# THE INTELLIGENT DECISION SUPPORT SYSTEM FOR DIAGNOSTIC OF DIFFICULT DISEASES OF VISION

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*Abstract: The work is devoted to methods and software tools of designing intelligent decision support systems (IDSS), which helps professionals (decision making persons) helping to diagnose complex problem situations on the example of complicated pathologies of view. Unlike traditional Bayesian belief networks, the proposed application of advanced multilevel (difficult-structured) networks, more convenient for complex research of the problem and providing expert data. Integration of Bayesian belief networks and Dempster-Shafer method allows using at diagnostics both expert data, and numerical (probabilistic) data obtained in the result of measurements. The proposed approach is implemented in the prototype of the intelligent decision support system for diagnostics of difficult diseases of vision.*

*Keywords: intelligent system, decision support, diagnostics, problem situation, Bayesian belief network, Demster-Shafer method.*

*ACM Classification Keywords: H.4.2 [Information systems applications]: Types of systems – Decision support; I.2.3 [Artificial intelligence]: Deduction and Theorem Proving – Uncertainty, "fuzzy," and probabilistic reasoning; I.2.4 [Artificial intelligence]: Knowledge Representation Formalisms and Methods – Bayesian belief network.*

## Introduction

At the Appiled Mathematics Department of National Research University “Moscow Power Engineering Institute, for more than twenty years researches on the development of mathematical methods and software for intelligent decision support systems (IDSS) intended for the help to experts (DMP – decision making person) in diagnostics and monitoring of complex problematic situations of different types [Vagin et al., 2001; Eremeev et al., 2009] have been actively conducted. Together with the Laboratory of Clinical Physiology of Vision of Moscow Helmholtz Research Institute of Eye Diseases the studies on creation of IDSS for diagnostics of complicated pathologies of vision have been carried out [Eremeev et al., 2013].

The joint use of the apparatus of Bayesian belief networks (BBN) [Bidyuk, et al., 2005] and the Dempster-Shafer method (DSM) [Lyuger, 2003], oriented to help the DMP in diagnostics of complex problematic situations is examined in this study. Unlike the classic BBN-system, a layered architecture, which combines methods and allows us to explore the problem in complex, is used. Split in tiers allows also reducing the scope of the search of different situations to find the most probable outcome. In the system, not just the reasoning of experts but also the analysis of numerical data in the various diagnostics with the use of probabilistic methods is used.

It is known [Eremeev, et al., 2009] that in applying the BBN in IDSS, especially in IDSS of real time (IDSS RT), is not enough to define the main components of the event in the network, and their relationships. One also needs to take into account all possible situations that the expert can foresee. It is recommended to use the hard-structured BBN. This type of BBN has been adapted and applied in the prototype of IDSS for diagnostics of complex eye

diseases on the example of retinal pathologies when it is impossible to say with absolute certainty what kind of disease a patient has and at what stage.

Even after detection of symptoms, with the help of special computer diagnostic tool and conclusions of experienced professionals, patients had to re-take examination due to inaccuracies and incomplete of available information. When creation the model and experimental approbation there was found that the use of the BBN allows us to analyze only one of the possible outcomes of (the existence of one of the diseases), ignoring the other options. Joint application of BBN and DSM would allow also assessing relationships between the possible outcomes (situations) and specify their probabilities.

## The based architecture of the intelligent decision support system

IDSS (including IDSS RT) is based on the integration of knowledge representation and knowledge operation models that are capable to adaptation, modification, and learning. Such models are oriented to specific problem areas and respective uncertainty types, what reflects the ability to develop and modify their states.

The generalized structure of an IDSS (IDSS RT) is shown in Fig. 1.

