A New Approach to the Solution of Expert Classification Problems

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Criteria for knowledge base construction

Knowledge base (KB) is a principal component of expert systems and many decision support systems. For these systems to be at a high level of sophistication, KB must meet the following set of requirements:

1. KB must be valid: it should be built on the basis of knowledge of a highly skilled expert;
2. KB must be full: it must contain answers to all possible questions within a preliminary outlined and structured problem area;
3. KB must be consistent: it must contain consistent answers to any questions put to it;
4. KB must be reliable. First, in the course of its construction, use is made of only those questions to the expert which are permissible from the standpoint of human information processing system. Second, any expert responses should be tested for consistency. Third, the answers to the experts should imitate a routine activity performed by experts within the frameworks of their professional activities.

Expert classification problem

Diagnostic problems constitute a sizable share of problems the expert systems are designed for. Thus, for example, in medicine it is necessary to diagnose on the basis of examination results, i.e. identify a concrete type of disease (Shortliffe et al., 1979), in chemistry the data on chemical compound structures lead to a conclusion on certain properties (Rosenblitt & Holender, 1983), in technical diagnostics a number of indirect characteristics make it possible to determine the cause of system breakdown or failure, or to conclude on the correspondence of the article to certain requirements, socio-economic studies aim at identifying homogeneous groups of population, economic regions etc.

The diagnostic expert systems arc in effect intended for solution of classification problems: they put each object (situation) out of some problem area in correspondence with its diagnosis (property, course of actions).

Classification problems were traditionally considered within the pattern recognition theory. Characteristic of the models employed is a common approach to classification problems. It assumes a preliminary structuring of the problem by way of assigning a variety of potential membership classes of objects under study, a set of attributes describing these objects, and their scales. In some classification problems recognition is exercised automatically. In others, membership classes for a number of objects are assigned (learning sample) and used as a foundation for the recognition algorithm, capable of identifying the membership class of an arbitrary object on the basis of its description.

The pattern recognition approach proved rather productive. The development of algebraic approach (Juravlev, 1978) and of structural minimization method (Vapnik, 1979) permitted construction of efficient classification algorithms for a wide range of problems. At the same time,

the experience gained in application of the pattern recognition techniques exposed some of their weaknesses.
This is primarily the case when the available empirical material (learning sample) is clearly insufficient for the construction of reliable classification algorithms. As applied to many problems, the generation of large homogeneous samples runs into considerable difficulties.
On the other hand in many areas dealing with classification problems, there are highly skilled specialists successfully performing their professional duties. A more efficient utilization of their knowledge could considerably improve solution of diagnostic problems. It is not always possible to use effectively the pattern recognition methods in the computational classification algorithms.
Finally, note a rather significant psychological constraint. The use of mathematical methods in applied research indicates that the rate of application of the decision methods and procedures largely depends on their clarity and explicability (Larichev, 1979). To be confident in the produced results, the user ought to understand the procedure of their generation and be able to verify them.
As is known, pattern recognition models are not, ordinarily, used by professionals in solving classification problems: the expert judgements in analyzing complex, ill-structured situations mostly result from logical reasoning rather than numerical procedures (Hayes-Rott, Waterman and Lenat, 1983). Therefore, the complex numerical methods of information processing related with pattern recognition models do not represent the real inferences of the experts, hence the logics of results derived by these methods sometimes engender their distrust and find no adequate application.
The recent development of interactive systems based on expert knowledge gave rise to a quite different approach to solution of classification problems (Ally & Coombs, 1981; Feigenbaum & McCorduck, 1983). This approach assumes the availability of skilled professionals in each problem area whose knowledge and experience are helpful for the less skilled specialists in solving similar problems.
The knowledge-based systems (KBS) apply their heuristic rules and simulate the substantive process of problem solution by experts. Thus, in contrast to formal algorithm approach based on quantitative information processing, the problem is solved directly by descriptive methods: it is assumed herewith that this would improve the quality and validity of the respective problem solution.
In spite of the before mentioned KBS advantages underlying their wide-ranging popularity and intensive development, a significant shortcoming of such systems is that the existing methods of their construction do not guarantee classification of each object studied by the system. The KBS are usually not designed to deal with the problem of full classification of the object under study. As was mentioned earlier, the major purpose thereof is to fix the expert knowledge in some subject area. The knowledge makes it possible to classify some object states leaving all other potential states beyond the developed system. Obviously, the very formulation of complete classification problem is feasible only when the subject area was structured in advance (definition of a set of attributes of their values) as is done, for example, in pattern recognition.
Thus, the strong point of pattern recognition approach is an explicit structuring of classification problem permitting full classification, whereas the major weakness is the construction of classification rules based on formal models. In recent years this shortcoming has been increasingly recognized by the pattern recognition specialists themselves. This is manifested in the fact that the methods oriented at expert information, logical decision rules are gaining an ever wider acceptance.
On the other hand, the principal advantage of KBS is an opportunity for a flexible and convenient presentation of expert information, utilization of logical inference rules permitting descriptive explanations of the decisions made. At the same time, the fragmentary nature of expert knowledge elicitation is a KBS shortcoming practically ruling out construction of full KB. In this connection, the KBS studies generated approaches where the process of knowledge elicitation from the expert is organized in a structured form, i.e. concrete answers to clear questions.

