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O.O. Varlamov

Bauman Moscow State Technical University, Moscow, Russia; Moscow automobile and road construction state technical university, Moscow, Russia; MIVAR, Moscow, Russia

THE MIVAR APPROACH AS A BASIS FOR A QUALITATIVE TRANSITION TO A NEW LEVEL IN THE FIELD OF ARTIFICIAL INTELLIGENCE

The mivar approach main originality is that three mivar technologies are combined on the basis of epistemological multidimensional evolutionary databases and the «Thing–Property–Relation» rules in which the automatic algorithm constructor with linear computational complexity and/or the logical inference on bipartite directed mivar networks «Object–Rules» are implemented. Mivar practical using proved that logical inference is made now on an ordinary laptop with a speed of more than 5 million product rules / second. The task of logical inference on products must be excluded from the class of NP-complete tasks, because mivar method of logical inference with a linear computational complexity solution not using either a full search of options or heuristics is found and patented. In computer science mivars solve the problems of accumulating and processing information. By results of 2017 software products based on the miware approach have already been created for: Expert systems – Wi!Mi; Razumator; Texts meaning understand – Tel!Mi; Decision-making systems for autonomous robots – Robo!Razum. Wi!Mi technology is used in Tel!Mi for meaning understanding. Tel!Mi automatically allows to teach Wi!Mi Razumator and Robo!Razum with the texts of the instructions. In total these products can be used for the Internet of things and other cyberphysical systems since mivar products Wi!Mi, Tel!Mi, Robo!Razum can work on one usual (rather cheap) computing module «processor-memory». So the mivar approach to the accumulation of data and information processing combines the main directions of artificial intelligence at the logical level of research: expert systems, language understanding, image recognition, ACS and intelligent autonomous robots. Therefore it is the mivar approach that is the basis for a qualitative transition to a new level in the artificial intelligence field.

Keywords: *mivar, mivar nets, intelligent systems, artificial intelligence, databases, expert systems, meaning understanding, image recognition, robot, algorithms calculation, mivar method of fast logical inference.*

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Введение

The materials on mivar technologies were first published in 2002 [1]. The generalization and development of the artificial intelligence (AI) theory on the basis of mivars were theoretically substantiated in the works published in 2007 [2, 3]. Since 2012, work has been initiated on the complex simulation of the processes of computer understanding of the meaning of texts, speech, and images on the basis of mivar technologies [4, 5]. It should be noted that the first publications on the use of mivars for robots and robotic systems (RSs) appeared already in 2004 [6], and in January 2017 for the first time an unmanned vehicle traveled through the winter streets of Moscow using the mivar expert systems [7]. The year 2015 played a special role in the development of mivar systems; during that year, the works on the use of mivars in almost all areas of AI were simultaneously published: analysis and comparison with ontologies and cognitive maps [8–10], the creation of a mivar logical inference machine [11, 12], application of mivar technologies for ACS (automated control systems)[13], medicine [14], school teaching [15], creation of virtual consultants [16] and various robots [17, 18].

It is important to note that since 2016, research and development of mivar technologies have been carried out at the IU5 department of N.E. Bauman Moscow State Technical University in the framework of the research direction «Hybrid Intelligent Information Systems» (HIIS) [19], which studies decision support information systems [20], metagraphs [21], methods for choosing solution options and management [22–24], semantic networks of concepts [25], program generation [26], neural network recognition algorithms [27, 28], visualization methods [29] and anamorphosing [30]. The development and research of mivar temporal database models are also underway [31–35].

Analysis of the place of the mivar approach in artificial intelligence

In the field of artificial intelligence (AI), various levels and directions of research on the creation of AI systems are distinguished, which can be displayed in the «Levels – Directions – Systems» three-dimensional space (Fig. 1).

The mivar approach to the data accumulation and information processing combines the main directions of artificial intelligence at the logical level of research:

1. Expert systems.
2. Understanding the language.
3. Pattern recognition.
4. ACS.
5. Intellectual autonomous robots (Fig. 2).

What are the mivar approach and mivar technologies

The mivar approach includes three new information technologies (Fig. 3):

1. Evolutionary multidimensional databases and rules, in which «mivar» is a point of the three-dimensional epistemological basis of «Thing – Property – Relation».
2. Logical inference (automatic constructor of algorithms from «causal-effect dependencies» modules) with linear computational complexity based on bipartite oriented «Object – Rule» «mivar networks» in multidimensional space, combining Petri nets with «If – That» productions.
3. Global information models for processing «contexts» and making decisions in real time, when databases, logical inference, and computational processing are a single whole in the mivar information space with the main basis «Thing – Property – Relation».

