The Cybernetic Revolution and Historical Process*

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The article analyzes the technological shifts which took place in the second half of the twentieth and early twenty-first centuries and predict the main shifts in the next half a century. On the basis of the analysis of the latest achievements in medicine, bio- and nanotechnologies, robotics, ICT and other technological directions and also on the basis of the opportunities provided by the theory of production revolutions the authors present a detailed analysis of the latest production revolution which is denoted as 'Cybernetic'. There are given some forecasts about its development in the nearest five decades and up to the end of twenty-first century. It is shown that the development of various self-regulating systems will be the main trend of this revolution. The article gives a detailed analysis of the future breakthroughs in medicine, and also in bio- and nanotechnologies in terms of the development of self-regulating systems with their growing ability to select optimal modes of functioning as well as of other characteristics of the Cybernetic Revolution (resources and energy saving, miniaturization, and individualization).

Keywords: *production principle, production revolution, Cybernetic revolution, nanotechnologies, medicine.*

Introduction

The present article presents the analysis of contemporary technological shifts and forecasts the future technological transformations on the basis of the *theory of production principles and production revolution* which was introduced elsewhere (*e.g.*, Grinin 2006a, 2007b, 2006b, 2012b; Grinin and Grinin 2013, 2015). These new explanatory concepts are relevant for the analysis of causes and trends of major technological breakthroughs in the historical process and for the forecasting of new technological shifts. The article presents a general outline of this theory and analyzes its predictive capacities. We hope that the reader will be convinced, from the evidence presented, that this theory is invaluable in interpreting the complex array of facts and trends of current technological development. We also posit that the proposed theory provides a solid basis for making forecasts of future technological developments. The main part of the article is devoted to the analysis of the last production revolution – the Cybernetic Revolution – and the changes which took place in its course starting from the 1950s. The focus is on the changes which will most probably occur due to the Cybernetic Revolution in the next 30–60 years (with a focus on medicine); for some aspects we have made forecasts up to the end of the twenty-first century.

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Section 1. THEORY OF PRODUCTION REVOLUTION AND ITS PREDICTIVE CAPACITIES

1.1. The main ideas and implications of the theory of production revolutions

According to the theory we have developed (Grinin 2006a, 2006b, 2007a, 2007b, 2012; Grinin and Grinin 2013, 2015), the most fundamental causes of transition from one stage of historical development to a subsequent one are global technological transformations which create an essentially new level of productivity and initiate a new technological epoch. We propose that these basic technological levels and epochs can be defined in terms of *production principles.*

We single out four **production principles**:

1. Hunter-Gatherer.

2. Craft-Agrarian.

3. Trade-Industrial.

4. Scientific-Cybernetic.

Among large technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian or Neolithic Revolution; 2) the Industrial Revolution and 3) the newest Cybernetic one.

Each production revolution launches a new production principle; so the three production revolutions represent the borders between four production principles (see Fig. 1).

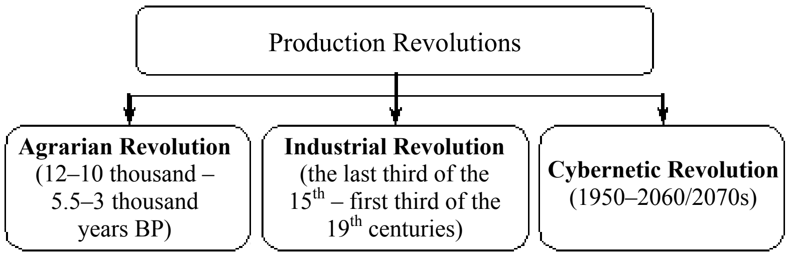

Fig. 1. Production revolutions in history

Each production revolution has its own cycle consisting of three phases: two innovative phases and between them – a modernization phase (see Fig. 2).

At *the initial innovative phase* a new revolutionizing productive sector emerges. The primary system for a new production principle emerges and for a long time it co-exists alongside old technologies. *The modernization phase* is a long period of distribution and development of innovations. It is a period of progressive innovations when the conditions gradually emerge for the final innovative breakthrough. At *the final innovative phase* a new wave of innovations dramatically expands and improves opportunities for the new production principle, which, at this time, attain full strength. As the final phase of the production revolution unfolds, the 'essence' of the production principle, its opportunities and limitations are revealed, as well as the geographical borders of its expansion 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, 2007b, 2012b; Grinin and Grinin 2013; about Industrial revolution see Grinin, Korotayev 2015).

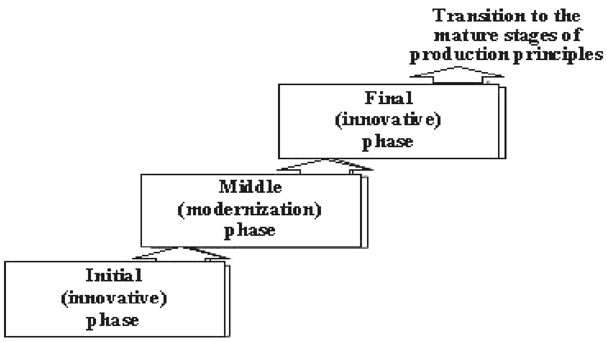

Fig. 2. The structure of production revolutions (phases and their types)

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

Table 1. The phases of the Agrarian Revolution

Phases	Type	Name	Dates	Changes
Initial	Innovative	Manual agriculture	12,000–9,000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Middle	Modernization	No designation*	9,000–5,500 BP	Emergence of new domesticated plants and animals, development of complex agriculture, emergence of a complete set of agricultural instruments
Final	Innovative	Irrigated and plow agriculture	5,500–3,500 BP	Transition to irrigative or plow agriculture without irrigation

Note: * In this and Table 2 below the titles are given only to the innovation phases; the modernization phases do not need special designation.

[1] Following V. Gordon Childe, the Agrarian Revolution is often called the Neolithic one. However, this notion is not quite satisfactory. First, it actually started during the Mesolithic era; second, it completed already in the Iron Age. One should not confuse the Agrarian Revolution as a global phenomenon with the British Agrarian Revolution of the seventeenth- eighteenth centuries (on the latter see, *e.g.*, Overton 1996).