Thus, the considered statements of classification problem tend to draw nearer. We believe that the problem statement representing the basic requirements of the both approaches should have the following form.

There is a set of attributes describing various states of the object under study. Each attribute is assigned a range of potential values. The Cartesian product of attribute scales determines a combination of potential object's states. It is necessary, on the basis of expert knowledge, to determine the properties of the object in each of its states, and so, classify all states of the object under study.

This statement of the problem will hereafter be referred to as expert classification problem. Note that in (Clancey, 1984) it is suggested a term "heuristic classification". It was shown in (Yagmai & Maxin, 1984) that irrespective of the form of knowledge presentation (frames, networks, products) a KB can be viewed as a totality of states of an object under study classified by the expert. We maintain that the term "expert classification" more intimately corresponds to the specifics oft he considered problem.

The formulated expert classification problem requires definition of various properties of the studied object, which is the part of a traditional diagnostic problem. We shall treat it as the key classification problem. Besides, in handling practical problems a necessity may arise to specify the degree of manifestation of the examined properties, which can be ordered in a natural manner. Note that the definition of groups of object's states in which the examined property manifests itself to one and the same extent, implies classification of the object states into a set of ordered groups. We shall refer to this expert classification problem as ordinal classification problem.

Approach to problem structure elicitation

The first stage in expert classification task solution is the determination of the problem structure set of diagnostic attributes, analyzed by the expert and describing different object's states.

Usually while constructing the knowledge base for expert systems, this set is defined in an informal way - the knowledge engineer asks the expert to give attributes necessary to take into account in the task of expert classification. It is clear that part of attributes may be omitted, and some auxiliary ones may be included into this set. In the other way of fulfilling this task the expert is asked to give the description of one of the situations to be classified and take attributes from this description. Let us note that usually such description reflects the typical, ordinary cases and, as so, some important attributes may be absent in this description.

The full set of necessary attributes may be formed to our mind as a result of logical combination of process of problem structuring with the routine for the expert diagnostic task. In accordance with such approach is the idea of diagnostic games, described above (see Gelfand, Rosenfeldt and Shifrin, 1985).

The main peculiarity of the diagnostic games is the simulation of a dialogue (in a distance) of an experienced expert with unexperienced specialist, who is to examine the object. The solution of a diagnostic task at a distance (upon telephone, radio, etc.) is rather popular, i.e. in medical diagnostics. It is possible to use this idea but for classification of a specially formed sample of such objects, so as to receive the mostly informative data on necessary attributes.

The proposed approach is the following. With the help of a computer the situation of a "remote consultation" is simulated. The computer informs about the probable class of decision and asks the expert to put necessary questions (parameters). After receiving the current parameter, the computer displays the question about its possible values (estimates), especially characteristic of the class under consideration. The sequential combination of characteristic parameters' values forms an image of the object under study from the analyzed class. After the set of attribute is full enough to make the decision (to put the diagnosis), the experts informs the system. Then the computer selects less characteristic values for parameters and the expert is able to add new attributes, necessary to make the decision in such, more complicated situation. The process is over when the expert does not add new attributes, but simply identifies another class for some untypical (for the class under consideration) situation.

