On the Formal Description of Decision-Making in an Intelligent System with Technology of the Direct Imposition of Knowledge

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Abstract. In this paper several approaches to decision making in intelligent systems of various kinds are considered. The most commonly used decision-making approaches are considered - engineering approach, purely scientific approach, system analysis, logical solution of problems, heuristic search, "the theory of inventive problem solving", direct search for solutions, method of “rational” decision-making. For a new intelligent system based on technology of direct imposition of knowledge with knowledge models in the form of molingas, a rarely used approach to solving problems for such systems is applied, as once put together by the famous mathematician Pólya - direct search for solutions. This reinforces the applicability of representation of such systems as Ackoff-Emery purposeful systems. The experience of use of a formal description of decision-making processes in such systems from the point of view of system analysis is applied. Several of comparative characteristics of decision-making systems related to intelligent systems are considered in comparison with the new direction of intelligent systems based on technology of direct imposition of knowledge. The analysis revealed a number of significant advantages of such a system compared to a number of approaches used for decision-making solutions, which is important in practice.

Keywords: knowledge, decision making, logical inference, problem solving.

1 Introduction

Throughout recent decades, active effort has been set off in different countries around the world to create various decision-making (DM) systems using artificial intelligence (AI) as the means [1-8]. Within the framework of systems based on AI methods currently in use, a limited set of options from known approaches to problem solving get applied [9-13]. There is a certain degree of tradition to a formal description of DM processes in such systems (from the point of view of system analysis) [2,11, 14-18]. The approaches are very different from each other due to the complexi-

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ty of the problem. Let us consider some comparative characteristics of modern DM systems related to intelligent systems (IS) in comparison with the new direction of IS based on the technology of direct imposition of knowledge (TDIK) [19-22].

Many of them belong to the category of purposeful systems [9], wherein IS "can change its tasks under constant environmental conditions: it chooses the means of their implementation. In so doing, it displays its' own will." This is due to the fact that in their case an active role is played by a person, which brings about, in some cases, certain features of structural makeup of algorithms and, as is typical for all ISs, change (more or less gradual) of knowledge bases used in ISs. These structural features of purposeful systems are particularly clear in IS with TDIK [19-22].

Let's consider the following main ISs that allow you to find solutions, for example, expert systems (ES) [1,7], IS Watson [6], in the dialogue mode with the decision maker (DM) in the IS with TDIK [19-22]. Then let's compare them with the more standard approaches - the engineering approach [11, 12,14,17,23], work with the Internet [3,4].

2 Analysis of existing approaches to solving problems / tasks

DM by humans is a relatively routine everyday activity. How a person (or other living creatures) does it is investigated in sufficient detail by psychologists [13], neurophysiologists [24], applied engineering specialists [11,12,14,23], and even mathematicians [2,10,16] and, specifically, AI specialists [1,7,15].

Psychologists (whose opinion is considered cornerstone) have yet to find a relatively acceptable solution on how a person thinks, and this understanding constantly slides further towards ever distant future [13, 24].

The mathematician Pólya believes "... a universal and infallible method for solving problems, unfortunately, does not exist: strict rules applicable to any situation have not yet been found and, in all probability, will never be found" [10].

"As the solver moves along towards solution, the appearance of the task is constantly changing. At each stage of the problem, the solver encounters a new situation, and once again faces the question of choosing the correct intermediate solution: what should be done in such a situation, what should be the next step? If he knows the perfect method, the infallible strategy for solving problems, then he can choose the next step via reasoning alone, based on the current situation and guided by a set of clearly defined laws [10]. In various embodiments, this is emphasized in [11, 14,17,23].

Over a long while, a set of approaches has developed that allows us to find solutions to problems / tasks:

- engineering approach;
- a purely scientific approach, in particular, solving problems in mathematics;
- system analysis;
- logical problem solving;
- heuristic search;

- “the theory of inventive problem solving” (TIPS);
- “brainstorm”;
- direct search for solutions;

Let’s consider some of the most well-developed technologies in science and technology for solving tasks / problems.