These information technologies, developed in Russia, made it possible to move to a qualitatively new level and create Logical Artificial Intelligence. Let us justify it in more detail. Until recently, the main constraint on the development of artificial intelligence systems at the logical level of «cause-and-effect reasoning» was the factorial computational complexity ($N!$) of the logical inference from N rules. As is known, the logical conclusion belongs to the class of sequential tasks that are practically not parallelizable and can be solved only on one «processor core». Therefore, the use of multiprocessor systems does not solve the problem of reducing the time of logical inference, which is analyzed below in more detail. The uniqueness of the mivar approach is the use of the mivar multidimensional database «Thing – Property – Relation» (TPR) and logical inference with linear computational complexity (on the mivar networks).

MIVAR is an abbreviation of «Multidimensional Information Variable Adaptive Reality». A mivar is a point of a multidimensional mivar space.

A mivar space <Thing, Property, Relation> (TPR) allows describing the real world in the formalism of multidimensional hypergraphs and generalizes all the basic models of knowledge representation: ontologies; trees (decision-making trees); binary graphs; ER-diagram («entity – relation» model); UML (business processes); Statistics – statistical models; database models (relational, network, hierarchical, etc.). Thus, the real world can be described in the seven-dimensional space $<X, Y, Z, T, Th, P, R>$.

The role of reducing the computational complexity of inference to linear complexity

Mivar networks allowed drastically reducing the computational complexity of the logical inference on productions (from factorial to linear complexity). This is a particular solution to one of the seven millennium problems: $NP = P$. Now the logical conclusion is a problem with linear computational complexity with respect to the number of rules, and not NP. Mivar networks allow logical processing in the multidimensional TPR space. Combined usage of mivar networks and the TPR space allows building large (with millions of vertices and edges of a multidimensional hypergraph) «world models» and using «contexts» at a qualitatively new level. This is the foundation for the logical artificial intelligence of the «third generation».

With the help of the program module «'Wi! Mi Razumator' Mivar (KESMI) Constructor of Expert Systems» (included in the Register of Russian software of the Ministry of Communications of Russia), qualitatively new expert systems were created that process more than 5 million rules in a fraction of a second on one regular processor, which is important for situational centers and autonomous robots. The logical conclusion in KESMI is implemented on mivar networks.

Understanding natural language

To understand natural language, it is necessary to construct large pictures of the world and take into account many contexts. The mivar product «Text Emulator of Personality» (TELMI) Tel! Mi allows building multidimensional models of texts in the formalism of the space <Thing, Property, Relation>. Currently, this made it possible, in less than a month's time, to create a Mivar TPR model using Ozhegov's Explanatory Dictionary and to accumulate training texts with the dimension of a mivar network (bipartite graph) of 160,000 vertices (things) for 600,000 edges (relations) in a 17-dimensional space. Note that most of the time was spent on the analysis and preliminary processing of the specific design of the explanatory dictionary. Automatic processing of the text itself, containing about 100 thousand entries (taking into

