A CONCEPT OF DESIGN PROCESS OF INTELLIGENT SYSTEM SUPPORTING DIABETES DIAGNOSTICS

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***Abstract**: The paper presents an approach to designing an intelligent system to be used in diabetes diagnostics as well as to creating a problem knowledge base for the system. The work also gives a description of constructing a decision tree for diabetes diagnostics and shows how to use it as a basis for generating knowledge base rules. Finally, the article also outlines how an intelligent diagnostic system works.*

***Keywords:** neural networks, artificial intelligence, expert systems, hybrid systems, decision tree diabetes diagnostics.*

Introduction

Diabetes is nowadays considered to be the one of the greatest health hazards of the XXI century. The number of diabetics patients has been increasing to reach 2 million in Poland and more than 200000 million worldwide. Diabetes has become a social disease, associated with the progress of civilization, that has been afflicting more and more people. It needs intensive monitoring and medical care. On account of this, scientific research to find new approaches and tools in order to support diabetes diagnostics and treatment is socially important and timely. Presently, such research is being conducted at numerous scientific research centres all over the world.

In recent years, teleinformation systems and Internet portals have been developed to both improve diabetes diagnostics and educate diabetics. A special telemedical programme has been created in EU (Telematic Management of Insulin- Dependent Diabetes Mellitus; T- IDDM) for patients with type 1 diabetes. There is, however, a shortage of advanced solutions and computer systems grounded on a knowledge base which support and facilitate medical diagnostics.

The purpose of the relevant research is to develop methods of designing and creating intelligent diagnostic systems founded on a knowledge base. The research also aims at implementing state-of-the-art methods and artificial intelligence tools to model and analyze knowledge acquired from various sources. The modelling of knowledge and processes will copy the human way of reasoning.

The basic task of the research is the development of a knowledge base as the foundation of an intelligent diagnostics supporting system which can be used in a dispersed medium, in teleinformation systems supporting the monitoring and treatment of people who have diabetes.

The paper presents an approach to the designing of an intelligent diabetes diagnostics system as well as to the creation of a problem knowledge base for the system. The work describes the construction of the decision tree for diabetes diagnostics and explains how to use it to generate knowledge base rules.

In recent years artificial intelligence tools (such as neural networks, genetic algorithms, vague logic and others) have been very popular and found their application in solving newer, more complicated problems including diagnosing and recognizing diseases. Artificial intelligence tools are the components of the expert systems that are being built to effectively support diagnostics. Many of them have already been developed and applied, among other things, to diagnose neoplastic diseases, heart and cerebrovascular diseases and many others.

The article is an introduction to developing an intelligent diagnostic system whose task is to initially find out whether the patient has diabetes and then to decide whether the illness is of type 1 or type 2. The paper also presents a decision tree which will help to tentatively determine whether a patient with clinical symptoms suggesting diabetes really has the disease or if it is only a group of symptoms indicative of his, e.g. sugar intolerance. In order to decide on the right line of further analysis we have to prepare, in the first instance, a set of data. The system is very helpful in diagnosing and can make a diabetologist's work much easier.

Basic principles of an intelligent diagnostic system designing

The proposed system of diabetes diagnostics should be a computer system of open architecture and molecular structure which will enable the application of a few methods of knowledge representation and integration of different knowledge processing schemes during the process of inference.

Intelligent diagnostic systems should integrate chosen contemporary methods and techniques of knowledge and process modelling, namely:

- artificial neuron networks - the most fascinating tool of artificial intelligence that can model complex functions and imitate (to some extent) the activities of human mind, namely the ability to learn,
- vague logic-technologies and methods of natural language formalization, linguistic and qualitative knowledge processing and vague inference,
- genetic algorithms and methods of evolutionary modelling - algorithms that can learn, based on the theoretical achievements of the theory of evolution and enriching the two aforesaid artificial intelligence techniques (as optimization algorithms they can be applied to teach neuron networks and neuron vague systems and/or to optimize the structure of networks and systems).

The combination of these tools with a traditional skeleton expert system where knowledge is symbolically represented will allow for the creation of comprehensive programme tools. They will be used to solve complex problems and tasks necessitating the processing of incomplete, fragmentary, vague or contradictory knowledge as well as in all the situations where the knowledge is difficult to formalize.