2.1 The engineering approach

The engineering approach to finding solutions is based on the widespread use of techniques, technologies, standards, research, development, in use sometimes for millennia. They are not always scientifically substantiated, but give good results in practice [11,12,14,23].

Disadvantages:

- these techniques, technologies, standards for each of the sub-directions with thousands of design options and technologies, there are quite literally thousands. No single person can know all of this; existing IT technologies are also insufficient. Therefore, either outdated solutions are made use of, or insufficiently effective, or decisions get not made at all;
- not finding the right solution, the decision maker is not able, as a rule, to quickly figure out and conduct at least some analysis. This leads to the fact that the decision maker cannot perform the task, or leads to gross errors in DM.

2.2 A “purely” scientific approach for finding solutions

A “purely” scientific approach for finding solutions, in particular, solving problems in mathematics, has also been developing for thousands of years and is based on strict methods for conducting research, experiments, processing results, checking results and discussing them. It does not always lead to quick results though. [2,10,15].

The engineering approach gives a quick answer, you can find solutions to tasks / problems and implement what you need, or you can’t do it at the current level of development. The scientific approach, if it gives a positive answer, is inaccurate (although it may seem precise). It must be checked and implemented often with respect to a point of view of engineering approach. The scientific approach will either not give any answer, or the answer will be incorrect (something is not taken into account), or the answer will be no. But it’s not certain that there is no decent solution. For example, a decision maker can find (invent) new solutions that cannot be reached using a purely scientific approach.

2.3 System analysis

System analysis developed as a kind of symbiosis of the scientific approach and the engineering approach to finding solutions. System analysis is based on the division of great uncertainty into more manageable parts, identifying relationships, relying on the mathematical theory of systems, clarifying the structure of goals, identifying criteria for their achievement, using not only formal, but also qualitative research methods, while ensuring the participation of specialists from different areas of knowledge [2,9,14,18].

System analysis alone is not able, as a rule, to find a satisfactory solution without the use of engineering approaches, in particular, due to its abstractness.

2.4 The logical solving of tasks and problems

The logical approach to solving tasks and problems has been considered one of the key and of most inherent in man approaches for quite a while, and is widely used [1,13,15].

Disadvantages:

- in order to perform logical inference (LI), objective knowledge of the relationship of individual concepts and facts with each other is necessary. This is possible only with scientific or engineering approaches, i.e. logical thinking does not have independent significance for solving problems;
- even with relatively small volume of initial data and concepts, the volume of logical connections begins to tend to infinity and a person without assistance of special technologies is unable to adequately draw conclusions.

2.5 Heuristic search

Heuristic search is a way to solve problems, based on special methods to reduce the enumeration of options and solutions called "heuristics" [1, 13]. One of the simplest options for heuristic search is actively used in the direction of AI based on heuristic evaluation functions [1, 19].

Disadvantages: insufficient validity of a number of applied techniques; lacking effectiveness.

2.6 "The theory of inventive problem solving"

The theory of inventive problem solving (TIPS) and on its' basis the algorithm of inventive problem solving (AIPS) was developed by G.S. Altshuller and his supporters during the 40-80s of the twentieth century [5,11-13]. It is based on the initial identification of contradictions. And through a sequential procedure, a situation is manufactured that is assessed by psychologists as "insight" [13,20], leading to the necessary solution. AIPS was implemented as a software package on a PC called "Inventing Machine" back in the days of the USSR [12,20].

Unfortunately, TIPS could not be used to solve most of the practical problems, which was partially corrected after Altshuller's death by his followers [5,11,12].

2.7 Direct search of solutions

Direct search for solutions is a special approach to the perception of solving a certain problem. It was described at time by the famous Hungarian mathematician G. Pólya [10] – “To find a solution to a problem means to establish a connection between pre-differentiated objects or ideas ... like ... a chain - perhaps it will be a long chain - of conclusions. The whole chain ... is not more durable than its weakest link ... ".

This is a rarely proposed and used method. The drawback (in the past) is the lack of clarity on how to practically implement it.

2.8 Method of “rational” problem solving

“Rational” problem solving is an approach that has been taught to managers and executives around the world in recent decades, gradually being refined in formulations.