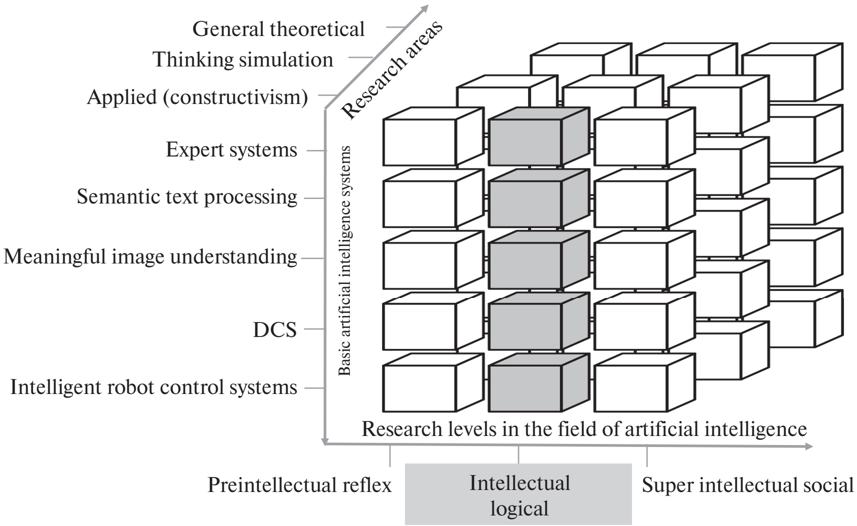

Figure 1. Artificial intelligence levels, directions and systems

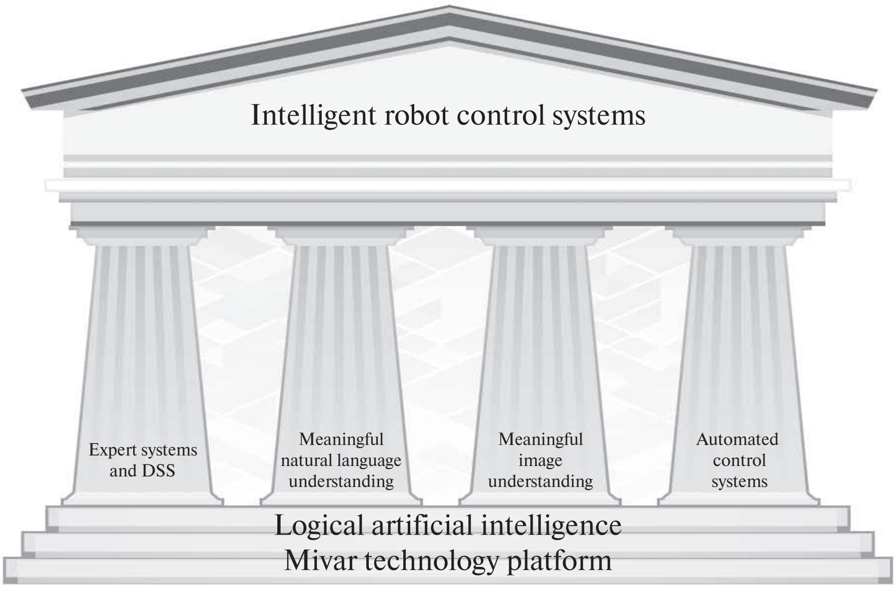

Figure 2. The role and place of mivar technologies in logical artificial intelligence

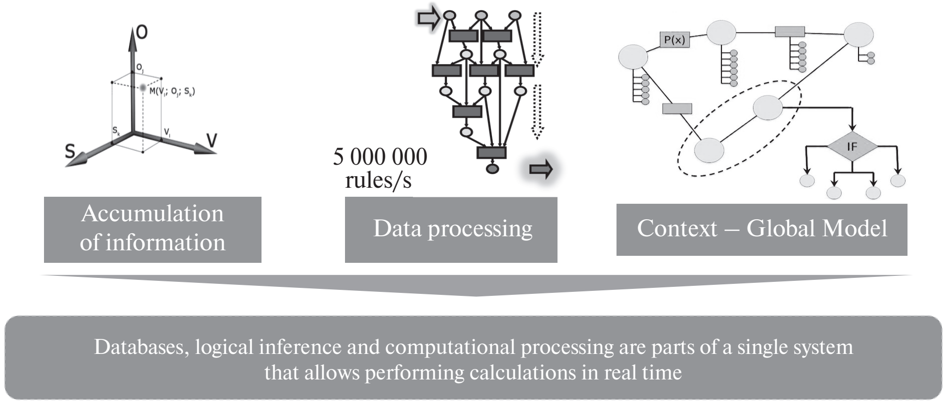

Figure 3. Three mivar technologies

account different meanings of one word), took less than two hours. The mivar approach allows processing texts on these extra-large volumes of bipartite graphs in real time on ordinary computers.

Let us define «understanding the meaning of a text». Formalization of the concept of «understanding the meaning» is based on distinguishing five levels of uncertainty (Fig. 4). To each spoken word (set of phonemes), there correspond several words with errors. To each word with errors, several word forms may correspond. To each word form, several words may correspond. To each word, several concepts may correspond. A concept is a word in its specific meaning, for example, as in the Russian Ozhegov's Explanatory Dictionary. Note that in the reverse order all relations are also multiple («many-to-many» type of relation): several words may correspond to each concept, several word forms may correspond to each word, several words with errors may correspond to each word form, several variants of pronouncing words (sets of phonemes) may correspond to each word with errors.

The text will be considered «understood» if all uncertainties are removed at the levels of word forms, words, and concepts, and one concept is found for each word of the sentence. Consider an example of understanding the meaning of a sentence (Fig. 5). The sentence, which is a set of word forms, is analyzed. For each word form, the corresponding word is found. Each word is matched with all its possible concepts in different contexts. Then it should be analyzed: is there the same value of the context of these concepts of each word? If there is such a value, then for each word concepts are selected from this context. If there is no such value, then one can proceed to the next sentence and analyze the entire text.