The artificial neuron networks, classified as basic tools in the paper, are indispensable for the solution of a lot of important tasks such as identification and classification of symptoms, grouping analyzed data or prediction based on historical data. An enormous asset of neuron networks is that they make it possible to look for models for only slightly familiar phenomena and processes. They also allow for controlling complex problems of multidimensionality. Another advantage of neuron networks is undoubtedly the previously mentioned ease of their application. Neuron networks, practically all by themselves, construct models the user needs. It is because they learn automatically while filling up their adaptation structure with the necessary parameters based on the user provided examples of the modelled system's behavior. To some extent, neuron networks copy the way human mind works although they are founded on a very simple model representing the very basis of the working of a biological nervous system.

An expert system is assumed to be a computer system which, as its name indicates, performs its tasks as efficiently as an expert in a particular branch of knowledge or science. The programme, using a given knowledge base as well as a rule base and facts, draws conclusions and makes decisions, just like a human being.

Expert systems can be classified in various ways. They can function as: advisory systems, i.e. they suggest the direction your activity should take; decision making systems, working without human help or interference; criticizing systems, i.e. those which, based on the specific problem and a man's predicted solution, analyze and comment on a particular way of reasoning or actions. Creating a system founded on a knowledge base means acquiring the knowledge of an expert who often finds the solution making use of relevant information and experience. The expert system that applies the written expert knowledge of a particular field can use it many times in an economical and effective way without the expert's presence. This enables the expert to avoid analogous reports and take up more creative tasks. Thus, a particular asset of such systems is the possibility of solving given tasks without the expert's participation, and also the possibility of aggregating knowledge within one system of a numerous expert team. [Kowalczuk,Wiszniewski, 2007]

Any expert system should contain a few fundamental components:

- knowledge base,
- data base,
- interference procedures - inferring engine,
- explanation procedures - explain interference strategy,
- procedures of dialogue control- input/output procedures enable the user to formulate tasks and the programme to transmit the solution,
- procedures that make it possible to enlarge and modify knowledge - its acquisition. [Kwaśnicka, 2005]

Hybrid intelligent systems are a relatively new category of systems based on artificial intelligence. They consist in the combination of the best features of such tools of artificial intelligence as: expert systems, learning systems, neural networks and genetic algorithms. Owing to this, the hybrid system is able to handle more difficult problems which a single system, which is a part of the hybrid system, could not cope with.

Structure of the expert hybrid system under construction

A hybrid system is a combination of an expert system with neural networks. This way, symbolic processing, characteristic of traditional expert systems is complementary in relation to dispersed, parallel processing typical of neural networks. In the simplest case, both ways of processing may occur independently. It is assumed that there should be a kind of superior medium. It distributes tasks between particular systems. Depending on the sort of problem the tasks are allotted to the system which guarantees the best solution. The functioning of this solution can be described briefly as follows. An expert system operates the interface, processes the data that have been entered into appropriate coefficients and searches the data base. It is accepted that in this field there are no clear and explicit rules; that is why an artificial neural network is the appropriate tool for processing this kind of vague knowledge. An expert system forms a file containing the calculated business coefficients as the input data for the neural network. After the calculation has been carried out by the neural network, the results obtained at its output are passed back to the expert system to be interpreted. In the end, the final results can be read in the displayed window. [Bubnicki, 1990]

The components of an expert system are:

- skeleton of the system consisting of:
  - user's interface - which enables asking questions, giving the system information and taking answers and explanations from the system,
  - knowledge base editor- which allows for the modification of the knowledge contained in the system enabling its growth,
  - inference mechanism - which is the main component of an expert system. It performs the whole reasoning process while solving the problem put by the user,
  - explaining mechanism - one of the components of the system-user interface which enables the user to learn why the system gave him just this answer of all answers or why just this question was asked.
- knowledge base - this is the declarative form of the expert knowledge of a particular field written by means of a chosen way of knowledge representation, most often rules or frames.
- variable data base – which is a working memory storing same facts entered during the dialogue with the user. The base enables the reconstruction of the way of inference conducted by the system and then presenting it to the user by the explaining mechanism.