Making a rational decision is not an elementary act. It is carried out in several stages [17]:

1. Formulation of the problem.
2. Setting goals and formulating the problem of choice.
3. Finding alternatives and determining their properties.
4. Design of selection model (DSM).
5. Solving the selection problem based on the selection model.
6. Assessment of the consequences of the choice and quality of the solution.
7. If unsatisfactory, then return to 3 (or 2, or 1).

This is more realistic in practical situations. Moreover, the degree of approximation to optimality is determined by the level of pretentiousness of the decision maker, which poses the question of whether he can achieve a solution to the problem at certain costs and what consequences are associated with this.

3 General formalized decision-making procedure

Now we shall provide a formalized procedure for finding solutions (based on [2,10,11,16]):

$$P(W,G,C,I,Q,Z) \overset{\Phi_1}{\Rightarrow} \quad ... \quad \overset{\Phi_i}{\Rightarrow} P_i(W_i,G_i,C_i,I_i,Q_i,Z_i) \overset{\Phi_{i+1}}{\Rightarrow} \quad ... \quad \overset{\Phi_R}{\Rightarrow} R(W_R,G_R,C_R,I_R,Q_R,Z_R) \tag{1}$$

Where *P(W, G, C, I, Q, Z)* - description of a certain initial state, in which

- W – a set of descriptions of the problem to be solved;
- G – a set of desired states;
- C – a set of goals and criteria;
- I – a set of current information in possession of decision maker;
- Q – a certain set of different descriptions in possession of decision maker;

- Z – a certain set of knowledge of decision-makers' (in the initial state of the system).

In (1) Φ – some transformation operator that helps decision makers move from one state to another. It can be a purely computer system with or without dialogue with a person, a purely organizational system, etc., and i – transformation stage number.

In (1) $R(W_R,G_R,C_R,I_R,Q_R,Z_R)$ - the resulting solution to the problem after the last transformation operator Φ_R.

It should be noted that in (1) the concept of "state" (especially intermediate) corresponds to the concept of "state at some point in time" [9], interpreted as "the set of essential properties that the system possesses at this point in time." The "set of desired states" in (1) then can be interpreted as a lot of variants of "events" that are desirable in terms of achieving a "result" [9]. The "result" of the action of a decision maker with or without IS is a change in this decision-maker (for example, obtaining information or knowledge), or IS, or in their environment, produced by this action [9]. "Result" is the product of the action of the decision-maker or IS.

Now let's consider sequentially different options for approaches to DM and various ISs, with the IS in question equipped with TDIK in the variant of the elinga, which was described in [19-22].

Let's present a formal procedure for finding solutions in elinga as (2) [19-22]:

$$P(W^{El},G,C,I,Q,Z) \overset{\Phi_1^{El}}{\Rightarrow} \; \dots \; \overset{\Phi_i^{El}}{\Rightarrow} P_i(W_i^{El},G_i^{El},C_i^{El},I_i^{El},Q_i^{El},Z_i^{El}) \overset{\Phi_{i+1}^{El}}{\Rightarrow} \; \dots$$

$$\dots \; \overset{\Phi_R^{El}}{\Rightarrow} R(W_R^{El},G_R^{El},C_R^{El},I_R^{El},Q_R^{El},Z_R^{El}) \qquad (2)$$

Where $P(W_i^{El},G_i^{El},C_i^{El},I_i^{El},Q_i^{El},Z_i^{El})$ - description of a certain initial state, in which

- W_i^{El} – a set of descriptions of the problem to be solved in the KB of elinga;
- G_i^{El} – a set of desired conditions given in the KB of elinga;
- C_i^{El} – a set of goals and criteria given in the KB of elinga;
- I_i^{El} – a set of current information in possession of decision maker;
- Q_i^{El} – a certain set of different descriptions in possession of decision maker;
- Z_i^{El} – a certain set of knowledge of decision-maker.

In (2) $R(W_i^{El},G_i^{El},C_i^{El},I_i^{El},Q_i^{El},Z_i^{El})$ is the resulting solution by elinga of the problem after the last transformation operator Φ_R^{EL}. Let us make a comparison with other approaches based on some qualitative assessments.

