From Tsetlin's School of Learning Automata towards Artificial Intelligence

V. L. Stefanuk[a,*]

[a] *Institute for Information Transmission Problems of the Russian Academy of Sciences (Kharkevich Institute), Moscow, 127051 Russian Federation*

**e-mail: stefanuk@iitp.ru*

Abstract—Though there is a widely spread opinion that Artificial Intelligence had been formulated as an independent science first of all in the United States, where it was supported with computer science, the present paper demonstrates that in Russia, AI development went through the study of some fundamental questions underlying intelligent activity applicable to various scientific and technical fields such as biology, engineering, linguistics, probability, control theory, and many others. The high scientific level of the school of Professor Mikhail Tsetlin is illustrated below via three important problems that confirm the role and the quality of his school at the Lomonosov Moscow State University, aimed towards development creative abilities among students, permitting them to formulate new and extremely promising tasks as a result of their intensive discussion in the main seminars of this school.

Keywords: Mikhail Tsetlin's School, Automata Theory Seminar, artificial intelligence, cybernetics, learning machines, collectives of automata, wideband wireless communication, semiotic introspection, abduction, creative problem solving semiotic introspection principle, 3D problem

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1. ARTIFICIAL INTELLIGENCE AS THE SUBJECT OF SCIENCE

As Artificial Intelligence strictly followed in time the science of Cybernetics, the connection of these two disciplines has remained rather strong. And that is not surprising, as nearly all the famous AI specialists came to AI from some cybernetic field. Essentially, Artificial Intelligence was born inside the framework of Cybernetics and it has become an independent science, when that framework turned out to be too restrictive.

Most scientists easily accepted the new scientific paradigm, which was called either machine intelligence or artificial intelligence, viewing it as a symbol of a new scientific direction. It was more difficult with its content: the so-called *computer metaphor* from the very start began to play a serious role in AI than in cybernetics, where computers were only one of many useful tools. Moreover, AI itself in the West was considered to be a part of Computer Science. Actually, in the United States, Cybernetics began to lose its authority. However, in our country Academician Axel Ivanovitch Berg, Chairman of the Council on Cybernetics, immediately supported the new scientific direction, in fact leading it. I then repeatedly had to explain to perplexed Americans that in our country, unlike the United States, there is no conflict at all between cybernetics and artificial intelligence.

Thus, the process of changing the scientific paradigm in Soviet Union scientific environment proceeded quite gently and naturally.

Artificial intelligence has been known to have periods of steep ascents and the deepest crises. Along with the emergence of new bright intelligence products, nowadays related to the use of neuro-like AI systems, today is not the best period for this field, aggravated by a serious complication of the world political situation.

I will mention just one of the many reasons for concerning the future of AI, which seems to me to be essential and, most importantly, closely related to the topic of my notes. I mean a change of generations involved in AI. On the international arena, new bright figures have not yet emerged comparable to John McCarthy, Marvin Minsky, Allen Newell, Herbert Simon and other stars. Their mere presence at any conference radically changed the scientific atmosphere and mood of the participants. Previously, at an IJCAI International Conference, remarkable Prof. John McCarthy literally ran onto the stage and began writing something quickly on the blackboard. The audience felt silent and watched intently. And after a short time, new scientific publications on AI appeared, in which some of John's ideas were developed.

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It should be noted that in the international community, as well as in ours, the "sense of community" had not yet been developed, the feeling of belonging of scientists to a single guild, which at one time forced M. Minsky and J. McCarthy to urgently fly from the United States to Europe and appear on television there in defense of Donald Mickey and the entire Machine Intelligence movement in Scotland from a dangerous attack on this scientific field in Great Britain after the publication of the critical "Lighthill Report" by the famous physicist and Nobel Laureate. Subsequently, I was sent a film from the United States with a recording of the TV debates, which I showed at the General Meeting of the Academy of Sciences, where a discussion of the situation took place at that time.

Without looking back, it is impossible to count with certainty on a successful future. In the notes below, we will try to briefly show how the formation of Artificial Intelligence proceeded in our country, since much happened before the eyes of the author and with his direct participation. Something may seem unknown or unexpected to the reader, as a certain element of drama, or, as they now say, intrigue, is contained in my notes. At the end, the processes of the formation of a new science that I am describing, are quite universal, and specific participants acting in the corresponding historical settings are making them bright and purely individual as they "are coloring" the processes by their personal activity, and thus making them bright and purely individual.

By the way, at a recent traditional summer school on Artificial Intelligence, organized by the Russian Association for Artificial Intelligence (RAAI) in Sochi, from conversations with a group of young students and postgraduates, it became clear, that they all liked my speeches at this school, and they asked me to publish what I had said there.

As Yuri Lotman wrote, "History reflected in one person, in his life, everyday life, gesture, is isomorphic to the history of mankind. They are reflected in each other, and are known through each other."

In any case, the author publishes the present notes in the hope that the description of some of the events of the past will help someone make the right choice today, half a century later.

