The Model of Development of Limnology as Informational System

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Abstract

Limnology is young and quite closed field developed by several hundreds of scientists. International Society of Limnologists is holding meetings since 1922. Proceedings of meetings were used to find out principal stages of history of this science (rapid and calm periods). The simulation model of limnology development was built on the basis of such analysis. Every scientist can generate with some probability new ideas and elaborate existing ones. The model includes as parameters the properties of scientists and surroundings (age, experience, level of contacts between scientists, etc). After the model was tuned experiments with different parameters was made. They demonstrate level of contacts influences most strongly on rapidity of the science development.

Keywords: simulation, information process, meme, development of science, limnology

1 Introduction

Limnology − the field of science about biological and ecological processes in lakes, − is relatively young sphere of investigation; it usually believes that limnology was originated from the publication of monograph of F.Forel (1912). The main approaches and methods, which were proposed in this book, are based on the studies of the Lake of Geneva. The International Society of Limnology ("SIL") was established in 1922. It is holding regular congress and conferences and is publishing detailed proceedings during already long time. Undoubtedly, the limnology, as a field of science, is now quite complicated and developing informational system. At the same time, this field is quite secluded one: the specific terminology, ideas, methods and approaches are often used only within it. Therefore the limnology is very suitable modern example in order to analyze the development of either scientific field.

Traditionally, the history of any science describes some static historical "sections" along its development, i.e., for instant, the numbers of publications, characters of the scientist community etc (Nalimov, Mulnichenko, 1969). But there are still not enough works where the process of arising of new discoveries is explaining. Not numerous existent publications about investigations of so called "scientific process" concerns as a rule physics and mathematics. In 2004, the oceanography researcher Louis Legendre has published his works "Scientific research and discovery: process, consequences and practice" (Legendre, 2004). This work was grounded on the experience of scientific investigations in the fields of marine sciences and ecology. Conceptually, Legendre' point of view is based on the limnology conceptions of F.H.Rigler and R.H.Peters

(1998). Another very interesting original approach, which intersects in some aspects with Legendre' view, is developing in the works of Otto van Nieuwenhuijze (2006).

These very remarkable (although sometimes disputable and even "extremist") works stimulated us to carry out own studies on the discovery process. It was especially interesting, because one of the authors of this article − Vladimir Menshutkin − is engaged with oceanography and limnology during many years too. We used at that some ideas and materials of above authors as well as the SIL' proceedings in order to create the simulation model of the limnology development. We suggest that some our results can be applied to explain the development of other fields of science.

The simulation of the science development allows to understand better, what are internal and external factors, which influence on the process of scientific investigations and probability of origin of new discoveries. It is not possible to make this by descriptive methods when the number of publications and citation index are in general discussed. We tried to include in the simulation model many other parameters, in particular, the level of communications between scientists, economy state, age of scientists etc. Of course, any modeling simplifies real situation especially in the case of such complicated informational system as science. But on the other hand, the modeling helps to examine how separate factors influence on multi-parametric systems that we are not able to clarify in reality (Levchenko, 1993; Levchenko, Menshutkin, 1987; Menshutkin, Aschepkova, 1988; Menshutkin, Natochin, Chernigovskaya, 1992).

2 The Description of the Model and Some Reflection About "What is the Science?"

Described below model is computer simulation, which is grounded on several known mechanisms of appearance and dissemination of knowledge. In order to verify the model the real data − proceedings of conferences on limnology − was used. All they are kept in the library of Ecological Center of Polish Acad. Sci. in Dzekanov Lesny, Poland, where Vladimir Menshutkin was working during long time. The philosophical basis of the model is Dawkins' approach (Dawkins, 1976) about so called "memes" − the units of cultural transmission. Moreover, some own evaluations concerning auto-canalization of evolution and cognition (Levchenko, 1999, 2003) are taken into account. It is important also to note that we try to define more exactly the term "meme" than Dawkins made that. The "**meme**" means here "teaching informational message of finite length, which is created by some intelligent subject in order to transmit it another intelligent subject" (Levchenko, 2004). The key word here is "teaching" but we will not discuss now the philosophical reasons of such definition because that needs special explanations (see about that the book Levchenko, 2004).

