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CLOSE IMITATION OF EXPERT KNOWLEDGE: THE PROBLEM AND METHODS

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The problems of the nature of expertise and the possibility to create a copy of expert knowledge in the computer are the main themes for the paper. In the first part of this paper, a short survey of existing knowledge about expert behavior is given. The new method for the construction of exact copy of expert knowledge-CONSER is described. The utilization of new method gives new information about the striking ability of expert to recognize and classify the situations on the basis of their knowledge.

Keywords: Expertise; imitation of expert knowledge; decision rules; classification task.

1. Introduction

In many fields of human professional activity, there are individuals demonstrating an excellent performance that clearly overcomes the average level. These individuals are called experts. According to the dictionary, an expert is "a person with great knowledge, skill, and experience in a particular field". The outstanding ability of experts to solve difficult practical problems in geology, engineering, chess, music, medicine and so on, has attracted the attention of researchers for the past 30–40 years.

There are two research directions aimed to study expert knowledge and performance: cognitive psychology and artificial intelligence. The psychologists are trying to investigate the organization of expert memory, expert behavior in problem solution, and the structure of expert knowledge. The researchers in artificial intelligence are trying to create computer systems to collect expert knowledge and develop the so-called knowledge base that is capable of helping a novice in performing practical tasks. It is possible to say that one of the main goals of artificial intelligence consists of developing artificial systems that imitate expert reasoning. Some problems and tools are common for both directions of research.

It is interesting to systematize the available knowledge that relates to expert behavior, and to develop computer systems imitating expert reasoning.

2. The Nature of Expertise

There are several different theoretical approaches to the nature of human expertise and reasoning.

Historically, the first explanation of outstanding expert performance was connected with the *belief in innate abilities and capacities of experts.* For many years, such explanation was very popular. Many books about geniuses, prodigies, and exceptional performers were published. The typical features of such books were descriptions of early signs of outstanding abilities of a future genius. According to general belief, talent is given to a genius as a gift. They need some exercises to support and develop the talent but the origin is given at birth.

There are psychological studies of expert abilities. First, it is necessary to mention the book of A. Luria, *The mind of a Mnemonist* (1987). The book was devoted to the analysis of exceptional performance of one "mnemonists"(a person who could remember and reproduce without errors a huge amount of information). A. Luria called him by the first letter of his name: Sh. The mnemonist Sh. was known in his twenties of the last century in Russia and his performance appeared as really mysterious. The famous Russian psychologist A. Luria investigated this phenomenon, found the special heuristics and tricks used by Sh. to a great extent uncovers the roots of his performance. A. Luria also demonstrated great variety of inherited capacities of the person including positive and negative features of his information processing system.

In the book by H. Gardner (1983), the theory of multiple intelligence is proposed. According to his point of view, outstanding expert abilities depend on the correspondence between the intelligence profile and the requirements of a professional field. He selected seven profiles: linguistic, musical, spatial, logical-mathematical, bodily kinesthetic, inter-personal and intra-personal. Each of them is independent and has special biological bases. Following this theory, it is necessary to investigate innate children ability to identify the type of intelligence. For example, the ability of small children to differentiate musical tones is a sign of musical intelligence.

K. A. Ericsson and his colleagues[6] proposed quite a different approach to the study of expert performance. They tried to use laboratory experiment to find reproducible results of expert performance. According to their opinion, the analysis of different experimental data demonstrates the leading and surpassing role of extended training. After extensive research, K. Ericsson developed the perception of superior performance through everyday extensive training. The critical factors for a new "talent" are early beginnings of training, a good supervisor and hard work: not less than 4 hours every day for musicians. It was found that for musicians it is possible to compute the number of practiced hours to differentiate top-level (best experts), average and low-level players.[8]

H. Simon and his school had a different view of expertise.[21] They did not deny the role of expert talent (in spite of the difficulty of evaluating its influence in experimental conditions). From the point of view of information processing methodology, the most important feature of an expert is the size and organization of the knowledge base. To simulate the process of knowledge base construction and chunking, EPAM (Elementary Perception And Memory) model has been developed. This model imitates for verbal learning experiment and the ability of an expert to create a chunk, save the chunk in long-term memory and distinguish new and old chunks. The memory of an expert is not only a collection of many chunks, but also an indexed encyclopedia with a convenient (for the expert) way of fast utilization.