Approach to expert knowledge elicitation

Two principal actors take part in knowledge base construction. These are, first, an expert or a group of experts whose knowledge is used in designing KBS and, second, a system designer or knowledge engineer determining the method of knowledge representation, system structure, requirements to the contents and format of expert information. The KBS development requires a large volume of expert information, therefore the organization and execution of expert interviews require considerable efforts on the part of both designers and experts.

Only a structured procedure of the expert's polling can provide a basis for a full and consistent diagnostic system KB, for it allows elicitation of all necessary information from the expert to fill in the KB. Naturally, the logics of such procedure must be related to that of KBS organization.

The expert knowledge elicitation system must be capable of analyzing the available information, determining its missing fragments, and enquiring the expert in a form so that the obtained expert information could be used for the construction of a full KB of the system. Thus, in contrast to the first method of knowledge elicitation whose pattern is determined by the expert himself the requirements to the format of expert information must in this case be determined by the interactive knowledge elicitation system which would have allowed systematization of the process of expert information elicitation.

In arranging an interview with the expert a considerable attention should be given to reliability of information elicited from the expert which, as is seen from descriptive research, is largely determined by the methods of its elicitation. As is known, building up of professional experience boils down to mastering skills in solving a certain range of problems. In the process of communication they use concrete forms of questions and messages which arc customary in the given professional area. As is indicative by the experience of interaction with experts, the use of traditional methods of information acquisition, they are familiar with, essentially improves its reliability and validity (Larichev, 1979).

In their practical activities, experts dealing with diagnostic problems have to determine classes of diagnosed objects membership on the basis of their description. In medicine, for example, the physician makes a diagnosis only following the patient examination. Hence, classification on the basis of some object description is common practice for experts in solving diagnostic problems. It seems more reasonable, in this connection, to organize the process of expert knowledge elicitation by rating (classifying) the concrete object states, i.e. to obtain information from the expert in the form of a list of membership classes of object states.

Note that in order to ensure the maximum approximation of the problem, suggested to the expert in the process of interview, to the form he (she) is accustomed to, it makes sense to use discrete scales of potential attribute value estimates expressed verbally. For example, in diagnosing heart diseases, the "Localization of pain" sign may have a scale of the following three values: (1) retrosternal pain; (2) heart pain; (3) pain elsewhere in the chest. In cases where there is a continuous scale of attribute values, it can frequently be transformed into discrete, for the expert usually takes account of only definite value gradations on the continuous scale. Thus, for the sign "Patient temperature" the following value scale often suffices: (1) higher temperature (over 37.0), (2) normal temperature, (3) lowered temperature (below 36.0).

Given this statement of the problem, an expert can easily apply his intuition, experience, etc. Note that the physician has to communicate information in a language close to the one he is accustomed to - assume a disease and the degree of the assumption, which highly resembles his routine activities. This makes it possible to consider the thus elicited information reliable.

Hence, given the traditional approaches to the construction of a diagnostic system KB, the expert has to solve a problem of his (her) knowledge synthesis, which is rather complex for him (her), while the suggested method corresponds to his routine case studies. Here he (she) unconsciously uses many of his skills and devices which can hardly be explicitly formulated. Therefore, we treat construction of a diagnostic system KB as an expert classification problem to be solved on the basis of a direct expert evaluation of the states of the object under study.

The implementation of the advanced approach to KB construction, however, faces a number of problems. The first one is conditioned by the dimension of the problem solved. The point is that the real expert classification problems are of large size determined by the number of properties, attributes and possible values on their scales. Accordingly, a direct classification of all states of the object is infeasible.

The second problem is associated with possible expert errors made when assessing complex, multiattribute situations. The psychometric experiments conducted thus far produced an extensive material relative to elicitation of reliable information from experts and decision makers. The principal output of the studies was a conclusion on the presence of a series of constraints on human capabilities to process huge volumes of information (Larichcv, 1982b).