2. TSETLIN'S SEMINAR ON THE THEORY OF AUTOMATA

My path to Artificial Intelligence was largely predetermined by the scientific and life school that I went through with Mikhail L'vovich Tsetlin, a talented mathematician and practitioner, an original scientist, Professor at the Lomonosov Moscow State University, and a leading researcher at the IPM of the Academy of Sciences, at his seminar "Theory of Automata." In this school, my interests were finally polished and consolidated, and my style of work was formed. I will always be grateful to my teachers for this, and first of all, to Professor Mikhail L'vovich Tsetlin.

I began to design my *Learning Machine*, which will be discussed below, as an "experienced electronics engineer" at the Faculty of Physics of the Lomonosov Moscow State University in my second year of the study there, that is, in 1957. The idea of the possibility of creating such a machine, in the development of the then already known machine of V. Buylov, was expressed by M.L. Tsetlin at one of the first seminars on the Theory of Automata, which the Professor organized at the Faculty of Physics of the Lomonosov Moscow State University.

When I said at the next meeting of the seminar that I knew how such a machine could be built, Mikhail L'vovich invited me to the blackboard, listened to my description of the machine project, organized a broad discussion among the participants of the seminar and as a result concluded: "You need to solder this!"

The fact is that with the introduction of computers, it has become a tradition to write a program that works as it was planned. In those years, however, the word "soldering" meant that the machine had to be built as an autonomous physical device that could be shown to people, allowing them to press the punishment and reward buttons to achieve the desired result at the output of the machine.

By the way, it should be noted that in the United States, some new universities had recently appeared, where the students learned to create physical devices by arranging the individual parts on a special plastic carrier, connecting them to each other in the desired way. Programming is used there only at the stage of thinking through the scheme of the future device.

In fact, Tsetlin's seminar was not limited only to the theory of automata. It considered a variety of tasks from Cybernetics, the science which had recently has been "legalized" in the Soviet Union. We also listened to genetics, which was told to us by a specialist from this new field for all of us. Subsequently, A.V. Butrimenko and I had to determine for ourselves what the nature of this seminar was, since we had to continue the seminar further, unfortunately without Professor Tsetlin. The only reasonable conclusion we came to was that "almost anything" deserves discussion at the seminar, if only the material presented was interesting and the speaker was experienced.

However, in the very first years of the seminar in question, Mikhail L'vovich was quite strict about the topic and nature of the seminar. Most often, he gave lecture series himself, assigning homework, as he said, home exercises. At that time, I happened to listen to lectures on the matrix method of synthesis of relay-contact circuits (I did not know that Mikhail L'vovich told us the content of his own Candidate's dissertation).

These lectures alternated with talks by Mikhail L'vovich's colleagues, his graduate students, and new students. There were lectures on genetics given by

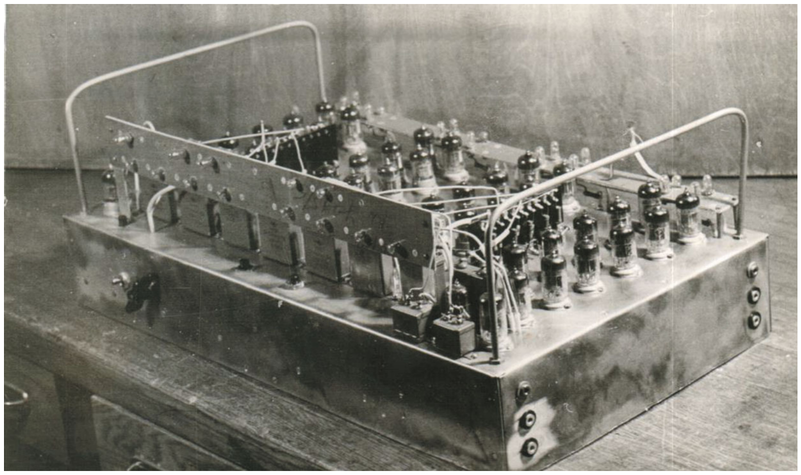

Fig. 1. Vadim Stefanuk's learning machine.

Y.M. Romanovsky; there were many different short reports. Vladimir Buylov once told me about the so-called learning machine that he created at the Department of Physics of Oscillations of the Faculty of Physics in Lomonosov Moscow State University, where I also studied. Buylov's scientific advisor, Mikhail L'vovich Lvovitch Tsetlin, has told about this machine something like this: "Imagine a box with one input bus and one output bus. Each bus has a neon light that can either glow or not. The box has two buttons: a reward button and a punishment button."

At the same time, M.L. Tsetlin spoke about the mathematical formulation of the problem of the behavior of a finite state machine placed in a probabilistic-reactive medium, describing in detail the complex mathematical apparatus he used [15]. As a matter of fact, Buylov was then making an electronic model of this automaton, where the role of the environment in which such an automaton was immersed was implemented by the experimenter himself.

But from the technical point of view, it can be said that Buylov's model implemented a differential counter based on tube triggers and logic circuits based on semiconductor diodes, which was part of a series of lectures on the synthesis of relay-contact circuits, where Mikhail L'vovich without any pauses moved from perfect disjunctive forms to matrices, Markov circuits, and logic circuits based on diodes and resistors. Home exercises were usually formulated in the "everyday" language for which Mikhail L'vovich was famous: "Imagine a communal apartment where the doors of the rooms open onto a common corridor. In the middle of the corridor is an electric light bulb. To save electricity, you need to make sure that everyone can turn on the lights when going out into the hallway or coming in from the street and turn off the lights in the hallway when entering their room. Please draw an appropriate diagram of the operation of the switches, but in such a way that there are few wires used."