2.1 The Graph of Limnology

The specific peculiarities of computer method force us to subdivide all history of limnology on the multitude of steps. The above limnology proceedings and important

books were used by us in this work (in particular, Forel, 1912; Hutchinson, 1957; Lampert, Sommer, 1997; O'Sullivan, Reynolds C.S., 2001; Rigler, Peters 1998; Wetzel, 2001). At that, every step of history is the appearance of new complex of data and (or) new methods as well as conception; all they are here separated memes. The majority of them can arise only when some sum of other memes already exists. One of attempts to build the limnology history in such context is represented below in the figure 1, where every node of graph is meme. We have introduced 75 memes (m_i), each of which is connected with concrete conception or notion. The criterions for the subdivision are the following ones: 1) any meme must have stable designation, which has to reflect some totality of knowledge; designation can consist of several words and can have several linguistic variations, 2) meme has to have author(s) and time of origin 3) meme must be stably propagated in many limnology publications. For example m_1 − "regime of water level", − implies the description of variations of water level for different lakes at different seasons; m_{14} implies creation of lists of species for macrophyta group (i.e. superior water plants) etc.

Beginning with such approach, some key limnology notions were distinguished as separated memes; there are, for instant, the temperature balance of lake (m_{28}) and conception about "primary production" and productivity (m_{18}). In other words, every meme concerns not only some set of data but implies the using of concrete methods, notions and sometimes even concrete scientific ideology. For example, if to take the above temperature balance then we have for it the following theoretical approaches: radiation balance, albedo, descriptions of the energy consumptions for evaporation and turbulent exchange with atmosphere, methods of measurement of these data and results of these measurements. Similarly, for the meme of primary production we have not only formal definition, but imply the methods of measurements of the corresponding data under concrete conditions in lake (Vinberg, Menshutkin, 1974). The detailed description of every meme of the figure 1 is not possible within a framework of this article, nevertheless note that not all memes are finally yet formed, some of them only begin to be organized in presented graph. There are, for example, the following ones: "optimal management of natural resources of lake" (m_{63}) or "juridical support of preservation and exploitation of lake resources" (m_{73}).

The most of memes, which are included in limnology and compose the continuum of knowledge of this field, are interconnected somehow with each other. With the exception of initial memes (marked by gray color in figure 1), the origin of any meme before the appearance corresponding other ones is impossible. For example, in order to elaborate the water balance approach (m_{27}) it is necessary to know the regularities of the water level regime (m_1). To create a mathematical model of variation of any fish population we need to learn the ichthyology (m_9); the elaboration of bio-manipulation ideas (m_{51}) implies detailed investigation of phyto- and zooplankton interactions (m_{46}) etc.

It is important also to note that we have excluded from the graph of the figure 1 any cyclic interconnections, some of which would be in principle added if to use our not enough rigorous considerations. We have made that just proceeding from general philosophical ideas about human knowledge development. Otherwise, we have to

suppose that "self-generation" of knowledge is possible outside any real surroundings and even without presence of material world. But we traditionally preferred here just materialistic model of our external world, because it is more verifiable and falsifiable one.