Thus, one can univalently move from words to concepts, and this means understanding of the meaning of the sentence. All concepts are vertices of a

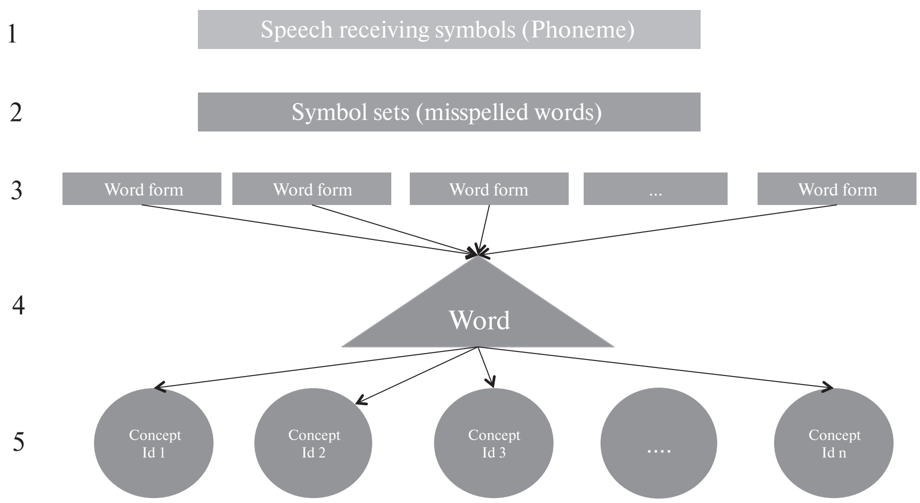

Figure 4. Five levels of meaning understanding

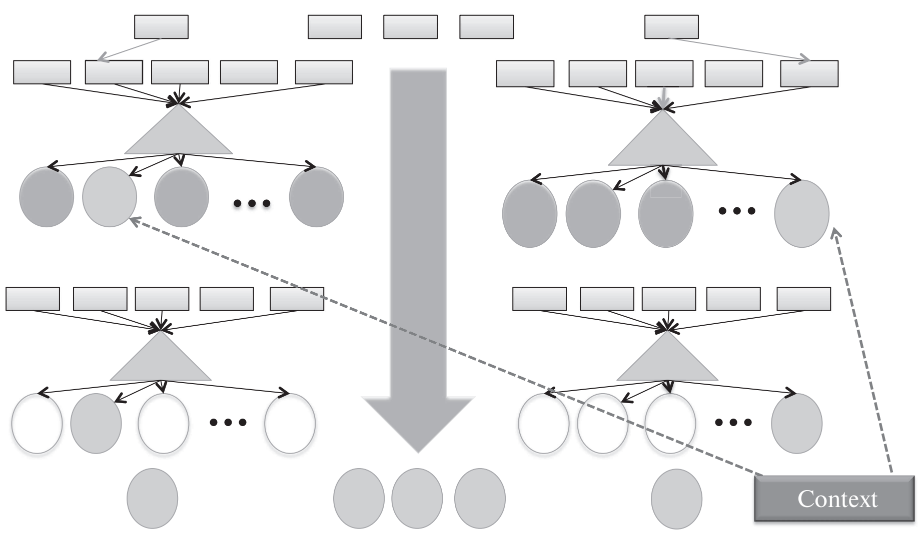

Figure 5. Formalization of «text meaning understanding» term

multidimensional hypergraph in the space <Thing, Property, Relation>. The entire «Picture of the World» is a multidimensional graph. A context is a subgraph of the «Picture of the World», in which all the concepts defining such a context are connected by edges. When executing an algorithm for understanding the meaning, the search for concepts and their contexts is carried out in a multidimensional graph by applying mivar networks. In this «Picture of the World» graph, mivar networks of oriented bipartite graphs are automatically formed for each context subgraph. When analyzing a sentence, for all words, possible concepts from the «Concept Database» (the set of all the vertices of the «Picture of the World» graph) are determined. For each concept, it is known which context subgraph it belongs to. If, when analyzing a sentence, uncertainty arises and several contexts are possible, then in each context subgraph, a logical inference mechanism (an analog of the «Wi! Mi Razumator» product) is automatically launched to search the paths in the multidimensional graph that link «vertices-concepts» within a single context subgraph. As soon as it is found that each word has a concept belonging to one and the same context subgraph, the sentence is considered understood and all other concepts are discarded.

If it was not possible to remove the uncertainty and the concepts remained in different contexts, then (as in the real process of understanding of the meaning of texts) the following sentence is taken for analysis, and it is analyzed taking into account the options of contexts obtained earlier. If the text is written «with meaning» and in «one context», then it will eventually allow removing all uncertainties and move from words to concepts. Otherwise, additional system training should be carried out. The general scheme of the Tel! Mi system is shown in Fig. 6.

The modules of semantic analysis and semantic database are based on an analog of the «Wi! Mi Razumator» product. In fact, with the help of the «logical inference mechanism of mivar networks» (Wi! Mi), one can quickly find subgraphs of contexts in a large multidimensional graph of the picture of the world. For all the concepts of each word of the sentence, one can go to the «Picture of the World» graph, in which the subgraphs with respect to contexts are distinguished. If one concept of each word falls into one context subgraph, then this context is defined as the main one, while all other concepts and their contexts are discarded. A concrete example of text analysis is presented in Fig. 7.

