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# Fuzzy Agent in a Medical Diagnosis Support System

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**Abstract**

This paper presents artificial intelligence techniques in a fuzzy logic-based model for the medical diagnostic process. The medical diagnostic system is an intelligent agent that interacts with the resident doctors while they are examining a patient to coordinate she/him with the questions they have to ask for an accurate diagnostic. The system computes the most appropriate disease and the next information needed for a clearer separation between possibilities at each step and in the end will give suggestions for the diagnostic.

Such an intelligent decision support system constitutes a class of computer-based information systems including knowledge-based systems that support decision-making activities. Ideally, it should behave like a human consultant, supporting decision makers in better understanding their problems.

The knowledge base is a database with information regarding diseases and diseases tree, possible symptoms, possible values for a symptom and disease symptom values – (symptom value indicating the disease) and the relation between disease symptom values, since there are cases when not all symptoms are mandatory. This system contains data from a psychiatry domain.

## 1. Introduction

This paper presents the prototype of a medical diagnostic system acting as an intelligent agent that interacts with the resident doctors while they are examining a patient to coordinate she/him with the questions they have to ask for an accurate diagnostic establishment. Considering the scope of the system we can name it as a decision support system for the medical stuff.

## 2. Theoretical backgrounds

### 2.1 Intelligent agent approach

An intelligent agent is an autonomous entity which observes and acts upon an environment and directs its activity towards achieving goals [1]. Agents and multi-agent systems are the actual terms and concepts for Distributed Artificial Intelligence - DAI. Intelligent agents may learn and use knowledge to achieve their goals. The diagnosis system represents a knowledge-based agent that interacts with a medical operator in the diagnostic establishment process supported by a diseases and symptoms database behind.

Software implemented intelligent agents are often described as an abstract functional system, but Russell and Norvig's definition [1] consider the goal-directed behaviour as the essence of rationality and so prefer the term rational agent.

In Medical Diagnosis Systems, the intelligent agent indicates the user that the program still needs some more data – other medical characteristics that have to be given a value in order to make a more accurate diagnostic. The nature of intelligent agents can be heterogeneous. For example, in a Decision Support System (DSS) the interaction takes place between a human and an artificial problem solver – this is the case of the Medical Diagnosis System.

## 2.2 Decision Support System

A Decision Support System (DSS) has evolved during time, it was considered to be "a computer based system to aid decision making" in the 70s (Sol[2]), definition that describes well the type of system to be presented. Later definitions contained a larger domain for DSS: "an interactive computer-based system which help decision-makers utilize data bases and models to solve ill-structured problems" in the 80s (Sol[2]). Decision Support System systems may be developed in any knowledge domain. Examples include a bank loan officer verifying the credit of a loan applicant or other applications used in business and management. Executive dashboard and other business performance software allow faster decision making, identification of negative trends, and better allocation of business resources. A growing area of DSS application, concepts, principles, and techniques is in agricultural production and marketing.

## 2.3 Fuzzy logic definitions

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. In contrast with binary sets having binary logic, also known as crisp logic, the fuzzy logic variables may have a membership value of not only 0 or 1.

Just as in fuzzy set theory with fuzzy logic the set membership values can range (inclusively) between 0 and 1, in fuzzy logic the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values {true (1), false (0)} as in classic propositional logic [3].

Paradoxically, one of the principal contributions of fuzzy logic is its high power of precisiation of what is imprecise. This capability of fuzzy logic suggests, as was noted earlier, that it may find important applications in the realms of economics, linguistics, law and other human-centric fields.

In mathematical logic, there are several formal systems of "fuzzy logic"; most of them belong among so-called t-norm fuzzy logics.

The notions of a "decidable subset" and "recursively enumerable subset" are basic ones for classical mathematics and classical logic. Then, the question of a suitable extension of such concepts to fuzzy set theory arises. A first proposal in such a direction was made by E.S. Santos by the notions of fuzzy Turing machine, Markov normal fuzzy algorithm and fuzzy program (see Santos 1970). Successively, L. Biacino and G. Gerla showed that such a definition is not adequate and therefore proposed the other one, like.