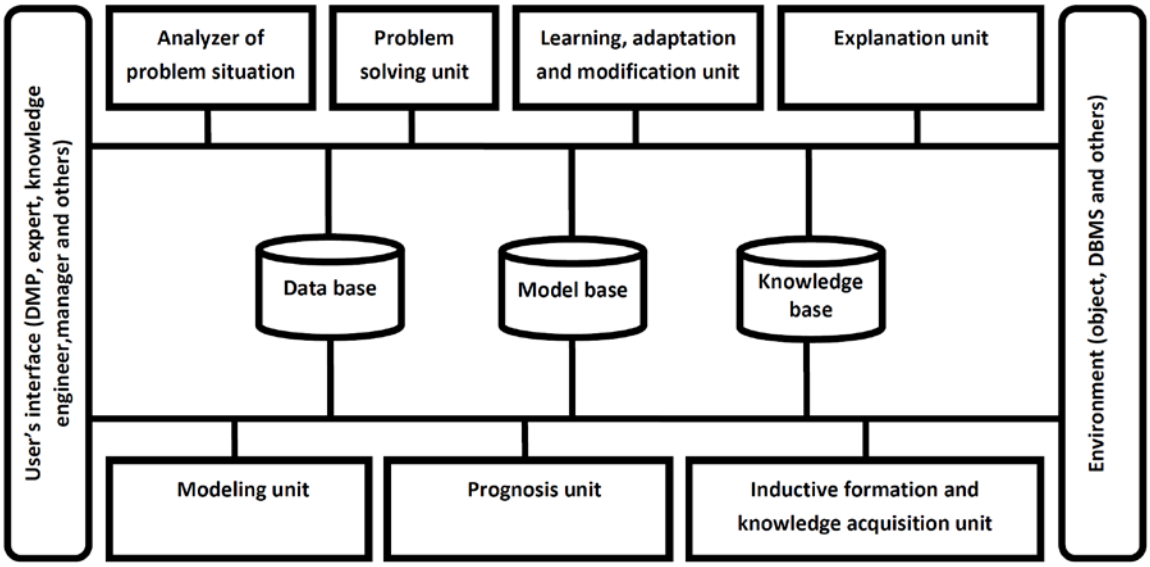


*Figure 1. General architecture of an IDSS*

By realizing methods of reasoning modeling in an IDSS one should take into consideration the features of these systems:

- The necessity to take a decision under time constrains defined by an actually controlled process;
- The need to consider a time factor in the description of a problem situation in a process of finding the solution;
- The impossibility of obtaining all the objective information necessary for decision making and in this connection the usage of subjective expert information;
- The multivariate character of search;

- The necessity of applying methods of plausible reasoning and the active participation of DMPs in decision making;
- The presence of incomplete, fuzzy and even inconsistent data for the description of situations.

## Diagnostics of the pathology of vision

Glaucoma had chosen as an object of research. The main symptom of this disease is the increase in intraocular pressure, and decreased vision. A violation of outflow and circulation of intraocular fluid lays in the basis of the disease [Neroev, et al., 2010]. Statistics data and patients' parameters were obtained in Moscow Helmholtz Research Institute of Eye Diseases. The created IDSS prototype should help DMP (doctor-ophthalmologist) in identifying early signs of glaucoma and clarifying the type of the disease in order the earliest adequate treatment.

Let us consider the main stages of research in the diagnosis of glaucoma. First of all, an ophthalmologist must carry out a complex of clinical examinations in the patient. At this stage, a specific set of psychophysical tests are applied for detection of pathologies. If there is reliable evidence that the patient has a disease, then further investigation is not reasonable; otherwise, the examination may continue due to the lack of available information. In particular, further examination is often necessary in the early stages of the disease or in difficult differentiable cases, e.g. low pressure glaucoma, when the data of clinical examination of the patient can almost do not differ from the normal state of a healthy person.

