Chapter 1

Global Technological Transformations: Theory and History

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

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

1. The Production Principles and Production Revolutions

1.1. Periodization of historical process

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

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

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

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

We single out four *production principles*:

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

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

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

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

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

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

1.2. The Production Revolutions

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

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

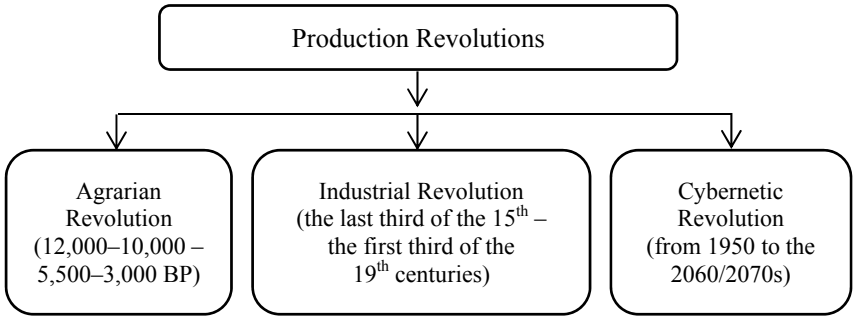

Fig. 1. Production revolutions in historical process

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

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

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

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

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

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

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

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

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

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

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

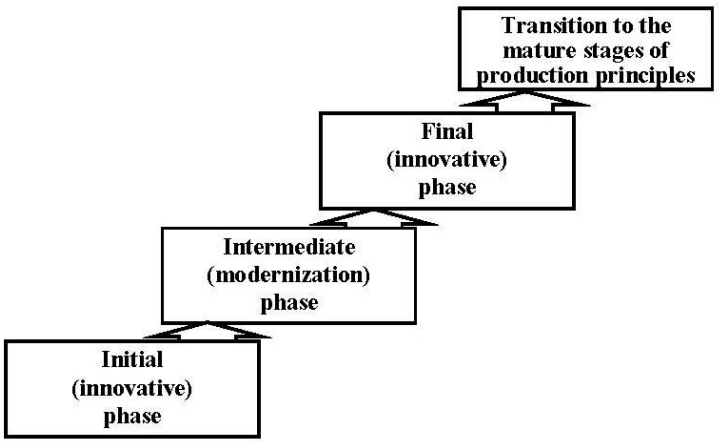

Fig. 2. A cycle of a production revolution (phases and characteristics)

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

limitations are revealed, as well as the geographical borders of its expansion via merging with new states.

The production revolutions also bring about:

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

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

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

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

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

Table 1. The phases of the Agrarian Revolution

Phases	Type	Name	Dates	Changes
Initial	Innova-tive	Manual farming	12,000–9,000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Interme-diate	Modern-ization	Distribu-tion of agricul-ture	9,000–5,500 BP	Emergence of new domesticated plants and animals, development of complex agriculture, emer-gence of a complete set of agri-cultural instruments
Final	Innova-tive	Irrigated and plough agricul-ture	5,500–3,500 BP	Transition to irrigative or non-irrigated plow agriculture

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

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

Table 2. The phases of the Industrial Revolution

Phases	Type	Name of the phase	Dates	Changes
1	2	3	4	5
Initial	Innovative	Manufac-turing	15^{th} – 16^{th} centuries	Development of shipping, tech-nology and mechanization on the basis of water engine, develop-ment of manufacture based on the division of labor and mecha-nization

1	2	3	4	5
Inter-mediate	Moderni-zation	Primary industry	17th – early 18th centu-ries	Formation of a complex indus-trial sector and capitalist econo-my, increasing mechanization and division of labor
Final	Innovative	Machinery	1730–1830s	Formation of sectors with the machine production cycle with steam energy

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

Its *initial* phase, which we call the *scientific-information epoch*, dates to the period between 1950s and 1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. We assume that the *final* phase will start in the nearest decades, that is in the 2030s or a bit later, and will last until the 2070s. This forthcoming phase can be called the *epoch of self-regulating systems* since the major point lies in the creation of self-controlled systems or systems indirectly controlled either via other systems or by means of point impact and corrections. As a result there will be much more opportunities to eliminate a direct human interference upon various natural, social, and production processes whose control is impossible or quite limited at present. The drivers of the final phase of the Cybernetic Revolution will be medical technologies, additive manufacturing (3D printers), nano- and bio- technologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulated production. We can denote this complex as MAN-BRIC-technologies.[2] As it was mentioned above, with respect to the sixth technological paradigm there is a widely used idea connected with the notion of NBIC-convergence[3] (see Lynch 2004; Bainbridge and Roco 2005; Dator 2006; Kovalchuk 2011; Akayev 2012). There are also

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

[3] Nano-Bio-Info-Cognitive.