It is important to emphasize that the mivar approach allows one to explicitly store information about the sequence of actions in the text (Fig. 8). This allows getting the texts of instructions to the input of the Tel! Mi system and, on their basis, construct the corresponding text models in the «Picture of the World». Then such models are automatically converted to bipartite oriented mivar networks, which are input data for the Wi! Mi expert systems.

Thus, there are practical realizations of teaching expert systems by means of text instructions, which allow automatically training the Wi! Mi expert systems by processing text in the Tel! Mi system. This solves the problem of creating complex real models with thousands and millions of rules for Wi! Mi.

To understand the meaning of pictures (semantic pattern recognition), mivar technologies are applied in the same way as understanding the meaning of texts. On the same multidimensional «Picture of the World» graph, subgraphs of contexts are built, but other characteristics obtained by recognizing patterns (for example, color, texture, shape, contour, mutual arrangement of objects) are used.

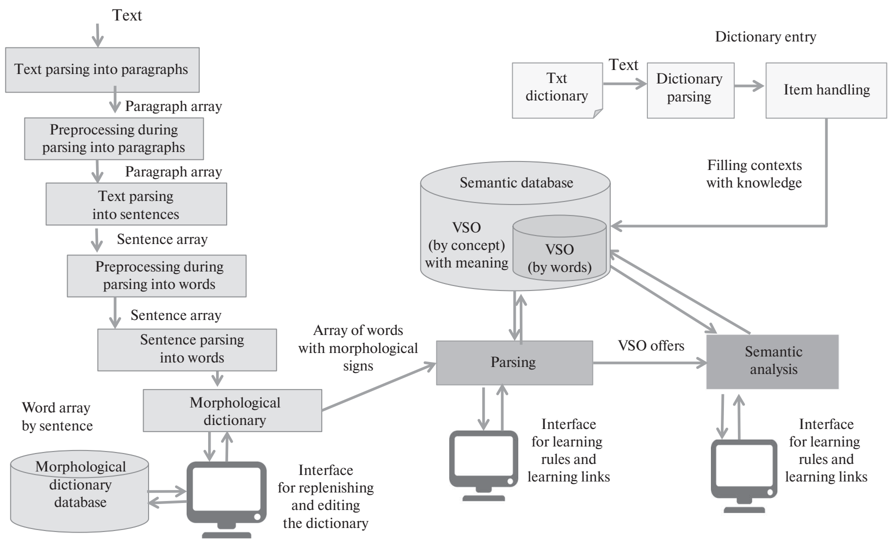

Figure 6. The general scheme of Tel! Mi system

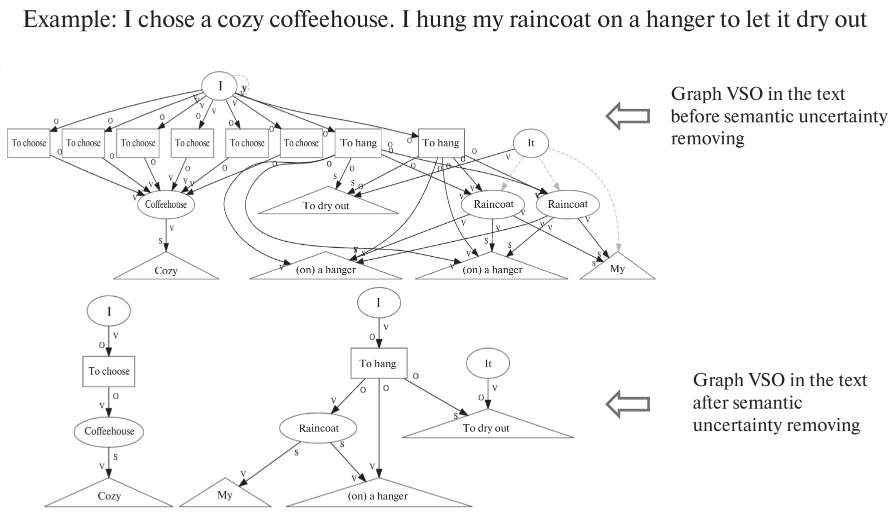

Figure 7. Example of removing semantic uncertainty in the text

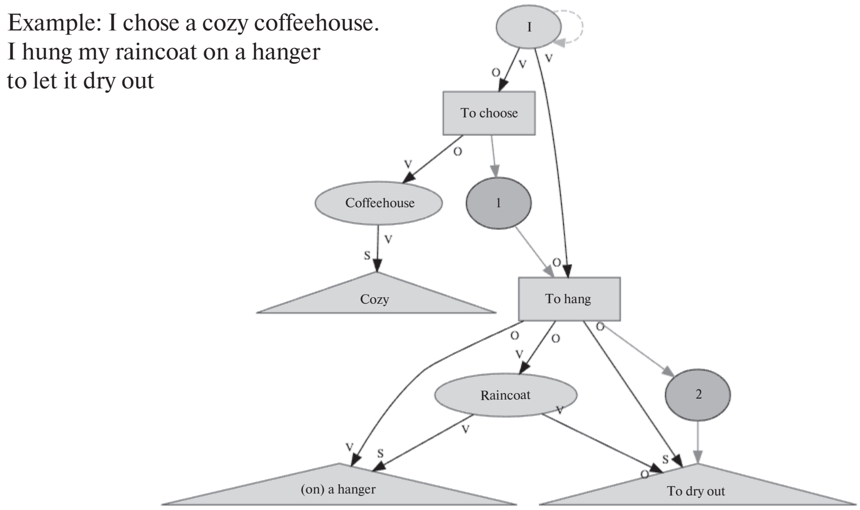

Figure 8. Example of action sequence understanding in the text

Mivars for automated control systems and robots

To create an automated control system (ACS), a formalized description of the control system is formed, based on mivar technologies, in the form of a multi-dimensional TPR hypergraph. Further, similarly to expert systems, a mivar network of a description of a control system using Wi! Mi is created. Unlike expert systems (manually launched by the analyst by pressing the key), for the automated control system, in addition to the Wi! Mi, a subsystem is created for the automatic input of initial data from sensors and starting the calculation of logical inference, as well as a subsystem for the control data output to «actors». For the ACS, one can only use the server version of Wi! Mi. The combination of Wi! Mi, the sensor data input subsystem, the subsystem of the actor control output, and also the necessary drivers (utilities) form another mivar product: Robo! Razum ACS.

An intelligent decision-making system (DMS) for controlling robots can include all three mivar products: Wi! Mi, Tel! Mi, Robo! Razum, but the server Robo! Razum is obligatory based on one autonomous computing module.

The main qualitative feature of the intellectual control system of robots is that all programs, data and knowledge are inside one small autonomous robot. Similarly, these technologies can be used for the Internet of Things and other cyber-physical systems, since Wi! Mi, Tel! Mi, Robo! Razum Mivar products can work on a conventional computing module (computational processor and from 4 GB of RAM).

The role of computational complexity of logic inference for decision making on logical rules in robotic systems