Then one should do the complex of electrophysiological tests, which analyze the electrical responses of the retina in different light stimuli. It uses various types of electroretinogram (ERG) in computer graphics, representing changes of retina electric potentials that occur in response to light flashes, and the amplitude and peak latency of the ERG waves (components) are estimated. Based on the type and degree of ERG change, the existing pathology is detected. At the final stage the expert-specialist (physiologist) or group of experts, on the basis of the obtained resulting data of the patient examination must confirm or deny the diagnosis of ophthalmologist (in the latter case it is necessary to clarify the diagnosis), after that the appropriate treatment can be recommended.

In Fig. 2 BBN is presented, which characterizes the process of glaucoma diagnosis in the form of multiple-defined events: T – results of ophthalmological examinations (suspicion for this disease); Z - is the conclusion of physiologist about the existence of the disease based on the ERG parameters and clinical data of ophthalmologist; I - is the result of ERG testing, D – is the resulting event, which characterizes the solution of the problem (the exact diagnosis, the current stage, recommendations for treatment or further examination etc.). Figures are events related to the stages of patient research.

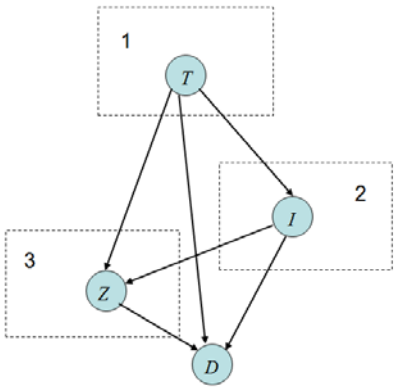


Figure 2. BBN-model for glaucoma diagnosis

Consider the event determining the result of the ERG study on the example of primary open angle glaucoma (POAG). For diagnosis of this disease (condition) and its stage it is necessary to analyze several kinds of ERG, to make conclusions about the detected signs (symptoms) of the disease, and to determine the degree of diagnostic confidence (probability).

In Fig. 3 the model of the second level is presented for definition the value of the event “The ERG testing results”, where *I*- is the target event (diagnosis), $I_K$,..., $I_{RT}$ - the results of studies; $I_K$ - the result obtained in the study of cone ERG, $I_M$ – maximal ERG, $I_P$ – rod-ERG, $I_{OP}$ – oscillatory potentials (OP), $I_F$ – photopic negative response (PhNR), $I_{PT}$ – pattern ERG (PERG).

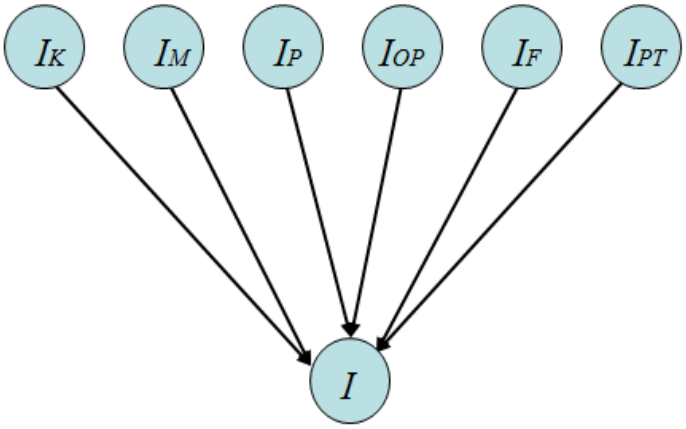


Figure 3. BBN-model for definition the value of the event “The ERG testing results”

In the model of the second level, the data of main types of ERG are presented, each of which has its own waveform, and varies depending on the type of the disease, i.e. the key values that characterize a particular disease are identifying. Rod, cone and maximal ERG are used to test the ability of the eye to the dark and light adaptation. Each of the ERG components is generated by different structures in the retina. In Fig. 4 the classic analysis of ERG components is represented (by Ragnar Granit) [Neroev, et al., 2010].