The acquisition of knowledge from experts is usually the responsibility of knowledge engineers. This is usually a long and tiring process since expert knowledge is of intuitive - practical nature, often difficult to verbalize.

The reasons for building this sort of systems based on artificial intelligence may be the following:

- It is not always possible to obtain heuristic rules for knowledge bases of the expert system. However, there are data that may be used for building a neural network.
- There is not always an appropriate data set to be based as a basis for teaching neural network. On the other hand, there is a possibility of building a knowledge base (e.g. when we have an open model).
- The problem that is being solved is of complex nature, and another kind of data processing technology seems to be more effective or convenient for solving each of the problems. [Białko, 2000]

In the case when various methods can be used for solving the same problem, same features of one of them can be decisive (e.g. it may be the ability of the expert systems to explain and codify knowledge).

The building process of a hybrid system, which is the effect of the neural network and expert system integration, in the PC- Shell system consists of the following stages (the sequence of points 1 and 2 is arbitrary)

- Generating neural applications (SN_1, … , SN_m), for selected sub problems by means of the Neuronix system.
- Elaborating knowledge bases (as knowledge sources) SE_1, … ,SE_n.
- Integration of the knowledge sources elaborated at the previous stages at the level of the knowledge presentation language of the PC- Shell system.

From the point of view of practical realization, the role of the Neuronix system boils down to teaching the network and generating the definition of the neural application as a defining file (files with **npr** extension) and a file containing weighing kit (files with weight extension). [Mulawka, 1996]

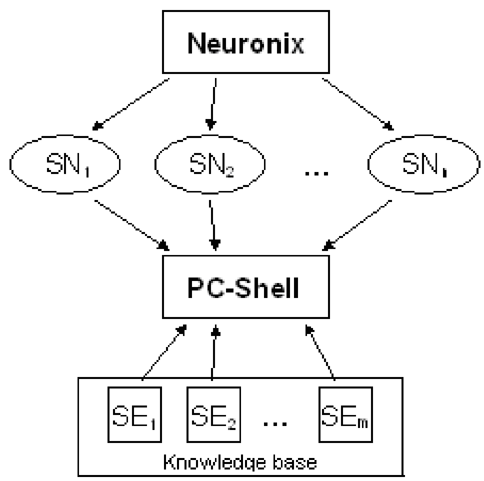

Fig.1. Structure of hybrid application (SE+SN) in the PC- Shell system

Decision tree as a model of diabetes classification

Decision tree structure

The decision tree is a flow diagram of a tree- like structure where each top means attribute testing, each edge stands for test exit (value or attribute value set), and each leaf represents a class.

To classify an unknown object the values of its attributes are tested following the information comprised in the decision tree. During the testing process, the path in the tree from the root to one of the leaves is covered - in this way the class the object is going to be classified into will be defined.

Decision trees can easily be transformed into classification rules.[5] The object to be classified is the set of objects, S, which are described by (m+1) - the dimensional vector of characteristics (x_1, x_2, … x_m, y).

Variable y is the explained variable - i.e. singled out, because of which the classification is performed. What is more, variable y, depending on the problem being solved, can be a quality variable - (linguistic, nominal or order variable) or continuous and binary variable.

The result of the classification in the decision tree induction method is the decision tree.

The main problem to face while building a decision tree is the defining of the criterion enabling the choice of the attribute applied in the development of the tree. In order to choose such an attribute it is necessary to calculate the entropy (entropy is the information contained in the teaching example set). Entropies are calculated following the formula:

$$I(E) = -\sum_{i=1}^{|E|} \frac{|E_i|}{|E|} \bullet \log_2\left(\frac{|E_i|}{|E|}\right) \qquad (1)$$

Where: E – set of teaching examples,

!Ei! – number of examples which describe i-th object,

!E! – number of examples in the teaching set

In order to choose the attribute that will be ascribed to the generated node of the decision tree, the criterion of the maximum relative information increase is applied; the increase is caused by the use of a particular attribute (the attribute for which the criterion function value is the highest is applied as the successive attribute):

$$\Delta I(E,a) = I(E) - I(E,a) \qquad (2)$$

Diabetes diagnostics

To start a diagnosis it is necessary to gather the proper number of data. The source of the data can be: the patient himself, his record, a primary doctor, a specialist, a biochemical lab and specialist tests. The system gathers data by means of a number of tests: subjective, objective tests, laboratory tests and extra tests.