4 Comparative review of formal decision-making procedures

4.1 Comparison with the possibilities of the Internet

Most often, the capabilities of elinga are compared with the capabilities of the Internet. Imagine a formal procedure as part of our methodology for finding solutions via the Internet.

$$P(W,G,C,I,Q,Z) \overset{\Phi_1^{Int}}{\Rightarrow} \ \dots \ \overset{\Phi_i^{Int}}{\Rightarrow} P_i(W_i^{Int},G_i^{Int},C_i^{Int},I_i^{Int},Q_i^{Int},Z_i^{Int}) \overset{\Phi_{i+1}^{Int}}{\Rightarrow} \ \dots$$
$$\dots \ \overset{\Phi_R^{Int}}{\Rightarrow} R(W_R^{Int},G_R^{Int},C_R^{Int},I_R^{Int},Q_R^{Int},Z_R^{Int}) \quad (3)$$

Please, note, you usually cannot get to Φ_R^{Int} – the final stage of obtaining a solution without making stops at the preliminary stages, drowning in vast volumes of intermediate information I_i^{Int}, the volume of which in thousands, tens of thousands, hundreds of thousands of links is much more than the amount of information that will be used in the process of problem solving by the elinga, i.e. $|I_i^{Int}|>>|I_i^{El}|$.

Moreover, in most cases you simply can't get to the stage Φ_R^{Int} – the final stage of obtaining a solution or the necessary intermediate algorithms for processing information at the final stages, because they simply are not clearly represented on the Internet, or are not singled out properly.

4.2 Comparison with capabilities of engineering approach

Let's compare the capabilities of the elinga with those of the "engineering approach". Imagine a formal procedure within the framework of our methodology to find solutions in the "engineering approach":

$$P(W^{Eng},G,C,I,Q,Z) \overset{\Phi_1^{Eng}}{\Rightarrow} \ \dots \ \overset{\Phi_i^{Eng}}{\Rightarrow} P_i(W_i^{Eng},G_i^{Eng},C_i^{Eng},I_i^{Eng},Q_i^{Eng},Z_i^{Eng}) \overset{\Phi_{i+1}^{Eng}}{\Rightarrow} \ \dots$$
$$\dots \ \overset{\Phi_R^{Eng}}{\Rightarrow} R(W_R^{Eng},G_R^{Eng},C_R^{Eng},I_R^{Eng},Q_R^{Eng},Z_R^{Eng}) \quad (4)$$

Where $R(W_R^{Eng},G_R^{Eng},C_R^{Eng},I_R^{Eng},Q_R^{Eng},Z_R^{Eng})$ - is achievable.

However, the initial volume of the problems being solved W^{Eng}, is much less then volume of solvable problems W^{El} for the elinga, i.e. $|W^{El}|>>|W^{Eng}|$. In addition, the final volume of intermediate and resulting concepts G_R^{Eng}, C_R^{Eng}, I_R^{Eng}, Q_R^{Eng}, Z_R^{Eng}, created using the engineering approach is smaller than G_R^{El}, C_R^{El}, I_R^{El}, Q_R^{El}, Z_R^{El} for the elinga. This is due to the fact that the elinga uses the same capabilities of the engineering approach, but additionally there are other possibilities due to the much wider set of sources that are fit to be entered into its' KB. In addition, the elinga, due to the

LI from different sources allows you to link together elements that are practically impossible for a particular specialist to quickly detect and use, i.e. the capabilities of systems implementing engineering approach are much less than the capabilities of elinga.

4.3 Comparison with capabilities of expert systems

In ES, due to the principle of construction, you get to Φ_R – final stage of decision making:

$$P(W^{ES},G,C,I,Q,Z) \overset{\Phi_1^{ES}}{\Rightarrow} \ \ldots \ \overset{\Phi_i^{ES}}{\Rightarrow} P_i(W_i^{ES},G_i^{ES},C_i^{ES},I_i^{ES},Q_i^{ES},Z_i^{ES}) \overset{\Phi_{i+1}^{ES}}{\Rightarrow} \ \ldots$$

$$\ldots \ \overset{\Phi_R^{ES}}{\Rightarrow} R(W_R^{ES},G_R^{ES},C_R^{ES},I_R^{ES},Q_R^{ES},Z_R^{ES}) \qquad (5)$$

Where $R(W_R^{ES},G_R^{ES},C_R^{ES},I_R^{ES},Q_R^{ES},Z_R^{ES})$ - is achievable.

