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On the Limits to Development in Technology & Knowledge

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Abstract

The possible development of the world must be considered first from the viewpoint of information about Nature and possible limits to human capability. The main question is whether there are limits to those notions or not. Despite the efforts of philosophers, we do not know the answers although we know the constants of Nature which dictate our existence. Secondly, in structural terms it is possible to distinguish the level of civilizations. Following J.D. Barrow's thought, there are several types of civilizations according to their ability to control larger or smaller entities. Such a classification starts from the size of everyday objects, then goes on to genes, molecules, atoms and to elementary particles, later ending up manipulating the basic structure of space and time. Presently, we are at the stage of controlling atoms but not all possibilities are yet known. We should ask if technological progress is inevitable or not; if it is, values and human side of the progress should be taken into account. If technological progress starts to hamper values, then the world could face critical situations and instabilities. Our present knowledge confirms that understanding the complexity of the world as a whole could also help to build up scenarios for future development. In this context, the activities of WAAS are analysed. However, we can be certain that everything is uncertain in the future not because we are wrong or there is some special situation right now but because we live in a complex world where interactions between the constituents may create new, unexpected and unpredictable qualities.

Prediction is very difficult, especially about future.
– Niels Bohr

It is still possible to arrive at a credible forecast for the next 40 years.
– Jørgen Randers, 2013

1. Introduction

We all agree that the World is changing fast—new technologies, the growing information flows, uneven developments of countries, energy shortages and pollution, just to name a few problems. And probably the most important question is how mankind can cope with all the changes and wishes. It has always been a challenge to predict the future. Ancients tried to use oracles like ancient Greeks did by asking advice from Pythia, the oracle of Delphi. The Chinese have used cracked bones for making predictions. Nostradamus, who lived in the 16th century, tried to forecast future events and his predictions are still studied. Nowadays,

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mankind has much more knowledge about Nature, possesses powerful computing facilities and understands the threats that the world faces. It is quite obvious that eternal questions about the future are asked again and again. In what follows, a short overview on possibilities (and impossibilities) to forecast the future is given from a viewpoint of a physicist. First, in Section 2, some philosophical ideas are described. Section 3 is devoted to actions which characterize the present activities in communities. In Section 4, some recent results of modelling the future are described. Finally, some conclusions are drawn in Section 5.

"We may regard the present state of the universe as the effect of its past and the cause of its future."

2. Philosophical Ideas

The first question one should ask about predictions is: are there certain limits? John Barrow (1998) asks this question and builds up a certain framework for understanding the possible edges of knowledge. Some remarks from history of thought are needed in order to understand contemporary ideas better. In the Judaeo-Christian tradition it is understood that with God all things are possible and this understanding has been in practice for a long time. Leaving aside many influential thinkers, let us mention Laplace's demon. This is an idea from the 19th century about causal determinism. Laplace said (cited from the English translation of the book in 1951):

> *"We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes."*

However, Laplace's demon does not take into account the irreversibility concept and the ideas of thermodynamics and quantum mechanics. Today, this statement is considered interesting from the viewpoint of the history of science.

From the vast cornucopia of interpretation of processes in Nature, it is worthwhile to mention the seven world riddles formulated by du Bois-Reymond (1874). He indicated four difficult but potentially soluble problems: the origin of life, the origin of language, the origin of human reason and the evolutionary adaptiveness of organisms (listed after Barrow, 1998). The three insoluble problems in his list were the following: the origin of natural forces and the nature of matter; the origin and nature of consciousness and sensation; the problem of free will. Although nowadays we know much more compared to what passed as knowledge in the 19th century, one has not found full answers to these problems.

The present understanding about the complexity of Nature with underlying simplicity allows us to envisage possible constraints and to classify the possible levels of future technological civilizations (Barrow, 1998). Four possible distinct futures are possible:

i. Nature unlimited and human capability unlimited;

ii. Nature unlimited and human capability limited;
iii. Nature limited and human capability unlimited;
iv. Nature limited and human capability limited.