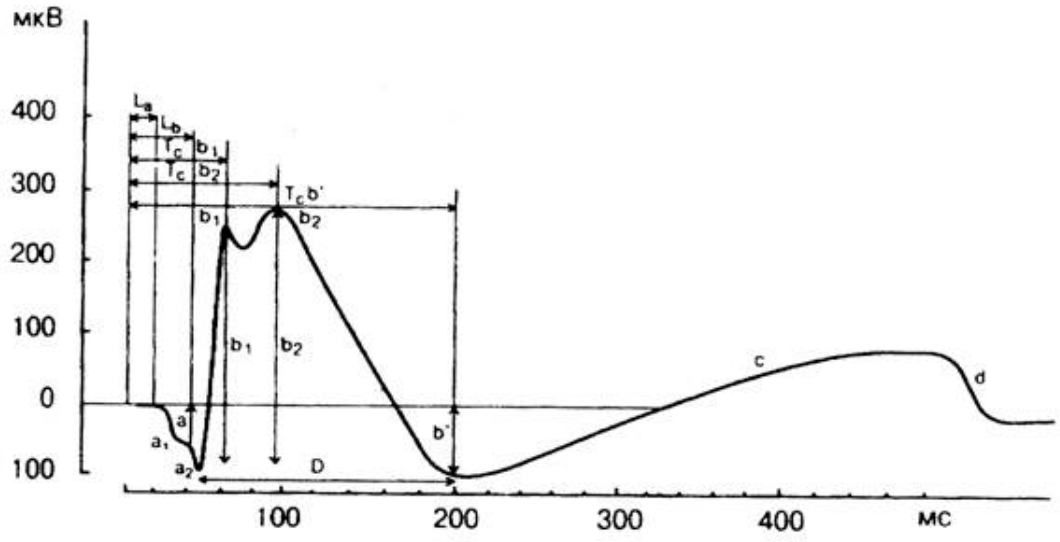


Figure 4. The Granit component analysis of ERG

Each of the ERG components is generated by different structures of the retina. The main indicators are the a- and b-waves. In the course of diagnostics, values of amplitude and peak latency of the components of various types of ERG are analyzing. In the Table 1 the statistical data of ERG amplitudes in the examined patients with POAG stage I and II are presented.

Table 1. Amplitudes of the *a*- и *b*-waves in the I and II stage of POAG (M±m)

| Kinds of standard ERG | | Norm, uV M±2SD | POAG I stage | | POAG II stage | |
|---|---|---|---|---|---|---|
| | | | **μV** | % of Norm | **μV** | % of Norm |
| Rod ERG | *b*-wave | 58,1±21,7 | 44,3±5,9 | 76,2% | 35,1±27,2 | 60,4% |
| Maximal ERG | *a*-wave | 103,7±37,3 | 87,8±7,9 | 84,6% | 70,3±30,4 | 67,8% |
| | *b*-wave | 203,2±55,0 | 176,5±13,3 | 86,8% | 196,6±46,1 | 96,7% |
| Cone ERG | *a*-wave | 18,2±7,5 | 16,7±2,7 | 91,7% | 15,1±6,1 | 82,5% |
| | *b*-wave | 91,2±21,0 | 49,0±6,0 | 53,7% | 49,6±21,8 | 54,4% |

According to the data of the amplitudes it is possible to analyze the changes in value of the signal, passed through the retina. In the presence of disease, there is the reduction of the a- and b-waves. In addition, one can change their culmination time (peak latency): it usually is delayed in the advanced stages of diseases, while latency remains unchanged in the initial stages. The progression of the disease contributes to a significant reduction in the amplitude and to a prolongation in the peak time of the ERG waves, resulting to the reduction of visual functions.

Consider the model (BBN) for the POAG diagnosis on the basis of the analysis of maximal ERG (Fig. 5), where *Aa, Ab* - the maximum amplitude of a- and b-waves; *Ta, Tb* – their peak time; *Va, Vb* – the conclusion on the basis of input data, defining the disease; $I_M$ - target event that corresponds to the common result of analysis of the ERG (diagnosis).