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

Its **initial phase** started in the fifteenth and sixteenth centuries with the development of shipping, technology and mechanization based on the watermill as well as with a 'more organic' (Durkheim 1997 [1893]) division of labor. The **final phase** was the well-known breakthrough of the eighteenth and nineteenth centuries with the introduction of various machines and steam energy. These changes are presented in Table 2.

Table 2. The phases of the Industrial Revolution

Phases	Type	Name of the phase	Dates	Changes
Initial	Innovative	Manufacturing	15^{th}–16^{th} centuries	Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization
Middle	Modernization	No designation	17^{th} – early 18^{th} centuries	Formation of complex industrial sector and capitalist economy, increase in mechanization and division of labor
Final	Innovative	Machinery	1730–1830s	Formation of sectors with the machine cycle of production using steam energy

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

Its **initial** phase dates back to the 1950–1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. The **final** phase is to begin in the 2030s and will last until the 2070s.

We denote the initial phase of the Cybernetic Revolution as **a scientific-information** one, and the final – as **a phase of self-regulating systems.** So now we are in its modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous phase (*e.g.*, computers, internet, cell phone etc.). The technological and social conditions are also prepared for the future breakthrough. We assume that the final phase will begin in the nearest decades, that is in the 2030–2040s. We suppose that the final phase of the Cybernetic Revolution will lead to the emergence of many various self-regulating systems.

In our opinion, it will start in the field of medicine, which in the conjuncture with other fields will create the revolutionizing system of **MBNRIC (medico-bio-nano-roboto-info-cognitive) technologies**, which will also bring about a fundamental correction or even modification of human biological nature. The scheme of the Cybernetic Revolution is presented in Fig. 3.

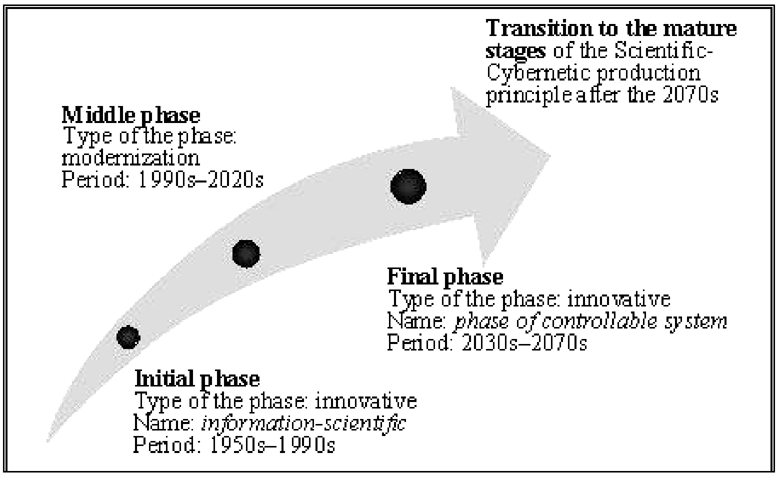

Fig. 3. The phases of the Cybernetic Revolution

1.2. Characteristics of the Cybernetic Revolution

What are self-regulating systems and why are they so important? Self-regulating systems are systems that can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment. They are systems that operate with minimal to zero human intervention. Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suitable mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (as robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and consumption of resources. Human life will become organized to a greater extent by such self-regulating systems (*e.g.*, by monitoring of health, regulation of or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, *etc.*).

Thus, we designate the modern revolution as 'Cybernetic', because its main sense is the wide creation and distribution of self-regulating autonomous systems. Cybernetics, as is well-known, is a science of regulatory systems. Its main principles are quite suitable for the description of self-regulating systems (see, *e.g.,* Wiener 1948; Ashby 1956; Foerster and Zopf 1962; Umpleby 1999; Tesler 2004; Beer 1959).

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. The fourth phase (*of maturity and expansion*) (the 2070s and 2080s) will come after the completion of the final phase of the Cybernetic Revolution. In this final phase, the achievements of the revolution will become quite systemic and wide-scale (for more details see Grinin 2006b).

Below we enumerate the most important characteristics and trends of the Cybernetic Revolution. One can observe them today, but they will be realized in mature and mass forms only in the future. These features are closely interconnected and corroborate each other.

✓ Using transformation and analysis of information as an essential part of technologies and increasing connection of the latter with environment.

✓ Implementation of smart technologies; as well as developing of trends a) towards humanization of their functions; and b) towards autonomation and automation of control.

✓ Qualitatively growing controllability a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic and using tiny particles as building blocks);

✓ The transition to a wide distribution of self-regulating systems, which will become the major part of technological process.

✓ The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies).

✓ The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system.[2]

✓ Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[3]

✓ Individualization as one of the most important technological trends.

✓ Resource and energy saving in many spheres.

✓ Increasing opportunities in the synthesis of materials with previously lacking properties in chemical, biological and bionic (techno-biological) systems.

✓ Miniaturization and micro-miniaturization as a trend of the constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*

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

1.3. The logic of the production revolution: The analysis of utility and correlations between the phases

The significance of the theory of principles of production and production revolutions is in the fact that they allow making more profound and more productive description of the

[2] 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 path to the epoch of self-regulating systems.

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

[4] Thus, for example, the resource and energy saving can be carried out via choosing optimal modes by the autonomous systems that fulfil concrete goals and tasks and *vice versa*, the choice of an optimal 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).

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 principle of production. The availability of such instruments proves 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 used in forecasting.

Let us remind that the fundamental idea of the proposed conception of production revolutions is that *for every production revolution each of its three phases plays functionally the same role and the ratio between the duration of phases within the framework of each cycle remains approximately the same*. Thus, on the basis of the regularities identified within the Agrarian and Industrial Revolutions, one can make assumptions about the following factors: first, about the duration of the middle (modernization) phase of the Cybernetic Revolution; second, about the beginning and approximate duration of the final phase of the revolution; third, about the sectors and directions that will be affected by the new technological breakthrough.