Of course, we understand that our considerations about the interactions between different limnology knowledge as well as the scheme of subdivision of all knowledge on fragments are quite subjective. Therefore we ask to be indulgent to this part of our work, all the more the main purpose of the simulation model is not to get exact "photography" of the limnology development but to understand either mechanisms of such development (Levchenko, 1983). Besides, note that creation of like graphs for any science is very laborious business, which is possible only in good specialized libraries (as in Dzekanov Lesny, Poland, in our case).
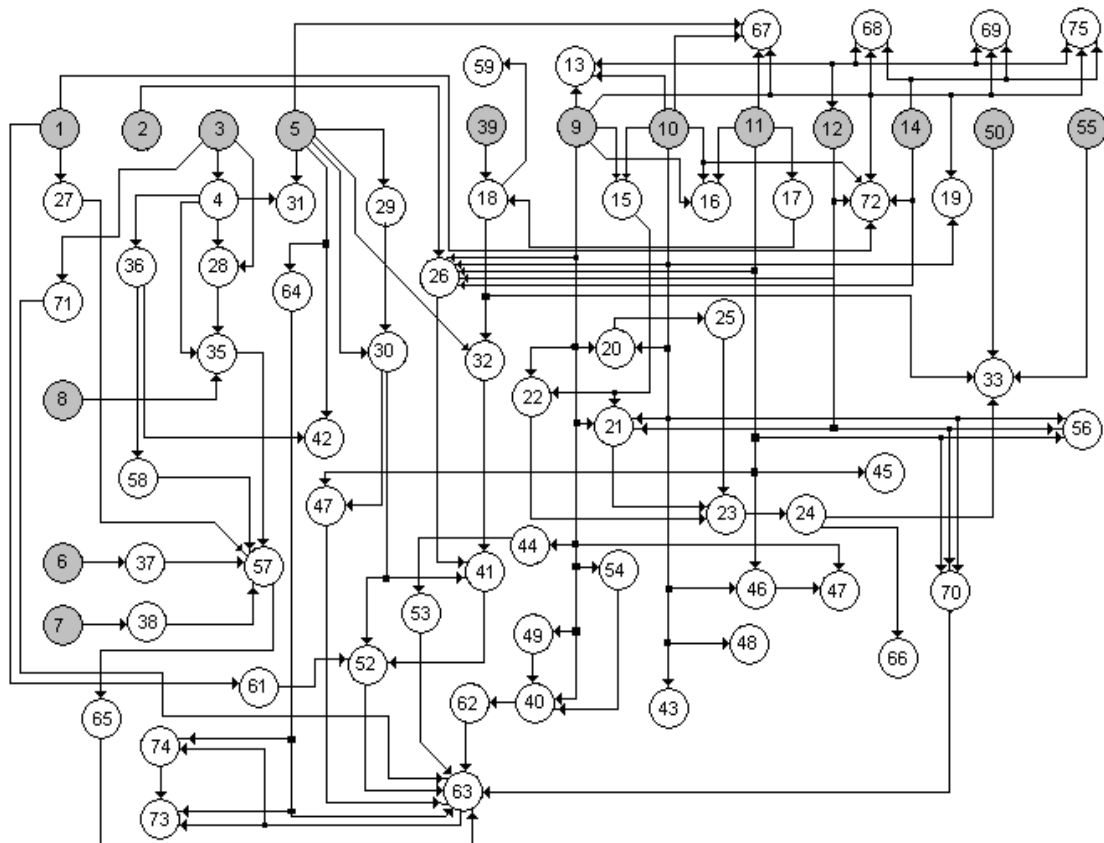

Figure 1: The graph of interactions for informational system of limnology. Principally new conceptions, approaches, i.e. initial memes (within a framework of limnology) are the following: 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 14, 39, 50, 55 – see section 2.1.1.

2.1.1 Description of the figure 1 in detail

The detailed legend of the figure 1 is given below: 1 – regime of the water level, 2 – morphometry of lake, morphometry of depression in the ground, 3 – the temperature