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

So now we are at the modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous stage (*e.g.*, computers, internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough.

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

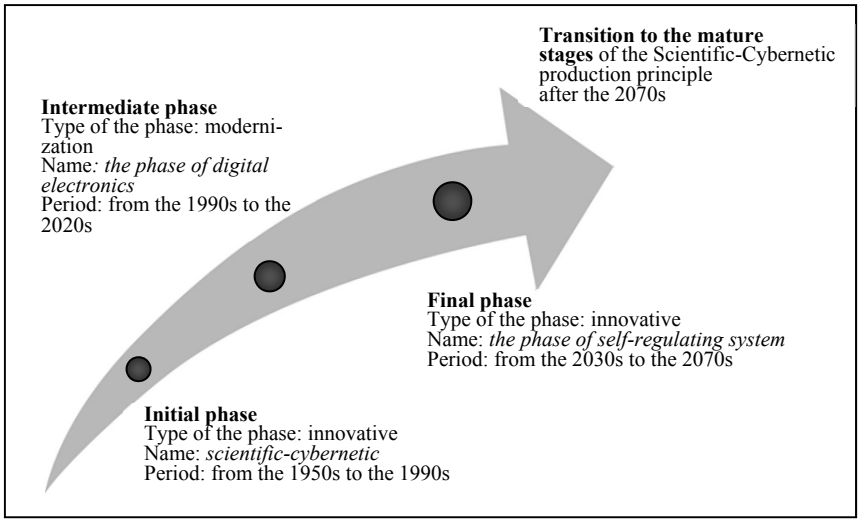

Fig. 3. The phases of the Cybernetic Revolution

1.3. Production principles

Phases of production principals. We believe that the production revolution can be regarded as an integral part of the production principle and as its first 'half' after which the development of mature relations occurs. This approach demonstrates in a rather explicit way the main 'intrigue' of the cyclical pattern of historical formations. During their first period we mostly observe dramatic changes in production, whereas in the second half we deal with especially profound changes in political and social relations, public consciousness and other spheres. Within these pe-

riods, on the one hand, political-judicial and sociocultural relations catch up with the more advanced productive forces, and, on the other hand, they create a new level which gives impetus to the formation of a new production principle.

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

1. The first phase – 'transitional' – is *the start of production revolution and the formation of a new production principle*. The latter emerges in one or a few places, although in rather undeveloped, incomplete, and imperfect forms.

2. The second phase is *the stage of initial modernization*. It is associated with a wider diffusion of new production forms as well as with reinforcement and vigorous expansion of a new production principle.

3. The third phase is *the final stage of a production revolution.* The production principle obtains mature characteristics.

4. The fourth phase is *the stage of maturity and expansion of a production principle*. It is connected with diffusing new technologies to most regions and production spheres. The production principle acquires its mature forms and this leads to important changes in social-economic sphere.

5. The fifth phase implies *an absolute dominance of a production principle*. It brings an intensification of production and the full realization of the potential of the principle.

6. The sixth phase is *the stage of non-system phenomena* or *a preparatory phase* (for the transition to a new production principle). Intensification leads to the emergence of non-system elements (for the given production principle) which prepare the formation of a new production principle (when under favorable conditions these elements can form a system thus, triggering the transition to a new production principle in some societies and launching a new cycle).

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

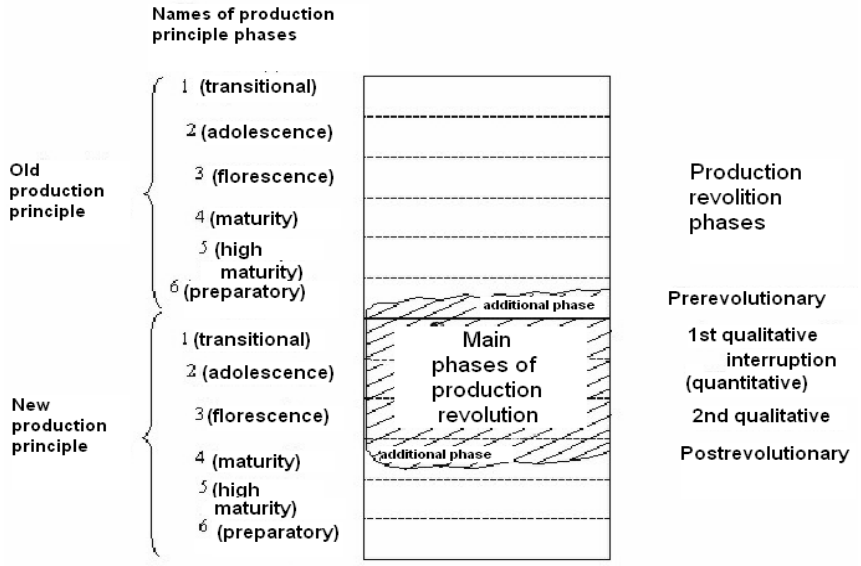

Fig. 4. The correlation between phases of production principles and phases of production revolutions

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

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

2.1. When did historical process start?

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

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

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

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

tain cave in the Kalahari Desert in Botswana the archeologists found a human-size stone figure of a python (Steiger 2007).