Home exercises were checked, and those who completed the task were usually invited to the blackboard with a story.

3. THE LEARNING MACHINE OF V.L. STEFANUK AND THE PROBLEM OF COLLECTIVE BEHAVIOR OF AUTOMATA

In the same simple way, it was proposed to the audience to think over a learning machine, in which, in comparison with the previous machine of Buylov, there should be two input buses and two output buses. Now, it was required that each bus already had two neon lights, and that it should be possible to teach this box to light a certain combination of these lights on the output buses in response to each combination of {00, 01, 10, 11} on the input bus.

As at the next seminar I said that I know how to build such a new machine, I was naturally invited to the blackboard to demonstrate my construction and explain how it should operate (Fig. 1).

I still remember that I had a hard time as the Professor required me to give the proof at the blackboard that my machine will do what was planned.

Probably, I had proved that everything was OK with the construction as, after a long discussion at the blackboard at the seminar on the theory of automata, it was proposed by Tsetlin that I have to "solder it"; I asked Mikhail L'vovich to provide me with someone to help me in starting the work on the creation of such a device, since according to my calculations, it was necessary to make 55 big round holes on a large sheet of aluminum metal for vacuum tubes of that time, as I remember now, they were 6N1P double triodes.

Yurii Kryukov and another young participant of our seminar played an important role as an assistant, while I hide myself in a remote place in University, far from the place of the seminar, in order to avoid hearing the terrible sounds of punching holes in an aluminum

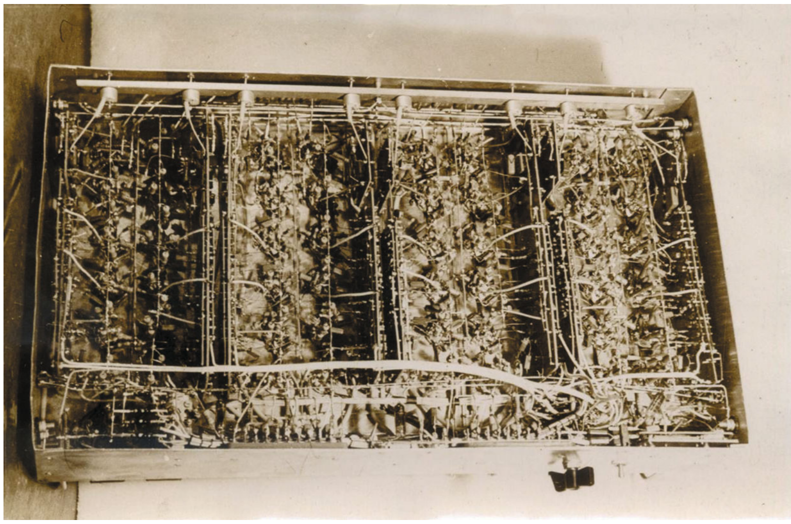

Fig. 2. Electronic content of V. Stefanuk's learning machine.

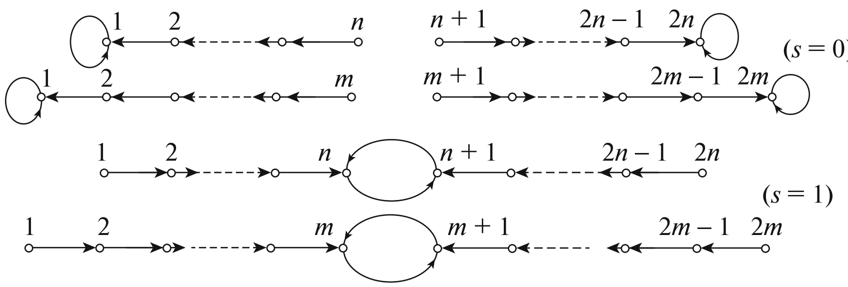

Fig. 3. State transitions for a couple of simultaneously running automata in the general case.

sheet using an impact punch and a heavy hammer, with which I supplied my kind assistants.

After several years of efforts my machine was finally built by myself. Its general view is shown in Fig. 1.

According to the photo shown in Fig. 2, it can be seen that my learning machine consisted of four parts that are quite similar in design, because each part supports the operation of two separate Tsetlin automata with linear tactics [15], but learning together, i.e., receiving punishments and rewards simultaneously until one of the user-required output values {00, 01, 10, 11} is reached.

According to the photo shown as Fig. 3, it can be seen that my learning machine consists of four distinct parts that are similar in design, which is quite reasonable, because each of these parts consists of two separate M.L. Tsetlin automata with linear tactics, which learn together, i.e., they receive punishments and rewards at the same time until one of the user's required output values {00, 01, 10, 11} is reached, as show in Fig. 3.

In papers [6, 10], by analyzing a two-dimensional Markov chain, it was found under what conditions successful training of such a pair of automata is achieved.