In spite of a different perception of the expertise nature, there are many common observations of expert behavior.

3. The Main Features of the Expert Knowledge

It is possible to select features of the accepted expert behavior by majority of researchers.

3.1. *Forward reasoning*

The phenomena of enhanced recall and forward reasoning were shown to be typical for experts.[19] It means that they have superior memory skills in recognizing the patterns in the domains of expertise and tend to work "forward" from the description of a problem to a decision. Novices are working backward from the set of possible decisions to the problem description trying to select a decision corresponding to the description.

3.2. *Fast reasoning*

For experts, it is typical to have fast solution of a problem in the domain of expertise. Sometimes, they demonstrate an instant solution of a problem saying that they have solved it by intuition. The example of Grandmasters playing chess with several players simultaneously is widely known. For medical experts, the behavior is similar: they read the description of a patient and make a diagnosis. They cannot verbalize the intermediate steps in the reasoning simply saying that there is enough information for such a decision. Sometimes, physicians spend more time to check the initial guess. But in the majority of cases the expert decision is usually the right one.

3.3. *The performance in different fields*

It is important that in different domains of expertise, the experts demonstrate the same kind of behavior as novices. In an experiment, physicians were given tasks from different medical fields.[19] They demonstrated the pattern of behavior typical for medical students. The chess experts have an outstanding ability to replace the chess pieces on a board that they have seen only for 3 to 5 seconds. However, for the random combinations of figures, the performance of the experts and novices is the same.[4]

3.4. *Magical 10 years*

It was found that approximately ten years of intensive training are needed even for the most talented people to become an expert in the field. For example, Mozart was composing at the age of 5, but his world-class music was composed at the age of 17. The same number of years is required by famous chess players: Kasparov, Fisher, etc. Even in natural sciences like physics, the same number of years was needed for Einstein before the publication of his first high-level paper.[21]

3.5. *The size of expert memory*

The outstanding performance of experts could be explained by the big size of the knowledge base located in long-term memory. For example, for the chess experts, according to the evaluation, the number of chunks (familiar patterns of pieces) held in the memory lie in the range from 50,000 to 100,000.[6] According to Simon, the memory of an expert could be presented as indexed in an encyclopedia.

3.6. *The difference between novices and experts in the organization of information*

H. Boshuizen and H. Schmidt (1992) found that physicians come to use a progressively smaller number of generalized clinical signs as they acquire more experience. They, probably, arrive at such signs by trials and errors. For cases where the experts and novices do not differ by the number of diagnostic signs,[22] the difference is in how experts use the signs, that is, in the decision rules. According to the ACT (Adaptive Control of Thought) theory advanced by J. Anderson (1983), the expert rules may be regarded as a "compiled knowledge". By reference to mathematical problems, Anderson has shown that complex productions are formed in the subjects as they master the material, and that they use the constructions as a single rule. This is, probably, how the experts form their decision rules. It was found that, in making a diagnosis, the experts tend to use binary scales of diagnostic signs, that is, to take into account clearly distinguishable and opposite values (for example, skin is dry or moist; breath is pathological or normal; etc.).

3.7. *Unconscious expert knowledge*

The interesting perception of the expertise is connected with the unconscious nature of expert knowledge. Really, the expert skill is predominantly unconscious.[11,20] It was demonstrated in the experiments that a person could develop a kind of skill without the possibility to verbalize his/her behavior. There is evidence that an essential part of expert knowledge in different professional fields is located on the unconscious level and could not be discovered by questioning the expert. It means that such popular tools, as verbal protocols (that have been used by the schools of Simon and Ericsson) are useless in the elicitation of expert knowledge.

Unconscious learning now becomes one of the most critical directions of the research in cognitive psychology. The first results in this direction belong to A. Reber. It was demonstrated that people could unconsciously discover and use some information about the relationships between events. The experiments demonstrate that the human information processing system could learn complex relations unconsciously and it processes the relations in a more effective way in comparison with conscious education. The unique feature of unconscious knowledge is stability for a long time. The hidden rules of the artificial grammar could be conserved in the memory from several weeks to several years.