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

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

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

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

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

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

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

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

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

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

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

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

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

relman 1989: 295–296; 2012a; Lips 1956; Lamberg-Karlovsky and Sabloff 1979).

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

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

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

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

The *second* phase can be conventionally dated to 8,000–5,000 BP (from the sixth to the mid-to-late fourth millennia BCE), that is up to the formation of a unified state in Egypt and the development of a sophisticated irrigation economy in this country. It includes the formation of new agricultural centers, diffusion of domesticated animals from West Asia to other regions. There developed the husbandry of sheep, goats and the first draught animals (Shnirelman 2012b; Meadows *et al*. 2007; see also Gupta 2004; Zeder and Hesse 2000). The active interchange of achievements (domesticates and their varieties, technologies, *etc.*) is observed. The first copper artefacts and tools in Egypt and Mesopotamia (and in Syria) date to this period (starting from the fifth millennium BCE) (Tylecote 1976: 9). According to Childe the so-called urban revo-

lution took place at that time (Childe 1952: ch. 7; see also Lamberg-Karlovsky and Sabloff 1979; Masson 1980; 1989: 33–41; Oppenheim 1968; see also Adams 1981; Pollock 2001: 45; Bernbeck and Pollock 2005: 17; Zablotska 1989: 34–38; Bondarenko 2006: 50; Mellaart 1975; Wenke 1990: 326–330; Turnbaugh *et al*. 1993: 464–465; Harris 1997: 146; Schultz and Lavenda 1998: 214–215; Balter 2006).[8]

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

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

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

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

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

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

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

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

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

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

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

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

The period from the late fifteenth century to the end of the sixteenth century is the initial phase of the Industrial Revolution, associated with the development of navigation, engineering and mechanization on the basis of watermill, spreading and improving of different machines, the development of division of labor. At this time, in different parts of Europe, there are significant breakthroughs in different directions, which by the end of the period are synthesized into the general Western Europe system (Johnson 1955; Braudel 1973; Wallerstein 1974; Barg 1991; Yastrebitskaya 1993; Davies 1996). Changes in one country tended to produce substantial impact on the economy and the lives of others – through the spread of innovations, through the publication of special technical books, through the movement of technical experts to different countries, through the introduction of various advances and innovations by kings and emperors to their realms, etc. Thus, we find impressive achievements in the field

of mechanization in mining operations in Southern Germany and Bohemia; major contributions to the development of navigation, geographical discoveries and world trade accomplished by the Spanish and Portuguese, but also by the British; significant developments of technologies of manufacturing in Italian and Flemish cities; significant shifts in agriculture in Northern France and the Netherlands; important scientific and mathematical discoveries made by scientists in Italy, France, Poland, England; new financial technologies developed in Italy (Barone 1993; Davies 1996, 2001; Collins and Taylor 2006; Goldstone 2009, 2012; Ferguson 2011; Porter 2012). But all of this, anyway, quickly became the common heritage of Europe.

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

Finally, the period between 1730 and 1830 may be identified as the final phase of the Industrial Revolution, which was accompanied by the creation of the sectors with the machine cycle of production and the use of steam power. Supplanting handwork with machines took place in cotton textile production that developed in England (Mantoux 1929; Berlanstein 1992; Mokyr 1993, 1999; Griffin 2010). Watt's steam engine started to be used in the 1760s and 1770s. A new powerful industry – machine production – had developed. The industrial breakthrough was more or less finalized in England in the 1830s. Although Britain was here clearly the leader, but we also observe in this period a number of

important processes that can be identified as pan-European (including the development of military technology, trade, science, pan-European commercial and industrial crisis of the second half of the eighteenth century, the beginning of the demographic revolution – see below). In this concept, we clearly see in the Industrial Revolution the result of the collective achievements of different societies of Europe, a sort of relay-race of achievements. The successes of industrialization were evident in a number of countries by that time and it was also accompanied by significant demographic transformations (Armengaud 1976; Minghinton 1976: 85–89).

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

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

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

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

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

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

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

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

show below, the final phase of this revolution may start in the sphere of medicine and will be connected with its innovative branches; thus, this will lead to serious modification of human organism and, perhaps, of its biological nature.

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

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