 'a mental gymnastics' (in the form of some multiplication tables) will be promoted as a very useful exercise, similar to simple physical activities today.

Human power increases with the growing number of technologies subjected to him, but along with that many changes occur in the mode of life as well as we face numerous previously unknown challenges. That is why, if we want to make use of emerging opportunities (and why should we miss them?), it is desirable to learn to foresee problems and to minimize their consequences since a more significant technological breakthrough is likely to bring more sweeping changes and 'future shock'.[1] Unfortunately, humankind learns little from own mistakes and pays little attention to future problems. At best we behave like the generals in famous Churchill's aphorism which prepare not for the future, but for the past wars. As a result, we solve the problems to which we have already adapted and not for the forthcoming problems.

It is known, the fight against scientific and technological progress has a long history. And each manifestation of this fight was caused not only by obscurantism, but also by a real necessity or grounded fears since the progress would often exacerbate the situation as well as lead to many bankruptcies and throw overboard entire professional categories; sometimes it would even desolate entire cities and territories, and also often deteriorate the quality of products. Sometimes it opened unexpected opportunities for abuses or was a source of desperate social fight and oppression. Nevertheless, nobody managed to slow down this pro-

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[1] We are constantly facing such shocks, therefore, the issue raised by Alvin Toffler in his well-known *Future Shock* nearly half a century ago still remains relevant (Toffler 1970).

cess. The toughening requirements to testing of new drugs, closing APS, banning GMO or human cloning today, as well as many other things are modern manifestations of this fight. It is clear that many of these restrictions and bans are absolutely necessary. Others are caused by natural and rather grounded fears. On the one hand, it is difficult to expect that one can get the development of scientific and technological progress under a full control. On the other hand, progress in fight for the environment-oriented production or safe drugs shows that it is quite possible to achieve a certain level of control here. In general, the mechanism of minimizing the damage from innovations consists in establishing certain institutes and rules optimizing the control over technologies; but it is especially important to make it beforehand.

One should also remember that there are always parties concerned with technologies and progress. Thus, there always exist ambitious forces that are interested in their development and advance hoping to get some profits; besides, innovations always have a number of mercenary as well as unselfish adherents, as well as there are always people who prefer simple illusion to a more difficult path of achieving a goal while thinking that science will be able to solve any problem in future. Hence any promotion of valuable and important innovations is usually far from altruistic.[2] Therefore, we should not become victims and all the more slaves of scientific and technological progress (according to Francis Fukuyama) and its impetuous apologists.

Due to the convergence of interests in the sphere of innovations it should be clear: it is much easier and cheaper to get control over the things that have not been created yet than over the things that has already been developed and earn billions in profit.

But it is rather difficult to anticipate problems; therefore, we need certain institutes (institutions or administrative-legal systems) which would generally take the technological development under control and would develop in cooperation with technologies while preserving their functionality. However, for this purpose it is necessary to regulate the pace of the world scientific and technological progress. We believe that sooner or later it will become possible (see, *e.g.*, Grinin 1998a, 1999, 2005, 2008; Grinin and Korotayev 2009). Unfortunately, so far it is unachievable since the competition between countries is primarily based

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[2] As well as the fight against these or those consequences of scientific and technological progress.

on the different level of economic growth. It becomes obvious that the control over hazardous changes will also require certain political transformations which can turn extremely complicated and sensitive (Grinin 2006b; Grinin and Korotayev 2010c).

The costs of progress. Thus, it becomes quite clear that the scientific and technological progress cannot be hampered. Lock the door before it, it will enter through the window, but will inevitably come. And still it depends on us what price we will pay for it. And the cost of progress is always considerable even if it is expressed not in bloody wars, but in pleasures. Has not such convenient and promoting growth of pleasure technologies as contraception led to the fact that women give birth to less children which turns the society into 'an institution for elderly care'? Another seemingly pleasant, but actually an expensive way of payment for progress is computer games whose unknown consequences are still to come in some decades. As a result, today many millions of children and young people (as well as grown-ups) are seriously dependent on them. While staying in the virtual world and exciting far from harmless passions and feelings in themselves, they waste time, lose health and normal human relations as well as miss opportunities. It is obvious that it would have been rather easy to perform timely pedagogical and psychological evaluations for such games and to take some preventive measures.

What will be the costs of the future development? One can hardly hope that further advancement will by itself correct everything to increase the glory of scientific and technological progress, since these corrections may turn rather costly. It becomes obvious that today technological and scientific achievements access the natural essence of human living and its biological nature. And, therefore, stakes are high. Thus, one should consider the real consequences and what we want to avoid for that matter. Moreover, the radical changes in human body can dramatically change the relation to such basic phenomena as family, relationships, gender, relation to life, to own body and many other things which it is even difficult to imagine now.[3] Meanwhile, our institutes and perceptions are not ready for the changes that revolutionary technological innovations can bring out.

Is the best always more preferable to good? During the last two centuries humankind has been living according the principle 'The best is

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[3] But it can be seen already that these concepts which used to be fundamental are degrading now.

often the enemy of the good'. But after a certain point this principle becomes rather dangerous and ruinous.[4] In some respects (*e.g.*, nature), fortunately, there appeared forces which appeal to people to behave from the position of reasonable egoism at least and to leave something for the future generations but not to live by the principle 'after us the deluge'.[5] In fact, the concern about the future of our own children and grandchildren gives us a strong impetus since we would like to provide them with the best conditions and preserve what is valuable for us. Undoubtedly, the link between generations is one of the pillars for a society's sustainability. However, the trouble is that this link is weakening at present. One of the reasons is that every ten years there emerges a new technosphere in which the seniors feel themselves uneasily unlike the juniors. That is why it becomes more difficult for parents to pass on their experience to children (see Grinin 1998a, 2006b; Grinin and Korotayev 2009).

But the most dangerous events in this context can expect us ahead. The future transformations can turn negative for the development of the next generations. In particular, are we ready that the link between generations can be interrupted entirely after the new reproduction technologies make it possible to incubate children in artificial wombs? Are we ready to refuse the concept of children and parents, grandparents and grandchildren? It is hardly probable. But if we do not think about it now nobody will ask us later. Has not the progress virtually taken away the only children from parents, brothers and sisters from hundreds millions of people? And if such an artificially brought up generation not knowing parents and relatives[6] appears, will the desire to take care of others weaken both among the senior and the younger generations?

Such a transition, if it takes place, will undoubtedly strike a mortal blow to the institution of the family which is already weakened. If at

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[4] For example, the economic growth at any costs can lead to resource depletion and senseless expenses; the abundant food together with ideology of consumption can cause obesity epidemic and increasing number of diseases; the hedonism ideology and infinite thirst for pleasure – to increasing selfishness and weakening of the sense of duty towards others and society; safe sex leads to crossing the line of permitted sexual behavior; increasing number of shows and games – to mental instability especially at younger generation, etc.

[5] It should be noted that the future climate warming so much spoken about, can cause a flood per se. However, climatologists definitely have little agreement about this problem.

[6] By the way, according to Platon in the development of ideal of utopia, in which he wrote that children have to be common in the exemplary state, let fathers not know their children, and children their fathers (Platon. State 5, 457d). Naturally society has rejected such ideas long ago. However, even Platon could not suppose that mothers can be common.

least one generation breaks this link between parents and children tested by countless generations and many millions of years there will be no way back any more. Hardly anyone will agree to bear this burden …

Systematizing the risks. While discussing future technologies in our monograph we have little spoken about the reverse side of the forthcoming changes. Therefore, it seems logical that this conclusion will reflect the possible problems and risks resulting from the logic of changes at the final phase of the Cybernetic Revolution.

Forecasting such problems can help to create in advance the appropriate social, legal, and other tools to prevent the unexpected changes and to minimize their negative consequences. Of course, over the three decades biomedical ethics has been done insufficient, although during this period it has become an established field of knowledge with broad specialization that has its own international centers and holds conferences and issues periodicals. The question is not so much about ethics, and ethical and legal collisions rather than about the future of the human as a biological organism. Therefore, one can rather speak about a *bio-humanitarian categorical imperative,* about the development of fundamental principles and forms which should be taken into account on the path to the new pattern (and which are desirable to be confirmed in some international legislation).

The analysis of various risks would demand a considerable extension (see Grinin L. and Grinin A. 2015 for details). Now let us focus mainly on the risks associated with the demographic situation changing under the influence of natural processes which are sharply strengthened by achievements in medicine.

The irreversible demographic transformations. Each phase of production revolution is always associated with demographic changes. During the initial and intermediate phases of the Cybernetic Revolution a tremendous growth of the world total population takes place. This growth occurs first of all in the developing countries and is actually the continuing trend of the demographic revolution of the Industrial era. But on the other hand, in the developed countries demographic revolution has been completed by the so-called demographic transition which means a decrease in birth rate. At the same time life expectancy and its quality have considerably improved. The demographic transition is actually the result of the initial phase of the Cybernetic Revolution. Not without a reason in an increasing number of developing countries the fertility rates have been declining today, in some of them we also observe a noticeable population ageing.