- subjective tests - general interview: the system takes such data as: name, surname, age, occupation, place of work, living conditions (diet, smoking addiction, nicotine addiction, alcohol), general health condition, eating habits, nutritional status (obesity, emaciation), history of body mass changes, family interview (did the family members suffer/suffered from similar diseases), the beginning of the disease (how many years ago), course of the disease so far, other organ and system complaints, past diseases and operations, present or previous infections, diabetes education, course of treatment (in the case of previously treated diabetes patients) medication applied,
- objective tests: height and body mass measurement (BMI), calculating the due body mass and comparing it with the real mass, personal development phase evaluation (sexual-bodily phase, old age phase), arterial pressure evaluation in the lying and standing position (with the measurement of the orthostatic reaction), ophthalmoscopes tests of fondues (at pupillary dilation), thyroid test, heart test, taking pulse and testing all the peripheral arteries accessible when fingering and ausculating, feet test, neurological test, teeth and gums test, skin and mucosa tests,
- laboratory tests: glycaemia test on an empty stomach and daily glycaemia profile, notation of glycated haemoglobin and fructosamine, notation of the lipid profile on an empty stomach: total cholesterol and cholesterol in lipoproteins of high density (HDL- high density lipoproteins), cholesterol in lipoproteins of low density (LDL- low density lipoproteins) and triglicerydes, urine test

(apart from glucosuria) to check ketone bodies and protein presence, (macro- and micro-albuminuria) and microscope test of the sediment, bacteriological test (urine cultures and possibly antibiogram), euthyroidism test and morphological status of the thyroid (concentration evaluation of T3, T4 and TSH, scintigraphy of the thyroid), peripheral arteries tests (potency and the rush of blood), electrocardiogram, echocardiography, ergometer test, neurological tests, especially the electromyography test, ophthalmic review (general test of the organ of sight),

- Additional tests: fundus test. [World Health Organization (WHO), 1999]

The diagnosis of diabetes is based, most of all, on checking the glucose level. However, many other symptoms that may suggest diabetes are also considered.

They include: increased thirst (polidypsia), polyuria, loss of body mass, urinating during the night, increased appetite, general fatigue, dermatomycosis and mucous membrane mycosis, skin infections (mycosis, furuncles) feeling of dryness in the mouth cavity, pruritus of the vulva, cramps, vision disorders. [Czech,Tatoń, 2009]

Biochemical criteria:

hyperglycaemia (glucose concentration of above 126mg/dl in venous blood found at least twice),

- casual blood glucose level in the serum (at any time of the day) of above 200mg/dl,
- blood glucose level of above 200mg/dl, two hours after a 75g glucose oral load (oral glucose tolerance test OGTT),
- glucosuria. [cukrzyca.info]

Principles of constructing a detailed decision tree for diabetes diagnostics

There is a set of three objects:

- diabetes (object E_1),
- impaired glucose tolerance (object E_2),
- lack of the disease (object E_3).

The characteristic features of the objects are:

- occurrence of diabetes in the family: yes, no
- thirst: great, normal
- urination: frequent, normal
- body mass: great (obesity), normal
- appetite: great, normal
- fatigue: great, little
- age: over 45, under 45
- hypertension: yes, no
- cholesterol level: high, normal
- triglyceride level: high, normal
- cardiovascular diseases: yes, no
- physical exercise: little, a lot
- dermatomycosis: yes, no
- glucose tolerance test: above 200mg/dl, below 200mg/dl
- glucosuria: yes, no
- skin infections: often, rarely
- xerostomia: yes, no
- cramps: yes, no
- vision disorders
- glucose level: above 126mg/dl, below 126mg/dl

- occasional glucose content in the serum: above 200mg/dl, below 200mg/dl

Figure 2 shows a decision tree representing the algorithm of type 2 diabetes diagnosis (the most common), considering the factors increasing diabetes hazard.