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

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

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

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

1. *A number of tendencies and innovations that used to be non-systemic within the previous production principle get a systemic character.* The non-systemic character means that within the previous production principle these phenomena did not play a crucial role and did not result from its main characteristics, whereas within a new production principle the role of these characteristics significantly increases. This can be shown by the example of automatization which to a certain extent was developed within industrial production long before the Cybernetic Revolution. One of the main characteristics of the industrial production principle is that the production process is carried out by means of machines which are

operated by humans using their sense organs, power and qualification. At the same time, some operations were performed without human involvement, in other words automatically. But the automatization of processes was not essential, in other words it was not a necessary characteristic of the industrial production principle but an extra bonus. In the early twentieth century, automatization started to develop vigorously (*e.g.*, in electrical engineering for the prevention of accidents, in engines for convenient control, *etc.*). But still it had no decisive importance as it was not generally used for the automatization of technological processes.

Therefore, in that period automatization can be regarded as a hyper-development of such essential characteristic as mechanization. Besides, in the first half of the twentieth century, automatization was not the leading direction of the industrial production principle. On the contrary, the leading position was taken by the processes of the latest division of labor including the wide distribution of assembly-flow production (a constant intensifying division of labor is an essential and transparent characteristic of the industrial production principle, strikingly manifested already in manufactures). The development of automatization in the second half of the twentieth century is quite a different matter. It has become the most important characteristic of the scientific-cybernetic production principle (in its initial stages), finding new forms of application and expression in releasing human costs in process control (especially in Information and communications technology [ICT]).

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

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

3. *An important factor with a powerful synergistic effect is the temporal density (the cluster pattern) of the formation and development of a number of directions which, to a greater or lesser extent, is typical of a new production principle.* Such directions in the 1950–1960s were the nuclear power industry, space exploration and usage of space frequencies for

communication and other purposes, deep-sea exploration, information and computer technologies, multiplying equipment, laser technologies, and other areas (*e.g.*, in genetics, medicine and biotechnologies).

4. *However, the future of these innovative spheres can be different*: some of them get particular and important development in the second half of the initial phase and in the middle phase; and other areas will not develop so intensively. Some can turn (at least, temporally) into dead-ends. Thus, at present the atomic energy industry faces severe constraints due to environmental problems, the hopes to master thermonuclear energy fell short of expectations and deep-sea exploration (except for shelf sea) still remains exotic. At the same time, the development of ICT has become the leading trend.

5. *The change of the leading sector in the course of the production revolution.* The leading role of the peculiar characteristics and sectors of a new production principle becomes especially obvious by the end of its initial phase or during its modernization phase (as in the case with ICT). These sectors need some time to reach maturity and acquire a systemic character. *Thus, during these two first phases of the production revolution there is a constant alteration of the leading branches and sectors as well as the formation of new sectors.* One of the branches of a new production principle starts to dominate over the other branches for quite a long period of time (from the end of the initial phase until the middle phase). This branch becomes a key symbol of the production revolution and its driving force. *But later its role as a driving force decreases.* Thus, the wool industry (the most important branch of the initial phase of the Industrial Revolution) appeared to be unimportant in the final phase when it was replaced by the cotton industry. So one can make an assumption that ICT will not remain the most important sphere of the final phase of the Cybernetic Revolution. Besides, advancements in this field will become only one constituent (albeit an important one) of the breakthrough which will be made in other fields.

Later, in the course of the final phase of the Cybernetic Revolution (approximately in the 2050s) one can expect a new qualitative breakthrough in ICT. For example, one can assume that sooner or later serious changes will inevitably occur in programming itself. At present this process is labor-intensive and slow. It will most likely develop in the direction of simplification and robotization of some part of programming and especially in implementation of programs. In other words, machine programming will mainly substitute human programmers and 'the self-programming' trend will be developed.

6. *Already in the initial phase there emerges a prototype of the sectors which will become the leading ones in the final phase. But in the initial phase they do not play the leading role* (see below).

1.3.2. The characteristics of the middle (modernization) phase: Accumulation of innovations and the search for a breakthrough point

1. *The large scale of already existing tendencies and the formation of new ones.* On the one hand, in this phase many processes develop (to a varying degree) that were formed in the initial phase of the production revolution. On the other hand, in the modernization phase we can trace the roots of those forms which will emerge as leaders in the final phase of production revolution. Therefore, it is important to distinguish between the tendencies which have already appeared to be mature and the tendencies which are only formed. It is important to

understand which of them will increase and which of them will be unimportant, become stable or later will decrease.

2. *The expanded development. Need for profound social and political changes.* The expansion of new technologies is especially noticeable in the first half of the modernization phase. In its second half this expansion faces certain saturation and slows down and this increases activity in the field of innovations. There appears an anticipation of something important. But the decisive component for the formation of a new system is still lacking. Besides, this gap can be manifested not only in the absence of basic technological innovations but also of the social conditions for its implementation. One of the most important characteristics of the modernization phase is that *during this period some profound changes or even breakthroughs in social and political relations should take place*. As regards the Industrial Revolution, the period between the seventeenth and eighteenth centuries is the time of social revolutions in England, the Netherlands, the USA, and France which changed the world. It was also the time of changes in the world policy: The Thirty Years' War (1618–1648) and the subsequent Piece of Westphalia laid the foundations of international relations for a long time. Globalization and the period which we denoted as the epoch of new coalitions (Grinin 2009, 2013; Grinin and Korotayev 2010) will also significantly change the world and this process is already under way.

3. *The idea of a decisive component.* During the modernization phase opportunities and improvements accumulate that will play a role in making the final phase of the revolution possible. All components should be ready before it starts. However, we emphasize that the innovations will form a new system only as soon as the key component emerges. At the same time the reconstruction of the relationships within the framework of a whole production system (fields, branches and innovations according to their value) will be considerable.

4. *The emergence of the decisive innovation in the new field.* Basing on our analysis of production revolutions one can conclude that the decisive innovation will appear not within the most important sector of the economy. Thus, irrigated agriculture failed to become the most important sector of agriculture in pre-state barbarian societies; while the cotton industry was not the most important industrial sector in the first half of eighteenth century. Moreover, in this field there should appear certain conditions which should include high commercial profitability and attraction, thus producing a steady demand for a long period of time. Nevertheless, the emergence of the decisive innovation can remain underestimated for some time.

The decisive innovation for the final phase of the Cybernetic Revolution to begin can appear in different fields of bio- or nanomedicine. There can be a series of innovations which will turn the growing number of innovations into a qualitatively new system. It is quite possible that such a breakthrough will be connected with the invention of successful methods to fight cancer as this disease differs significantly from other diseases and requires solutions at the genetic level as well as the application of fundamentally new technologies.