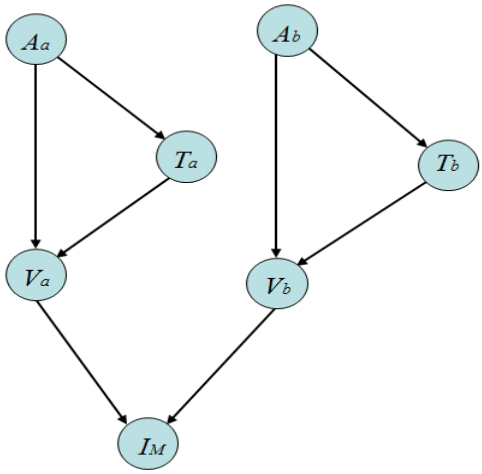


Figure 5. BBN-model for the diagnosis on the base of maximal ERG

The proposed model takes into account all the key values of standard ERG for POAG. At this step of POAG diagnosis, only possible stage of POAG are the I and II stages, therefore, we can note a number of peculiarities: $A_a$, $A_b$ - can take on different meanings depending on the type and stage of the disease in some range relative to the average values of the amplitudes listed in the table. 1, for example, for the POAG stage I, each event has three states: “more typical for the POAG stage I”, “typical for the POAG stage I”, “less typical for the POAG stage I”. The zones of states can intersect, i.e. it is necessary to analyze all of the states, if the values of maximal amplitudes of a- and b-waves are in the area of intersection; $T_a$, $T_b$ - change only when the POAG of II stage, therefore, it is possible to allocate two states: “more than normal for a healthy person”, “normal for a healthy person”; $V_a$, $V_b$ - depending on the key values it is possible to ascertain the most appropriate state (diagnosis): “The POAG stage I”, “The POAG stage II” or “Healthy”; $I_M$ - this is the event, which result in the analysis of all conclusions according to maximal ERG, has states similar to $V_a$, $V_b$.

Consider a patient with the suspected POAG stage I. In Tables 2 and 3 the key values of the amplitude and peak time of the a- and b-waves in the analysis of maximal ERG are set, as well as relevant event states and the coefficients of confidence.

Table 2. Amplitudes of the *a*- и *b*-waves in the analysis of maximal ERG

| Parameters | $A_a$ – *a*-wave amplitude | $A_b$ – *b*-wave amplitude |
|---|---|---|
| **μV** | 85,1 | 177,1 |
| % of Norm | 82 % | 87,1 % |
| The most appropriate event status | Typical for the POAG stage I<br>Less typical for the POAG stage I | Typical for the POAG stage I |
| The coefficient of confidence, P(x), x=$A_a$, $A_b$ | 0,8 (typical for the POAG stage I);<br>0,75 (less typical for the POAG stage I) | 0,8 |

Table 3. Peak latency (the culmination time) of the *a*- и *b*-waves in the analysis of maximal ERG

| Parameters | $T_a$ – the *a*-wave peak latency | $T_b$ – the *b*-wave peak latency |
|---|---|---|
| **μV** | 24 | 46 |
| % of Norm | 135 % | 124,1 % |
| The most appropriate event status | exceeds the normal value | exceeds the normal value |
| The coefficient of confidence, P(x), x=$T_a$, $T_b$ | 0,65 ($A_a$= “typical for the POAG stage I”);<br>0,8 ($A_a$= “less typical for the POAG stage I”) | 0,65 |

The value of a-wave amplitude corresponds to the two states of events – “typical for the POAG stage I” and “less typical for the POAG stage I”, one need to calculate the probability of execution of both events. The most likely value of events states $V_a$ and $V_b$ is “The POAG stage I”. Set the probability of these events: $P(V_a/A_a,T_a)=0,68$

when $A_a$ = a "typical for the POAG stage I'; $P(V_a/A_a,T_a)=0,62$ when $A_a$ = a "less typical for the POAG stage I'; $P(V_b/A_b,T_b)=0,68$.