4. Computer Imitation of Expert Knowledge

The unique features of expert knowledge and its role in human society attract the attention of computer scientists. It is interesting that the first test for the existence of artificial intelligence, A. Turing test, was in reality an analysis of the computer ability to imitate human judgments and reasoning.

There are numerous attempts to collect expert knowledge in the computer. The goal of such efforts consists of the creation of sources of expert knowledge-artificial systems helping novices in complex problem solutions. The computer systems based on expert knowledge is known as expert systems.

The purpose of the expert system construction is to disseminate the expert's knowledge, provide opportunities for the less-skilled users to have an advice as if from the expert himself at any time and place. It is clear that this objective requires the creation of an expert's "double" in the computer. Accordingly, the knowledge base is the core element of an expert system.

The problem of expert knowledge base construction is especially important for a certain kind of problems. There are no reliable and adequately verified quantitative models for these problems, making it possible to relate the input and output, a concrete situation and the outcome. They are characterized by uncertainty, a description of situations in qualitative (rather than quantitative) language, insufficient certainty of the consequences of decisions made by the expert. Most appropriate here is the definition suggested by H. Simon: ill-structured problems, i.e. such problems where "qualitative, hardly formalizable and indefinite factors tend to dominate". We may cite numerous examples of such problems: medical diagnostics, technical diagnostics, organizational surveys, etc.

Human intuition is of special value when applied to ill-structured problems. The expert knowledge allows him or her to solve problems at a surprisingly high level. Should it be the case, and then there arises a tempting idea to impart this knowledge to computer, to imprint this ability in the knowledge base. It is evident how complex this process of reasoning is.

5. Main Difficulties in the Construction of Expert Knowledge Base

The main problems in the expert imitation by a computer model are as follows:

First, the amount of expert knowledge about the problem area can be very large (see above).

Second, there arise difficulties associated with the method of knowledge elicitation. The expert knows much, but this is concrete knowledge-based on the past experience, on a combination of practical cases. At the same time, the built-in knowledge base must be an "ability to analyse", which does not necessarily follow from practical cases.

Third, an expert could demonstrate his or her skill by the evaluation of a whole image (gestalt)-complete description of a situation. A well-known fact follows from here: the expert knows more than he is aware of. In other words, the expert's ability to present his knowledge in the form of clear rules is always limited. The essential part of the expert's knowledge has an implicit nature.

Fourth, the expert's behaviour is largely determined by the specifics of human information processing system. It would be wrong to treat an expert as an infallible source of information. People, even the most experienced individuals, make errors in their judgements. Besides, in complex situations, people tend to introduce simplifications in the handled problem and they make use of heuristics, simplify the problem, etc. Hence, knowledge bases are to be constructed with respect to the specifics of the knowledge source — the expert.

6. Existing Methods of Expert Knowledge Base Construction

The available methods of Knowledge Base (KB) construction are largely designed for the problems whose structure (a set of signs and a list of diagnostic decisions) is known. The ideas of the methods could be presented in the following way.

6.1. *The rules of reasoning*

The expert himself articulates the chains of his logical reasoning leading from causes to effects. A strong point of the method is that the expert presents his knowledge in the form of a chain of cause-and-effect relationships of the type "if, . . . , then" (productions) which are easily "mastered" by the computer. This approach is connected with some problems. The amount of rule-productions required for the construction of a full KB is rather large in any real-life problem. Thus, the process is time consuming. Second, it is necessary to have skilled specialists working with experts. They are to know how to ask experts and how to put expert knowledge in the computer. That is why there has emerged a special field-knowledge engineering. The realization of difficulties associated with knowledge elicitation from experts lead to the conclusion: it is necessary to train specialists with some skills in the problem area and programming — sort of intermediaries, and let them question the experts and build a KB.

The knowledge engineers are to have special computer tools for collection of expert knowledge. Special expert knowledge shells have been developed in big amounts. Knowledge engineers are to have computer programs to represent collected knowledge, to demonstrate it to the expert, and to draw the conclusions from the collected knowledge. Many computer systems employing such goals have been constructed. The most popular is KADS system developed in the University of Amsterdam.[23]

The idea of step-by-step expert knowledge collection defined to a great extent the way of construction and utilization of the expert system. Typical parts of expert systems are: the block of logical inference (finding the solution of a particular case on the relatively small set of collected productions); the knowledge base (a set of collected productions); and the interface user-computer (questions to a user helping to find some rule in a knowledge base).