regime, 4 – vertical stratigraphy of lake, 5 – chemical composition of the lake water, 6 – the lake stream conception, 7 – conception about seiches (specific standing wave) and internal waves, 8 – the ice regime of the lake, 9 – list of species of the lake fishes (ichthyology), 10 – list of species of zooplankton, 11 – list of species of phytoplankton, 12 - list of species of benthos, 13 – information about endemic species; information about origin of flora and fauna in the lake, 14 – list of species for macrophyta group, 15 – biomass conception, 16 – trophic levels conception, 17 – photosynthesis in lakes, 18 – the conception about primary productivity, 19 – intensity of respiration for hydrobiontes, 20 – the energy balance of organisms, 21 – food competition interrelations, 22 – predator-pray interrelations, 23 – food (trophic) chains in limnology, 24 – conception of trophic net, trophic web, 25 – the energy and matter flows, 26 – conception about a like as united ecological system, 27 – water balance of lake, 28 – the temperature balance of lake, 29 – theory about that concentration of different biogens influence on primary production, 30 – nitrogen and phosphorus dynamics in the lake ecosystem, 31 – dynamics of water-dissolved oxygen in the lake ecosystem, 32 – conception about "trophic classification" of lakes, 33 – the energy balance of the like ecosystem, 34 – conception about ecosystem balance of biogens (phosphorus, nitrogen and other), 35 – mathematical theory of "terimcs" (i.e. small local excesses of temperature), 36 – conception of turbulent diffusion, 37 – mathematical theory of lake streams, 38 – mathematical theory of seiches (see 7) and internal waves, 39 – physics of the light propagation in water, 40 – mathematical theory of the fish populations, 41 – conception of anthropogenic eutrophication of lake, 42 – conception about sedimentation and the matter exchange between bottom water and reservoir water, 43 – mathematical theory of zooplankton population, 44 –different fish communities, 45 – conception about phytoplankton ecological succession, 46 – phyto- and zooplankton interaction, 47 – conception about "outbreak of numbers" of Cyanophyta, 48 – vertical migration of zooplankton, 49 – reproduction of fishes, 50 –bacteriaplankton and its productivity, 51 – conception of management of the lake bio-resources, 52 – conception of phosphorus load, 53 – the introduction processes of new species in lake ecosystem, 54 – genetic structure of the hydrobiontes populations, 55 – the lake periphyton and its productivity, 56 – spatial distribution of phyto- and zooplankton, 57 – tree-dimensional hydrodynamic model of lake, 58 – experimental investigations of turbulent diffusion in lakes, 59 – productivity of paleolakes, 60 – mathematical model of lake ecosystem, 61 – conception about that like and its water collections contain united system, 62 – optimisation of fishery, 63 – optimisation of use of all resources of like, 64 – investigation of different pollutions of likes, 65 – dissemination of pollutions in the lake ecosystem, 66 – dissemination of radioactive nuclides in lake ecosystem, 67 – distinctive features of saltish and saline lake, 68 – distinctive features of storage pond, 69 – distinctive features of mountain lakes, 70 – biodiversity of lakes and protection of biodiversity, 71 – thermal pollutions of likes, 72 – long time measurements of characters of the lake ecosystems ("data sequences"), 73 – juridical aspects of lake exploration, 74 – economical aspect of lake exploration, 75 – popularization of limnology knowledge.

2.2 Formalization and the Model Description

As a result of our work, we have gotten the graph, which consists of the memes m_i (multitude $M \equiv \{m_i\}$) and oriented connections s_j (multitude $S \equiv \{s_j\}$); all they constitute the oriented graph $\Gamma(M,S)$ – see figure 1. Several memes (nodes, marked by gray color) have no incoming connections and are named as **initial memes** of limnology. They can't be explained within a framework of limnology (remember the theorem of Gödel!). Some of them were known at the beginning of this field i.e. at the end of XIX century and were included in the basis of limnology by Forel (1912).

Any field (L_n) of science ($\{L_n\}$) is developing because new knowledge (including data, conceptions, ideas), are emerging and the net between components of this informational system is becoming more complicated. This is, of course, result of real activity of living scientists but not of some immaterial substance named as "science". In this connection, we insert in the model the simplified description of some abstract scientist. The description includes such character as "memome" – $\{\mu_k\}$, where every binary μ displays the presence ($\mu=1$) or absence ($\mu=0$) of knowledge of a meme with number k. In other words, the **memome** (by analogy with "genome") characterizes scientific baggage of the scientist in some field $L_{n,}$. As we discuss here only limnology we don't introduce additional indexation (the such as $\{\mu_{kn}\}$).

At the beginning of scientific career (we take it as 25 of yang) the most of $\mu_k = 0$, but if the scientist is working diligently and is communicating with colleagues then the situation changes along time and this scientist stays specialist. Any scientist can get only one new meme per the time quantum. In order to outline possible individual ways of development of each scientists, we used above oriented graph $\Gamma(M,S)$. Of course, in reality we suspect beforehand nothing about yet unknown discoveries (memes) but in the case of the simulation we are forced to take already ready scheme of the science development.