The final event for data analysis of maximal ERG is the event of $I_M$, which is the most probable consequence of the patient disease or a denial in suspicion during the clinical examination. In this case it is necessary to confirm or deny that the patient has the POAG stage I. The coefficient of confidence in this situation is: $P(I_M/V_a,V_b)= 0,95.$ Calculate the joint probability of the event, provided that $A_a$ = a "typical for the POAG stage I"

$$P(A_a,T_a,A_b,T_b,V_a,V_b,I_M)=P(A_a)\cdot P(T_a)\cdot P(A_b)\cdot P(T_b)\cdot P(V_a/A_a,T_a)\cdot P(V_b/A_b,T_b)\cdot P(I_M/V_a,V_b)\approx 0,119$$

In order to ensure that the result of the analysis of maximal ERG is the presence of the disease one need to determine the highest value of the joint probability of events. When calculate the joint probability of the event, provided that $A_a$ = a "less typical for the POAG stage I", we'll get $P(A_a,T_a,A_b,T_b,V_a,V_b,I_M)\approx 0,125$

Thus, the result (diagnosis) $A_a$ = a "less typical for the POAG stage I" has the highest value of the joint probability of events. In order to ensure that the result of the analysis of maximal ERG is that the patient has the POAG stage I, it is necessary to calculate the corresponding conditional probability (when the given events), which determine the value of the key points on the ERG.

The calculation is made according to the formula

$$P(I_M \mid A_a,T_a,A_b,T_b) = P(I_M,A_a,T_a,A_b,T_b) / P(A_a,T_a,A_b,T_b) = (P(I_M,,A_a,T_a,A_b,T_b,V_a,V_b,) + P(I_M,A_a,T_a,A_b,T_b,V_a,\neg V_b,) + P(I_M,A_a,T_a,A_b,T_b,\neg V_a,V_b) + P(I_M,A_a,T_a,A_b,T_b,\neg V_a,\neg V_b)) / ((P(A_a,T_a,A_b,T_b,V_a,V_b,I_M) + P(A_a,T_a,A_b,T_b,V_a,\neg V_b,I_M) + P(A_a,T_a,A_b,T_b,\neg V_a,V_b,I_M) + P(A_a,T_a,A_b,T_b,\neg V_a,\neg V_b,I_M) + P(A_a,T_a,A_b,T_b,V_a,V_b,\neg I_M) + P(A_a,T_a,A_b,T_b,V_a,\neg V_b,\neg I_M) + P(A_a,T_a,A_b,T_b,\neg V_a,V_b,\neg I_M) + P(A_a,T_a,A_b,T_b,\neg V_a,\neg V_b,\neg I_M)).$$

After appropriate calculations we obtain the result 0.67 (67 %), meaning that in the analysis of maximal ERG of the patient the most likely diagnosis is the presence of the POAG stage I, but this information is not sufficient to confirm (or refute) the conformity of a given diagnosis to the reality, because, as it was already noted, the use of BBN allows us to analyze just one of many possible diagnoses, in particular, the presence or absence of the POAG stage I. To address this shortcoming, i.e. to conduct the comprehensive analysis with accounting and other possible diagnoses, one can offer in addition to BBN also use the DSM, which allows to compare all the available values, as a set of elements that characterize the disease.

For example, the value of $V_a$ can have three possible values (states). Depending on the entered values of the amplitude and peak time of the ERG waves, one can set the probability of facilities for all possible states of the event $V_a$. Let each of $V_a$ states be considered as the opinion of one expert, who argues that when entered data his conclusion is the most probable. Proceeding from this, one can determine intervals of the belief and plausibility (likelihood) for each of the diseases. In Table 4 the corresponding values of measure, coefficients of belie and plausibility, used for calculations are shown.