"One of the most highly developed skills in contemporary Western civilization is dissection: the split-up of problems into their smallest possible components. We are good at it. So good, we often forget to put the pieces back together again." – Alvin Toffler

There are pros and cons for all these possibilities and the discussion is still going on. In the near future, one can be sure that knowledge is growing but whether the process of acquiring knowledge at the large (cosmic) scale will go on or there are limits, is a question. If such distinct futures give rise mostly to philosophical discussions, then the knowledge about the possible technological levels is clearly related to available energy resources and every forecast must be based on energy production, transmission and storage (Christophorou, 2018). The possible civilization types following Barrow (1998) may be characterized by their ability to manipulate the large-scale world around them:

- Type I is capable of manipulating objects over the scale of themselves like building structures, mining, etc.;
- Type II is capable of manipulating genes and altering the development of living things;
- Type III is capable of manipulating molecules and molecular bonds;
- Type IV is capable of manipulating individual atoms, creating nanotechnologies and artificial life;
- Type V is capable of manipulating the atomic nucleus;
- Type VI is capable of manipulating the most elementary particles of matter;
- Type Ω is capable of manipulating the basic structure of space and time.

Leaving aside these types, one should note that such a classification deals with the physical world. However, this is just one side of the coin because the other side is related to human values and social systems (see Section 4).

The ideas described briefly above are just a general framework of our understanding and one should analyse further the structural properties of natural and social processes before coming up with possible forecasts.

3. Complexity and Dynamic Mechanisms

The World around us is complex, which in a nutshell means that it cannot be understood only by analyzing its constituents (whatever they are), physical entities or living organisms. The notion "*complexus*" itself means what is woven together and this togetherness makes the world not only richer but much more interesting. By 'complex' we characterize the processes, phenomena, etc. which involve also many parts or constituents and because of their interaction with each other, new qualities may emerge which often are unpredictable. This means that the full system cannot be characterized by summing up the behaviours of its constituents.

Classical research aims to split general problems into their simpler components and then to study them as deeply as possible. An extremely impressive explanation is given by Alvin Toffler (1984): "*One of the most highly developed skills in contemporary Western civilization is dissection: the split-up of problems into their smallest possible components. We are good at it. So good, we often forget to put the pieces back together again*."

Complexity theory is characterized by holistic view, i.e. the pieces are put together as a whole. Put very briefly, the properties of complex systems are (Weiler and Engelbrecht, 2013):

i. non-additivity and nonlinear interactions;
ii. deterministic unpredictability;
iii. sensitivity to initial conditions;
iv. there are several typical phenomena characterizing the behaviour of nonlinear systems (bifurcation, emergence of new patterns, multiple equilibria, coherent states, chaotic regimes, adaptability, self-organization, etc.);
v. despite the variety of phenomena and motions, there are several rules which govern the processes in complex systems.

The main structural cornerstones of complex world and processes are *fractals, networks*, and *hierarchies* (see Scott, 2005; Barabasi, Frangos, 2014, etc.) Structures and phenomena together constitute the basis in the analysis of complex systems. However, the complex physical and social systems are different because in social systems one should also take values into account (Engelbrecht, 2016). Whatever happens in the world, human behaviour is strongly influenced by values. In general terms, the basic values accepted by society according to T. Ash (2007) are: freedom, peace, justice, prosperity, diversity, and solidarity. But the values are space-dependent and environment-dependent, they are related to the cultural and personal values of people which may not entirely coincide with the general norms in societies. And certainly the societies are different when we speak about values. Inglehart and Welzel (2004) have constructed a cultural map of the world, where survival values and self-expression values are depicted against traditional values and secular-rational values. This map clearly shows the groupings of English speaking countries and Latin America, catholic Europe, protestant Europe and Confucian countries, ex-communist countries and Africa.