Thus, the Cybernetic Revolution has significantly changed the type population replacement: a) it has reduced fertility rates along with a sharp reduction of child mortality, this has led to the fact that the average number of children in families has considerably decreased; b) it has sharply reduced total mortality that has resulted in the unprecedented life expectancy; c) we observe the population aging when in a number of countries the average (median) life expectancy is 40 years and more. As a result, the demographic structure has significantly changed. It has transformed from pyramidal (when children and youth make the main part of the population) into a rectangular one when the number of older persons is almost equal to youth number.

Yet, the already available achievements as well as the future advances in medicine and other branches can make a more substantial contribution to the change of the replacement pattern. In the next decades we will observe the global population aging resulting in its structure becoming a reverse pyramid in shape (when the number of children and young cohorts will be less than of the elderly people). Let us consider some consequences and possible risks of this situation.

In some developed countries the life expectancy can increase up to 95–100 years old, and generally it can reach the level of today's most successful countries (such as Japan), that is 80–84 years, but it may even become higher. Meanwhile, an especially rapid growth of elderly cohorts will be observed in the next three decades. As a result *in three decades the world will be divided not into the first and third worlds, but into the worlds of old and young nations.*[7]

But by this time the population aging will become noticeable in most countries of the world (probably except for the African states). At the same time the decreasing fertility rates and the exhausted demographic dividend in most countries of the Third World will lead to the fact that the demographic structure will change considerably, and the share of children and youth will dramatically decrease while the proportion of the elderly people will grow.

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[7] It can also lead to a certain geopolitical tension when the world is divided into the North where women of advanced age will be set the pace in politics as Francis Fukuyama wrote, and the South where angry young men with untied hands (as T. Friedman called them) will be the driving force (Fukuyama 2002).

The decline of democracy and struggle between generations? Population aging can lead to the decline of democratic system. Democracy can evolve into gerontocracy which will be difficult to escape from, and the crisis of democratic governance is generally quite probable in the conditions of fighting for votes. The matter is that with the growing life expectancy and reduction of youth share in population structure, the number and role of elderly and old people will inevitably increase along with a probable sexual distortion: prevalence of women in the western countries and men in some eastern countries. Since the elderly generation is more conservative in its predilections and habits, it can influence the choice of policy and many other political, social and economic nuances which can put young and middle-aged generations in disadvantage.

Especially alarming is the fact that the growing life expectancy and activity can cause a conflict between generations since to make provision for the increasing number of the aged people will require to raise the labor age and to increase the working capacity for 10–20 and even more years along with a full involvement of disabled people into labor process due to the new technical means and achievements in medicine. However, in that case senior generation will probably impede the younger generation's career development; also the elderly population can contribute to society's growing conservatism that can also slow down the technological growth in the future (besides it will be difficult to replace elderly workers for whom it will be very difficult to be retrained). To move the aged from the young people's way will become a hard task, and as Fukuyama (2002) suggests that we may eventually have to adopt a form of institutional ‘ageism’ in order to allow young people to enter the workforce in the world with high expected life duration. It is time to think about how to combine the need of increasing working age for the elderly and the possibility of advance for the young people.

It is important to note that such a turn to gerontocracy will be most quickly outlined in the European countries and the USA. On the one hand, these countries have the strongest democratic traditions, and on the other, the ethnocultural disproportion is also the most notable here (thus in the future, one can expect in the USA an opposition between the young Latin and elderly white population, while in Europe it will be between young Islamic and elderly white Christian population). It means that the North–South divide will be reproduced in every country where the elderly indigenous people will live alongside with much younger alien population with different cultural traditions (Fukuyama 2002; on the different education levels of indigenous people and ethnic migrants see Sarrazin 2010; Buchanan 2015).

The conflicts between generations in these countries caused by the above-described crisis of democracy will inevitably affect the destinies of the whole globalizing world.

The geopolitics of an artificial reproduction? Now let us return to the issue of possible changes in human reproduction. If technologies of growing up children beyond the maternal placenta appear, the population reproduction structure will considerably change (especially if there appear some other technologies such as cloning). We have considered this issue in terms of breaking links between generations. But there is also a global aspect. Will the countries and the world in general be ready for such changes? And will not some countries want to derive benefit from their demographic advantages that would be quite a natural course of things? Here is some room for imagination. On the one hand, it is obvious that in the future while creating some all-planetary structures and developing the quotas for different states a country's population number will become much more important characteristic than it is today, especially in international relations (today a country's position is rather estimated by its wealth and military power). But will the West take it that the countries with much larger population will begin to dictate their terms?

On the other hand, why do not some political elites use new reproductive technologies? Therefore, it is quite possible that political elite in the future will be able to use 'industrial' reproductive technologies in their geopolitical purposes. For example, they can launch a population growth race. But if some countries try to solve the problem of shortage of children by incubating them in artificial placenta, the race of 'reproduction of children' will inevitably start, and nobody knows what it will bring.

Standing on a lame leg? The quicker changes proceed, the more difficult is for the society to follow them and the more heterogenic it becomes in social (and often ethnocultural) terms. Not incidentally during the last half of the century more and more minorities emerge often asserting rather vague rights, and society yields to their pressure under the slogan of tolerance. But how long can this process go on? Tolerance and political correctness will eventually lead to the situation when it becomes more and more difficult to distinguish good from bad (the criteria of these concepts are eroding), the moral categories become the categories of an individual choice or taste, but not an estimation of 'good and bad, due and harmful', *etc*.

Meanwhile, since long ago and till now two main regulators have been working in society without which it cannot exist. These are morals and law which are also based on psychological structures of society and people, operating at almost subconscious level (see Grinin 1997, 1998a, 2003b, 2006b). But the quicker technology develops, the less recognized becomes moral as it fails to find a new balance.[8] Also it is rather possible that beyond some limit of speed of scientific and technical development there will begin a noticeable destruction of moral or its disintegration into numerous group versions. And it is all the more dangerous when powerful technological opportunities of transformation of the human body can appear. Because of the lack of moral constraints and in aspiration for large profits from morally questionable innovations various ugly phenomena can prevail: from fashion for annual corrections of body to attempts to turn into superhumans by means of new medical technologies.

Having appeared in the agrarian and craft societies the Law became mature during the period of industrialism (while the rule-making process takes place within any society). Being more flexible than moral the law, nevertheless, demands a certain stability which is hardly achievable in the conditions of rapidly changing technologies as we can see it. According to Stanisław Lem (1968), society and its legal rules most often turn weak in the face of technological innovations if only they do not enter into a direct conflict with laws. And, as Stanisław Lem fairly notes, the intensity with which 'the technical means facilitate performing tasks' undermine the values has a positive correlation with their efficiency. This means that the more effectively technologies solve certain problems, the more they change the society, its moral and legal pattern, whose consequences we begin to realize much later. Therefore, although the law will apparently exist longer than moral (of course, if not to take radical measures to preserve it and reduce the degree of tolerance),

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[8] Thus, for example, the need for women to come into work massively has significantly changed their behavior, clothes, the way of life and relationship with males, has sharply increased the number of divorces and strengthened female legal protection etc. The weakening role of religion under the influence of education and science has brought enormous changes to interpretation of the moral principles.

however, there is a definite risk that it will also erode.[9] Similar to morals, the law can transform from common for everybody to different laws for various religious and other groups as it was observed in the Medieval Ages (*e.g.*, today some claim to adjust school curricula and some other rules for the Muslim habits). Or under the pressure of different groups the law can transform so it will permit many of things forbidden today (this process has been observed for several decades). All the more the law has already been challenged by the integration of the national and international principles.

In what way the future society will organize itself in that case is not clear. During the previous epochs, the moral and law could be compared with two feet on which the society stood quite firmly (and if there was some imbalance, *e.g.*, the law was insufficiently developed the society was also obviously destabilized). But, figuratively speaking, if one 'foot' (moral) disappears and the other (the law) weakens will the society be able to keep the balance on such a weak basis at such high speed of progress?

The issues of the future societal institutes can become extremely important also in connection with the emergence of innovations capable to replace or modify the previous forms of regulating the relations. The fully developed self-regulation is available just within social systems. Although when speaking about the future era of self-regulating systems we have marked out the techno-biological systems, the development of these systems will also inevitably affect the mechanisms regulating public relations. Therefore, it is worth thinking about technology of social anticipation and correction before mass distribution of dangerous innovations. Thus, in the future we are expecting either to find the way towards new unprecedented horizons or to unprecedented problems and even cataclysms.