4. GENERAL ATMOSPHERE OF TSETLIN'S SEMINAR

The fact is that neither of my assistant students came to the next seminar by Tsetlin. I was very upset, thinking that it was my fault for forcing the guys to punch a lot of round holes for the vacuum tubes of my future learning machine, and I told Mikhail L'vovich about my anxiety. He reacted to this quite calmly. And he was right. In fact, one of these assistants, Yurii Kryukov, came to the next seminar and became a very close friend and colleague of mine. However, my second assistant somehow disappeared....

Although I was an experienced radio amateur, the learning machine turned out to be quite complicated, and it took several years for me to build and debug it. It contained more than fifty vacuum tubes and a great number of logic circuits based on silicon semiconductors, which had just appeared at that time.

The fact is that the standard germanium used have been working unreliably, since the machine became very hot during its operation, despite the fact that it was blown by several fans at once. There were no silicon diodes on sale at that time. Yet, completely unfamiliar people constantly came to my laboratory, and in paper bags, like candies, they brought from somewhere unsoldered silicon diodes "with twisted legs" (see Fig. 2).

That process was obviously organized by my Professor Mikhail Tsetlin, who had many colleagues outside the Lomonosov Moscow State University.

In addition to what was in Buylov's machine, there were several pairs of additional blocks in my design: memory and chance. As for the rest, everything that was in Buylov's learning machine, whose design seemed perfect to me, was copied into my device with minor changes. Though in my case everything had grown a lot in quantity (look again at Figs. 1, 2).

My learning machine was finally "soldered" and tested in operation at the demonstrations attended with my university classmates from other departments of the Lomonosov Moscow State University.

But, strangely as it may seems, my machine was not demonstrated at the defense of my graduate thesis [10], but was only mentioned by the head of the department, the chairman of the diploma commission Professor K.F. Teodorchik. Probably, because it was believed that everyone had the opportunity to practically get acquainted with my Learning Machine in the laboratory at the Department of Physics of Oscillations, where it was designed and widely demonstrated.

The main fundamental content of my Lomonosov Moscow State University diploma was my own mathematical model of the collective behavior of a pair of automata (Fig. 3), which was born from the observation of the work of my learning machine that was essentially the next generation of learning devices proposed and built by myself.

The fact is that when my seemingly well-thought-out machine began to work, I, as its author, doubted the possibility of training it. I noticed that by pressing the punishment button, I was actually simultaneously punishing a pair of Tsetlin's automatons with linear tactics [15], one of which may have already performed the action required of it, and the other had not. As a result, the automaton that did what it was supposed to do could change its action to the wrong one, and the learning process might never be completed.

I was urgently engaged in theoretical research despite the fact that my diploma presentation was approaching. I had obtained an important result that successful learning is not always possible, but only under certain conditions imposed on the learning environment, which with some probabilities punished or rewarded the automata for their actions. For the theoretical analysis, we had to use the methods of studying Markov finite circuits, which we were taught at the seminar on the theory of automata, i.e., in the Tsetlin School. However, the Markov chain in my case was two-dimensional and the analysis turned out to be very, very cumbersome, but it led me to a solution, which I showed to Mikhail L'vovich, and the latter recommended that I publish the result in the form of an article in the journal *Avtomatika i Telemekhanika*. This is how the very first publication on the collective behavior of automata learners appeared [6], although I already received the diploma of a graduate in Moscow State University with this result back in 1961.

5. COMPLETELY WIRELESS MOBILE COMMUNICATION

Being a radio amateur in the past, and then a graduate of the Department of Radiophysics of the Faculty of Physics of Lomonosov Moscow State University, I naturally came to the idea of using a team of automata to simulate the communication system of radio stations. That is, I began to think about what later (in the 1980s) came to be called mobile or set communication. This also happened in the course of training under the guidance of Tsetlin.

At first, I inquired in the relevant department of the IITP AS what communication systems existed at that time, and I found that even in important government spheres, the simple wire communication reigned supreme. Radio communication, if it appeared at all, was in the form of an individual connection of two speakers, in relation to which a very inconvenient preliminary agreement had to be made in terms of frequencies and the time of contact.

True, in the Soviet Union quite a long time ago a successful attempt was made [2] to go beyond these restrictions, as the world's first so-called half-wireless automatic communication system was created, when a radio connection was established with the nearest switching center of an ordinary city telephone exchange, and, afterwards, this station provided contact with the called subscriber through the same station, connecting with him again by radio net [2]. At present, this communication system is described in detail on the Internet, its authors and creators are well known, although there were attempts by Bulgarian specialists to challenge the "palm of victory," declaring their priority for such a communication system.

Taking into account the obvious shortcomings of Kupriyanovich's system [2], it became clear to me that it was necessary to build a full wireless communication, on the basis of our model of a team of radio stations, instead of a team of finite state machines, as before. I described the principles of my model of a team of radio stations to Mikhail L'vovich Tsetlin as a conversation between several comrades at a friendly table, when unstable communication may arise, since the speakers in one pair disturb all the other interlocutors at such a table with their private conversation.