Society as a complex social system can be modelled using networks and clusters, communities and alliances and is spatially and temporarily differentiated. Society is able to function not only because of its structures but also by the behaviour of its members (constituents in the physical sense) and the links (interactions in physical sense) between them play the most important role. Turning to complexity of physical systems, the interactions between the constituents are described by physical laws and can be measured at least with certain accuracy. In complex social systems the situation is much more complicated because the links are based on accepted rules (laws), traditions, language, and governance, on economic and environmental conditions and certainly on values.

It is important to understand the possible constraints or limits of complex systems. Engelbrecht (2016) has stated that in *physical complex systems* constraints (often *thermodynamical considerations*) exist in order to limit or guide the processes, and *in social systems* it looks like *values are the leading and guiding factors*.

The modelling of social systems is a cornerstone of all future studies. For example, the Conference on Complexity and the Policy Studies 2019 (www.caps-conference.org) was set up with the aim to advance social goods in a complex world. The basic understanding from complex systems is declared as basic: (i) social systems are complex adaptive systems; (ii) social systems are embedded in specific socio-ecological environments; (iii) socio-ecological environments are the result of long, historic processes; (iv) invisible system variables such as values and beliefs strongly affect outcomes; (v) change in social systems results from ongoing interactions between multiple variables; (vi) interactions between system variables are mostly non-linear; (vii) straight causal relations are not sufficient to understand social change as effects are non-linear and largely unpredictable.

Another important question is, how to behave in complex systems? There are several issues that must be understood. The first is, causality as mentioned above. Granger is widely accepted (Granger, 2003): (i) the cause occurs before the effect; (ii) the cause contains information about the effect that is unique, and is in no other variable. However, it is not always possible to use Granger causality principles. Paluš et al. (2018) have shown that coupled chaotic dynamical systems violate the first principle of Granger causality. This is a problem in mathematical models but cannot occur in Nature. In this context, the forces in social systems must be studied. For example, Bednar et al (2006) have found that forces for consistency and conformity slow convergence in a model of cultural formation and they have also noted the non-linear additivity in such processes.

Finally, there are two important notions: synergy and stigmergy that are useful in the actions in complex systems.

Synergy, as it is understood nowadays, comes from the Greek '*synergos,'* meaning working together. This notion was accepted in psychology in the 19th century but more widely used in many fields of science after the groundbreaking studies of Fuller (1975) and Haken (1977) on synergetics. This is meant as an interdisciplinary field of studies, which explains the self-organization of patterns and structures in thermodynamically open systems. One can say that synergy is related to the famous saying of Aristotle—the whole is more than the simple sum of its parts. Clearly, this is also the characteristic of social systems.

Stigmergy comes from the Greek words '*stigma'*, mark or sign, and '*ergon',* work or action. Originally, it was used in biology to describe termite behaviour (Grassé, 1959), but nowadays it is understood as a mechanism of indirect coordination through the environment (Theraulaz, Bonabeau, 1999). Heylighen (2015) gives the following definition: "*stigmergy is an indirect, mediated mechanism of coordination between actions, in which the trace of an action left on the medium stimulates the performance of a subsequent action*." So stigmergy is not only related to the behaviour of social insects but also to the behaviour of crowds, division of labor and cooperation in general (Miller, 2010). It stresses the importance of feedback, markers and cognition.

Equipped with the knowledge about complex systems, values, limits, causality, synergy and stigmergy, one could make possible (or impossible) predictions.

4. Modelling of Future

4.1 Some General Ideas

Scientific modelling simulates processes or phenomena for better understanding, quantifying and predicting the outcome. In this context, the conceptual models help to understand the links and causality, while mathematical models help to quantify and predict the values of variables in time. Future studies have been in focus for ages and nowadays many special institutions and research centres are into this field. It is impossible to present a systematic overview on studies about the future in one paper but some ideas are briefly analysed in the following sections. As explained in Section 3, the world is complex and the mathematical models for the forecast should take into account the properties of complex systems, regardless of their physical or social character.