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We are rapidly moving forward groping as usual along an unknown path and not thinking about the consequences of innovations. And this is really disturbing. Even without realizing it the human rapidly changes the life on Earth (Field 2015). But it is high time to think of the consequences of every new step forward. And since there is no other alterna-

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[9] It is easy to imagine, for example, the robots or other systems will become subjects of law in the future.

tive but to move on the way, we need a maximum care, wisdom, prudence and even some humility before the majesty of the Universe and the world, as well as a deep respect for the heritage resulting from the billion-years biological evolution. And then our persistency, knowledge and (although still weak) ability of anticipating will allow reaching new summits of human power safely and leaving the descendants capable to preserve it.

Appendices

Appendix 1
Some Issues in the Theory of Historical Process

1. On Historical Process

A few words are necessary to clarify our understanding of the 'historical process' notion (for more details see Grinin 2007a, 2012a). The first point to note is that this concept is in no way synonymous with 'world history'.[1] Of course, the notion of historical process is based on world history facts. However, firstly, there have been chosen only those facts that are the most important from the point of view of process and changes; secondly, this set of facts has been ordered and interpreted in accordance with the analyzed spatial and temporal scales, trends and logics of historical development of humankind (or at least the World-System) as a whole, as well as the present-day results of this development. In other words, historical process is in no way a mechanical sum of the histories of numerous peoples and societies, it is not even just the process resulting from movement and development of these people and societies. The historical process is a growing and even cumulative process of societal integration that has a certain direction and result.[2]

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[1] However, even the very notion of 'world history' and 'universal history', although a number of scholars recognize it as an important concept (*e.g.*, Ghosh 1964; Pomper 1995; Geyer and Bright 1995; Manning 1996), had been considered rather useless for a long time by historians and social scientists. But the most important is that 'while historians increasingly recognize the importance of world history, they remain relatively ignorant about it as a developing field' (Pomper 1995: 1).

[2] Between World History and the theory of historical process there are macrohistory, that is history on the large scale, sometimes telling the story of whole civilizations, sometimes of the entire world (Reilly 1999), but sometimes of particular dimensions of historical process. So macrohistory is a certain conceptualization of historical process. It is close in some respect to the theory of history. On the relation between macrohistory and theory of history see, for example, Galtung and Inayatullah 1997; Reilly 1999; Little 1998, 2000a, 2000b. However, it is already evident from the recommended reference list on macrohistory that includes in particular *Shapes of Philosophical History* by Frank E. Manuel (1965); *The Shapes of Time* by Peter Munz (1977); *The Rise of the West: A History of the Human Community* by William H. McNeill (1963); *The Great Divergence: China, Europe, and the Making of the Modern World Economy* by Kenneth Pomeranz (2000); *The Sources of Social Power* by Michael Mann (1986, 1993); *Civilization and Capital-*

The notion of the historical process of *humankind* does not imply that humankind has always been a real system. It implies the following: (a) we select a respective scale for our analysis; (b) we take into account the fact that over all the periods of historical process the societies, civilizations and its other actors have been developing unevenly, that is at a different rate of social progress; (c) from the methodological point of view it indicates that for the analysis of historical process the most important is the model of the influence produced by more developed regions on the less developed ones; (d) the interaction scale expands from one period to another until it reaches the scale of the whole planet (in this situation it becomes equal to the notion of the World-System); (e) hence, the historical process of humankind is, first of all, the process of movement from autonomous and isolated social mini-systems towards the formation of the present extremely complex system of intensely interacting societies; (f) when (and if) humankind transforms into a subject whose development as a whole is determined (at least partially) by a general and explicitly expressed collective will, the historical process in its current meaning will come to its end, and this will lead to the transition to a new generation of processes.

Thus, ***historical process*** *is a notion that generalizes an intricate complex of internal transformations and actions of various historical subjects, as a result of which important societal changes and integration, continuous enlargement of intersocietal systems take place, transition to the new levels of development is going on, and in general (taking into consideration the present results and future prospective), humankind gets transformed from a potential unity into an actual one.*

Of course, this definition of historical process is rather conventional; however, it has a considerable heuristic potential and makes it possible to construct generalizing theories. The critics of the notion 'world history process' rely on the idea that humankind is not a system that can be regarded as a real subject and that the humankind's history is the history of particular societies; thus, it is impossible to speak about the historical process of humankind (see, *e.g.*, Milyukov 1993 [1937] 43–47; Hotsej 2000: 488–489). In the meantime it becomes more and more evident that the globalization process is making (and, in some respects, has al-

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ism, 15th – 18th Century, Vols I–III by Fernand Braudel (1982); *ReORIENT: Global Economy in the Asian Age* by Andre Gunder Frank (1998); *The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia* by E. L. Jones (1981), *etc.*

ready made) humankind a real subject. But if humankind is becoming a real supersystem and the process of this system's structuralization starts producing more and more tangible results, then why is it impossible to study the historical process of the humankind system formation? For example, McNeill (2001: 1) suggests that historians should 'make a sustained effort to enlarge the views and explore the career of humankind on earth as a whole'.

Quite often the notion of *humankind* is actually substituted with some other notions, like *civilizations*, starting from Danilevsky (1995 [1869]), Spengler (1939), Toynbee (1962−1963), and ending with Huntington (1996), or *the World System* (Frank 1990, 1993; Frank and Gills 1993; Wallerstein 1974, 1987, 2004; Chase-Dunn and Hall 1994, 1997; Arrighi and Silver 1999; Amin *et al.* 2006). Although we ourselves support the World System approach and try to offer our mite to the development of this theory (Grinin and Korotayev 2006, 2009; Korotayev and Grinin 2006; Grinin 2011a), we believe that such notions can be of much use, but only at a certain level and in certain aspects of analysis. And, of course, they differ from the notion of *humankind* both temporally (as the whole pre-agrarian epoch and the early agrarian period are left outside their limits) and spatially (if we do not try to make one notion a full synonym of the other). The attempts to substitute the notion of humankind with any other, less encompassing, notions are basically attempts to prohibit any research at a higher level of generalization; this is just a substitution of one level of research with another, a narrower one.[3]

2. On the Rules of Periodization

Many scholars emphasize the great importance of periodization for the study of history (*e.g.*, Jaspers 1953; Green 1992, 1995; Gellner 1988; Bentley 1996; Stearns 1987; McNeill 1995; Manning 1996; Goudsblom 1996; White 1987; Dyakonov 1999; Ershov 1984; Zhigunin 1984; Pavlenko 1997, 2002; Rozov 2001a, 2001b; Korotayev 2006). Gurevich emphasizes that 'the human thought cannot avoid dividing the historical process into definite periods' (2005: 681). There is no doubt that periodization is a rather effective method of data ordering and analysis, but it deals with exceptionally complex types of processual, developmental

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[3] These attempts have a long history. For example, Milyukov (1993 [1937]: 43–47) declared the world historical view obsolete and insisted that the natural unit of scientific observation is nothing else but a 'national organism'.

and temporal phenomena and thus, it simplifies historical reality. This might be the reason why some scholars belittle the role of periodization and some of them even directly oppose the notion of process and stages as mutually exclusive (see, *e.g.*, Shanks and Tilley 1987; see also Marcus and Feinman 1998: 3; Shtompka 1996: 238). One may agree that the contraposition of process and stages is a false dichotomy (Carneiro 2000) because stages are continuous episodes of a continuous process, and the notion of process can be used for the development of the notion of stages (Goudsblom 1996).

In fact, any periodization suffers from one-sidedness and certain deviations from reality, but as Jaspers noted, '…the purpose of such simplifications is to indicate the essentials' (Jaspers 1953: 24). Moreover, the number and significance of such deviations can be radically diminished as the effectiveness of periodization is directly connected with its author's understanding of the rules and peculiarities of this methodological procedure.

Our own research and analysis of different statements presented in the works on the problems of globalization allowed, with the account of the general systemic requirements, settling a system of methodological rules for developing a periodization of history, however, some of these rules we had to formulate completely independently.

- *Rule 1.* The presence of the same bases or criteria.
- *Rule 2.* The hierarchical scale of bases.
- *Rule 3.* The equality of the periods of the same level of division.
- *Rule 4.* The close association with theory.
- *Rule 5.* Necessity of additional basis.
- *Rule 6.* The correspondence to the main events and facts.

Regarding some of the rules (for more details on these laws and procedures see Grinin 1998b: 15–28; 2003a: 67–78; 2003b: 219–223; 2006a, 2006c, 2007c; Grinin and Korotayev 2009; see also Shofman 1984). Unfortunately, an insufficient attention is paid to these issues (and problems of periodization in general), which leads to complicated problems.

In particular, to develop a periodization one needs to observe the rule of the 'same bases', that is, to use the same criteria for the identification of periods with the same taxonomical significance, whereas many periodizations are not based on rigorous criteria, or the applied criteria are eclectic and change from one stage to another (*e.g.*, Green 1995), or the scholars just base themselves on the following scheme: Antiquity – Middle Ages – Modern Age (see Green 1992).