Selected values in Table 4 can be interpreted as the lower and upper boundaries of the intervals at which the values of the corresponding probabilities are contains. According to the obtained data the values of the probabilities for BBN can be then corrected. The combined use of the BBN and DSM allows improving the effectiveness of diagnostics when increase of disease databases and methods of their analysis.

Table 4. The values of the coefficients of belief and plausibility for the event $V_a$

| Events | Measure | Belie | Plausibility |
|---|---|---|---|
| a value NULL | 0 | 0 | 0 |
| Healthy | 0,05 | 0,1 | 0,15 |
| POAG I stage | 0,55 | 0,62 | 0,65 |
| POAG II stage | 0,3 | 0,35 | 0,4 |
| One of the (healthy, POAG I stage, POAG II stage) | 0,1 | 1,0 | 1,0 |

## The prototype of the intelligent decision support system for glaucoma diagnostics

For realization of the prototype of diagnostic IDSS, promising artificial intelligent language Clips was selected [Giarratano, et al., 2007]. Clinical trials of patients, data of various kinds of ERG and the conclusion of ophthalmologists and physiologists are used as the input information. The output information is the diagnosis with corresponding probability (confidence) and recommendation for treatments or for further examinations of the patient. According to the data obtained in the analysis of different kinds of ERG, the database (evidence base) is constructed that stores the original description of the task (information about the patient) in the form of verbal descriptions. To build BBN and to operate with database of facts, the knowledge base (rules) is used, which contains the methods for obtaining results.

Below there is a fragment of the program in language Clips with the sample of rule of adding a new element - the maximum amplitude of a wave when it gets into the interval for the POAG 1 stage:

```
(defglobal ?*Vvod-Aa-m* = 0)
(defrule opredelenie-Aa-max-ERG-2 ""
(declare (salience 98))
(not (varAa ?))
(AaPOUG 1 st.)
=>
(printoutt "Select the interval at which gets the value of the maximum a-wave amplitude:" crlf)
(printoutt "Response options" crlf)
(printoutt "[1] more typical of the disease POAG I stage" crlf)
(printoutt "[2] typical of the disease POAG I stage" crlf)
(printoutt "[3] less typical for disease POAG I stage" crlf)
(bind ?*Vvod-Aa-m* (ask-question " Response: " 1 2 3))
(if (eq ?*Vvod-Aa-m* 1)
then
  (assert (varAa more for POUG 1 st.))
(printoutt "Aa = more typical of the disease POAG I stage" crlf)
else
  (if (eq ?*Vvod-Aa-m* 2)
then
```

```
   (assert (varAa norm for POUG 1 st.))
(printoutt "Aa = typical of the disease POAG I stage" crlf)
else
   (if (eq ?*Vvod-Aa-m* 3)
then
     (assert (varAa less for POUG 1 st.))
(printoutt "Aa = less typical for disease POAG I stage" crlf))))
(assert (labelAaSingularlabel
Plurallabels)))
```

After we set in the system many facts to describe events $A_a$, $A_b$, $T_a$, $T_b$ based on the coefficients of confidence, the search of rules is performed for the determination of status of events $V_a$ and $V_b$. In the search process one can be a situation when several rules are followed that form the certain set of facts under the same conditions. This is because the extrema of the a- and b-waves can correspond to several states. In this case the highest value of the conditional probability of an event $I_m$ is used.

In Fig. 6 an example of the dialog box for DMP is shown when specifying the patient data at the maximal ERG. Note that this example demonstrates only use one of the methods of diagnosis (BBN), and does not show the final result.

## Conclusion

In conclusion we note that the proposed formal apparatus and implementing it software tools are included in the basic tools of constructing of modern IDSS, including IDSS RT, on the basis of integrated methods and models of knowledge representation and decision making in the conditions of different types of uncertainty (incomplete, incorrect, unclear, contradictory) in available information (data and knowledge).