The computer experiment began from the loading of some population of yang scientists (i.e. individuals with knowledge of only initial memes) in the "field of possibility", which is predetermined by the graph $\Gamma(M,S)$. Only initial memes exist as already discovered and known ("**public**") in the "scientific world" at the beginning. Each scientist searches own ways of movement along the graph scheme. With some probability $p_1>0$ it can make a **transition** to some new node of the graph, if all public memes, which are necessary for such route, already exist in his memone and in $\Gamma(M,S)$.. If at least one scientist has achieved some new meme, such meme is indicated as existent and public for all scientific community (more exactly, that happens not at once but after some part of all scientists acquirement this meme; the rate of the process depends on the level of communication). We can vary the number of population of scientists, the average period of "scientific life", the level of communication, the probability of transition and some other parameters in every experiment (see below).

It is not difficult to see that we use here the cybernetics ideology of "Artificial life" faculty, including ideas of the fields of "Cellular automates" and "Genetic algorithms" (Neumann, 1966; Mitchell, 1999). If to remember well known in these fields "**Ant**

Task" then one can say that scientists in our model are like peculiar ants, which try to survive in specific surroundings of limnology. Some other ideas and methods, which were used by us in this simulation, are described in our publications about computer models of biological evolution (Levchenko, Menshutkin, 1987; Levchenko, Menshutkin, Tsendina, 1988; Menshutkin, Aschepkova, 1988; Levchenko, 1993, 2004; Levchenko, Menshutkin, 2006).

Louis Legendre in his work (2004) discussed two mechanisms of scientific discovery. The way, which was briefly described above, conforms to the first of them. But before to turn to the second mechanism, it is else important to consider algorithmic realization of above case more in detail. In Legendre' view this first way is simply mechanical addition (with some probability) of new data and conceptions to already existent "scientific construction" within a framework of present paradigms. In Dawkins' language the same means that new memes arise along scientific development because each scientist combines new and known data and conceptions in order to fill up empty positions in "puzzle" of existent scientific field L_n (Levchenko, 1993). For example, the making of the discussion paragraph for the article about some new results can be sometimes suitable illustration of such process.

In order to realize this mechanism of scientific discoveries, two blocks of the simulation program are used. At the functioning of the first of them, the random selection of any unknown, not yet public meme − "potential discovery" − is accomplished. The search is going among memes which are possible according to graph $\Gamma(M,S)$. Special generator of random numbers is used for that in the program. After the selection of not public yet meme, it is examined on the practicability. For example, the creation of m_{33} (scheme of energy flows in the lake ecosystem, balance of energy) isn't possible before elaboration of the conception of primary production of organic matter by photosynthetic organisms (m_{18}), as well as before development of the ecological conception concerning different trophic levels (see figure 1). Similarly, the appearance of meme m_{57} (tree-dimensional hydrodynamic model of lake) isn't possible without not only knowledge about lake streams, temperature variations etc, but also before sixties of XX century because efficient computing instruments don't exist yet (special simple control on technical feasibility is introduced in the simulation too).

In order that potential discovery comes to be, it is important also to find at least one scientist who possesses memome which is necessary for that. The search of suitable scientist is accomplished by second block. The memome of such scientist must contain all memes which are needed for the discovery (see graph $\Gamma(M,S)$). If the search is successful then the discovery is declared as taken place and new limnology public meme arises (that happens not at once − see above). The corresponding scientist obtains recognition as "limnology pioneer".

Thus, the first mechanism works by the following way: when all necessary for discovery memes stands to be known and public ones (in other words the conditions of surroundings are appropriate) and when some suitable scientist, who has proper qualification, exist, then the discovery can be made.

The second mechanism of scientific discoveries is connected with scientific intuition, insight (Legendre, 2004). In this case, the investigator attempts to extrapolate own

knowledge into not enough known fields of studies. Such extrapolation isn't simple mechanical addition of new data as well as of sequent conclusions to empty positions in existent scientific construction, but this is just the building of new construction. In real situation, this means the creation of new meme(s) for given scientific field, when multitude of existent memes is not enough in order to make discovery with the aid of the first mechanism. This way can be possible when some scientist has intuitive knowledge, which is more comprehensive, then actual "scientific environment" can grant to him. In fact, this is consequence of just **anticipatory activity** of ingenious scientists in contrast to the first mechanism where by "trial and error" i.e. "**robotic**" method is applied.