The second point is how well the periodization bases are reasoned, and how they are connected with a scholar's general theory (Rule 4), as well as with the goal of periodization. For any periodization its basis is a very important point. One can choose different bases for periodization if to use constantly the same criteria. Different scholars choose different bases for periodization, ranging from changes in the types of ideas and mode of thinking (*e.g.,* Comte 1974 [1830−1842]; Jaspers 1953) to ecological transformations (Goudsblom 1996) and intercultural interaction (Bentley 1996). Many scholars, from the 18th century thinkers (Turgot, Barnave, Ferguson, Smith) to modern post-industrialists like Bell (1973) and Toffler (1980), base themselves on economic and technological criteria (see Grinin 2011b). Two extremes can be observed depending on the choice of criteria. Too often, when scholars ascribe absolute meaning to the chosen factors, in Pitirim Sorokin's words (Sorokin 1992: 522), 'they turn out to be partially right, but one-sidedly wrong at the same time'. Some do not think at all about the connection between periodization and theory (on this issue see Stearns 1987; Bentley 1996), or periodization is used as a sort of 'headband' for the main theory (*e.g.*, Toffler 1980).

Sometimes it is said that historians do not need periodization but these are usually precarious claims. In the history of any society the historians necessarily distinguish some periods. It is especially important for archaeologists whose generalizing work is unthinkable without connection with periodization procedure. However, it is necessary to separate local periodizations from global periodizations of world history.

Appendix 2
Mathematical Interpretation of Historical Process

With regard to social disciplines, a question continually arises: are mathematical methods suitable for analyzing historical and social processes? Obviously, we should not absolutize differences between fields of knowledge, but the division of sciences into two opposite types, made by Wilhelm Windelband and Heinrich Rickert, is still valid. As is known, they singled out sciences involving *nomothetic methods* (*i.e.* searching for general laws and generalizing phenomena) and those applying *idiographic methods* (*i.e.* describing individual and unique events and objects). Rickert attributed history to the second type. In his opinion, history always aims at picturing an isolated and more or less wide course of development in all its uniqueness and individuality (Rickert 1911: 219).

However, since the number of objects and problems investigated and solved by precise methods is growing rapidly, we may assume that, with time, historical knowledge will also be analyzed by some branches of mathematics.

Thus, the problem remains debatable. Nevertheless, rational attempts to use mathematical methods in theoretical or applied trends of the humanities are on the whole positive. Yet, they 'dry up' the soul of history to some extent, but at the same time, they promote self-discipline and self-testing of thoughts, ideas, and concepts of many specialists in the humanities, who, unfortunately, often do not bother to find any methods of testing their conclusions. In addition, this could somewhat reduce the polysemy of the scientific language of the humanities. Rudolf Carnap in his *Philosophical Foundations of Physics* (Carnap 1966) wrote that, even in Physics, the use of terms from ordinary language (as the notion of *law)* for an accurate and nonambiguous expression of ideas complicates proper understanding. However, physicists, as well as other representatives of natural sciences, long ago agreed on fundamentals (such as units of measurement and symbols). As for the humanities, which analyze social phenomena, the same objects sometimes have up to ten meanings and hundreds of definitions. Perhaps, the very necessity to formalize the humanities will lead at last to certain conventions and the ordering of terminology. Nevertheless, even today the use of mathematics may help in searching for a common field of research.

Can we after all construct any mathematical models for such a complex subject of inquiry as the historical process? The answer to this question is obvious: yes, it is quite possible when examining countable objects.

However when we speak about some global general theories, like macroperiodization of the world historical process, any figures, cycles, diagrams and coefficients, of course, cannot prove too much by themselves. Especially, if the respective analysis includes ancient periods for which all the figures are likely to be too much approximate and unreliable. Thus, for general theories covering immense time spans and space, the main proofs are a good empirical basis, logics, internal consistency and productivity of theoretical constructions; that is, a theory's ability to explain the facts better than other theories do. On the other hand, any theory is better when it is supported by more arguments. Mathematical proofs can be rather convincing (when they are relevant, of course). This is especially relevant with respect to those aspects that are more liable to mathematical analysis, for example, those connected with demography.

In this chapter we have chosen such an aspect that is liable to mathematical analysis and quite suitable for it. This is the *temporal* aspect of history. Its suitability for mathematical analysis is connected with the following: though it is quite possible to speak about the tendency of historical time toward acceleration (and this is the subject of the present chapter), the astronomic time remains the same. Thus, within this study we have a sort of common denominator that helps to understand how the ‘numerator’ changes. Hence, we believe that for the analysis of periodization of history the application of mathematical methods is not only possible, but it is also rather productive.

Now we can start our mathematical analysis of the proposed periodization. Mathematical methods are quite widely used in historical research, but, unfortunately, mathematical studies of historical periodization are very few indeed.[1] However, it is worth mentioning that there have been published several issues of the almanac with a speaking title – History and Mathematics (Grinin, de Munck, and Korotayev 2006; Turchin, Grinin, de Munck, and Korotayev 2006; Grinin, Herrmann, Korotayev, and Tausch 2010; Grinin and Korotayev 2014b; Goldstone, Grinin, and Korotayev 2015). In the meantime the discovery of mathematical regularities within an existing periodization may serve as a confirmation of its productivity and as a basis for tentative forecasts. *Time* as a parameter of historical development is quite suitable for mathematical analysis, for example, economic and demographic historians study actively temporal cycles of various lengths (about Juglar and Kondratieff cycles see Grinin and Korotayev 2010a, 2014a; Grinin, Korotayev, and Malkov 2010; Grinin, Korotayev, and Tausch 2016; see also Appendix 3). Cycles used as a basis for this periodization are not different in any principal way from the other temporal cycles with regard to the possibility of being subject to mathematical analysis.

Table 1 ('Chronology of Production Principle Phases') presents dates for all the phases of all the production principles. However, it should be taken into account that in order to make chronology tractable all the dates are approximated even more than the ones used in the text above. Table 2 ('Production Principles and Their Phase Lengths') presents the absolute lengths of the phases in thousands of years.

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[1] It appears reasonable to mention here the works by Chuchin-Rusov (2002) and Kapitza (2004b, 2006). Some ideas about the detection of mathematical regularities were expressed by Igor Dyakonov. In particular, he wrote the following: 'There is no doubt that the historical process shows symptoms of exponential acceleration. From the emergence of *Homo Sapiens* to the end of Phase I no less than 30,000 years passed; Phase II lasted about 7,000 years; Phase III – about 2,000, Phase IV – 1,500, Phase V– about 1,000, Phase VI – about 300 years; Phase VII – just over 100 years; the duration of Phase VIII cannot yet be ascertained. If we draw up a graph, these Phases show a curve of negative exponential development' (Dyakonov 1999: 348). However, Dyakonov did not publish the graph. Snooks suggests a diagram called 'The Great Steps of Human Progress' (Snooks 1996: 403; 1998: 208; 2002: 53), which in some sense can be considered as a sort of historical periodization, but this is rather an illustrative scheme for teaching purposes without any explicit mathematical apparatus behind it.

Table 1. Chronology of production principle phases (figures before brackets correspond to absolute datings (BP); figures in brackets correspond to years BCE. **Bold** figures indicate phase lengths (in thousands of years)

Production principle	*1st phase*	*2nd phase*	*3rd phase*	*4th phase*	*5th phase*	*6th phase*	*Overall for production principle*
1. Hunter-Gatherer	40 000–30 000 (38 000–28 000 BCE) **10**	30 000–22 000 (28 000–20 000 BCE) **8**	22 000–17 000 (20 000–15 000 BCE) **5**	17 000–14 000 (15 000–12 000 BCE) **3**	14 000–11 500 (12 000–9500 BCE) **2.5**	11 500–10 000 (9500–8000 BCE) **1.5**	40 000–10 000 (38 000–8000 BCE) **30**
2. Craft-Agrarian	10 000–7300 (8000–5300 BCE) **2.7**	7300–5000 (5300–3000 BCE) **2.3**	5000–3500 (3000–1500 BCE) **1.5**	35000–2200 (1500–200 BCE) **1.3**	2200–1200 (200 BCE–800 CE) **1.0**	800–1430 CE **0.6**	10 000–570 (8000 BCE – 1430 CE) **9.4**
3. Trade-Industrial	1430–1600 **0.17**	1600–1730 **0.13**	1730–1830 **0.1**	1830–1890 **0.06**	1890–1929 **0.04**	1929–1955 **0.025**	1430–1955 **0.525**
4. Scientific-Cybernetic	1955–2000 (1955–1995)* **0.04–0.045**	2000–2040 (1995–2030) **0.035–0.04**	2040–2070 (2030–2055) **0.025–0.03**	2070–2090 (2055–2070) **0.015–0.02**	2090–2105 (2070–2080) **0.01–0.015**	2105–2115 (2080–2090) **0.01**	1955–2115 (2090) [forecast] **0.135–0.160**

Note: In this line figures in brackets indicate the shorter estimates of phases of the Scientific-Cybernetic production principle (the fourth formation). Starting from the second column of this row we give our estimates of the expected lengths of the Scientific-Cybernetic production principle phases.