In constructing the models, one should be aware of paradigms which mean distinct sets of thought patterns. The word comes from the Greek '*paradeigma*'—that is 'pattern, example, sample.' Already, Plato has used the word '*paradeigma*' for a model or pattern used by God to create the cosmos. The contemporary understanding of paradigms in science goes along the ideas of the American philosopher of science Thomas Kuhn (1962). According to him, the normal evolution of science is based on a widely accepted framework of certain understandings using well-known experiments and theories. This framework may be described as a paradigm. The revolutionary idea of Kuhn was to propose that such continuities in science were interrupted by periods called paradigm shifts. During these shifts new basic concepts are formulated and existing theories and understandings are reformulated. The history of science knows many such paradigm shifts: from Ptolemaic cosmology to the model of Copernicus; from Phlogiston theory to Lavoisier's theory of chemical reactions; blood circulation by William Harvey; from Newtonian mechanics to the theory of relativity etc. Certainly, the old ideas are not left aside voluntarily and the understandings engraved on stone tablets seem to last forever. The quote attributed to Lord Kelvin in 1900, for example, states: "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." Sometimes the process of paradigm shift is called 'paradigm war'. Indeed, it is not always easy to accept fresh ideas, simply considering the reason that we have always done so! Some changes are easy to accept, some need a lot of proofs. It is certainly not only in science, it also holds true in social life, management, economy, etc. In modelling the future, one should carefully consider existing paradigms because the future might need completely different ideas compared with existing principles.

Once the mathematical models are constructed then there are other issues which need attention. These are singularities and catastrophes. The concept of singularity was introduced by J. von Neumann in 1950 and nowadays, in the field of technology, the definition given by Kurzweil (2006) is used: technological singularity is "... a future period during which the pace of technological change will be so rapid, its impact so deep, that human life will be irreversibly transformed. Although neither utopian nor dystopian, this epoch will transform the concepts that we rely on to give meaning to our life, from our business models to the cycle of human life, including death itself."

In mathematics, 'singularity' means discontinuous change. Such problems are dealt by the so-called catastrophe theory derived by Thom (1968) and Zeeman (1976). A 'catastrophe' means that in a nonlinear system the equilibria can appear or disappear due to small changes in some leading parameter. Geometrically such catastrophes are classified according to Thom as fold, cusp, swallowtail, butterfly, etc. depending on the shape of the potential function called control surface which describes the process. In physics, catastrophe theory can be used for describing the phase transitions and gravitational lensing (detecting of black holes). In physiology, the human behavioural patterns including nervous disorders can be described by using the concept of a control surface. Catastrophe theory has been used for describing the behaviour of stock markets: jumping from bull market (index rising) to bear market (index falling) which causes a crash. The geometry of control surfaces, however, shows that beside jumps there also exist smooth paths from one equilibrium regime to another. Such processes need careful changes in control parameters or in other words, deep understanding of processes. For example, it has been shown that large-scale social processes like war-peace can also be described using the catastrophe theory. In this case when public opinion is divided between "hawks" and "doves", the negotiation may move the process of the war threat to peaceful solutions. Similar description could be used in the analysis of riots.

4.2 Modelling Scenarios

Coming to predictions about the possible future, this has been a growing trend during the last half a century and several models have been proposed. In principle, a model describes the changes in general variables like population, industrial output, food supply. There are many think-tanks, professional networks and foresight organizations all over the world devoted to futures studies. A ground-breaking model was proposed by Meadows et al. (1972) in the famous book *The Limits to Growth* commissioned by the Club of Rome. Three scenarios were proposed: the standard run, comprehensive technology, and stabilized world. Only the latter avoided the collapse that was estimated to happen before the year 2100. Note that in this context growth means quantitative increase in physical dimensions.