1.3.3. The peculiarities of the final phase

1. *The main characteristics of the production revolution come to maturity.* One can find all the basic characteristics of the final phase of the revolution already in its initial phase though in undifferentiated, incomplete or undeveloped state. These characteristics of the

future system are revealed in the middle phase when the production principle takes a relatively complete although undeveloped form.

The first conclusion. *One may infer about the main characteristics of the Cybernetic Revolution on the basis of an analysis of the initial and middle phases, through a focus on their features and the dynamics of development.* This analysis allows for a singling out of the most important characteristics of the Cybernetic Revolution including resource savings, miniaturization, individualization, wider use of new materials, *etc.* These characteristics already show up in our epoch but they will absolutely dominate in the next epoch.

2. Given the *numerous directions that will appear during the initial phase, there will be some that will necessarily become leading directions in the final phase.* At the same time in the initial phase they play a less significant role. Thus, while in the final phase of the Industrial Revolution the main point is mechanisms, machines, replacement of manual labor by machinery, in its initial phase machinery was only a part of this new direction. In the beginning of the Industrial Revolution, the technical innovations (replacement of manual labor by machines) were not so important and the main point was the process that intensified the division of labor. If you consider the Agrarian Revolution, the leading direction of manual (hoe) agriculture was the use of fertile areas with the help of manual labor (*e.g.*, with the help of a sharp stick). The soil fertility was natural or was achieved by burning of plants. As to irrigation technologies, in the initial phase of the Agrarian Revolution they were not so widespread and were linked to the local environment. But in the final phase they became the leading factors and remained such during the whole period during which the craft-agrarian principle dominated production.

The second conclusion. Therefore, the leading sector of the final phase of the Cybernetic Revolution has already formed, but it is one of those sectors which does not, as yet, play a decisive role in the economy. In our opinion, medicine will play the leading role in the unfolding final phase of the Cybernetic Revolution (see below).

3. *The mutual integration of innovative sectors starts after the formation of the decisive innovations or their group.* This process especially intensifies in the final phase of the production revolution. Innovations are mutually integrated and form a fundamentally new system. That was the case with the invention of the power spinning loom (which was later improved). Before that time, for two decades separate important directions (steam engines, steam energy, new types of machines, principles of management at large enterprises, established institution of inventions and different technological innovations) allowed formation of the fundamentally new sector of cotton mills. This caused the cumulative effect of rapid invention of missing innovations in the field of cotton carding (*i.e.*, the separation of cotton fibers), painting, printing, *etc.*

The third conclusion. The breakthroughs in medicine and allied technologies will cause the 'catching up' and an amalgamation of different innovations into a system which might bring about the completion of the Cybernetic Revolution (see below).

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

'meaning', 'sense' and 'essence' on the basis of the processes occurring during the initial and middle phases of the production revolution.

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

1.3.4. The determination of the future sector of the breakthrough. Why medicine?

Thus, an assumption from the theory of production revolutions entails that one of the number of directions defined in the initial and middle phases of any production revolution becomes a breakthrough area by the beginning of its final phase. But this factor does not play a leading role in the economy until the beginning of the breakthrough. The analysis of the actual development of production revolutions also suggests the following characteristics of the future sector:

- the commodity produced in this sector should be of prime necessity. Thus, cereal in the period of the Agrarian Revolution and cotton in the period of the Industrial Revolution were basic necessities;
- the direction of development of the sector should conform to the leading tendencies and problems in the society (irrigation agriculture could support and increase the sudden exponential population growth; the cotton industry met the needs of increasing urbanization and made use of the surplus labor force which had emerged in the agrarian sector);
- the sector can influence a significant number of spheres and integrate them (*e.g.,* in the period of the Agrarian Revolution the irrigation facilities required joint actions in society; and in the period of the Industrial revolution the transition to machines and steam-engine in the cotton industry caused a rapid growth of economy, the reconstruction of transportation routes and trade);
- technological conservatism in this sector is relatively weak;
- the breaking through 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 breaking through sector of the final phase of this revolution should have already developed. But which of the existing ones meets the mentioned characteristics? We argue that there will be no breakthrough, for example, in the field of green (low-carbon) energy sector (despite the fact that at present wind power demonstrates high growth rates) because green power will be unable to completely replace traditional energy resources but it will coexist with it similar to hydro- and nuclear power coexist with carbon energy. We think that robotics could become the break through direction if there were created robots that could perform different functions in the services sector. Not without reason the future scientific and technological progress was thought to be connected with developments in the sphere of robotics. At present robotics finds wide application and is rapidly developing (see, *e.g.,* Makarov and Topcheev 2003; Gates 2007). But still one can hardly say that robotics will become the breaking through direction judging by the current investment volumes in the sphere, by the level of resolution of problems (including the projects of the neural-network technologies), and the interest in this 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 after the Cybernetic Revolution is completed (see Conclusion).

On the basis of the analysis of the current situation one can conclude that the only field which meets all the requirements is medicine. That is why medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, the development of self-regulating systems will cover the most diverse areas of production, services and life. We treat medicine in a broad sense, because it will include (and already actively includes) for its purposes a great number of other scientific-technological branches (*e.g*., the use of robots in surgery and taking care of patients, information technologies in remote medicine, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor an organism; new materials for growing artificial organs and many other things to become a powerful sector of economy).

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

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

b) There are far fewer social, cultural or structural obstructions to the application of these technologies in medicine than in other fields (as well as the obstacles to adoption of innovations).

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

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

e) A rapid growth of the world middle class and of population education level, especially in the developing countries (NIC 2012) is anticipated in the nearest decades and these two factors mean that there will be a sharp growth in the demand for health services.

f) The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. Many spheres (including but not limiting to biotechnologies, nanotechnologies, robotics, use of the latest ICTs and various devices, cognitive technologies, synthesis of new material) will be integrated in this field.[5]

Medicine as a sphere of the initial technological breakthrough and the emergence of MBNRIC-technology complex. It is worth 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. Given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area is to be highly commercially attractive and have a wide market, we predict that the final phase (the one of self-regulating systems) of this revolution will begin in one of the new branches of medicine. Perhaps, it has already formed (as biomedicine or nanomedicine) or it can form as a result of involving other innovative technologies into medicine.