Table 2. Production principles and their phase lengths (in thousands of years)

Production principle	*1st phase*	*2nd phase*	*3rd phase*	*4th phase*	*5th phase*	*6th phase*	*Overall for production principle*
1. Hunter-Gatherer	10	8	5	3	2.5	1.5	30
2. Craft-Agrarian	2.7	2.3	1.5	1.3	1.0	0.6	9.4
3. Trade-Industrial	0.17	0.13	0.1	0.06	0.04	0.025	0.525
4. Scientific-Cybernetic	0.04–0.045	0.035–0.04*	0.025–0.03	0.015–0.02	0.01–0.015	0.01	0.135–0.160

Note: * This line indicates our estimates of the expected lengths of the Scientific-Cybernetic production principle phases.

Table 3 (‘Ratio of Each Phase [and Phase Combination] Length to the Total Length of Respective Production Principle [%%]’) presents results of our calculations of the ratio of each phase's length to the length of the respective production principle using a rather simple methodology.[2] Table 4 (‘Comparison of Phase Length Ratios for Each Production Principle [%%]’) employs an analogous methodology to compare lengths of phases (and combinations of phases) within one production principle. For example, for the hunter-gatherer production principle the ratio of the first phase length (10,000 years) to the second one (8,000 years) equals 125 per cent; whereas the ratio of the second phase to the third one (5,000 years) is 160 per cent. In the meantime the ratio of the sum of the first and the second phases' lengths to the sum of the third and the fourth phases (3,000 years) equals 225 per cent. Tables 3 and 4 also present the average rates for all the production principles.

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[2] The absolute length of a phase (or a sum of the lengths of two or three phases) is divided by the full length of the respective production principle. For example, if the length of the hunter-gatherer production principle is 30,000 years, the length of its first phase is 10,000, the one of the second is 8,000, the duration of the third is 5,000, then the ratio of the first phase length to the total production principle length will be 33.3 per cent; the ratio of the sum of the first and the second phases' lengths to the total production principle length will be 60 per cent; and the ratio of the sum of the first, the second, and the third phases' lengths to the total production principle length will be 76.7 per cent.

Table 3. Ratio of each phase (and phase combination) length to the total length of respective production principle (%%)

Production principle	*1*	*2*	*3*	*4*	*5*	*6*	*1–2*	*3–4*	*5–6*	*1–3*	*4–6*
1. Hunter-Gatherer	33.3	26.7	16.7	10	8.3	5	60	26.7	13.3	76.7	23.3
2. Craft-Agrarian	28.7	24.5	16.0	13.8	10.6	6.4	53.2	29.8	17	69.1	30.9
3. Trade-Industrial	32.4	24.8	19	11.4	7.6	4.8	57.1	30.5	12.4	76.2	23.8
4.Scientific-cybernetic	28.1 (29.6)*	25 (25.9)	18.8 (18.5)	12.5 (11.1)	9.4 (7.4)	6.3 (7.4)	53.1 (55.6)	31.3 (29.6)	15.6 (14.8)	71.9 (74.1)	28.1 (25.9)
Average	30.6**	25.3	17.6	11.9	9	5.6	55.9	29.6	14.6	73.5	26.5

Note: * In this line figures in brackets indicate the shorter estimates of the scientific-cybernetic production principle's phases (the fourth formation).
** The calculation of average value took into account only one version of the scientific-cybernetic production principle evolution (that is the figures before the brackets).

Table 4. Comparison of phase length ratios for each production principle (%%)

Production principle	*1:2*	*2:3*	*3:4*	*4:5*	*5:6*	*(1+2): (3+4)*	*(3+4): (5+6)*	*(1+2+3): (4+5+6)*
1. Hunter-Gatherer	125	160	166.7	120	166.7	225	200	328.6
2. Craft-Agrarian	117.4	153.3	115.4	130	166.7	178.6	175	224.1
3. Trade-Industrial	130.8	130	166.7	150	160	187.5	246.2	320
4. Scientific-Cybernetic	112.5 (114.3)	133.3 (140)	150 (166.7)	133.3 (150)	150 (100)	170 (187.5	200 (200)	255.5 (285.7)
Average*	121.4	144.2	149.7	133.3	160.9	190.3	205.3	282.1

Note: * The calculation of average value took into account only one version of the scientific-cybernetic production principle evolution (that is the figures before the brackets).

Thus, the proposed periodization is based on the idea of recurrent developmental cycles (each of them includes six phases); however, each subsequent cycle is shorter than the previous one due to the acceleration of historical development. No doubt that these are recurrent cycles, because within each cycle in some respect development follows the same pattern: every phase within every cycle plays a functionally similar role; what is more, the proportions of the lengths of the phases and their combinations remain approximately the same (see Tables 3 and 4). All this is convincingly supported by the above mentioned calculations, according to which stable proportions of the lengths of phases and their combinations remain intact with the change of production principles.

In general, our mathematical analysis represented in diagrams and tables indicates the following points: a) evolution of each production principle in time has recurrent features, as is seen in Diagrams 1–4; b) there are stable mathematical proportions between the lengths of phases and phase combinations within each production principle (Tables 3 and 4); c) the cycle analysis clearly indicates that the development speed increases sharply just as a result of production revolutions (see Diagram 5); d) if we calibrate the Y-axis of the diagram,[3] the curve of historical process acquires a hyperbolic (Diagram 6) rather than exponential shape (as in Diagrams 1–4), which indicates that we are dealing here with a blow-up regime (Kapitza, Kurdjumov, and Malinetskij 1997).

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[3] Within the calibrated scale the changes from one production principle to another are considered as changes by an order of magnitude, whereas changes within a production principle are regarded as changes by units within the respective order of magnitude. Such a calibration appears highly justified, as it does not appear reasonable to lay off the same value at the same scale both for the transition from one principle of production to another (for example, for the Agrarian Revolution), and for a change within one production principle (*e.g.*, for the development of specialized intensive gathering). Indeed, for example, the former shift increased the carrying capacity of the Earth by an order or two magnitude, whereas the latter led to the increase of carrying capacity by two-three times at best.