Since 1972, much has changed in technology (progress in IT and nanotechnology, genetics, etc.), nature (sea level rising, agricultural land degradation, pollution growing, etc.), community (the widening gap between the rich and poor, GDP per capita declining in many countries, etc.), decrease in non-renewable resources etc. It is of great interest to analyse what has happened in the world and compare the data with the proposed model and predictions made about 40 years ago. Turner (2012) has used the UN data about the world economy and population and came to the conclusion that "the standard run scenario compared well with the global data for the majority of variables." The conclusion of this study is that a collapse could occur within a decade or might even be underway. It is stressed that the issue of resource constraints is a greater problem than climate change. This is explicitly explained by Brown et al. (2011) by the analysis of energy constraints on economic growth, ecological impact, etc. Their conclusion is that higher rates of energy consumption are needed to sustain developed economies. The fundamental question is how to proceed further.

One could always argue about the assumptions of a model or criticize the methods used for calculation. One way or another, the official data used by Turner (2012) demonstrate clearly the tendencies of changes close to the standard run. Randers (2013) has proposed his model with predictions up to 2052. He starts by asking how the human ecological footprint will evolve towards the middle of the 21st century. Altogether his model has 11 variables starting from the global population, GDP, productivity, consumption, etc. up to ecological footprint. Randers uses a mix of models and tries to improve them with several feedbacks. As a result, growth in world population and GDP will slow down over the next generation, there will be more episodes of extreme weather and there will be huge regional variations in economy.

One way or another, the perspective is not glorious. However, one might always ask whether variables in a model are really important or whether they are too specific or too general, etc. For example, GDP alone does not characterize reality well but the values related to the GDP give more information about the welfare of countries (Caldarelli et al., 2012), which is a sign of economic complexity. It seems that contemporary understanding of future studies should also include social and ethical dimensions.

Returning to the ideas briefly described in Sections 2 and 3, it seems that there is no need to be afraid of technological limits. Technology predictions are certainly based on present knowledge and include many possible changes on earth and also extraterrestrial activities. However, the appearance of new materials or breakthroughs in the IT or medicine fields cannot be predicted in the long run. This also concerns the changes in value chains, consumption patterns and social upgrading (Lee and Gereffi, 2015). The emerging technologies also include the risks in economy, environment, society etc. (WEF Report, 2017) and disruptive impact. There is a need for better governance in order to avoid negative consequences.

Considering technological inventions, especially for scenarios, one cannot forget Amara's law on the effect of technology (named after Roy Amara, past President of the Institute for the Future, Palo Alto): "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run." This is an example of a hype cycle as explained by the IT company Gartner: a peak of inflated expectations is followed by a trough of disillusionment, after which the process slowly tends to reach a plateau of productivity at a much lower level than the expected peak. This law is certainly not based on strict analysis but must be considered more like a warning. Such a tendency calls for a careful planning of all scenarios.

In the context of modelling (cf Meadows et al., 1972; Turner, 2012; Randers, 2013, etc.) it seems that the next step is to apply the knowledge about the dynamics of complex systems. Indeed, it is difficult to find such global models where the possibility of chaotic regimes is taken into account, or where the sensibility of initial conditions and the existence of multiple equilibria are analysed. Contrary to that, the curves demonstrated by Turner (2012) or Randers (2013) are smooth with maxima and minima or showing exponential growth. Quantified variables are extremely important to account for values. In complex societies values play the role of possible constraints, like the physical systems are governed by thermodynamical conditions (Engelbrecht, 2016). The possible changes in existing paradigms make all the predictions questionable. The coupling of variables into the complex network (see Randers, 2013) is to be specified with care, especially with a special analysis of causality. It is not enough to follow classical rules of Leonardo da Vinci (cited after Truesdell, 1968):