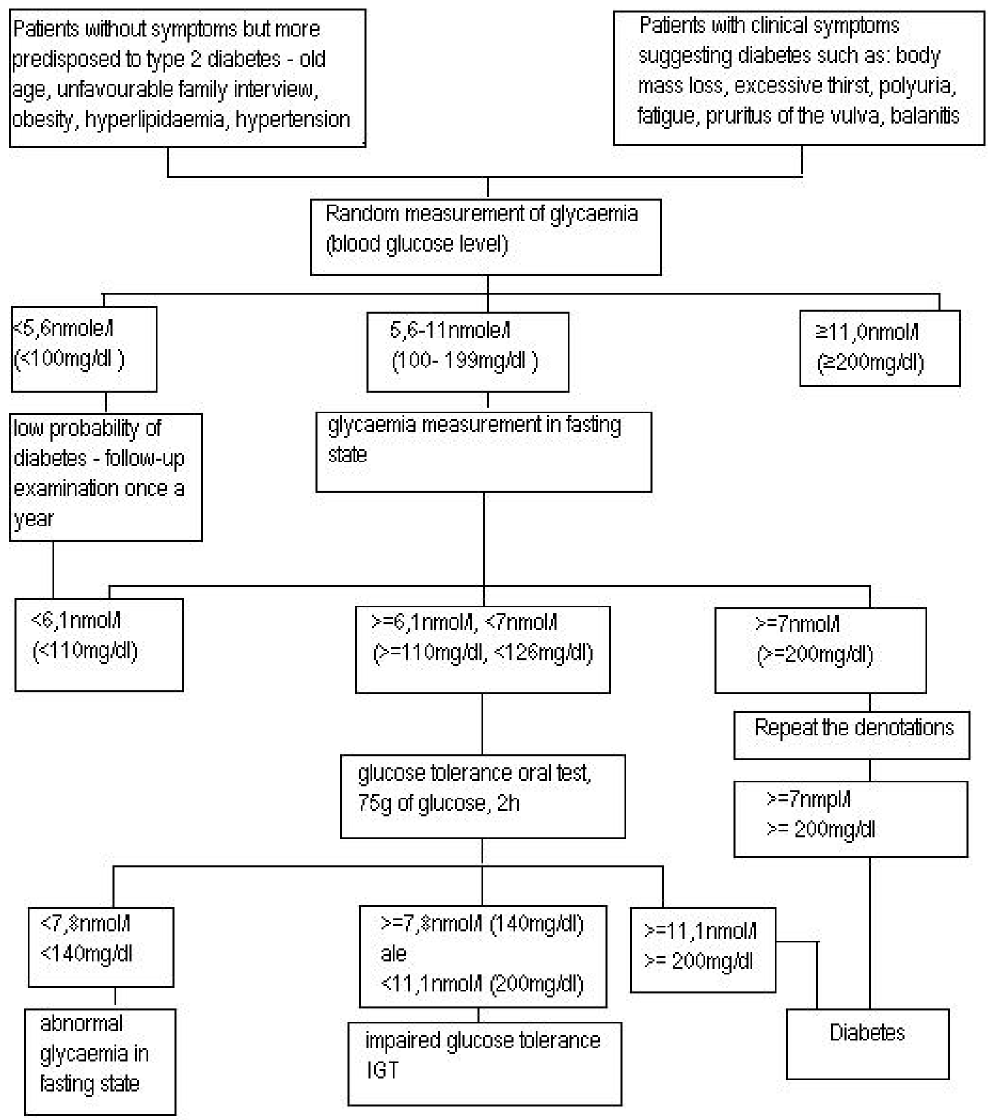

Fig. 2 Diagnostic scheme of diabetes with regard to factors increasing diabetes risk

Due to a multitude of symptoms that might suggest diabetes two groups of patients were selected:

- patients without clinical symptoms, but with more diabetes predisposition,
- patients with clinical symptoms suggesting diabetes.