6.2. *Evaluation of the whole by separate parts*

The expert measures the probabilities with which the situations fall in concrete states depending on individual attributes. Thus, for example, a skilled physician indicates to what probability some or other value of the diagnostic sign corresponds to one or other disease. Clearly, this approach sharply reduces the labour-intensity of KB construction. For example, it is possible to cover a large quantity of signs and diseases, for each pair "sign-disease" is considered separately. However, there are two difficulties connected with the utilization of this approach.

First of all, people are far from good at assigning probabilistic estimates — this problem is rather complex for the human information processing system, which has been convincingly proved by numerous psychological tests.[10]

Besides, it is precisely that the combinations of signs determine, in real-life situations, whether some or other state possesses a property (e.g. a certain disease of the patient) or not. Given such presentation, the expert loses the integrity of the situation, and only the integrity allows him to take a full advantage of his intuition. Finally, the rules of the aggregation of individual probabilistic estimates are extremely primitive. They usually use the sum total of probabilistic estimates and take maximum or minimal probabilities. This rule is neither assigned nor tested by the expert. But the KB programmer-designer defined as convenient for him (her).

No difference appears in the case of utilization of the fuzzy set approach. In constructing a KB, the expert aims to make an essentially uncertain situation more certain (e.g. to classify). Fuzzy sets are conductive to quite the reverse — uncertainty is added to the initial problem. Starting with an attractive (for the expert) introduction of verbal concepts, these methods quickly turn them into numbers by utilizing arbitrary and invalid membership functions.

6.3. *A knowledge base as a set of practical cases*

The third method of KB construction is "by examples", when the descriptions of real situations with expert's solutions are entered in a KB. It is worth noting that direct use is made of the outcome of the expert situational analysis. It is clear, however, that with this approach the number of such examples must be huge for practical problems. Besides, these cases must be diverse — they should cover various combinations of attribute values (diagnostic signs). One expert whose knowledge base is under construction must solve all of these cases. Altogether, this makes the approach very difficult for implementation.

7. CONSER: The Method and System for CONstraction the Space of Expert Reasoning

Our approach to KB construction could be called an exact imitation of an expert reasoning for the classification task in a relatively narrow professional field.[12,14,16] As was stated above, the strong feature of an expert behaviour is its ability to classify any possible scenario in his or her professional field. The main idea of the approach presented below is to collect complete expert knowledge in a professional field and to describe it in a compact way. We shall present below the main features of the approach, taking some examples from the field of medical diagnostics.

7.1. *Statement of the problem*

The problem under consideration can be formulated in the following way.

Given:

$K = \{K_1, K_2, \ldots, K_N\}$ — a set of diagnostic signs for estimation of an object;

$K_q = \{k_1^q, k_2^q, \ldots, N_{\omega_q}^q\}$ — a set of estimates on the scale of qth diagnostic sign; where ω_q — a number of estimates on the scale of qth criterion; the estimates are ordered from the best to the worst;

$Y = K_1 \times K_2 \times \cdots \times K_N$ — the Cartesian product of diagnostic sign scales that defines all possible objects (combinations of estimates);

$y^i \in Y$, $\boldsymbol{y}^i = (y_1^i, y_2', \ldots, y_N^i)$, where y_q^i is a gradation on the scale of qth diagnostic sign;

$C = \{C_1, C_2, \ldots, C_m\}$ — is a set of decision classes.

The linear reflexive anti-symmetric transitive relation Q_C is given on the set C so $(C_i, C_j) \in Q_C$ if $i \leq j$.

The linear reflexive anti-symmetric transitive relation Q_q is given on each set K_q so if $(K_i^q, k_j^q) \in Q_q$ if $i \leq j$.

Relations Q_C and Q_q reflect ordering correspondingly the decision classes and scale gradations on the basis of expert knowledge. We introduce a reflexive anti-symmetric transitive *dominance relation*

$$Q = \{(\mathbf{v}, \mathbf{w}) \in Y \times Y | \forall q \in 1,\ \bar{Q}(v_q, w_q) \in Q_q\} \tag{1}$$

on the set of all possible vectorial estimates Y.