In my publications [7–13] a mathematical description of all the processes that arise here is given, and all the necessary solutions are found. What makes my mathematics and my results particularly original is that I have chosen the signal-to-noise ratio as the criterion for the operation of each radio station, rather than the criteria used in classical or Shannonian information theory, such as bandwidth, error probability, types of coding, and the like, which, as I have shown, are not at all suitable for the work of my radio station collective.

Let me remind you that at the IITP Institute of the USSR Academy of Sciences, all the work that preceded my mobile system was carried out within the framework of the Shannon theory of communication, as it has been so far, and apparently that is why my publications and numerous reports did not attract the attention they deserved (see details below).

Unfortunately, at that time Mikhail L'vovich became very ill and was taken to the hospital of the Academy of Sciences. So, my dissertation [10] was defended under the guidance of the famous mathematician Sergei Vasil'evich Fomin, who kindly agreed to temporarily replace my head of the postgraduate program, dear Professor Tsetlin.

Nevertheless, I published one of the very first papers as a joint article with Tsetlin, who prematurely passed away. Indeed, it was Mikhail L'vovich who, from the very beginning, warmly supported my idea of a team of radio stations and asked me to speed up the research. My friends told me, for example, that the day after my conversation with the hospital on the phone, Mikhail L'vovich was already telling someone how the tankers, having my system of radio stations, could agree on joint actions during a combat attack. I was very glad to learn about this, because the opinion of Tsetlin was the main thing for me, if not decisive.

Without going into details, I would like to note that my mobile communication model has both ardent supporters (Prof. M.L. Tsetlin, Academician S.K. Korovin, Academician K.V. Rudakov, Prof. N.N. Chentsov) and some opponents (S.I. Gelfand, General Zakharov, V.K. Zyablov, V.M. Vishnevsky, R.L.Dobrushin). The latter group turned out to be more active, contributing as much as possible to the fact that my system and its ideas were not only not implemented, but were generally hidden from a wide audience, although I regularly spoke about my communication scheme at conferences and seminars.

Some specialists from Princeton then working at Purdue University in the United States, produced, in fact, just unfair copies of my publications as they did not bother to cite my name in their book. This is not fair of course, but from the other side, it only proves that my approach was unique for communication, being, however, described in my publications in the Russian Federation and abroad that were issued several decades before the appearance of their book.

Let me remind you that in 1966 the Moscow Institute of Physics and Technology (MIPT), one of the main suppliers of modern personnel working on communication systems at the IITP, refused to accept my dissertation for considering without any reason. However, a year later, I successfully defended this Candidate's dissertation in the Institute of Control Sciences (ICS RAS), the central journal of which was recommended to me for my publications by Mikhail L'vovich Tsetlin.

As you know, silence is one of the powerful methods of dealing with everything new, allowing you to then smoothly move on to the stage of plagiarism (i.e., borrowing other people's ideas and results), which later almost happened in my case.

For example, some officials of Purdue University in the United States, did not bother with complex modifications of my papers. They simply made a copy of our papers [8, 9] and others, without any references to our research that had been carried out many decades earlier (starting from 1967), i.e., from the time when there was not even an idea of any fully available mobile communication in the scientific literature.

The initial silencing of my research on mobile communication lasted for about ten years after 1967, until the Management of the Motorola Company (United States) visited Moscow, possibly because I made presentations abroad on the then new (wireless mobile) communication system at MIT (United States), at the University of Texas (United States), and at the University of Paris 6 (France).

The Motorola company released a button mobile phone about ten years after our meeting in Moscow. My explanation for their long delay is the persistent, albeit unsuccessful, attempts to challenge my original proposal to use the principle of adjustment of power and other elements of my invention, which were based on my researches of the collective behavior of learning devices [12], that I have proposed, thanks to pretraining at the Tsetlin School, which has provided the listeners with many ways for creatively solving a variety of problems.

I will now describe one of the difficult but interesting problems in the field of creative solutions in a little more detail, to make it clear what I am talking about.

6. CREATIVE PROBLEM SOLVING

In one of his most recent publications [4], Professor J. McCarthy from Stanford University, United States, expressed creativity this way: "A solution to a problem is creative if it involves concepts not present in the statement of the problem and the general knowledge surrunding it."

This definition of creative problem solving is taken from his article "Tough Nut problem," where John McCarthy gives three options for how Tough Nut can be solved successfully. One of the options was my set of a number of useful new ideas to solve the problem, that I passed on to McCarthy during my visit to Stanford University on his invitation.

6.1. Creative Solution of Combinatorial Problems

In general, when people reason about creative problem solving, they often mean insight, or "the mystical power of guesswork," which is mentioned in one way or another in many sources (Finn [1], Vagin [16]). In discussing whether it is possible to reduce the "level of mysticism," scientists most often resort to the following approaches, quite famous in Artificial Intelligence:

Induction is the reasoning from the particular to the general.

Deduction is the reasoning from the general to the particular.

Abduction is the reasoning from the particular problem formulation to another formulation.