The beginning of the tree consists of the alternatively presented syndromes of the patient's condition. The next component is the examination (diagnostic activity) for which the scheme predicts three possible results: the first suggest completing the procedure, the second – another examination, the third points to the specific condition of the patient (diagnosis). Two results are anticipated for the next examination. One of them- like the result of the first examination - suggests diagnosis, the other, however, insists on another examination whose possible results (given separately) somehow enhance the previously suggested diagnoses. The principle of the practical interpretation of the scheme is like that in the previous case: finding such and such initial state necessitates conducting such and such examinations whose nature and sequence depend on the results obtained and which finally lead to such and such diagnosis. [Czech,Tatoń, 2009]

Inference rules can be formulated based on the generated decision tree.

> ***If*** *(the patient's state without symptoms and more predisposed to diabetes = random glycaemia measurement <100mg/dl),* ***then*** *the probability of diabetes low.*
>
> ***If*** *(the patient's condition without clinical symptoms and more predisposed to diabetes = random glycaemia measurement>100mg/dl but ≤199mg/dl) and (glycaemia fasting state measurement=<110mg/dl),* ***then*** *the probability of diabetes low.*
>
> ***If*** *(the patient's condition without clinical symptoms,* ***and*** *more predisposed to diabetes= random glycaemia measurement from 100mg/dl to 199mg/dl) and (glycaemia fasting state measurement=≥110 but <126mg/dl and (oral glucose tolerance test=<140mg/dl),* ***then*** *abnormal fasting state glycaemia.*
>
> ***If*** *(the patient's condition without clinical symptoms, and more predisposed to diabetes= random glycaemia measurement from 100mg/dl to 199mg/dl) and (fasting state glycaemia=≥110 but <126mg/dl) and (oral glucose tolerance test=<200mg/dl),* ***then*** *impaired glucose tolerance.*
>
> ***If*** *(the patient's condition without clinical symptoms, and more predisposed to diabetes= random glycaemia measurement from 100mg/dl to 199mg/dl) and (fasting state glycaemia= ≥110 but<126mg/dl) and (oral glucose tolerance test=≥200mg/dl),* ***then*** *diabetes.*

The other rules are formulated in the same way.

Conclusions

If follows from the aforesaid consideration that each information processing technique has its advantages and disadvantages. Consequently, some complex problems may be difficult to solve if only one technique is applied, which finally leads to making use of hybrid solutions. At least three factors can be mentioned that can encourage hybrid solutions:

- reducing the drawbacks of a given technique by applying another technique,
- multiplicity of tasks fulfilled by the application requires the use of various techniques,
- it is necessary to emulate different techniques within the scope of one architecture.

To make the system work it is necessary to create a detailed base of knowledge and an inference mechanism.

The successive stages of building the expert system can be presented as follows:

- Problem identification. Its aim is to create an informal description, define the needs to be met by the expert system and the function scope of the system (the scope cannot be too wide so as not to include the problems whose solution methods are not known. The circle of users is to be determined as well.
- Defining the function principle of the system, where the way the expert works when solving similar tasks is analyzed. A few typical tasks to be solved by the system are selected together with the expert. Then the process of their solution is watched closely.

The most important criteria are:

- the system's ability to apply the knowledge base,
- the possibility of changing and completing the knowledge base,
- the possibility of giving explanation.

Describing the essence of the expert system functioning it is necessary to define: the course of the dialogue with the user (who makes a dialogue), the way the dialogue goes (determination of the menu, the questions and the

kind of language), the way the system reacts (immediately, after the inference cycle) and how answers will be formulated. Additionally, it is advisable to define the programme tools to be used, what computers will be used.
The definition of the knowledge base extent and the choice of the way of representation involves answering the following questions:

- do the demands we want the expert system to meet lead to the choice of the definite way of representation?
- is high effectiveness (speed) necessary?
- is it possible to apply the existing skeleton systems?
- is the system compatible with other systems?
- will it be necessary to change the knowledge base during the operation?
- are the tools of knowledge acquisition necessary?

The construction and verification of the prototypes on the properly selected examples.
Testing investigations and the evaluation of the applicability of the system involve the evaluation of the quality of the decisions suggested by the system, correctness of the inference techniques, the quality of the cooperation with the user, efficiency, transferability reliability, testing convenience, simplicity of modification methods.