Needed: to build a reflection $F : Y \to \{Y_l\}$, $l = 1, \ldots, m$ on the basis of expert knowledge (where Y_1 is a set of vectors belonging to lth class) so if $(\boldsymbol{v}, \boldsymbol{w}) \in Q$ and $\boldsymbol{v} \in Y_i$ then $\boldsymbol{w} \notin Y_j$ for any $j < i$.

None of the vectors from Y dominating the given one could be assigned to a less preferable class. We refer to the partition of the set Y as non-contradictory if this requirement is fulfilled. More formally, the partition of Y is *non-contradictory* if it meets the following condition

$$\text{if } y^i \in Y_k,\ y^j \in Y_l,\ (y_i, y_j) \in Q \text{ then } k \leq l\,. \tag{2}$$

Let us note that a certain verbal description corresponds to each class of solutions, each attribute, and each value within the range of each attribute.

The vectors of the space Y create all possible cases for which it is necessary to collect expert knowledge. If such knowledge is collected, a KB is called complete — it is able to give an answer to any question in this professional field.

Example

Recently, there have been a lot of cases of acute drug intoxication in Russia, and there exists a lack of qualified specialists capable of forming proper diagnosis of this condition. According to some estimates about 50% of all poisonings are provoked by improper use of medicines. Such medicines are available in every family and it is very easy to exceed the critical dosage that could lead to a fatal intoxication. That is why the problem consists of developing an expert system for diagnostics of poisonings caused by an overdose or misuse of widespread medicines.[2] Such a system could be helpful for emergency room physician.

In order to find the solution of the problem, we have to construct a knowledge base of an expert system that can help a physician to having great experience in the diagnostics of acute drug intoxication. The majority of medicines could be divided into 19 different groups having quite different pattern of intoxication. For each group, a knowledge base is to be constructed.

One of the examples of expert knowledge base construction is the case of poisoning by barbiturates. The typical drug for this condition is amitryptyline. Let us assume that a patient is to be poisoned and in a coma.

Table 1 presents the diagnostic signs used by the expert (the first values are the most typical ones for such kind of intoxication).

Let us note that diagnostic sign values are ordered by typicality par respect to the first decision class: "There is suspicion of intoxication by barbiturates".

All possible combinations of diagnostic sign values create complete space of possible objects (possible patients). The expert diagnostic skill demonstrates itself in the ability of the expert to classify such objects into two decision classes:

C_1 — there is suspicion of intoxication by barbiturates;

C_2 — there is no suspicion of intoxication by barbiturates.

We could imagine that there are Y "boxes" in multidimensional space. The goal is to collect expert knowledge and give a "label" to each "box". After the construction of such a knowledge base, the expert system could give direct and full recommendations to a user providing the exact answer to any question.

Table 1.

1	Patient's behavior before a coma
1.1	Motor excitation, aggression
1.2	Hallucinations, tactile and auditory
2	Color of skin
2.1	Normal
2.2	Hyperemia
3	Convulsions
3.1	There are convulsions
3.2	No convulsions
4	Pupil
4.1	Mydriatic
4.2	Miotic
5	Pulse
5.1	Tachycardia (pulse $>$ 110)
5.2	Moderate tachycardia (pulse 90–100)
6	Characteristic of pulse
6.1	Arrhythmia
6.2	Normal

The knowledge base of such kind could create possibility for collection and *conservation* of expert knowledge, or CONSER method.

7.2. *The main ideas of CONSER method*

The CONSER method could be presented in the following steps:

Step 1. Preparation for expert-computer dialogue

The structure of the classification task is put into computer as decision classes, diagnostic signs and estimation scales of signs. The Cartesian product of criteria scales defines the set of possible objects — possible descriptions of objects in terms of criteria. An expert is asked to order diagnostic sign estimates by the typicality for each decision class (see the example above).

Step 2. Elicitation of expert knowledge

As was stated above, an expert could use his or her knowledge by analyzing the problems presented in a familiar way. The first idea of CONSER method consists in elicitation of expert knowledge by presentation of a complete description of an object in terms of diagnostic signs. Taking the example presented above we could formulate a possible question to an expert as follows:

"There is the following condition of a patient:

Motor excitation, aggression before a coma; Skin: hyperemia; There are convulsions; Mydriatic pupil; Pulse: tachycardia, no arrhythmia.