In the simulation such mechanism can be described as several steps. At the beginning, we choose at random some qualified scientist who is able to jump over to either node, which is inaccessible if to use the first mechanism. We suppose that can be with some probability $p_2=<p_1$ when memome of this scientist as well as $\Gamma(M,S)$ don't contain any one public meme. In principle, we could presume that is also possible if there are absent several public memes but then the probability is too small, therefore we don't take into account such cases. After the suitable scientist has found the additional examination on feasibility of discovery (for example, the presence of powerful computers in given time) is accomplished. As above, if all necessary conditions are satisfied then new meme (discovery) is declared as taken place.

Thus, two mechanisms of scientific discoveries − "anticipatory" and not anticipatory ones − are included in this model. Several additional parameters, in particular the life time of scientist are used in the simulation too. We assume that probability of death for individuals permanently increases along age if it is higher of 40; the memome of deceased scientist has disappeared.

The simulation program is realized in Visual Basic 6.0 language, the experiments were made in personal computer with AMD Sempron (tm) processor at 1.66 MHz frequency.

3 Some Results of Modeling and Discussion

The model experiments were made for the period of 1900 to 2000. Twenty limnologists of $25 − 50$ years are defined at initial stage of the simulation; their knowledge corresponds to the beginning of XX century and has totally 16 memes. There are taxonomy of different water organisms, descriptive data on the lake hydrology and hydrochemistry.

The typical results of the functioning of the model are given on the figure 2. As all processes of development, including the increase of informational capacity of limnology (M) and variations of the number of limnologists (N), have stochastic character (because we used the generators of random numbers), we apply Monte-Carlo method and give here the multitude of separated realizations. We tried to make up to 1000 realizations under equal initial parameters in our first experiments. But results have demonstrated that in order to provide some relative stable image, which the figure 2 illustrates, it is enough less then 100 realizations.
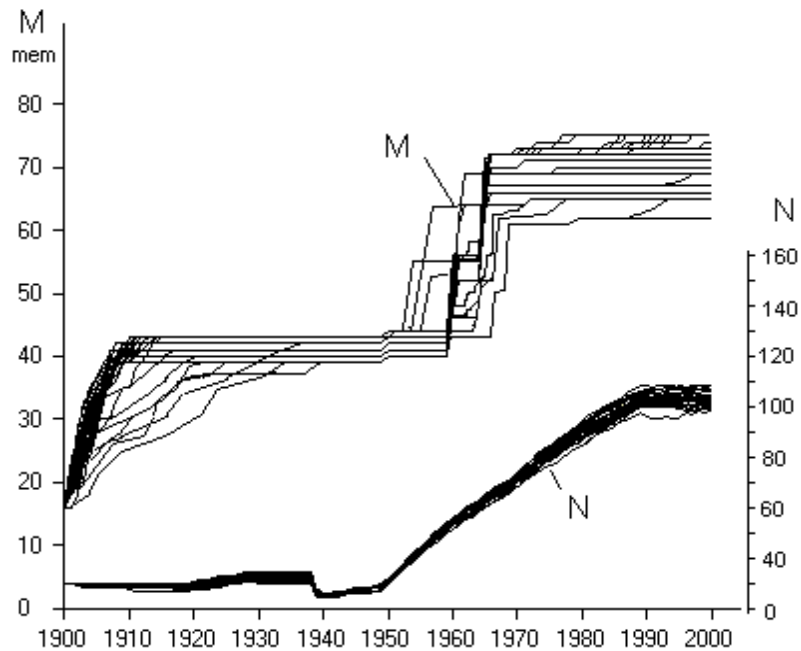
Figure 2: Increasing of informational capacity of limnology (M) and variations of number of limnologists (N). The results of 30 realizations are given. The probabilities of transitions and jumps p_1=p_2=0.02 per scientist per year. The probability to acquirement any new meme ("level of education") e=0.01 per scientist per year.