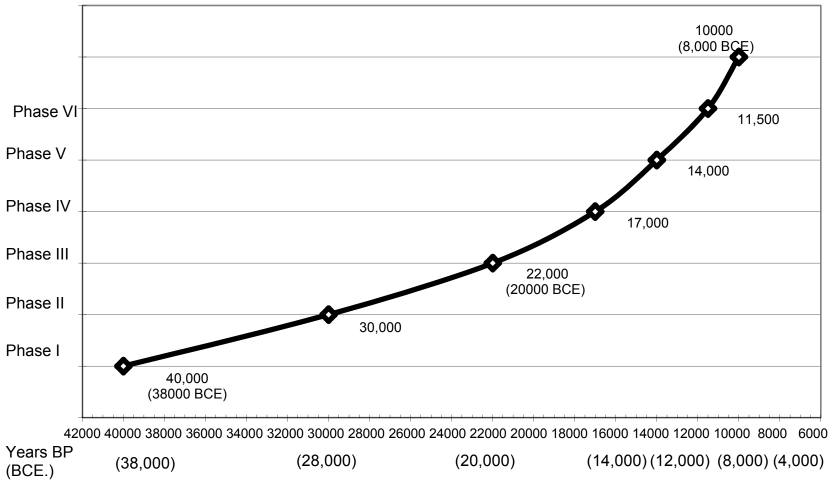

Diagram 1. Hunter-Gatherer production principle

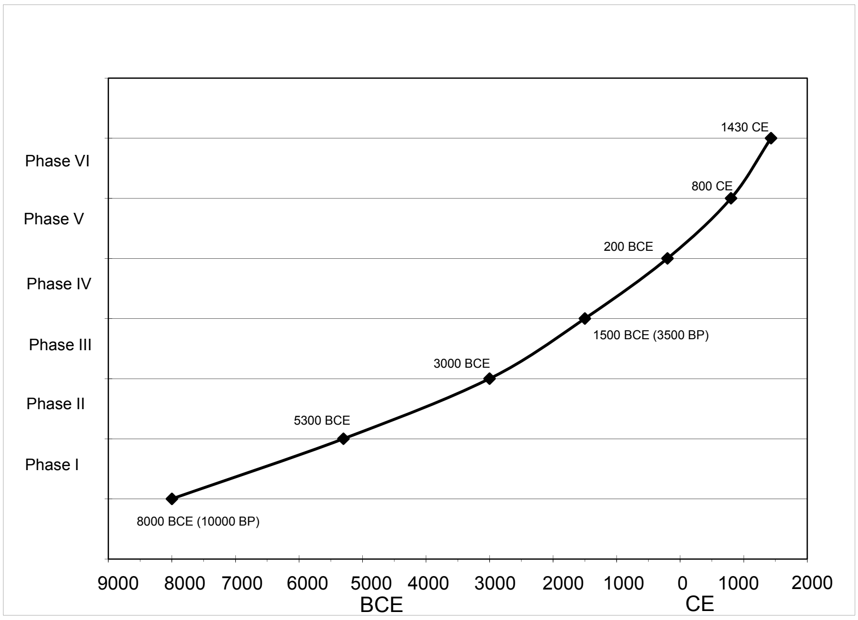

Diagram 2. Craft-Agrarian production principle

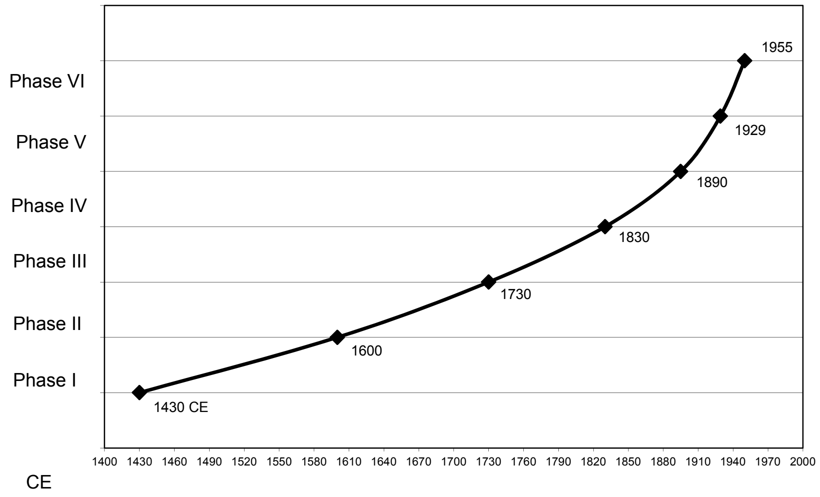

Diagram 3. Trade-Industrial production principle

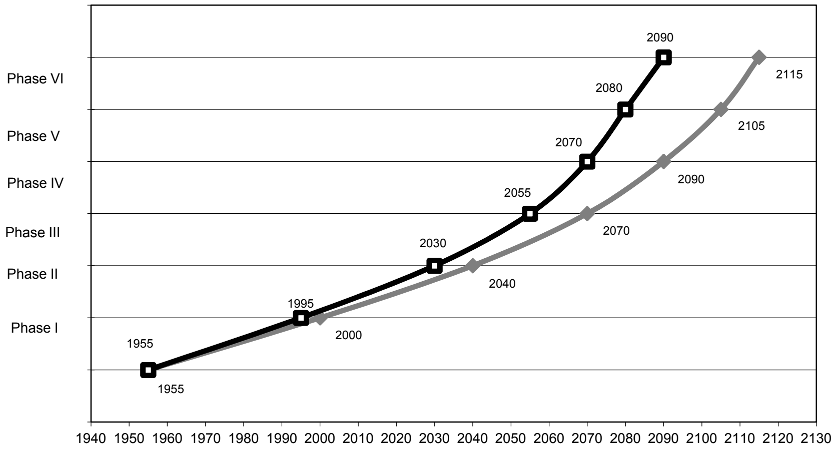

Diagram 4. Scientific-Cybernetic production principle

Note: The broken line indicates the forecast version for the expected development of the scientific-cybernetic production principle corresponding to the dates in the brackets in the line of the scientific-cybernetic production principle in Table 1.

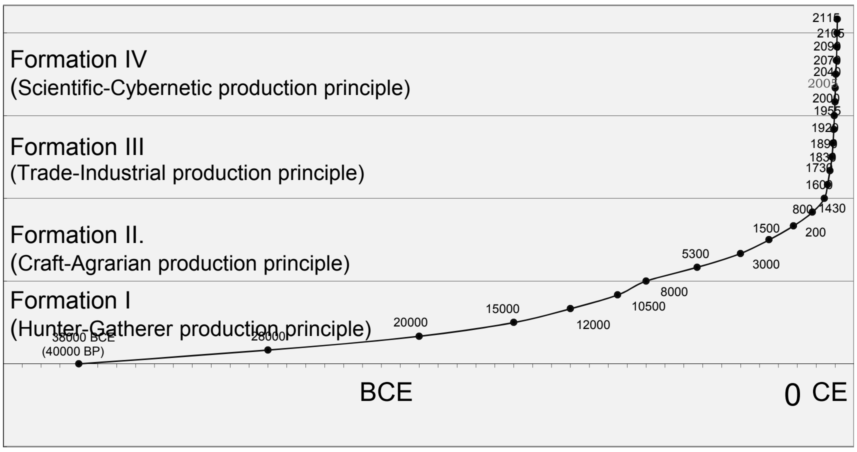

Diagram 5. Evolution of historical process in time

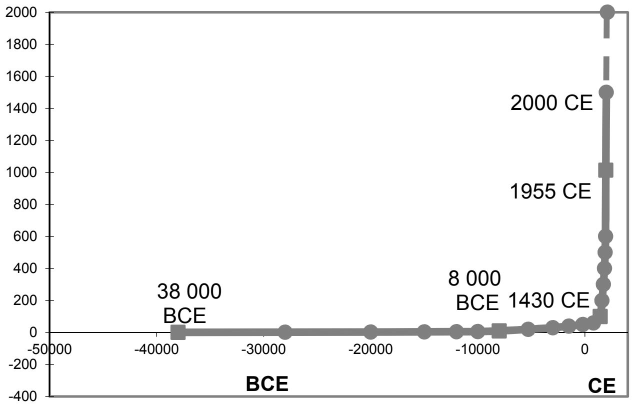

Diagram 6. Hyperbolic model of historical process dynamics

The analysis of stable proportions of production principle cycles makes it possible to propose some tentative forecasts (in particular, with respect to the lengths of the remaining phases of the fourth production principle).

And the last comment. The historical process curve (see Diagram 6) might look a bit embarrassing, as it goes to infinity within a finite period of time. In this respect Dyakonov (1999: 348) notes the following:

> As applied to history, the notion [of infinity] seems to make no sense: the succession of Phases, their development ever more rapid, cannot end in changes taking place every year, month, week, day, hour or second. To avoid a catastrophic outcome – let us hope that wise *Homo Sapiens* will find a way – then we have to anticipate intervention from as yet unknown forces.

However, it should be taken into account that the diagram depicts the development of just one variable of the historical process – the technological one, whereas the high correlation between general development and technological development is observed within certain limits. Outside these limits various deviations (both with respect to the development vectors and its speed) are possible. First of all, it is quite evident that the general development of the system does not catch up with the technological one; secondly, the growing gap implies that the price for progress will grow too. In other words, uncontrolled scientific-technological and economic changes lead to the growth of various deformations, crisis phenomena in various spheres of life, which slow down the overall movement and in many respects change its direction. Actually, if the system persists, the overall speed of its development cannot exceed the speed of the least dynamic (most conservative) element (*e.g.*, religious-ideological consciousness, law) whose change needs the change of generations. The growth of the system gaps in connection with changing economic, information, and technological realities can lead to its breakdown and its replacement with another system. And the price paid for such a rapid transformation of such an immensely complex system as modern humankind may be very high indeed.

There would be even no future shock that Toffler discovered for public in 1970 (Toffler 1970). This implies an immense acceleration of development that can be hardly compatible with the biopsychic human nature. Indeed, in view of the growing life expectancies all the immense changes (the 2040s to 2090s) will happen within the span of one generation that will appear in the 2010s. The significance of these changes will be no smaller (what is more, it is likely to be greater) than the significance of the ones that took place between 1830 and 1950 that included gigantic technological transformations, the transition from agricultural to industrial society, social catastrophes and world wars. However, these metamorphoses took place within 120 years, whereas the expected period of the forthcoming transformation is twice as short. And if they occur within a lifespan of one generation, it is not clear whether human physical and psychic abilities will be sufficient to stand this; what will be the cost of such a fast adaptation? Thus, we confront the following question: how could the gap between the development of productive forces and other spheres of life is compensated?[4] Besides one should take into account the point that precisely this generation will have the 'controlling stake' of votes during elections (taking into account the fertility decline that is likely to continue throughout this century), and it is not clear if this generation will be able to react adequately to the rapidly changing environment.

In this context the issue of preserving the purely human nature in the man of the future (which we spoke about in *Introduction*, Chapter 3, and *Afterword*) becomes particularly urgent.

But here one should add that the global ageing increases the conservatism of the elderly generation (see also *Afterword*); thus, ageing can become a brake which will adjust the rate of changes to human psychophysiological capabilities. Yet, there are also some trends to slow down this development. Sergey Tsirel (2008) pays attention to one of them. He points out that 'ordinary' time (*i.e.* everyday and common tempos and rhythm within the limits of usual human existence) starts to hamper historical changes, because it is hard for people to break themselves of the habit of what they got accustomed in childhood and youth, they deliberately or unconsciously resist changes in various ways. Actually one may completely agree that such a sound conservatism is able to prevent acceleration. However, will not this conservatism become the cause of great problems in other spheres (see *Afterword*)?