Please, select one of two possible diagnoses:

C_1 — there is suspicion of intoxication by barbiturates;
C_2 — there is no suspicion of intoxication by barbiturates".

Step 3. Processing the expert information

It is clear that the number of possible objects is too big for direct presentation of all of them to an expert. The second idea of CONSER method consists in the utilization of *binary relation of domination by typicality.*

Let us suppose that the expert put an object into class C_1. It means that the expert perceives the "image" of the objects as closest to this class. However, values of some diagnostic signs could be different from the most typical ones for the class C_1. This fact could be used for indirect classification of several other objects.

It is possible to use a linear reflexive anti-symmetric transitive relation Q_q given on each set K_q so if $(k_i^q, k_j^q) \in Q_q$ in $i \leq j$.

On the basis of transitive *dominance relation* (1) on the set of all possible vectorial estimates Y one could classify, in an indirect way some object and construct *the cones of domination by typicality.* In other words, it is possible to use one decision of an expert to classify several objects.

Let us take the example presented above. Let us suppose that the expert assigns the object presented above to class C_1. The values of diagnostic signs "Skin" and "Characteristic of pulse" are not most typical for class C_1. So, we could create the objects replacing the values of such signs by more typical for class C_1 and allocate them to this class.

Let us note that in a general case, the operation of expansion by transitivity of dominance relation is valid by the condition of diagnostic sign independence in multidimensional space. Fortunately, it is possible to check the supposition about independence property of the space (see below).

Step 4. Choice of an object for classification

The number of indirectly classified objects depends very much from the selection of next object to present for expert decision. The problem arises: to find a good strategy for selection of objects for the presentation to an expert. The third idea of CONSER method consists in finding the most *informative questions* to an expert. Algorithms for the solution of this problem are to be evaluated by the criteria of minimum average number of questions to an expert needed for the construction of complete classification. The criterion of efficiency for the classification method is the minimal load on the expert: the minimal number of questions needed for the construction of a complete classification. Indeed, expert time is very valuable. A knowledge base may include hundreds and thousands of objects. The process of knowledge base construction could be very time consuming. That is why the criterion of minimal number of questions needed for the construction of a complete classification goes well with method of efficiency estimation.

Several algorithms have been developed for the solution of this problem.[15] In the first algorithm-CLASS, before presentation of an object the computer calculates every not-yet-classified object for the expected amount of information that could be received after the presentation and selects the most informative object.[12] The family of algorithms based on different ideas has been developed. The survey of some of them is presented in Ref. 17. The most advanced CYCLE algorithm allows one to classify 500–700 objects per one hour of expert work.

Step 5. Check of expert information for consistency and check of independence property for multidimensional space

During the dialogue, the expert could make contradictory decisions. The reason could be an error or violation of independence property of multidimensional space. Fortunately, the cones of domination by typicality (see above) are intersecting ones. In other words, some objects (up to 25%) could be classified several times. It gives the possibility to evaluate the expert information for consistency. For the cases of contradictions, contradictory information is presented to an expert for a detailed analysis. The consequences of such analysis could be a simple correction of a random error or development of a new combination of diagnostic signs to eliminate interdependence among them. The fourth idea of CONSER method consists of *checking the expert's information for contradictions* (intransitivity) and providing a useful guide for its analysis.

The computer system puts a question after a question until all possible objects are classified. In this case, a complete knowledge base of the expert for a narrow professional field is constructed. As a result, it is possible to build a complete and fairly large contradiction-free expert knowledge bases in a rather short time.

8. The Quality of Imitation

The main criterion for evaluation of expert knowledge bases quality is the degree of coincidence for decisions taken by the expert and the computer. The estimation of the basis of criterion has been done several times.

For small knowledge bases (about 200 objects) an expert have been asked to estimate every situation. After some time (from two to three weeks) a knowledge base was constructed by the method presented above. The coincidence of the results was practically full (the difference was only 2–3 objects from 200).[14]

For big knowledge bases the check of coincidence was done by the presentation of some objects especially difficult for the diagnostics. Such objects were "located" near the "boundary" that divided decision classes (see below). It was full coincidence for the majority of objects. Thus, the knowledge bases developed on the basis of CONSER approach create good enough approximation of expert implicit skill.