However, the set of the problems being solved by ES W^{ES} is much less than a set of problems solvable with the help of elinga W^{El}, maybe by tens or even hundreds of times $|W^{El}|>>|W^{ES}|$. Thus, the possibilities of elinga are much more serious in terms of the breadth of the tasks / problems being solved.

4.4 Comparison with capabilities of Watson System

It is interesting to compare the technology of elinga with the latest development of IBM - IS Watson [6]. For one of the first Watson demos in the competition with humans, a KB that was used contained results of processing sources in form of about 200 million pages. IS Watson rapidly automatically responded to questions and won the competition over a person. The IS was built on a very powerful computing complex with 10 servers with a total of 2880 processor cores. The competition demonstrated the limitation of memory of people in remembering large volumes of specific information and the speed of its processing. Here is another important point - the Watson system made mistakes as well during the game. The level shown by Watson IS in the game, in practice with automatic DM, is unacceptable and in narrow specific areas people give better results. In the DM process, a specific specialist uses either special literature to clarify the situation, or connects a different type of computer system, or consults with another specialist. This is a form of dialogue between the decision-maker and something (someone) in an explicit or veiled form, before making a decision. In elinga, the mechanism of dialogue-associative search for a solution is built in from the start [19-22], it is used in the process of finding a solution, and not at the end with formulation of new request, if the solution does not satisfy, as is currently the case for IS Watson. Over the years, IBM has been able to bring Watson IS to an acceptable DM results for some medical applications where solution stability is valued.

Thus, the Watson IP IS procedure has the form of:

$$P(W^W,G,C,I,Q,Z) \overset{\Phi_1^W}{\Rightarrow} \dots \overset{\Phi_i^W}{\Rightarrow} P_i(W_i^W,G_i^W,C_i^W,I_i^W,Q_i^W,Z_i^W) \overset{\Phi_{i+1}^W}{\Rightarrow} \dots$$

$$\dots \overset{\Phi_R^W}{\Rightarrow} R(W_R^W,G_R^W,C_R^W,I_R^W,Q_R^W,Z_R^W) \tag{6}$$

Where $R(W_R{}^W,G_R{}^W,C_R{}^W,I_R{}^W,Q_R{}^W,Z_R{}^W)$ - achieved only in the long run.

The fact is that Watson is becoming a hostage to its approach. It makes an attempt to automatically create a KB with a volume much larger initially than in the elinga, but it does not use the TDIK mode, which drastically reduces the volume used by KB of elinga [19-22]. The TDIK functions with the participation of expert editors who initially solve many linguistic problems in the texts [25] while creating a KB of elinga, which then sharply accelerates the LI [21]. As a result, IS Watson is forced to use a much more powerful computing complex than elinga (a laptop is enough), and developers are forced to debug the resulting solutions for a long time in narrow subject areas, as it happens in ES [1, 7].

Thus, the elingas' capabilities are more suitable for mass use in varied subject areas, creating relatively quickly necessary knowledge bases. But the elingas still allow for a wide range of calculations, including intermediate, and find rare or new solutions. The latter is especially problematic for the Watson IS, because in the process of working with giant knowledge bases, they simply "drown" in the total volume and do not get a pass from the final statistical models that highlight the most "reliable solutions" based on the highest frequency of their application.

5 Conclusion

The practice of developing and using IS for DM has been demonstrating unconditional success in certain areas and for individual methodologies for decades. For example, this applies to ES, but it also revealed their limited capabilities. On other hand, the use of the Internet and the IS Watson, despite the enthusiasm for them, also revealed fundamental shortcomings and limitations of the development and impossibility of solving many simple tasks / problems that arise before the decision-maker, compared with ISs based on the use of TDIK.

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