Certainly, it is almost impossible to predict the concrete course of innovations. However, the general breakthrough vector 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 (bodies, receptors), *etc.*

This will make it possible to *radically expand the opportunities to prolong life and improve its biological quality.* It will be the technologies intended for common use in the form of mass market services. Certainly, it will take a rather long period (about two or three decades) from the first steps in that direction (in the 2030–2040s) to their common use.

The drivers of the final phase of the Cybernetic Revolution will be medicine, bio- and nanotechnologies, robotics, ICT, cognitive sciences, which will together form a sophisticated system of self-regulating production. We can denote this complex as *MBNRIC-technologies.* As is known, there is a widely used abbreviation of NBIC-technology (or convergence), that is nano-bio-information and cognitive (see Lynch 2004; Dator 2006; Akayev 2012). However, we believe that this complex will be larger.

[5] It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the Sixth Kondratieff Wave (according to his approach, until the 2050s) (Nefiodow 1996; Nefiodow and Nefiodow 2014a, 2014b). We generally support his ideas (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.

Section 2. MEDICINE, BIO- AND NANOTECHNOLOGIES IN THE CYBERNETIC REVOLUTION

Having no opportunity to describe the whole range of MBNRIC-technologies (for more details see Grinin and Grinin 2015) in this paper we will concentrate on describing current and future transformations in medicine. Our focus will be 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.

2.1. Medicine in the initial and middle phases of the Cybernetic Revolution (the 1950–2020s)

In the initial phase of the Cybernetic Revolution (between 1950 and the1990s) there was a rapid growth of medicine as an increasingly important service sector. *At the same time the growth of health services constituted the general process of a rapid increase in service sector. In the economies of developed countries the service sector is the leading sector in terms of GDP.*

During this initial phase of the Cybernetic Revolution new directions of medicine emerged while those directions that had emerged earlier (*e.g.*, electroencephalography, electric shock therapy, transplantology, active use of electronics, laser and new methods of diagnostics such as ultrasound) reached a certain level of maturity. 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.

The period from the 1990s till the present represents the modernization phase of the Cybernetic Revolution. 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 transplanting 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. In medicine there appear new directions such 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.*

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).

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. 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 trends' a wide use of approaches based on the methods of molecular and cell biology. A new perspective direction – biomedicine – has emerged (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 (Demire and Mazzucato 2008). By 2006, the production of drugs doubled, and the total global market volume of drugs was estimated at US$ 640 billion, about half of which was accounted for in the USA (Kondratieff 2011). This field remains one of the most profitable fields with a sales profitability of 17 per cent (*Ibid*.). Every year the volume of consumed drugs increases by several percent. 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.

2.2. Forecasts regarding developments in medicine. In what way will the characteristics of the Cybernetic Revolution appear in the development of the medical sphere?

2.2.1. Two decades before the beginning of the final phase of the Cybernetic Revolution

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, fat excision, implant teeth, transplant hair 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. Doctors from the University of Maryland Medical Center gave a new face including jaw, teeth and tongue, to thirty-seven year old Richard Norris.

During the next two decades some directions of medicine such as cosmetic and aesthetic medicine are supposed to rapidly develop (though it can cause rather serious psychological problems including those connected with individual's self-identification). Along with the new technologies there will be a wide spread of already proven technologies (*e.g.*, different 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.

The struggle against incurable diseases 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 as the 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 and 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 there developed the trend to perform surgeries with the help of special flexible instruments 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.

2.3.2. The premises for a breakthrough

As we have mentioned that the field of some innovative branches of medicine will be the sector where the final phase of the Cybernetic Revolution will start and develop. The unfolding situation will arise by the 2030s in the growth of the economy, demography, culture, living standard *etc.*, will contribute to this. And this will determine a tremendous need for a scientific and technological breakthrough.

Let us denote these premises:

– a large volume of medical services which amounts to about 10 per cent of the world GDP;

– leveling of peripheral and developed countries;

– formation of a huge middle class, reduction in poverty and illiteracy. As a result, the focus of efforts will shift from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc*. So, there is a great potential for the development of medicine;

– by that time we will face the problem of population ageing. Moreover, this problem will be typical not only of the developed countries where it will become crucial for democracy, but also for a number of developing countries, in particular, China and India. The problem of pensions will become more acute (as the number of retirees per worker will increase) and at the same time the lack of a qualified labor force will increase (which in a number of countries, including Russia, is very critical). *Thus, we will have to solve the problem of labor force shortages and pension contributions by increasing the retirement age by 10 or 15 years (of course, it is necessary to solve complex social problems at first).*

It also refers to the adaptation of people with disabilities for their full involvement in the working process due to new technologies and achievements of medicine;

– at the same time by that time, the birth rates in many developing countries will significantly decrease. Therefore, the government will start to be concerned with the health of the national population and not with limiting population growth.

On the whole, these successful conditions will entail major investments in medicine: increase in the number of well-off and educated people and middle-aged and elderly people (who particularly are willing to actively spend money on medicine), strengthening of the need for extra labor force and interest of the state in improving the working capacity of elderly people. In other words, the conditions for activization of business, science and state in order to provide a breakthrough in the field of medicine can be unique and *the formation of such unique conditions is necessary for the beginning of a new phase of the Revolution!*

2.3.3. The shifts during the final phase of the Cybernetic Revolution

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 semi-autonomous and autonomous 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.

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.

The third direction can be associated with the development of the health monitoring system that will allow early diagnosis and preventing diseases. All these measures will provide control over diseases.

Finally, a number of functions of a doctor can be performed by the patients themselves with the help of different devices and systems. At present the tests for important indices (such as blood pressure, on pregnancy, blood sugar level) can be made without doctors by means of special devices. On the basis of the test results one can define the norm and abnormalities. Perhaps, in the near future diagnostics will be transferred from specialized institutions to mobile devices on the basis of nanochips which do not require the specialists' participation. There has been notable progress in this sphere.

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). It is unlikely that such devices will appear in the very near future and besides similar devices most likely will work only on a narrow spectrum of issues. Nevertheless, the emergence of such forecasts is quite remarkable as they show the movement towards the development of self-regulating systems. However, nowadays in order to remotely control patients, the company Applied Digital Solutions proposes the device 'Digital Angel'.