An expert knowledge base of very big size has been checked in the hospital for one and half year. In this case the level of the expert knowledge has been checked simultaneously. For 750 real objects, the diagnosis of the expert system "Acute Stomach" was confirmed in 94–97% cases.[7]

9. Boundary Objects and Decision Rules

After the construction of a complete knowledge base, it is possible to make a formal analysis of the collected objects. It is possible to find upper and low Pareto sets for each decision class. The objects of upper Pareto set and low Pareto set are not dominated by their typicality.

Let us introduce the notion of *boundary object*. Let us call an object as a boundary one for the decision class if the change in one value of a diagnostic sign changes the classification of the object. Boundary objects could represent the constructed classification due to the fact that any object presented to computer could be classified by the comparison with boundary ones.

In the paper,[14] the hypothesis has been put forward: boundary objects represent implicit expert decision rules. To check the hypothesis boundary objects were combined into groups having either the same diagnostic sign values or the same structure (number of most typical values for the corresponding decision class). It was found that the groups could be described by relatively simple decision rules.

A typical decision rule could be represented as: "$p_k^i, \ldots, p_{k+l}^i$ and no less than t values typical for the class C_n from the remaining diagnostic signs". Here, the representation $p_k^i, \ldots, p_{k+l}^i$ signifies a conjunction of the values of the most important (for the allocation to the class C_n) diagnostic signs, that should be supplemented with no less than t values of less important attributes. Typically, the number of such rules for a decision class does not exceed 3 or 5. An additive property of the rules appears to be important because unconscious addition is a widely encountered procedure performed by the human system of information processing. In a particular case, when all diagnostic signs are equally important, the decision rule could be represented as "no less than t values typical for the class C_n from all diagnostic signs".

The study has shown that the behavior of an expert dealing with the problems of classification can be simulated to a good accuracy with the use of a small number of decision rules having a fairly simple structure. This made it possible to advance the hypothesis that, as a result of long-standing practice, an expert forms subconscious rules for recognition of similar structures.

For the example presented above one expert decision rule is as follow:

"There is suspicion of intoxication by barbiturates for the cases when no less than four diagnostic sign values from six are typical for such intoxication".

The analysis of several knowledge bases constructed by CONSER method is given in Table 2. In this Table: L-size of the problem (the multiplication of number of values of diagnostic signs); F-number of decision rules describing expert decisions.

During the classification we were trying to make observations following how an expert would make decisions. For the majority of objects, decision was made while

Table 2.

L	64	64	128	256	256	1728	4096	20736	36864
F	4	5	5	4	5	3	5	7	5

the expert was reading its description. After reading the last line (and sometimes before it) the expert made a fast and mostly noncontradictory conclusion. But for the difficult objects, the expert recalled the past cases — patients of similar nature. Almost all such objects were boundary ones.

During classification, an attempt was made to use a verbal protocol. The protocol proved to be extremely uninformative. The expert simply quoted the values of the diagnostic signs typical for the class under consideration and stated that they were sufficient for decision making.

An attempt was made to find the decision rules directly. One expert was presented cards describing objects belonging to one class and asked to formulate the rules whereby they were assigned to a particular class. This attempt failed. The rules formulated by the expert described only some part of the decisions.

10. Discussion

The striking ability of experts to recognize and classify the situations is based on their knowledge. The results described above allow us to define some specific features of such knowledge. First of all, knowledge of a good expert is very stable. If one puts a question in the form usual for everyday practice, one mostly receives the same answer.

It is possible to assume that, during many years of practice, experts have developed very informative and compact diagnostic rules. If the number of their rules is relatively small, say no more than 7, for knowledge bases of different sizes, then it is considered as in the limit of short-term memory capacity.

The diagnostic rules represent the craft of the expert. As with any craft, it cannot be verbalized. It is known that the transfer of a craft from an individual to another is possible only by imitation. The craft is predominantly unconscious. The expert repeatedly classifies objects in full compliance with the unconscious decision rules, but cannot explain or even recognize such rules.

11. Conclusion

The results presented above are directly related to the well-known product of artificial intelligence or expert systems. The logic of an expert reasoning could not be completely understood on the basis of separate production elicitation. Of course, productions represent pieces of expert knowledge. But the entity is not a simple sum of the parts. It is demonstrated by a popular Indian tale on how a group of blind persons could not receive the right image of an elephant by feeling its legs and tail.

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