Thus, it is obvious that our civilization stands at the threshold of dramatic seminal transformations which require being more careful on the way to further technological and social changes.

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[4] On the acceleration of historical time and the necessity of stabilization see Grinin 1998a, 2006a; see also Dyakonov 1999: 348; Kapitza 2004a, 2004b, 2006; Korotayev, Malkov, and Khaltourina 2006a, 2006b.

Appendix 3

The Sixth Kondratieff Wave and the Cybernetic Revolution

Many economists believe that there exist large-scale cycles with a characteristic period of 40 to 60 years. Joseph Schumpeter (1939) named these long cycles 'the Kondratieff cycles' after the famous Russian economist Nikolay Kondratieff who showed in the 1920s that in the long-term dynamics (about half a century) there is a certain cyclical regularity, in the course of which an *upswing* wave of rapid economic indexes' growth is followed by a *downswing* when the indexes drop (Kondratieff 1925, 1935). Those long cycles are also called Kondratieff waves or K-waves for short.

Thus, Kondratieff waves (Kondratieff cycles) are the repeated fluctuations of important economic variables with a characteristic period of about 40–60 years, within which at one (upswing) phase the growth rates of indicators tend to accelerate, and at the other (downswing) phase they tend to slow down. We will refer to the upswing phases as *A-phases* and the downswing ones – as *B-phases.* These long cycles have particular strong connections with innovations (for more details see Korotayev and Grinin 2012; Grinin and Korotayev 2014a; Grinin, Korotayev, and Tausch 2016).

We have established a close correlation between production principle cycles and Kondratieff cycles (for more details see Grinin 2012c, 2013; Grinin L. and Grinin A. 2014; Grinin, Korotayev, and Tausch 2016). Taking into account that K-waves emerge only at a certain level of economic development of societies, we can consider the *K-waves as a specific mechanism connected with the emergence and development of the industrial-trade production principle and the way of expanded reproduction of industrial economy*. Given that each new K-wave does not just repeat the wave motion, but is based on a new technological mode, *K-waves in a certain aspect can be treated as mature phases of the development of the trade-industrial production principle and the* *first phases of development of the scientific-cybernetic production principle.*

1. The Trade-Industrial Production Principle as a Cycle Consisting of K-Waves

As it has been shown in our above mentioned papers the first three K-waves are connected with the industrial production principle. The special attention is paid to the correlation between the duration of the industrial production principle phases and the duration of K-wave phases. Certainly, there can be no direct duration equivalence of both K-waves and their phases, on the one hand, and the industrial production principle phases, on the other, due to the different duration of the industrial production principle phases (that is within the principle of production's cycle its phases differ in duration, but their duration proportions remain the same in each production principle [see Appendix 2; Grinin 2006a, 2009b]). However, we have succeeded in establishing a more complex ratio according to which *at the average one K-wave correlates with one phase of the industrial production principle.* In general, we found out that three and a half waves coincide with three and a half phases of the industrial principle of production! It is clearly seen in Table 1. Such a correlation is not coincidental, as innovative development of the industrial production principle is realized through long Kondratieff cycles which are largely defined by large-scale innovations.

Table 1. Periods of the trade-industrial production principle and Kondratieff waves

Phases of the Trade-Industrial Production Principle	The Third Phase, 1730–1830 **≈ 100 years**	The Fourth Phase, 1830–1890 **≈ 60 years**	The Fifth Phase, 1890–1929 **≈ 40 years**	The Sixth Phase, 1929–1955 **≈ 25 years**	Total: ≈ 225 years, from 1760 – **195 years**
1	2	3	4	5	6
The Number of the K-wave	Zero (B-Phase) / The First Wave (A-Phase), 1760–1817 – about **60 years**	The End of the First Wave / The Second Wave, 1817–1895 – more than **75 years**	The Third Wave, The Upward Phase, 1895–1928 – more than **35 years**	Third wave, The Downward Phase, 1929–1947 – **about 20 years**	About **190 years**

1	2	3	4	5	6
The Phase of K-wave	B-Phase of the Zero Wave,[1] 1760–1787	The Second half of the Downward Phase, 1817–1849	The Upward Phase, 1895–1928	The Downward Phase, 1929–1947	
The Phase of K-wave	The Upward Phase, 1787–1817	The Upward Phase, 1849–1873			
The Phase of K-wave		The Downward Phase, 1873–1895			

Note: For simplicity, we take concrete years for the beginning and the end of the periods, though such a transition obviously lasts for a certain period of time.

2. The Cybernetic Revolution, Scientific-Cybernetic Production Principle, and the Fourth, Fifth, and Sixth K-Waves

Table 2 demonstrates the connection between three first phases of the scientific-cybernetic production principle (which coincide with three phases of the Cybernetic Revolution) and three Kondratieff waves (the fourth, fifth and sixth). Correlation is here even stronger than between the first three K-waves and the trade-industrial production principle phases, due to the shorter duration of the scientific-cybernetic production principle phases in comparison with those of the industrial production principle.[2]

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[1] We took as the beginning a zero K-wave which downward phase coincided with the beginning of the Industrial Revolution, *i.e.* the 1760s (as we know, it is downward phases that are especially rich in innovations).

[2] The reason for the shorter duration is the general acceleration of historical development.

Table 2. The scientific-cybernetic production principle (initial phases) and Kondratieff waves

Phases of the Scientific-Cybernetic Production Principle	The first phase (initial phase of the Cybernetic Revolution) 1955–1995 **≈ 40 years**	The second phase (middle phase of the Cybernetic Revolution) 1995 – the 2030s/40s. **≈ 35–50 years**	The third phase (final phase of ‘self-regulating systems’ of the Cybernetic Revolution) the 2030s/40s–2055/70s **≈25–40 years**	Total: ≈ **100–120** years
K-Wave and Their Phases	The Fourth Wave, 1947 – 1982/1991 **≈ 35–45 years**	The Fifth Wave, 1982/1991 – the 2020s. The beginning of the upward phase of the sixth wave (2020–2050s) **≈ 30–40 years**	The sixth wave, 2020 – 2060/70s. The end of the upward phase and downward phase (the latter ≈ 2050 – 2060/70s) **≈ 40–50 years**	About **110–120 years**
K-Wave and Their Phases	Upward phase, 1947 – 1969/1974s	Downward phase of the fifth wave, 2007–2020s		
K-Wave and Their Phases	Downward phase, 1969/1974 – 1982/1991	Upward phase of the sixth wave, 2020 – 2050s.		
K-Wave and Their Phases	The fifth wave, 1982/1991 – 2020s, upward phase, 1982/1991 – 2007			

3. K-waves and Changing Main Technological Sector

It is known that many researchers correlate each Kondratieff wave with a change of the leading technological sector in economy (see Note 3 for the literature sources). Applying the theory of production principles and production revolutions allow us to revise the sequence of the major (leading) production sectors during the change of K-waves (Grinin 2012c).[3]

Table 3. K-waves, technological modes and leading macrosectors

Kondratieff Wave	Date	A New Mode	Leading Macrosector	Production Principle and Number of Its Phase
1	2	3	4	5
First	1780–1840s	The textile industry	Factory (consumer) industry	Trade-Industrial, 3
Second	1840–1890s	Railway lines, coal, steel	Mining industry and primary heavy industry and transport	Trade-Industrial, 4
Third	1890–1940s	Electricity, chemical industry and heavy engineering	Secondary heavy industry and mechanic engineering	Trade-Industrial, 5/6
Fourth	1940-e – the early 1980s	Automobile manufacturing, manmade materials, electronics	General services	Trade-Industrial, 6, Scientific-Cybernetic, 1
Fifth	1980s – ~2020	Micro-electronics, personal computers	Highly-qualified services	Scientific-Cybernetic, 1/2

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[3] During the table compiling we took into account ideas and works cohering with the theories which explain the nature and pulsation of K-waves by changing of technological ways and/or *techno-economic paradigms:* Mensch 1979; Kleinknecht 1981, 1987; Dickson 1983; Dosi 1984; Freeman 1987; Tylecote 1992; Glazyev 1993; Mayevsky 1997; Modelski and Thompson 1996; Modelski 2001, 2006; Yakovets 2001; Freeman and Louçã 2001; Ayres 2006; Kleinknecht and van der Panne 2006; Dator 2006; Hirooka 2006; Papenhausen 2008; see also Lazurenko 1992; Glazyev 2009; Polterovich 2009; Perez 2002.