In my paper [12] it is shown that the choice of another problem representation, when it is difficult to solve the task directly [13], can serve as a basis for a creative solution, i.e., a solution that does not necessary follow from prior knowledge of the field to which the problem belongs. I believe that the choice of a new representation of the problem is just one of the examples of abduction [1, 16], which is used when an immediate logical solution is not seen. For the sake of explanation, we present below a separate example of a creative solution to a problem from the author's practice, a solution whose origin could not have been foreseen in advance.

In order to systematically select a "good" representation for some combinatorial problem, we proposed to use a heuristic, which we call the principle of semiotic introspection (SIP) [12]. Its use is contrasted in [12] with other methods of finding creative solutions.

The usefulness of SIP is demonstrated in [12, 13] by examples that are in one way or another related to the Tough Nut problem, which drew a special attention of specialists in the field of Artificial Intelligence [3]. A number of scientists have mentioned this problem, and shortly before his tragic death, John McCarthy himself had returned to it.

At the end of the present chapter, we show a spatial (3D) problem, where the application of the principle of semiotic introspection (SIP) leads to a new representation of the problem that is initially not obvious at all, from which the problem solution follows immediately. We believe that combining the SIP heuristic with the traditional GPS heuristic of Artificial Intelligence allows us to expect serious advances in solving a variety of intellectual tasks within the framework of AI.

6.2 The Choice of Representation for our 3D Problem

In collection [5] it was proved that a cube of size $6 \times 6 \times 6$ cannot be built from identical bricks of size $1 \times 2 \times 4$. The proof given in [5] for the three-dimensional problem is provided in about two book's pages. To do this, the cube was previously colored by the authors of book [5] in a checkerboard manner, since the authors have tried to solve this problem by analogy with the Tough Nut problem, using the concept of an invariant. However, the solution obtained in this way had led to a rather cumbersome combinatorial problem, since the checkerboard representation, which was quite adequate in the 2D Tough Nut problem, was not suitable at all in the case of 3D version.

We will show that in the three-dimensional version it is necessary to use the principle of semiotic introspection (SIP) that was proposed in [12], which is formulated as follows: "One should try to call similar things by a common name, and for things that differ from them other names should be used," which helps in solving some problems. This principle is certainly applicable in the problems being described in [12], as I once had informed Prof. John McCarthy during one of my visits to his lab.

The purpose of current section of the present article is to show that a suitable insight can be actually found, using our principle of semiotic introspection SIP. For clarity, the main stages will be illustrated with help of several figures demonstrating the change of the problem representation. In this connection, let us recall that changing the representation of the problem is precisely an abductive step.

Let us start with the remark that each brick, as a spatial orthogon [11], in its successful three-dimensional placement in the original cube, must be oriented in such a way that its faces are in parallel to the faces of the original cube. Hence, the geometrical position of all the faces of the bricks in any successful placement might be shown in the following Fig. 4 if, of course, such a placement is always possible; that, however, we have yet to verify by confirming or refuting such a possibility.

From Fig. 4, one can see that each brick necessarily encompasses eight adjacent "microcubes." All that remains for us to do, is to apply our principle of semiotic introspection SIP [12] to give similar microcubes the same names, and provide different names to different microcubes.

The similarity is determined by how we try to arrange the first and the rest of the bricks in the hope that the original large cube can be folded as a tight combination of bricks, i.e., without gaps or brick protrusions.

Consider three important shapes: the original cube, the $1 \times 1 \times 1$ microcubes, and the $2 \times 2 \times 2$ cubes made up of them.

1. Let us start placing a brick at the center of the original cube and give the central parallelogram $1 \times 2 \times 2$ the name "1."

2. All the surrounding bodies $1 \times 2 \times 2$ are given the other same name "2" by virtue of their similarity, as shown in Fig. 4. Let us take a look at a cross like this one but one microcube deeper in space inside the main cube. Then, by virtue of a similar cross found in the next plane, it can be admitted that the cross depicted in Fig. 5 is already composed of cubes $2 \times 2 \times 2$ with the names shown. To all the microcubes that make up each of the $2 \times 2 \times 2$ cubes, we will naturally give the same name.

3. All the microcubes that make up $1 \times 2 \times 2$ bodies with a certain name are similar, and we, by virtue of our heuristics, will identify them by giving to all them the same name "2."

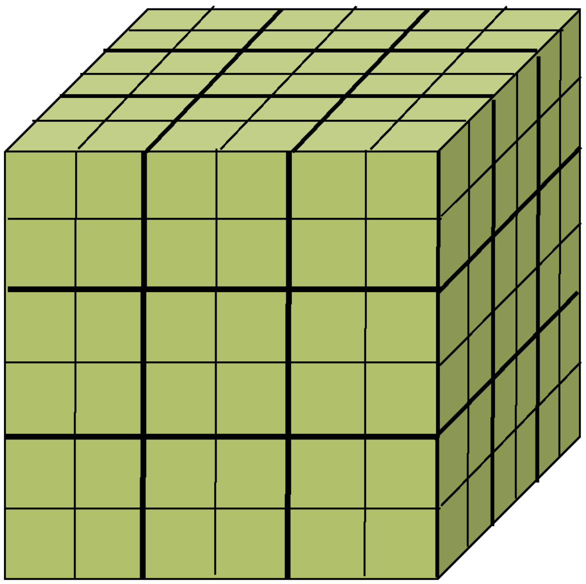

Fig. 4. Marking the "target" 3D orthogon [12].