In this connection the profession of a doctor in its current form can lose a number of its present attributes, first of all due to the transfer of its functions to different smart systems, secondly, due to the expanding competency of users due to different intelligent systems and rapid obtaining of information. 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 be even reduced. 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.

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.*

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

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

Artificial antibodies and the growth of opportunities to use the immune system. There will never be any universal drug against all diseases. But strengthening the immune system is one of the universal directions which can transform this situation and help the struggle against different diseases. 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**.[6] Medicine is always connected with a patient's individuality. However, in the twentieth century there was a tendency towards mass medicine (connected with mass vaccination, preventive examinations, *etc.*). At present there are some signs of transition from mass medicine to individual medicine (in particular, in aesthetic medicine), which is related to the general tendency of the Cybernetic Revolution towards individualization. But individualization to an even greater extent will be manifested when based on the unique characteristics of the organism one of which is the immune system. 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.* 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

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

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.*

Constant health monitoring as a self-regulating supersystem. Let us consider another promising direction of medicine – biosensors, which 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.

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.
3. The development of different organ substitution technologies (the most promising direction).

Besides, in medicine scientists already use or work to design different artificial organs: skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, lungs, pancreas, bladder, ovaries. Even combination of the above-mentioned opportunities is rather possible. There is already an opportunity of tissue engineering. In laboratories they cultivate healthy skin or cartilage cells to replace injured bone or cartilage. 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. Cells grow in these structures as they would in their natural environment. The potential of this technology is the formation of cell therapy and methods to regenerate tissues.

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, 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).

Will the development proceed in the direction of cyborgization? All that we have written about artificial organs and tissues will contribute to the breakthrough in the field of both production of absolutely new materials which will expand the implementation of non-biological elements in the human body. Thus, we will follow 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.

However, we should be aware of the fact that this actually means not only the formation of a new direction in medicine, but also the moving towards the **cyborgization** of a human being and the creation of transcybernetic systems (that is the systems which combine the 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, glasses or contact lenses, artificial teeth, tooth fillings, bones, aerophones, artificial blood vessels, mitral valves, *etc.* allow hundreds of millions of people to live and work and these people still remain humans. The same is true with respect to more complex systems and functions. However, we suppose that the idea that someday the human body will be fully replaced by non-biological material and only the brain or the organs which support the senses will remain are just pure fantasy. This will never come true (see about such fantasies in Rybalkina 2005: 333). People who propose such solutions, for example, to replace supposedly less lasting and comfortable biological material by the technological inventions (such as replacement of haematocytes by billions of nanorobots, *etc.*) in their forecasts try to use the outdated logic that was widespread several decades ago in science fiction or scary stories: the replacement of biological organisms with technical ones. The modern logic of scientific and technological progress including the latest achievements in bioengineering shows the movement towards the synthesis of biological forms and technical solutions into a unified system. Technical achievements can hardly replace the biological mechanisms which have been selected for many millions of years. On the contrary, we should follow the path of 'repair', improvement, the development of self-regulation and support of biological mechanisms via some technical solutions.

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.

In this context one should mention the neural interfaces.

Neural interfaces are an 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, the case of the famous scientist, 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-years old drummer Robin Ekestam who lost his arm as a result of cancer.

The technologies creating the interaction between an individual's nervous system and external devices are called neural interfaces (Brain-Computer Interface). Despite the fact that neural interfaces show impressive results, their implementation is connected with many difficulties. For instance, many nanostructures and nanotubes are quite toxic for cells (Kotov *et al.* 2009). Implanting external devices leads to the traumatizing an organism despite the availability of many methods of mitigating the traumatizing effect (Grill, Norman, and Bellamkonda 2009). Another problem is the different electrical conductivity of biological tissue and of the technical device. Probably, new nanostructures from which nanofibers for neural interfaces are made, can solve this problem (Abidian and Martin 2009).

Development follows not only the path of implementation of electronic systems in biological systems but also the pattern of improvement of mechanical prostheses and microprostheses.

For example, the development of artificial cornea by the scientists of Stanford University (USA) has become a breakthrough in medicine. 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).

Thus, people with disabilities can make the most of the development of medicine and cyborgization as they will be able to significantly compensate their drawbacks.

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 optimal 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).[7]

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.

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. One should mention the technologies of growing an embryo outside the woman's body. The transplantation of reproductive organs becomes possible. The scientists are developing the artificial womb which can be transplanted to a woman with the damaged womb or even to a man that will radically change the concept of sex (McKie 2002) and will cause new ethical problems. Artificial womb experiments have been successfully conducted in Italy where artificial womb was grown and transplanted to a woman.

[7] How it will be 'perfect', of course, and which can be problems with these technology it is hard to say. For example, the possibility to know a sex of baby created a big disproportion between sexes of young people in China. As a result there are a disproporitionate number of boys relative to girls born. However note that Francis Fukuyama calls to receive the future achievements 'biotechnology revolution' with great prudence (Fukuyama 2002). We agree with such position.

Section 3. FORECASTS: BIOTECHNOLOGIES IN CYBERNETIC REVOLUTION

3.1. The development before the beginning of the final phase of the Cybernetic Revolution (the 2010–2020/30s)

The modernization phase of a production revolution is characterized by the two major tendencies: 1) the extensive distribution of new technologies with simultaneous improvements as a result; 2) the strengthening of social struggles for necessary changes in some spheres of social life due to the introduction of these technologies. In order for the final phase of a production revolution to begin, the development of technologies during the modernization phase has to achieve both a rather large variety and 'density'. Taking into account that biotechnologies are innovative branches, any country which wants to be the leader in this field, will have to develop them anyway. 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 into our lives: in nutrition, various nutritional supplements, influence on our body (through various branches of medicine, in particular cosmetic and one's own treatment of the body as, for example, body-builders do) *etc*. There must quickly develop both the branches which have already become a reality (*e.g*., the cultivation of genetically modified plants, affecting the productivity of domestic animals, production of biofuel), as well as the technologies which are less spread today, in particular in the development of biomaterials.