One of general regularities, which we found, is irregularity of the limnology development. The first tens of XX century can be characterized as the period of quite fast accumulation of new information, but visible stagnation arises later. At the $60 - 70^{th}$ of XX the development accelerated again but some deceleration occurs at the end of century. Such oscillations are connected not only with external factors (as, for instant, World War II that was considered in the model), but also with the nature of the science as such. We come to this conclusion because the control experiment with "calm" conditions and uniform receipt of young scientists has demonstrated qualitatively like irregularity of the limnology development.

The figure 3 gives the image of changes of level of the limnology development. It demonstrates the dependences of informational capacity of limnology (M) on the average life time of scientists (T). The simulation was made for the period $1900 - 2000$ years under verisimilar conditions (i.e. the such which give the image of the limnology development as we had in reality). One can see that if we abridge T less than 40 years then M is essentially declined.

This interesting result illustrates the fact about significance of presence of experienced scientists in any scientific community. For example, if limnologists interrupt to work after 30 years of age then the limnology has the level of the first half of XX century (i.e. when conception of primary production still arises). Another conclusion from this dependence is the genuine "scientific youth" of scientist begins only after 40, so science couldn't develop effectively when the life time of men was too

short. This comes to idea about unknown yet kinds of human activity which request more prolonged average life time than it is now.
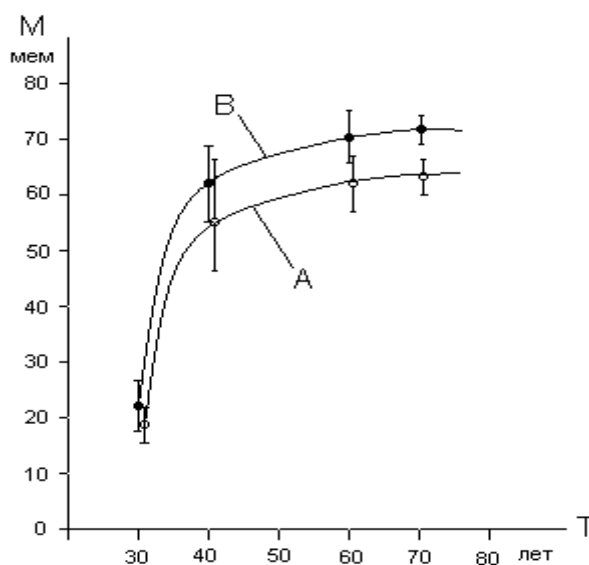

Figure 3: The dependences of informational capacity of limnology (M) on the average life time of scientists (T) for 2000 year. The curve A: $p_2=0$ (only "robotic" way to make discoveries), the curve B: $p_1=0$ (only "anticipatory" way to make discoveries).

The dependences of informational capacity of limnology for 2000 year on probabilities p_1 and p_2, which describe the possibility to make discovery, are given in the figure 4. The growth of M with these probabilities isn't surprise but here is more interesting irregular character of such increasing. We can see that high probabilities are not so effective as it could be if the rise is simply proportional. We suggest this deceleration is consequence of not enough fast rate of dissemination of new memes among scientists. This result, which was checked up several simulation experiments, displays also that even large group of genius scientists are not able to accelerate greatly the development of science. In other words, the science is united system but not mechanical sum of separated attainments. Nevertheless, it is interesting that the "anticipatory" mechanism (we believe that is more appropriate for genius) works more effectively on average then by "trial and error" one.