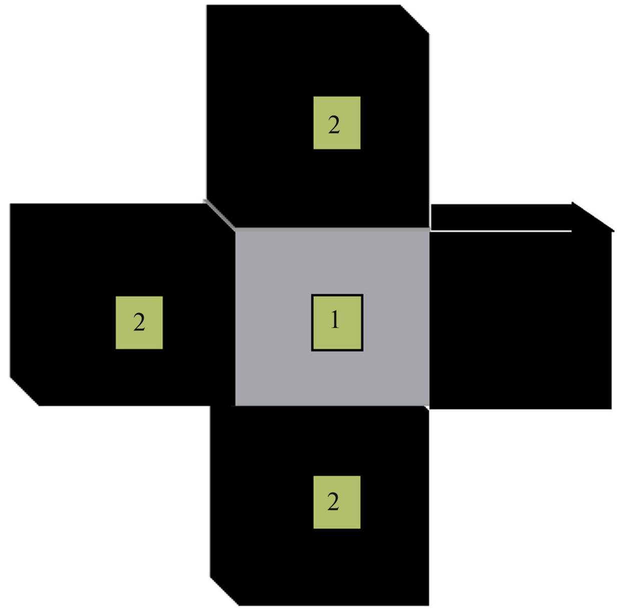

Fig. 5. Getting started with *SIP* heuristics.

4. Let us now consider a similar "cross" in the horizontal plane, which passes through the middle part of the cube named with "1."

In the horizontal plane, yet unmarked cube is also formed. Let us temporarily give it the name N, where N is a natural number.

5. The $2 \times 2 \times 2$ cubes surrounding it will be named "$N + 1$" due to their similarity, by analogy to step 1.

Due to the SIP heuristic, all the constituent microcubes of the central body $1 \times 2 \times 2$ are similar and therefore have the same name "N."

6. Since the four microcubes that make up the new $1 \times 2 \times 2$ body already have the name "1," then the $N = 1$. And, therefore, the six microcubes of the central cube are named with "1."

7. Let us consider the same cross in the horizontal plane, but one microlevel higher than the previous one. All the microcubes of this $1 \times 2 \times 2$ body will also be named with "1" in the same way.

8. Hence, all 8 microcubes that make up the central cube will be named 1 and, therefore, the central cube itself, due to the SIP heuristic, will be named with "1."

9. Due to the SIP heuristic, all adjacent cubes obtain the same name.

10. Let us limit ourselves to two names. Let name "1" be replaced with the black color and name "2" with white to make a final result shown in the Fig. 6.

In this representation of the "cube and brick problem," the proof of the original statement is quite trivial [14].

Indeed, there are 13 black cubes and 14 white ones. Each brick always includes exactly 4 white and 4 black microcubes. From this we get that there is no way a cube $6 \times 6 \times 6$ can be built from the bricks of size $1 \times 2 \times 4$.

The required statement has been proven.

6.3. Wrapping up

The resulting solution of the problem satisfies the definition of Prof. J. McCarthy as a creative solution, since there was no hint of this solution in the formulation of the original problem and the solution was not contained in the related problems like his Tough Nut problem about the impossibility of covering the dominoes of a chessboard with two squares removed from the ends of the main diagonal.

What is more, our solution was found through a simple, logical abduction program that implements the SIP heuristic.

Let us summarize the intermediate results for this subsection.

1. We answered affirmatively to the question of whether a computer can obtain a creative solution to a problem, in the sense of the informal definition put forward by Prof. McCarthy.

2. We have shown that the issue of choosing of an appropriate presentation of the problem is relevant and deserves further development.

3. Formally, the choice or modification of the problem representation is an example of logical abduction, i.e., deviation from the initial representation of the problem to be solved.

4. For this purpose, we have proposed and used a fairly universal principle or heuristic of semiotic introspection (SIP), which helps to overcome the combinatorial complexity of problem solving, if, of course, such heuristics are applicable in the problem under consideration.

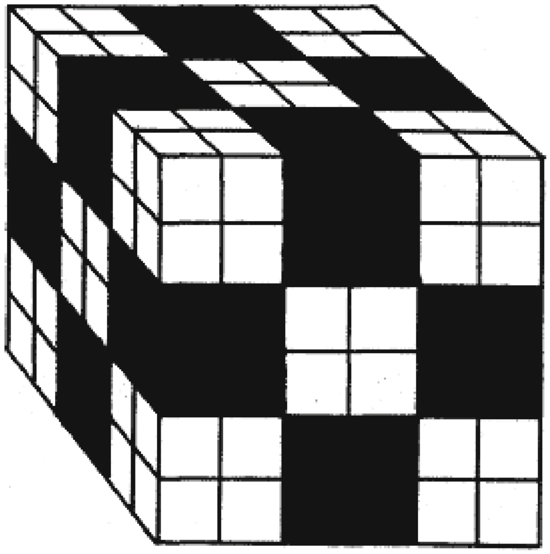

Fig. 6. Final representation for the spatial problem.