According to a hypothesis advanced in (Simon, 1981) the constraints are largely conditioned by a limited capacity of short-term memory of people, their inability to handle a huge amount of unstructured information at a time. As experiments indicate, in facing complicated situations people use diverse simplifying heuristic rules aimed cither at information aggregation or its sequential consideration (Kahnemann, Slovic & Tversky, 1982). The application of such rules can distort the obtained expert estimates, reduce their accuracy, lead to errors.

Thus, the developed procedures of the expert's polling must, on the one hand, minimize the scope of expert efforts and, on the other, facilitate the analysis of information elicited from the expert with respect to its consistency.

Approach to organization of the expert's polling

In structuring an expert classification problem we use a hypothesis that estimates upon different attributes' scales may be differently inherent in one and the same property (or, which is the same, class) (Larichev et al. 1987). The expert is assumed to be able to order estimates upon each attribute scale with respect to their inherence for the corresponding class, and this ordering is independent of the estimates upon other attributes.

Let us explain the suggested approach for medical diagnostics as an example. As may be seen from Table 1, the estimates upon attribute "Pain localization" are differently inherent to the three different diseases: "myocardial infarction, stenocardia, and cardialgia.

Most inherent to myocardial infarction is, according to the expert judgement, retrosternal pain (1). Less inherent is pain to the left of sternum (2), and much less - pain elsewhere in the chest (3). As for stenocardia and cardialgia, various localizations of pain manifest themselves in a somewhat different manner (see Table 1). Similar information about various attribute estimates for different diseases can be obtained for all other attributes.

	Retrosternal Pain	**Pain to the left of sternum**	**Pain elsewhere in the chest**
Myocardial infarction	**1**	**2**	**3**
Stenocardia	**2**	**1**	**3**
Cardialgia	**3**	**2**	**1**

Table 1: Different inherence of estimates in different diseases

The experience gained in solving expert classification problems (classification of R&D projects (Larichev, 1982a), architectural designs (Larichev, Naginskaya and Mechitov, 1987), scientific publications (Larichev, Grechko and Furems, 1981) expert classification in medical diagnostic problems (Kim et al., 1987), etc.) indicates that the assumption about ordering of estimates upon attribute scales for different properties holds for many practical problems and, naturally, the considered statement encompasses a wide range of expert classification problems.

Such information may be used for an indirect classification of a number of objects without presenting them to the expert. Let the expert, following examination of a patient condition (an earlier presented example) arrive at a conclusion that this condition is indicative of myocardial infarction. Then all conditions with more inherent in infarct estimates indicate this disease. Should the expert conclude that the presented condition is not characteristic of cardialgia, then all conditions with less inherent to cardialgia estimates than the present one, do not relate to cardialgia either.

The possibility of obtaining indirect information about the classes of objects membership makes it possible to design a rational procedure of expert interview with a view to minimizing the number of questions to him (her). Besides, as will be seen further, this information is also conducive to identification of potential errors in expert responses.

Informativeness of expert responses

The problem of choice of the object to be presented to the expert is analogous to the problems of search for the most informative points traditionally handled by the information theory for the purpose of code construction (Yaglom & Yaglom, 1973), problems of decoding monotonic functions of the algebra of logic (Sokolov, 1980), problems of questionnaire compilation (Parhomenko, 1970), etc.

The general concept of the problem solution implies identification of information obtained from the test in some point (i.e. putting the given question, computation of function in the given point, etc.) and choice of the search principle for the most informative point. As a matter of fact, the obtained information is dependent not only on the point chosen for the test, but also on the outcome of the test (i.e. what answer will be given to the question, or the obtained function value, etc.). Thus, each test is associated with a kind of uncertainty leading to the necessity of estimating the information obtained under each potential outcome of the test.

There are quite various approaches to determining the general informativeness of the conducted tests. The choice of the most informative point often employs the maximum principle implying the following. Each point is assigned a guaranteed minimum of the obtained information in conformity with potential outcomes of the test. At each step a point with a maximum estimates is chosen. Thereby, the maximum criterion secures elicitation of a guaranteed minimum of information.

Yet another widespread approach is maximization of the expected amount of information generated by an individual test. Herewith use is made of the probability estimates of occurrence of each outcome. The sum total of products of probability estimates of each outcome by the amount of information generated from it serves as a measure of test informativeness.