- The expert system, which has the knowledge written by an expert in a particular field, can make use of it in an economically effective way as the expert's presence is not necessary. This way the expert does not have to repeat the same expertise and can concentrate on more challenging tasks,
- The comparison of the results obtained by the expert system with those obtained by man shows explicitly that in many fields the expert system is not as fallible as a human,
- The expert system can precisely prove its inference process, which a man, an expert falling back on his intuition and experience, is not capable of,
- The expert system can solve a large group of problems from a particular field and each task that begins to exceed the inference rules causes steady work quality deterioration of the system. (in the case of an expert there occur irregular drops in quality or a complete lack of answer),
- Future expert systems will be able to solve tasks from various, not interrelated, fields of knowledge based only on the structural similarity of the inference rules,
- The expert system can be used even in those fields that cannot be easily described by rules, but a human can deal with them fast and in the right way. In such cases the expert system, that can substantiate the decisions taken, can be applied as a sort of help by people who are not familiar with the particular branch of knowledge well enough to start working independently,
- Future expert systems that corroborate the decisions taken in the inference process will adjust the difficulty level of their explanations to the user's level of knowledge. An expert might get other explanations than a person not knowing a particular field,
- The expert system can contain mechanisms enhancing its working - enlarging the knowledge by new facts and inference rules. The mechanisms include: check of lack of discrepancy between the rules newly entered into the knowledge base and the rules that have already been there, check of the congruity of the rules with the newly entered facts, the mechanism of the evaluation of the application frequency of particular rules, and the mechanism of extending the existing rule base beyond the scope of the given knowledge base,
- The model of the expert system structure means a qualitative change in computer programming. It enables a simple adjustment of a computer programme elaborated for a definite field to effective use in another field,
- Expert systems can be created by means of editorial programmes which enable avoiding a lot of mistakes. The programmes have the following properties: a user- friendly communication system

and automated registration operation during information distribution, checking the spelling and syntax correctness of the entered text information, checking lack of semantic discrepancy between the present content of the data base and the newly entered facts, facilitating the creation of the data base by applying appropriate window systems and enabling the user to enter the information in the graphic medium,

- After the identification of mistakes in the expert system function it is possible to rebuild the knowledge base of the system. The process can be performed or supervised by a knowledge engineer or done automatically by the expert system,
- Some expert systems can automatically, without any supervision, create successive knowledge bases (so learn by themselves) being aided by a filter that can stop false information (information noise) based on its discrepancy with the already existing knowledge base. [Bizoń, 2008]

The hybrid system I made is to function as a medical expert diagnosing diabetes. It is supposed to replace, in a sense, the doctor in the first phase of the illness diagnostics (it allows for an interview and a detailed blood test).

The knowledge base created so far was confined to the determination of three object groups.

After getting the information about the patient, symptoms and the disease, and after completing the basic medical examinations, the moment is reached when our expert system, based on the above information, draws the relevant conclusions. Diagnosing involves moving in the decision tree. As aforesaid, the system discussed recognizes three classes of the disease: type 1 diabetes, type 2 diabetes and diabetes mellitus in pregnancy. Secondary diabetes is very difficult to recognize and of great diversity. It takes a separate interpretation and analysis. For that reason it was ignored in initial tests.

The scheme of the diagnosis is quite simple and in a way obvious. The final result may be a statement that the patient suffers from a particular kind of diabetes and the recommended remedy is simply an appropriate diet together with pharmacological treatment.

It is this way that we reach the stage of diagnosis. If we analyzed in detail one of the possible ways, we would observe that its particular stages do not differ from the proceedings adopted by the doctor. Our expert system is to come to the right conclusion behaving like an expert in a given field, that is, a doctor.

The next stage is the classification of the symptoms and the division into two types of diabetes (objects type 1 and 2), considering differential diagnostics. Training files containing verified patient data will be prepared by an expert.

Further analysis can be carried on in different ways, which will be decided after the data set is ready.

It is very important that there should be a close cooperation between the system engineer and the experts in the field in question when constructing the appropriate expert system. Nothing can replace the doctor's knowledge and his long-standing experience.

The system of diabetes diagnostics based on artificial intelligence that we constructed would be the first system of that kind made in Poland.

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