5. In the absence of combinatorial complexity, traditional AI inference (GPS) methods can be used. So, it seems that with the addition of our semiotic introspection heuristics (SIPs) to overcome combinatorial complexity, there is a real possibility of developing a full-fledged artificial intelligence, but still making significant use of human intelligence in how to apply the SIP heuristic.

6. In other words, so far, artificial intelligence is not superior to natural intelligence, being a kind of technical auxiliary tool similar to various expert systems or artificial neuro-like systems, in which the preparation of initial data for an intelligent system is also still done, in fact, by a person!

7. CONCLUSIONS

In 1974, the question of where the next International Joint Conference on Artificial Intelligence (IV-IJCAI) would be held was decided. I participated in a meeting of the organizing committee of the next such conference, having been sent to the United States on behalf of the Council on Cybernetics of the USSR Academy of Sciences.

At that time, there were three countries claiming to host the IV-IJCAI conference: Germany, Japan, and the Soviet Union.

When it was my turn, I said that the term "Artificial Intelligence" is not yet very common in our scientific community, but I can name several scientific areas and their leaders, whose works, in my opinion, are directly related to Artificial Intelligence. After that, I spoke about the results of Tsetlin on learning finite state machines and about the work of M.M. Bongard on the problem of pattern recognition, and also referred to my own work on the collective behavior of automata and that of mobile communication.

As a result of an open vote, the Organizing Committee supported our application to hold the next international conference of the IJCAI-IV in the Soviet Union.

The leadership of the Academy of Sciences decided to organize this conference in Tbilisi.

The IJCAI-IV international conference in 1975 was a great success, with almost all the world's leading AI experts participating in it. Prof. Dmitrii Pospelov from the Computing Center also presented a paper at this conference, but we were not yet familiar with him personally.

The National Organizing Committee of the IV-IJCAI in the Council for Cybernetics at that time consisted of V.L. Stefanuk and two of my talented young collaborators from the IITP RAS, Yu.I. Kryukov and D.A. Belov, who provided significant assistance in drawing up the program of the conference.

Later, I met Pospelov in person at the Moscow House of Scientists, where I spoke at a meeting with his participation about the problems of AI as a result of my visit to the United States. Gradually, we agreed with him on the organization of the Soviet Association of Artificial Intelligence in the Soviet Union, in which, by virtue of the public vote of the Russian experts on Artificial Intelligence presented at that time, Dmitry Pospelov was elected to be the President of our association, and I was elected its Vice-President. At the same time, the AI association's journal *Artificial Intelligence News* was started.

Although the scientific schools of Tsetlin and Pospelov differed greatly in their interests and approaches to solving problems, there were no major contradictions between them. In some of his books, Pospelov has listed some examples of the automation behavior of Tsetlin's automata, also mentioning my works on the problems of collective behavior of automata.

At one of the international conferences of the IJCAI in the United States, I made a brief remark about the importance of the works by Tsetlin and his students; as a result, a rapid translation of Tsetlin's book into English was soon published in the United States, which has now become an AI bestseller in the West.

In recent years, the work of Tsetlin has received the greatest attention at the Massachusetts Institute of Technology (United States), where I once made a presentation of my mathematical model of broadband wireless mobile communication (see above). I also gave a similar talk at the University of Texas. As was noted above, the executives of Motorola (United States) came to Moscow, talked to me, and took with them all my publications on this topic. Obviously, it stimulated the appearance in the West of wireless mobile communication, and I am glad to see it came to the people.

It is worth to mention that reinforcement learning, popular in the United States, is a weak copy of the works of Tsetlin and his colleagues on learning automata that receive rewards and punishments from the external environment in which the automaton is immersed. Unfortunately, most foreign authors usually do not make any references to our pioneering works.

In conclusion, it should be noted that the school of Tsetlin was the one having obtained fresh new results, sometimes significantly ahead of foreign ones, installing in young people a taste for creative solutions of fundamental and applied problems.

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CONFLICT OF INTEREST

As author of this work, I declare that I have no conflicts of interest.

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Vadim L. Stefanuk Doctor of Technical Sciences, Leading Researcher of the IITP RAS graduated from the Faculty of Physics of Lomonosov Moscow State University in 1962 in the Department of Theory of Oscillations of the Department of Radiophysics, with a diploma "Some Problems of the Behavior of Automata," defended his Candidate's thesis "Collective Behavior of Automata and the Problem of Stable Local Control of a Radio Communication Network" in 1968. In 1990, he defended his Doctoral dissertation (Dr. Sci.) on the topic "Local Organization of the Expedient Behavior of Technical Systems."

Concurrently with IITP RAS, Stefanuk is a Professor at the Department of Information Technologies of the Peoples' Friendship University of Russia, he is an Academician of the Russian Academy of Natural Sciences and a Full Member of the European Coordinating Committee on Artificial Intelligence (Fellow ECCAI/EurAI), and Vice-President of the Russian Association for Artificial Intelligence (RAAI).

He holds two patents, he is the author of two monographs, three textbooks, and 280 publications. He has published translations into the Russian language of 24 books on Artificial Intelligence and its applications.