As was noted above, information elicited from the expert in classifying one object's state may be extended to other states. The expert classifies these states in an indirect manner. The number thereof is dependent on the state presented to the expert and the answer of the latter, i.e. to what class and with what degree of confidence he (she) placed the analyzed state.

Thus, in the considered problem the test is presentation to the expert of an individual state of the object, the test outcome consists in the state classification, and the potential measure of the test informativeness is the number of indirectly classified states on the basis of inherence relation. It is possible to find this number for each state given any potential answer of the expert, and calculate the mean or minimal value. By making use of these variables, one may compare all unknown states of the object with respect to their informativeness and select the most informative state. The presentation of the most informative states to the expert produces on the average the maximum amount of information given any answers of the expert.

Search for and elimination of errors in expert answers

Any procedure of expert questioning should account for possible errors in his answers. The errors arise due to his (her) carelessness, fatigue, as well as complexity of the handled problem (see below). Since the KB must be consistent, there is a need for the analysis of information elicited from the expert, identification of inconsistencies. The possibility of a direct determination of classes of state membership makes it possible to verify the consistency of expert estimates. Should there be discrepancies between indirect and direct state estimates, this is indicative of an error (errors) in his answers.

The conflicting answers should be presented to the expert with a view to understanding and finding a correct means for the assessment of a series of states. Here we proceed from the fact that though experts use different decision rules, they do their best to make them consistent and logical.

There are two strategies for eliminating inconsistencies in KB. One assumes a continuous comparison of information elicited from the expert with that obtained earlier, and checking for consistency. Should there be an inconsistency between the last answer of the expert and the preceding information, this inconsistency is presented to the expert for analysis and selection of a consistent policy. Another strategy envisages elicitation of either a portion or all necessary information from the expert followed by the location of inconsistencies in it and a stepwise elimination thereof. The first strategy is good in that in the course of the interview the expert as if learns, he is assisted in elaboration of a consistent policy. In some cases, however, the second strategy is more suitable (sec chapters that follow).

Note that the problem of search for and elimination of inconsistencies in identifying decision rules was first stated in (Larichev et al., 1978; see also Larichev, 1982b). As applied to classification problem, these concepts were further developed in (Larichcv & Moshkovich, 1986).

Specifics of human behaviour in solving classification problems

Though there is a voluminous literature on human behavior in solving multiattribute, multidimensional problems (see review Larichev, 1982b) only a few dealt with problems of expert classification of multidimensional objects. Note that a systematic study into human behaviour in solving multidimensional classification problems was first undertaken in (Larichev et al., 1980, Larichev, 1982b).

In (Hoffman et al., 1968) it was showed that people fail to cope with classification problem given more than 5 criteria and 7 decision classes. As is seen from (Larichev et al., 1980) however, given 7 criteria and 2 decision classes the subjects succeed in solving classification problems.

One of the purposes of the present research effort was to study human behaviour in handling ordinal expert classification problems. A hypothesis was advanced that there is a certain limit to human information processing capacities in these problems, and that this limit is a function of problem size. With a view to verifying this hypothesis we conducted a large number of experiments (see below). The procedure of the latter was as follows. A complete set of potential states was generated for various problems differing in the number of attributes, number of estimates on the attribute scales, and the number of classes. The topic of experiments was chosen so that the estimated object was quite familiar to the subjects. Special measures were taken to motivate subjects for a successful solution of the problem: the problems constituted a part of instruction assignments to students or pupils, or were secretly introduced in the real-life problems handled by decision makers.

The results of experiments really showed that depending on the size of problem the subjects' behaviour changes sharply, though differently for ordinary people and experienced decision makers. Should a certain dimension be exceeded, the problem came to be too complex for the subjects. The students and pupils experienced a sharp increase in the number of inconsistencies such that the conflicting estimates simply did not allow to discern a line between the classes. The experienced managers generally retained the policy consistency but it became primitive attributes were substituted by one estimate on the scales. The experiments made it possible to define variable limits to human capabilities in ordinal classification problems.