1. Observe the phenomenon and list quantities having numerical magnitude that seems to influence it.

2. Set up linear relations among pairs of these quantities as they are not obviously contradicted by experience.

Quite probably, the coupling is of nonlinear character and will have a significant influence on the process, especially in the long run. This brings us to phenomena which are known in complex systems (see above). Another aspect to be taken into account is related to values or "soft" constraints. Daly (1987) has distinguished two general classes of limits to growth: biophysical limits on the Earth and ethicosocial limits. The first class of limits involves resources, ecological connections etc., resulting in changes in economic subsystems, explicitly shown in *The Limits to Growth*. The second class involves (i) cost imposed on future generations; (ii) extinction of a number of sub-human species; (iii) effects of welfare; (iv) corrosive effects on moral standards. And besides GDP and material goods, there are intermediate goods (Hirsch, 1977) and public goods (Puu, 2006). Among the intermediate goods is education, which facilitates professional and social advance (Hirsch, 1977). Intriguing questions have been formulated by Puu (2006): is culture needed for developing the economy or is the economy needed for developing culture? In other words, this is a question about the values of material goods *vs* public goods. In our contemporary technological world, these questions must be answered in order to build the future, where communications and connectivity play an important role.

To sum up, one cannot be too optimistic about making predictions in the long run. The predictions formulated up till now serve as warnings but cannot be used for predicting advances. Surely these predictions explain what could be the consequences of doing nothing. Clearly not only the material values but also soft values need to be taken into account in all discussions about the future. Voros (2001) has formulated "The three 'Laws' of futures": (i) the future is not predetermined; (ii) the future is not predictable; (iii) future outcomes can be influenced by our choices in the present. It seems that the 'worldview' analysis as stated by Aerts et al. (2005) and permanent risk analysis (WEF Report, 2017) permit us to construct the global image of the world. It needs permanent orientation in the world (collective conceptualisation of the nature of the physical, the social and the ethical world), followed by evaluation and action models. One cannot forget that the social world is changing rapidly and even the deviance (the behaviour that goes against the norms and values) may offer re-calibration of societal norms (Thorlindsson and Bernburg, 2004).

5. Final Remarks

Models like "The Limits to Growth" (Meadows et al., 1972) or "2052" (Randers, 2013) certainly have warned the world about the consequences of growing consumption in the conditions of limited resources. In order to avoid that, changes in policy are needed, much like Voros' (2001) third law—future outcomes can be influenced by our choices in the present. However, as stated by Bengston (2018), future is fast and the actions should also be fast. Although the changes can be slow, one should be aware of the Seneca effect (known also as Seneca cliff or Seneca collapse). The Seneca effect can briefly be characterized by the slow growth of a phenomenon but the fast collapse under certain conditions. Lucius Annus Seneca, the ancient Roman philosopher, has written in his letters (about 62 AD) that fortune is of sluggish growth, but ruin is rapid. Using the theory of complex systems, Bardi (2017) has analysed many examples starting from the collapse of Rome to physical phenomena like fracture or avalanches and the collapses of social systems like financial crises and overexploitations. He showed explicitly that such changes are not the results of mistakes but embedded properties, and instead of fighting the changes, one should embrace the changes. Following the ideas of the catastrophe theory, the proper choice of control parameters may avoid the singularities (collapses) and follow a smooth path of changes. The risk analysis of actions in policy, economy and society (WEF Report, 2017) keeps the world on track to development that is stable.

The World Academy of Art and Science (WAAS) has embraced actions to address many global issues. These concern human-centered economic theory, new paradigm for global human development, transdisciplinary social science, global higher education, etc. *All these activities leave traces.* It means that following the principles of *stigmergy* (see Section 3), the influence of WAAS will be spread in the world helping to be better equipped for the year 20??, following the motto: promoting leadership in thought that leads to action.

Finally some monographs must be mentioned where the authors have analysed the future prospects of the world in more detail: Djurovic (2017), Christophorou (2018) and Šlaus (2019).

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