In the field of robot action planning, there is an indicator of «decision-making time in various situations».

This time is measured in seconds. Traditionally, to estimate the decision-making time, a complete enumeration of all possible combinations of elementary actions was used. In expert systems, an «elementary action» is understood as a «rule» in the «If – That» format. Accordingly, a typical combinatorial problem is obtained: if in some situation there are possible N elementary rules, then the total number of «combination options in such a situation» will be N! (factorial). A solution is a «set of sequential rules» (algorithm), and it can be found randomly and in one step. However, according to tradition, when determining the time for finding a solution, one proceeds from the concept of the «worst case» – this is when the solution to the problem is guaranteed to be found, that is, for robots (or for situational centers) it will be an algorithm consisting of elementary actions. It was assumed that the «automatic algorithm constructor,» or «logical inference», is an NP-complete problem, that is, the total number of situations in the «worst case» is equal to the factorial of the number of rules – $N!$.

In computational mathematics, the concept of «computational complexity of a problem» is defined: to obtain a guaranteed solution to a problem, it is necessary to perform a certain sequence of operations on a computer, which makes it possible to determine for each problem how many operations need to be performed on a computer. For example, for logical inference, the concept of «problem solving step» is used, when one variant of the problem solution is tested. Recall that the total number of variants is defined as $N!$ (factorial). The time to perform a single operation on a computer is known (for each processor, this is its «speed», which is measured by the «number of operations per second»).

The time to solve a problem is defined as follows: it is the ratio of the number of «problem solving steps» to «computer speed».

For computers, computing power is measured in flops (the number of floating-point operations per second) and currently it is about 10 to the 11th power for a single processor.

Presently, it is customary to consider as supercomputers the systems with a computing power of more than 10 teraflops (10×10^12, or ten trillion flops; for comparison, the average modern desktop computer has a performance of about 0.1 teraflops). One of the most powerful computer systems on the HPL test, the Chinese Tianhe-2 has a performance of more than 33.8 petaflops.

Thus, to calculate the approximate time of solving a problem, the number of «rules» is divided by the computer speed in seconds. For an approximate determination of speed, one can simply divide $N!$ by 10 to the 11th degree.

The table shows an example of evaluating the time for logical inference or automatic construction of algorithms using complete enumeration.

It can be seen that already 15 rules require more than 10 s, which does not allow making decisions and controlling the robot in real time.