Approach to construction of explanation system

The new opportunities provided by expert systems consist in explanation of the system operations. The system must not simply answer the user question but render this answer understandable for him (her). Two goals are pursued herewith:

- to win the user confidence, explain the rationality of the system operation to him;
- to train the user, i.e. help him get an insight into the expert logics built in the system.

Let us focus on the approach to explanations typical for the majority of existing expert systems. Explanation in these systems is generally defined as demonstration of the system behavior logic to the user. And since the system has a collection of rules, the user is given information on the rule that was behind the concrete answer to the user question. This rule is presented as the system "track of actions" ((Hayes-Rott, Waterman and Lenat, 1983), i.e. a totality of states (usually arranged in an order from the more general to the more particular) that resulted in the outcome. In other words, the user is offered a portion of the relevance tree where in the general goals precede particular ones.

It is precisely this explanation pattern - demonstration of the sequence of system logical steps leading to a conclusion that is considered a characteristic feature of the expert system.

Now consider generation of explanations as a standard problem of human behaviour. Recall the way people usually explain the logics, the causes of their actions. Usually a human being exemplifies solution of an expert classification problem and explains the characteristic attributes behind the object classification. Thus, in teaching medical students an experienced physician suggests a diagnosis and points out to the characteristic signs in the patient's states that led him to that conclusion. He also answers to the question "Why this rather than the other disease?" in the language of attributes.

This approach to explanations has gained wide practical acceptance, therefore it is customary for users of expert system. In comparing this approach and explanations generally employed in expert systems, it can be easily seen that the explanations of expert systems /a fragment of relevant tree) are far from most effective. In response to a question "Why", the expert system presents the entire "track of actions to the user, involving a large amount of general information, without identifying attributes particularly characteristic of the considered situation. Given this method of explanation, an attempt is made to teach the user "to think like machine", i.e. marshal one's knowledge in conformity with the relevance tree. It is clear that this method of knowledge storage is not characteristic of human beings.

The suggested approach to KBS construction, containing a full and consistent expert knowledge base, is also conducive to the most natural approach to explanation generation. At a stage of knowledge elicitation, we constructed a matrix of individual signs typicality with respect to individual diseases. It is precisely this matrix, repeatedly verified in the course of knowledge base construction, that is capable of generating effective explanations to the user. These explanations take form of indications to the most characteristic attributes for the given class of decisions. Thus, for example, for a situation:

- pain localization - not retrosternal and not in the area of heart
- but elsewhere in the chest;
- cause of the pain - pain occurs in the course of palpation;
- pain lasts for over 15 minutes following nitroglycerin treatment;
- normal pressure;
- normal temperature;
- moist skin;
- ECG data - normal,

the knowledge-based system states that there are strong indications to cardialgia, and in response to a question "Why" issues the following answer: "Because the given situation is dominated by a set of attribute values: pain localization -notretrosternal and not in the area of heart but elsewhere in the chest; the cause of pain - pain occurs in the process of palpation; pain duration - more than 15 minutes following nitroglycerin treatment; ECG is normal" which are most characteristic of cardialgia. Such explanation corresponds to a natural situation of teaching a man the decision rules.

Conclusions

Above we stated a set of concepts conducive to:

- formation of the set of diagnostic attributes;
- correct elicitation of information from the expert;
- valid dissipation of this information;
- search for the most informative states to be presented to the expert;
- detection and elimination of errors in the expert's response;
- due regard to capacities of human information processing system.

The above set of concepts provides a real opportunity for designing a man-machine system of KB construction meeting a set of requirements (see details in Larichev et al., 1991).
First, it is necessary to structure the problem, identify a set of attributes and scales, determine decision classes. The attributes and scales of their estimates determine a complete list of potential states of the object under study. In line with the available algorithm, computer assesses the potential informativeness of all feasible states and selects the most informative one. This state is presented to the expert. The latter classifies the presented state. Then the expert's answer is verified for consistency (note that verification may be carried out following a series of answers of the expert). Once the inconsistencies arc eliminated, the following informative point is determined, etc. until all states are classified.
Note that the suggested approach makes it possible to rather adequately imitate the activities the expert is accustomed to in solving classification problems. It takes into consideration the specifics of human information processing system. It is helpful in constructing full and consistent knowledge bases.

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