1	2	3	4	5
Sixth	2020/30s – 2050/60s	*MANBRIC-technologies* (medical, additive, bio-nano-, robotics, info- and cognitive)	Medical human services	Scientific-Cybernetic, 2/3

4. Peculiarities of the Fourth K-wave with Respect to the Beginning of the Cybernetic Revolution

The fourth K-wave (from the second half of the 1940s to the 1980s) fell on the initial phase of the Cybernetic Revolution. The beginning of a new production revolution is a special period which is connected with the fast transition to a more advanced technological component of economy. All accumulated innovations and a large number of new innovations generate a new system that has a real synergetic effect. It would appear reasonable that *an upward phase of the K-wave coinciding with the beginning of a production revolution can appear more powerful than A-phases of other K-waves*.[4] That was the feature of the upswing A-phase of the fourth K-wave (1947–1974) which coincided with the scientific-information phase of the Cybernetic Revolution. As a result a denser than usual cluster of innovations (in comparison with the second, third and fifth waves) was formed during that period. All this also explains why in the 1950s and 1960s the economic growth rates of the World System were higher, than in A-phases of the third and fifth K-waves. The downswing phase of the fourth K-wave (the 1970s – 1980s) in its turn also fell on the last period of the initial phase of the Cybernetic Revolution. This explains in many respects why this downswing phase was shorter than those of the other K-waves.

5. The Fifth K-wave and the Delay of the New Wave of Innovations

It was expected that the 1990s and the 2000s would bring a radically new wave of innovations, comparable in their revolutionary character with the computer technologies, capable to create a new technological mode. Those directions which had already appeared and those ones, which are

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[4] Therefore, it appears reasonable that A-phase of the sixth K-wave can also make a great progress, as it will coincide with the beginning of the Cybernetic Revolution final phase. Thus, the sixth wave is to have a stronger manifestation than the fifth one. We will return to this point below.

now supposed to become a basis for the sixth K-wave were considered to be a breakthrough. However, it was the development and diversification of already existing digital electronic technologies and rapid development of financial technologies that became a basis for the fifth K-wave. Those innovations which were really created during the fifth K-wave as, for example, low carbon energy technologies, still have a small share in the general energy, and, above all, they do not grow properly. Some researchers believe that from the 1970s up to the present is the time of the decelerating scientific and technological progress (see discussion about it in Brener 2006; see also Maddison 2007). Polterovich (2009) also suggests a notion of a technological pause. But, in general, the mentioned technological delay is, in our opinion, insufficiently explained. We believe that taking features of the intermediate modernization phase of a production revolution (that is the second phase of the production principle) into account can help explain this. Functionally it is less innovative; rather during this phase earlier innovations are widely spread and improved. As regards the 1990s – 2020s (the intermediate phase of the Cybernetic Revolution) the question is that the launch of a new innovative breakthrough demands that the developing countries reach the level of the developed ones, and the political component of the world catches up with the economic one; all this needs changes of the structure of societies and global relations (see about some aspects Grinin and Korotayev 2010b, 2015). Thus, the delayed *introduction of innovations of the new generation* is explained, first, by the fact that the center cannot endlessly surpass the periphery in development, that is the gap between developed and developing countries could not increase all the time. Secondly, economy cannot constantly surpass the political and other components, as this causes very strong disproportions and deformations. And the appearance of new general-purpose technologies, certainly, would accelerate economic development and increase disparities. Thirdly, introduction and distribution of the new basic technologies do not occur naturally, but only within the appropriate social political environment (see Grinin 2012c, 2013; see also Perez 2002). In order for basic innovations to be suitable for business, structural changes in political and social spheres are necessary, eventually promoting their synergy and wide implementation in the world of business.

Thus, the delay is caused by the difficulties of changing political and social institutions on the regional and even global scale, and also (and, perhaps, first of all) within the international economic institutions. The latter can change only thanks to the strong political will of the main players, which is difficult to execute in the framework of the modern political institutions. These institutions rather can change under the conditions of depressive development (and probable aggravation of the foreign relations) compelling to reorganization and breakage of the conventional institutions that could hardly be changed due to the lack of courage and opportunities under ordinary conditions.

The above said explains as well the reasons of different rates of development of the center and periphery of the World System during the fifth K-wave (for more details see Grinin 2013; see also Grinin and Korotayev 2010a; 2015; Grinin, Korotayev, and Tausch 2016). The pe-riphery was expected to catch up with the center due to the faster rates of its development and slowdown of the center development. However, one should not expect continuous crisis-free development of the periphery – a crisis will come later and probably in other forms. Without slow-down of the development of the periphery and serious changes full harmonization of the economic and political component will not happen. Consequently, it might be supposed that in the next decade (approximately by 2020–2025) the growth rates of the peripheral economies can also slow down, and internal problems will aggravate that, as said above, can stimulate structural changes in the peripheral countries and strengthen international tension. Thus, we suppose that in the next 10–15 years the world will face serious and painful changes.

6. The Phase of Self-Regulating Systems and the Sixth K-Wave

6.1. A-Phase of the sixth K-wave: Acceleration to enter the final phase of the Cybernetic Revolution

The sixth K-wave will probably begin approximately in the 2020s. Meanwhile the final phase of the Cybernetic Revolution has to begin later, at least, in the 2030–2040s. Thus, we suppose, that a new technological mode will not develop in a necessary form even by the 2020s (thus, the innovative pause will take longer than expected). However, it should be kept in mind that the beginning of the K-wave upswing phase is never directly caused by new technologies. This beginning is synchronized with the start of the medium-term business cycle's upswing.

And the upswing takes place as a result of the levelling of proportions in economy, the accumulation of resources and other impulses that improve demand and conjuncture. One should remember, that the beginning of the second K-wave was connected with the discovery of gold deposits in California and Australia, the third wave with the increase in prices for wheat, the fourth one with the post-war reconstruction, the fifth one with the economic reforms in the UK and the USA. And then, given an upswing, a new technological mode (which could not completely – if at all – realize its potential) facilitates overcoming of cyclic crises and allows further growth.

Consequently, some conjunctural events will also stimulate an upward impulse of the sixth K-wave. And, for example, the rapid growth of the underdeveloped world regions (such as Tropical Africa, the Islamic East, and some Latin American countries) or new financial and organizational technologies can become a primary impulse. Naturally, there will also appear some engineering and technological innovations which, however, will not form a new mode yet. Besides, we suppose that financial technologies have not finished yet its expansion in the world. If we can modify and secure them somehow, they will be able to spread into various regions which underuse them now. One should not forget that large-scale application of such technologies demands essential changes in the legal and other systems, which is absolutely necessary for developmental levelling in the world. Taking into account a delay of the new generation of technologies, the period of the 2020s may resemble the 1980s. In other words, it will be neither a growth recession, nor a rise, but rather an accelerated development (with stronger development in some regions and continuous depression in others).

Then, given the above mentioned favorable conditions, during this wave the final phase of the Cybernetic Revolution will begin. In such a situation it is possible to assume that the sixth K-wave's A-phase (the 2020–2050s) will have much stronger manifestation and last longer than that of the fifth one due to more dense combination of technological generations. And since the Cybernetic Revolution will evolve, the sixth K-wave's downward B-phase (2050 – the 2060/70s), is expected to be not so depressive, as those during the third or fifth waves. In general, during this K-wave (2020 – the 2060/70s) the Scientific and Information Revolution will come to an end, and the scientific-cybernetic production principle will acquire its mature shape.

6.2. Another scenario

The final phase of the Cybernetic Revolution can start later – not in the 2030s, but in the 2040s. In this case the A-phase of the sixth wave will terminate before the beginning of the regulating systems revolution; therefore, it will not be based on fundamentally new technologies and will not become as powerful as is supposed in the previous scenario. The final phase of the Cybernetic Revolution in this case will coincide with the B-phase of the sixth wave (as it was the case with the zero wave during the Industrial Revolution, 1760–1787) and at the A-phase of the seventh wave. In this case the emergence of the seventh wave is highly possible. The B-phase of the sixth wave should be rather short due to the emergence of a new generation of technologies, and the A-phase of the seventh wave – rather long and powerful.

7. The End of the Cybernetic Revolution and Disappearance of K-waves

The sixth K-wave (from about 2020 till the 2060/70s), similar the first K-wave, will proceed generally during the completing production revolution. However, there is an important difference. During the first K-wave the duration of a phase of the industrial production principle significantly exceeded the duration of the whole K-wave. But now a phase of the K-wave will exceed the duration of a phase of production principle. This alone should essentially alter the unfolding sixth K-wave; the seventh wave will be feebly expressed or will not start at all (on the possibility of the latter see above). This forecast is based also on the fact that the end of the Cybernetic Revolution and distribution of its results will promote the integration of the World System and considerably increase the influence of new universal regulation mechanisms. It is quite reasonable, considering the fact that the coming final phase of the revolution will be the revolution of the self-regulating systems. Thus, the economic management should reach a new level. *So, K-waves appear at a certain stage of social evolution and are likely to disappear at its certain stage.*

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