20 rules are 2,432,902,008,176,640,000 variants, i.e. 2×10 to the 18th degree; by dividing it by 10 to the 11th power, one can get about 10 to the 7th power of seconds (one year).

30 rules are 265,252,859,812,191,058,636,308,480 ,000,000, that is, approximately 10 to the 32nd power, and the decision-making time will be 10 to the 20th power of seconds (84 billion years).

One can continue this analysis and, for example, for 300 rules it will be about 10 to the 614th degree of variants:

306057512216440636035370461297268629388588804173576999416776741259476533176716867465515291422477573349939147888701726368864263907759003154226842927906974559841225476930271954604008012215776252176854255965356903506788725264321896264299365204576448830388909753943489625436053225980776521270822437639449120128678675368305712293681943649956460498166450227716500185176546469340112226034729724066333258583506870150169794168850353752137554910289126407157154830282284937952636580145235233156936482233436799254594095276820608062232812387383880817049600000000000000000000000000000000000000000000000000000000000000000000000

and the solution time will be more than 10 to the 600th power of seconds.

The KESMI «Wi! Mi Razumator» program, developed by the MIVAR company, solves the problems with 300 rules in a fraction of a second. In terms of the time criterion of solving the problem, mivars allowed proceeding from factorial growth of time (thousands of years and more) to «linear growth» and real time of solving the problem at a speed of more than 5 million rules per second. This is a breakthrough technology.

One can get a «comparison indicator» in the form of «decision-making time in various situations». The complexity of the situation is determined by the number of rules, whereas the time for making decisions is measured in seconds. For example, for modern robotic systems (RS), the actual operating time should not exceed a second. Traditional approaches already with 15 rules no longer work in the real world, whereas the mivar approach overcomes this limitation.

The problem of «Equality of the classes P and NP» is one of the most important problems in the theory of algorithms. This problem is of great importance for the most diverse areas of knowledge, but it has not been solved for more than 40 years already. It is one of the so-called Millennium Prize Problems. It is believed that if it is solved, this will mean that it is theoretically possible to solve many complex problems much faster than now.

Table. Problem solving time for the searching (*N!*) computational complexity of the logical output on *N* rules

N	Number of combinations (*N!*)	Solution time (in seconds)	Decision time (in years)
1	1	< 1	< 1
2	2	< 1	< 1
3	6	< 1	< 1
4	24	< 1	< 1
5	120	< 1	< 1
6	720	< 1	< 1
7	5 040	< 1	< 1
8	40 320	< 1	< 1
9	362 880	< 1	< 1
10	3 628 800	< 1	< 1
11	39 916 800	< 1	< 1
12	479 001 600	< 1	< 1
13	6 227 020 800	< 1	< 1
14	87 178 291 200	1	< 1
15	1 307 674 368 000	13	< 1
16	20 922 789 888 000	209	< 1
17	355 687 428 096 000	3 557	< 1
18	6 402 373 705 728 000	64 024	< 1
19	121 645 100 408 832 000	1 216 451	< 1
20	2 432 902 008 176 640 000	24 329 020	1
21	51 090 942 171 709 400 000	510 909 422	16
22	1 124 000 727 777 610 000 000	11 240 007 278	356
23	25 852 016 738 885 000 000 000	258 520 167 389	8 192
24	620 448 401 733 239 000 000 000	6 204 484 017 332	196 608
25	15 511 210 043 331 000 000 000 000	155 112 100 433 310	4 915 206
26	403 291 461 126 606 000 000 000 000	4 032 914 611 266 060	127 795 352
27	10 888 869 450 418 400 000 000 000 000	108 888 694 504 184 000	3 450 474 513
28	304 888 344 611 714 000 000 000 000 000	3 048 883 446 117 140 000	96 613 286 375
29	8 841 761 993 739 700 000 000 000 000 000	88 417 619 937 397 000 000	2 801 785 304 884
30	265 252 859 812 191 000 000 000 000 000 000	2 652 528 598 121 910 000 000	84 053 559 146 510
31	8 222 838 654 177 920 000 000 000 000 000 000	82 228 386 541 779 200 000 000	2 605 660 333 541 820
32	263 130 836 933 694 000 000 000 000 000 000 000	2 631 308 369 336 940 000 000 000	83 381 130 673 338 100
33	8 683 317 618 811 890 000 000 000 000 000 000 000	86 833 176 188 118 900 000 000 000	2 751 577 312 220 160 000
34	295 232 799 039 604 000 000 000 000 000 000 000 000	2 952 327 990 396 040 000 000 000 000	93 553 628 615 485 400 000
35	10 333 147 966 386 100 000 000 000 000 000 000 000 000	103 331 479 663 861 000 000 000 000 000	3 274 377 001 541 990 000 000

Note. Initial data: processor speed (operations per second) = 10x10^11; average number of seconds in a year = 31 557 600.