On the other hand, such a wide implementation of biotechnologies, undoubtedly, will intensify public, diplomatic and economic struggle against the change of traditions, national features, real or imaginary harm. Such a movement against cloning, GMO, computer selection, *etc.* has been already taking place in different countries. Such a reaction is quite natural, legitimate and in many respects useful though it may happen that conservatism will suppress progress. Just within the framework of this struggle and collisions, there may originate decisions which become important in the long term and will not only promote achieving of some balance, but also give an impetus to the development (let us remember that the ban on the importing of cotton fabrics in England served as a trigger for the development of its own cotton industry which became a cradle of the Industrial Revolution [Mantoux 1929; Allen 2009; Grinin, Korotayev 2015]).

3.2. The beginning of the final phase of the Cybernetic Revolution and the development of the Scientific-Cybernetic production principle

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

Certainly, it is very difficult to anticipate the direction and moment of concrete discoveries. We suppose that at the very first stage biotechnology, as an independent direction, will play a less important role than medicine. It will be rather an important component of medical technologies, providing breakthroughs in the area of the treatment of diseases and the regulation or monitoring of organism functions. But, probably, in adopting biotechnological achievements, it will become possible to make an organism successfully attack certain diseases.

Achievement of self-regulation of system without intervention of a person. 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, Priefer, and Pühler 1983), but a whole set of necessary genes which will operate depending on environmental conditions. Such characteristics will be extremely important in the case of climate changes which are quite probable. It will become possible to choose the most optimal varieties of seeds and seedling for a unique combination of weather conditions and territory (the sort of imitation of evolutionary selection via automatic search in databases). Consequently, huge databases of such plant varieties and variations will be created. It is quite possible that in the future the whole process of getting a transgenic plant will take place without human participation, thus, it will become self-regulating.

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

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

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

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

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

The breakthrough in the sphere of resource saving. Biotechnology can help to solve many global issues, for example, to cheapen the production of medicines and foodstuffs including producing and making them in ecologically sound ways that can also keep or make the environment pristine, thereby considerably expanding their production. The solution to the food problem will come in the different ways, in particular due to the mass production of food protein whose shortage is sharply perceived in many societies (at present the feed protein for animals is generally produced in this way). Even now there are results based on the production of food proteins or, for example, imitation meat. But so far such a production is too expensive. Now a gram of laboratorial meat costs 1000 dollars (Zagorski 2012), but this is part of the usual process from the laboratory to mass cheap production.

The creation of new materials. The opportunities of creation of self-regulating and self-operating systems by means of biotechnologies, in particular genetic manipulations, opens an important direction in the field of new materials with desirable properties. It potentially allows for making substitutes for the natural process feedstock, for example, leather. The respective projects are already present now. For example, the Modern Meadow Company aims at making a revolution in the clothing industry by growing leather and other types of animal skin in the laboratories (Zagorski 2012).

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

Section 4. NANOTECHNOLOGIES

The modernization phase (the period of distribution of innovations) of the Cybernetic Revolution is the period of the formation of 'modern nanotechnology' (the 1990–2020/30s). Nanotechnologies became an area of industrial production, the nanotechnological race between countries has started, dozens of projects and whole institutes of nanotechnologies have been created. The number of goods produced with nanotechnologies is rapidly increasing. The investments into researches increase, and the nanomaterials penetrate into various spheres: engineering, medicine, transport, aerospace and electronics industry, *etc*. According to the data of analytics of BBC Research (2012), the sales volume of products of nanotechnologies in 2009 amounted 11.67 billion dollars. Very soon they will amount 20 billion dollars.

4.1. Forecasts

4.1.1. Nanotechnologies as a breakthrough component in the final phase of the Cybernetic Revolution (the 2030–2070s)

One can trace all the characteristics of the Cybernetic Revolution in the future development of nanotechnologies: bionanotechnology and nanomedicine will start a vigorous development, the invention of technologies of regulating systems (in which nanorobots independently or as a part of more complex technology will play an important role), the production of new materials, saving of materials and energy (*e.g.,* in house due to nanomaterial for window glass; 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 regulatory systems. We have already mentioned some directions of integration of these branches in the previous sections. In general the prospects of such an integration are already evident. So, according to some forecasts, 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. At the Engelhardt Institute of Molecular Biology (part of the Russian Academy of Sciences) they applied nanotechnologies to create a biochip allowing quick diagnosing of a number of dangerous diseases, including tuberculosis. Quite promising will be the development of nanotechnologies to create materials imitating properties of, for example, bone tissue. 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 that the neighbouring healthy cells are almost not injured.

The important direction of research in the area of oncotherapy consists in automatic 'smart' hitting of the malignant cells by nanoparticles. The thing is that, only one-millionth part of the revolutionary new substance Herceptin, used to treat a considerable number of patients with breast cancer, would target the diseased cell. To make the transportation of Herceptin more effective, a group of American scientists invented a special model of a capsule from porous silicon into which the medicine is injected and is directly delivered just to the damaged cell. Now this technology is being clinically tested. The American 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 regulatory systems in the area of 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.

It is expected that by means of nanotechnologies and use of robots the development and application of biotechnologies will significantly advance in the direction of creating self-regulating systems of farming, where agricultural operations will be for the most part performed in an autonomous mode. Many technologies will appear to promote this process. Thus, the implementation of membrane systems for cleaning, and also special biocidal coverings and silver-based materials will facilitate and increase the level of managing the farm livestock and providing them with high quality water. It is assumed that the use of nanotechnologies will allow changing technology of cultivation of lands due to the use of nanosensors, nanopesticides and a system for decentralized water purification. Nanotechnologies will make it possible to treat plants at the genetic level and allow creating high-yielding plant varieties especially resistant to the unfavorable conditions (Balabanov 2010).

Various prospects of using nanotechnologies in the Cybernetic Revolution and at the mature stages of Scientific-Cybernetic production principle. Nanotechnologies have considerable prospects. The components of nanoelectronics, photonics, neuroelectronic interfaces and nanoelectromechanical systems will be developed. Then on the basis of the achieved results it is expected to advance to a regulated self-assembly of nanosystems, the creation of three-dimensional networks, nanorobots *etc*. One can also speak about the use of molecular devices, nuclear design *etc*. Especially alluring prospects are observed in the development of nanomechanics, nanomechanical engineering and nanorobotics.