The figure 5 displays the important role of the scientific information exchange among scientists as well the significance of education in the case of young scientists. The displayed curves demonstrate as M increases irregularity with the growth of probability **e**, which describes the possibility to acquirement new memes (in particular, the value **e** characterizes the level of scientific communication – see also figure 2 and above). If **e** is small (for instant, all scientists speak in different languages) then the development of science depends strongly on not so modern but in general ancient discoveries because new memes are not accessible for the most of members of the community. When the probability **e** achieves some critical quantity (about 0.2 per

scientist per year in our simulation) then the rate of scientific development begins to depend in general on only other factors.
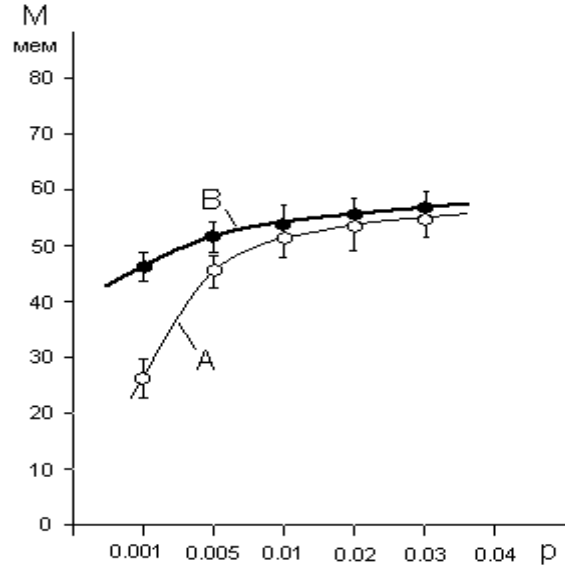

Figure 4: The dependences of informational capacity of limnology (M) on probabilities p_1 and p_2 for 2000 year. The curve A: $p_2=0$ (only "robotic" way to make discoveries), the curve B: $p_1=0$ (only "anticipatory" way to make discoveries).
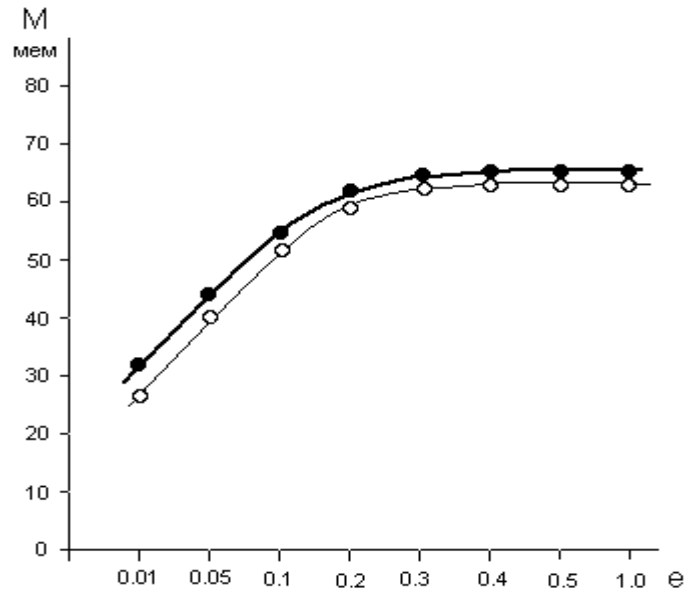

Figure 5: The dependences of informational capacity of limnology (M) on probabilities **e**, which describes the possibility to acquirement new memes. The curve A: $p_2=0$ (only "robotic" way to make discoveries), the curve B: $p_1=0$ (only "anticipatory" way to make discoveries).

4 Conclusions

Thus, our experience to build the model of the science development demonstrates that is in principle possible and the results of such modeling can be verified on the basis of real scientific fields (limnology in this case). We reveal in our computer experiments the following regularities, some of which were described before us only in philosophical works:

1) at least, two mechanisms of scientific discovery exists: by "trial and error" method and "anticipatory" one, which is based on intuition and possibility to forecast;

2) the rate of scientific development depends on the probability to acquirement new knowledge by both of above mechanisms;

3) the "anticipatory" mechanism is more effective and allows to get principally new knowledge;

4) the rate of scientific development depends strongly on the level of scientific communications;

5) the "scientific age" for effective scientific activity begins after approximately 40 years old and has no any restrictions, except for the biological life time of scientist;

6) any field of science is open informational system, which is using advances of other fields, but which is developing within itself with own specific regularities.

We understand perfectly the conventional character of our results but suggest they can help to clear up better what is the human knowledge and how it is accrued together with the development of civilization.

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