There is an entire list of problems belonging to the class of NP-complete. One of them was a logical inference, which, after creating the mivar bipartite networks, must be excluded from the class of NP-complete problems. It is possible that the application of the new mivar approach will allow accelerating the solution of some other problems from this class, but these questions are beyond the scope of this article. The proof of the cardinal acceleration of the search for solutions and the transition from the NP-complexity of logical inference (on «If-That» productions) to the linear computational complexity of the mivar method of processing the logical data and rules was carried out and published in 2002 [1–2]. Since 2002, this scientific direction has continued to develop: research is conducted, papers and reports are published, dissertations are defended [1–22]. These scientific achievements underlie all the developments of the MIVAR company.

Practical comparison of three ways to solve problems of automatic construction of algorithms and logical inference (situational control)

To prove the effectiveness of the mivar approach in solving practical problems, it is proposed to consider the solved problem of automation of the customer support services: an example is described on the MIVAR website www.mivar.ru. This work was done in the MIVAR company, and the material was prepared by Anastasia Latysheva and Pavel Chernyshev.

Let us present a brief description of the problem. Customer support services are widespread in various areas of economy related to customer service. They are groups of people-operators who help customers use the company's products. For the most part, user questions are typical, repeated, and the operators' responses to them are becoming mechanical actions. Often, the burden on service operators is very high, and such recurring questions take a significant amount of time on workers. To relieve operators, it is proposed to automate the mechanism for responding to typical user requests.

It is proposed to consider three options for solving the problem of automation:

1. Complete enumeration of answer options (search over the «decision tree»).
2. Search over a set of pre-calculated «probable scenarios» of the request-response (database search).
3. Building a model of automatic responses using the KESMI software module «Wi! Mi Razumator» based on «mivar networks».

Consider each of the options.

Complete enumeration of the response options

To automate the response, it is necessary to identify a block of typical requests and, based on this block, build a tree for receiving a response on the «If – That» rules. Suppose that the number of typical queries is n. Then $n!$ is time spent for searching for an answer over the tree. As the number of typical queries increases, the time of searching for the correct answer increases faster than exponentially and tends to infinity (measured in hours).

Search over a set of pre-calculated «probable scenarios» of the request-response

In this case, a set of «probable scenarios» can be presented as an instruction book, and the probable scenarios, as chapters of this book. Then, in the case of a non-standard scenario, which is essentially a gluing, it is possible to give the user only all the scenarios of which the non-standard one consists. The time spent for searching for an answer will be measured in hours and may tend to infinity.

Building a model of automatic responses using the KESMI software module «Wi! Mi Razumator»

To obtain a solution, it is necessary to identify the parameters (incoming and outgoing, communicated by the user) and the rules that connect the incoming parameters with the outgoing ones. This problem also uses the «If – That» rules. The construction of the algorithm according to these rules proceeds from the desired parameter: the program understands what parameters it needs to find, and, based on the rules associated with these parameters, it constructs an algorithm for obtaining a response.

The time spent on finding the needed answer is linear with respect to the number of parameters. KESMI processes more than 5 million rules in 0.05 s, that is, in this case, all solutions are obtained in real time (in a fraction of a second).

Conclusions

Thus, the mivar approach to data accumulation and information processing combines the main directions of artificial intelligence at the logical level of research:

1. Expert systems.
2. Understanding language.
3. Pattern recognition.
4. ACS.
5. Intelligent autonomous robots.

Based on the mivar approach, software products have been created for:

- expert systems – «Wi! Mi Razumator»;
- understanding the meaning of texts – Tel! Mi;
- decision-making systems for autonomous robots – Robo! Razum.

The Wi! Mi technology is used in Tel! Mi to understand the meaning. The Tel! Mi product allows automatically teaching «Wi! Mi Razumator» and Robo! Razum using the texts of instructions. Taken together, these products can be used for Internet of Things and other cyber-physical systems, since the Wi! Mi, Tel! Mi and Robo! Razum mivar products can work on one conventional processor-memory computational module.

The main qualitative feature of mivar intellectual systems is that all of them are based on multidimensional evolutionary databases and «Thing – Property – Relation» rules with the logical conclusion with linear computational complexity on bipartite oriented Object – Rule mivar networks. Consequently, it is the mivar approach that is the basis for the qualitative transition to a new level in the field of artificial intelligence.

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AUTHOR

Varlamov Oleg, Dr., professor, Bauman Moscow State Technical University, Moscow automobile and road construction state technical university; CEO, MIVAR, 72, Oktyabrskaya ulitsa, Moscow, 127521, Russian Federation, tel.: +7 (926) 276-76-45, e-mail: ovar@narod.ru.