Quite long ago there appeared an idea where data creation and storage is performed not by means of a special condition of the environment (*e.g*., magnetic, electric, and optical), but through the use of nanotechnologies, for example, the replacement of silicon, the basic material in the production of semiconductor devices, by carbon nanotubes. In this case a bit of information can be stored in the form of numerous atoms, for example, of 100 atoms. It would reduce the sizes of processors by an order of magnitude or would essentially increase their operation speed. Now the number of transistors in the processor reached a billion and more. However, a few years ago the goal was set to create a processor with more than one trillion transistors by the 2010s (that would lead to radical increase of the ICT opportunities). Most likely, this is an unreal task to solve even by the 2020s, before the beginning of the final phase of the Cybernetic Revolution. It is supposed that this level will be achieved later, as we are already in the process of developing this phase (this would also open new horizons of full replacement of the information computer equipment due to a transition from using silicon to nanomaterials).

However, it is possible that the smallest computers will have an essentially new basis. According to Eric Drexler, nanomechanics and not nanoelectronics can become such a base. He has developed mechanical constructions for the main components of the nano-computer. 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 two nanometers wide consuming light energy. It consisted of about three hundred 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 nano-mechanical engineering is quite real, though a long-term perspective. It will most likely happen close to the end of the current century. The same refers to nanorobotics. At the present, the expected designs of nanorobots and their use exist only in forecasts.

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

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

Conclusion

The described processes must prove the idea that the final phase of the Cybernetic Revolution will be the era of a rapid development of self-regulating systems. Actually, already now we use 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 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.

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

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

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

Transport and communications. Eventually the production revolution surely changes the ways of transportation and communication. But it is difficult to mark out any distinct regularities here. At the beginning of the only one (industrial) revolution the development of transport became one of its driving forces: the long-distance sailing ships played a crucial role in the organization of the oceanic trade which became one of the impulsive forces of communication. We mean the invention of printing. The role of the new types of communication and connection was even more essential at the beginning of cybernetic revolution. Thus, the initial phases of the production revolution can be caused by the emergence of the new types of communication. However for the final phase of production revolution it is not necessary (though writing appeared on the eve of the final phase of the agrarian revolution, its role was not essential).

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

As it was already discussed, there also took place different changes in the transport area. The Agrarian Revolution was not connected with them. The transition to the riding and development of sea communications happened already in the course of its final stage on the periphery and during the later period. The Industrial Revolution on its initial phase was connected with already tested oceanic water crafts capable of moving in any wind (not only the fair wind). Such crafts were widely developed during this revolution. Great Geographical discoveries without which the Industrial Revolution would have collapsed were also connected with this innovation. But the emergence of the steamship and further the engine happened already toward the end of the final phase of the Industrial Revolution. The emergence of a new means of transport gave it an unprecedented scope. New means of transport appeared much later (a car, a plane), and it was quite enough to start the Cybernetic Revolution. It, certainly, brought very fundamental changes to all means of transport, but created nothing essentially new so far (space transport is no object) though one may note the development of high-speed railways (but they play a secondary role).

Deduction. In the middle or the end of the final phase of the Cybernetic Revolution (approximately in the 2050–2060s) there can be expected the emergence of some new means of transport. An electric car with a large power capacity and speed could be a possible example. But taking into account 'the sense' of the Cybernetic Revolution (as the revolution of self-regulating systems) the breakthrough most likely will happen in the direction of self-governed vehicle traffic and its control. That is the means of transport and systems will become self-regulating. Even today there exist some ideas concerning the realization of this opportunity.

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

Almost the whole period of the industrial revolution, since the sixteenth century and, at least, till the last third of the nineteenth century, passed under the banner of battles pitting the skilled craftsmen against the Leviathan of technological progress. This period is full of episodes of prohibitions on inventions, the acceptance by the representatives of factories of various constraining laws, and a history of destroyers of machines, *etc*. Thus the grounds for such bans and constraints were the most serious: product degeneration, falling of earnings, competition between the people who do not have the necessary professional skills. However as a result, machinery replaced manual operation, waves of technological innovations wiped out the groups of experts. The initial phase (and even the middle one) of the Cybernetic Revolution, especially during the extensive use of computers, led, in a great number of cases, to the replacement of professional skills, including in the area of intellectual functioning: books proofreading, magazines and newspapers, translation from one language into another (though of poor quality but still helpful), collection of information, library and archiving, design, advertising, photography, cinematography *etc*. No wonder that the time when books in the standard form will be treated as a rarity is around the corner. The emergence of the opportunity 'to be your own' (the cameraman, the publisher, the artist, the photographer, bank and ticket cashier *etc*.) became the sign of the times.

Deduction. Not least, further development will undermine the grounds of very many professions – from a doctor (what we mentioned above) and a teacher to the nurse and taxman. As a whole the general course of development has to move towards the reduction of the number of people employed in the service sectors (both simple types and more difficult), but a lot of new professions will be required at the same time. Reduction of the people employed in the service sector happens at least in part as a result of development in the field of robotics.

Legal, ethical, pedagogical and ideological problems in the development of medicine. The faster the pace of scientific and technological progress, the more difficult it is for society to keep pace with those changes, the more flexible become morals, more sophisticated the right, different minorities are emerging, defending their, not always clear rights, the society becomes more tolerant. But at the same time traditions are subverted more easily and quicker and it becomes more difficult to distinguish good from bad (criteria for these concepts are disappearing), it is more difficult for parents to pass on their experience to children *etc*. We have already discussed these changes (Grinin 2006; Grinin, Korotayev 2009; Grinin and Grinin 2013, 2015). The well-known book by A. Toffler 'Future Shock' (Toffler 1970) did not lose its topicality at all (see also Fukuyama 2002). These problems surely demand much attention. In particular, it should be noted that very complicated ethical problems can appear and a potential risk of violation of the social and biological basis of human existence can emerge. It is difficult to imagine, what will be the outcome of all of these changes. Radical changes in the human body are able to affect seriously such basic things as understanding of the family, gender, attitude to life. Just for this reason forecasting of the development of the Cybernetic Revolution is useful. It can help us become aware of the creation of the optimal social, legal and other instruments in advance, so that such changes would not take us completely unaware and so that it would be possible to minimize negative consequences. Eventually, the Cybernetic Revolution (constituted largely of regulatory systems) also involves or includes social systems. Therefore, technologies based on social insight and elimination of social problems have to be developed; importantly these technologies must be tested before the mass distribution of innovations leads to serious misgivings.

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