## Acknowledgement

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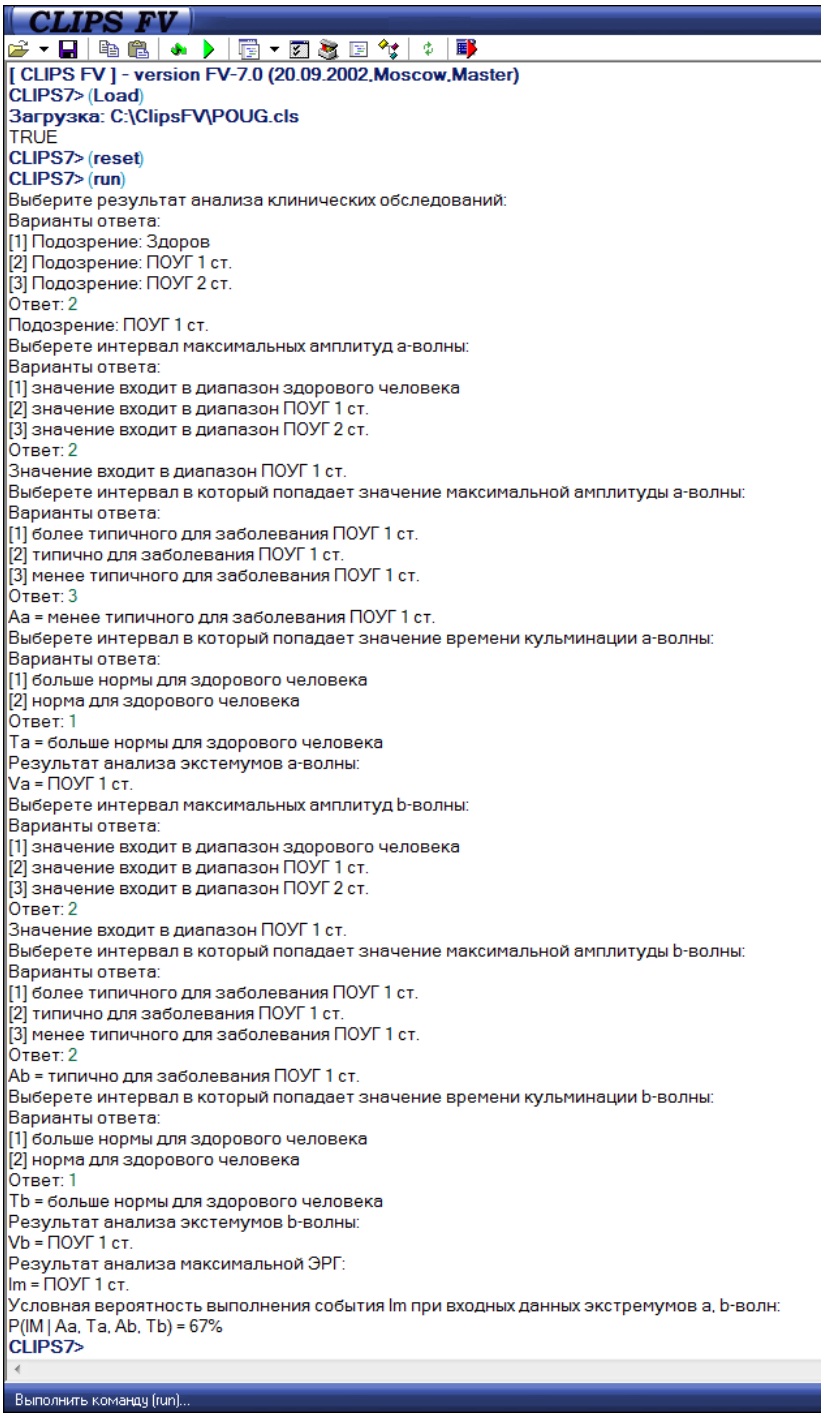


Figure 6. Example of a dialog box for DMP

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