U denotes the set of rational numbers in [0,1]. A fuzzy subset s : S ->[0,1] of a set S is recursively enumerable if a recursive map h : S×N ->U exists such that, for every x in S, the function h(x,n) is increasing with respect to n and s(x) = lim h(x,n). We say that s is decidable if both s and its complement –s are recursively enumerable. An extension of such a theory to the general case of the L-subsets is proposed in Gerla 2006. The proposed definitions are well related with fuzzy logic. It is an open question to give supports for a Church thesis for fuzzy logic claiming that the proposed notion of recursive enumerability for fuzzy subsets is the adequate one [4].

### 2.3.1. Linguistic variables and fuzzy if–then rules. Computing with words.

The concept of “computing with words”(CW) is rooted in several papers, starting with Zadeh paper in 1973 – “Outline of a New Approach to the Analysis of complex Systems and Decision Processes”, where the concepts of linguistic variable and granulation were introduced[9].

Computing with words evolved in a distinct methodology during time and it reflects many advantages of fuzzy logic and soft computing, advantages that took place within the past few years. A key aspect is that it involves a fusion of natural languages and computation with fuzzy variables[9].

The machinery of linguistic variables and fuzzy if–then rules is unique to fuzzy logic. This machinery has played and is continuing to play a pivotal role in the conception and design of control systems and consumer products.

Rules are usually expressed in the form:

IF variable IS property THEN action

For example, an extremely simple temperature regulator that uses a fan might look like this:

IF temperature IS very cold THEN stop fan

IF temperature IS cold THEN turn down fan

IF temperature IS normal THEN maintain level

IF temperature IS hot THEN speed up fan

The AND, OR, and NOT operators of boolean logic exist in fuzzy logic, usually defined as the minimum, maximum, and complement; when they are defined this way, they are called the Zadeh operators, because they were first defined as such in Zadeh's original papers. So for the fuzzy variables x and y:

NOT x = (1 - truth(x))

x AND y = minimum(truth(x), truth(y))

x OR y = maximum(truth(x), truth(y))

There are also other operators, more linguistic in nature, called hedges that can be applied. These are generally adverbs such as "very", or "somewhat", which modify the meaning of a set using a mathematical formula.

In fuzzy logic everything is or is allowed to be granulated, with a granule being a clump of attribute-values drawn together by indistinguishability, similarity, proximity or functionality. Graduated granulation, or equivalently fuzzy granulation, is a unique feature of fuzzy logic. Graduated granulation is inspired by the way in which humans deal with complexity and imprecision.

An important concept which is related to the concept of a linguistic variable is the concept of a granular value. A granular variable is a variable which takes granular values. In this sense, a linguistic variable is a granular variable which carries linguistic labels. It should be noted that a granular value of Age is not restricted to young, middle-aged or old. For example, ‘‘not very young” is an admissible granular value of age [79,81].

Fuzzy logic has many facets. Mathematically, the logical facet and the fuzzy-set-theoretic facet are the basic facets of fuzzy logic. A facet which plays a pivotal role in almost all applications of fuzzy logic is the relational facet – a facet which is focused on linguistic variables and fuzzy if–then rules [5].

# 3. Presentation of the Medical Diagnosis System

The Medical Diagnostics System is intended to be a software application mainly destined to orientate the resident doctors in the diagnostic process for patients' examinations. The system will be implemented for psychiatry diseases, but the architecture will try to make it flexible for further modules covering other medical areas.

## 3.1 System functionalities

The medical diagnostic system will expose the following functionalities

1. Orientate the doctor with the questions to be addressed to the patient based on the information from the previews answered question and the medical file data. Because there is a large amount of data and some symptom values automatic exclude certain diseases an intelligent system using artificial intelligence techniques will guide the user (resident doctor) throw the process of the questions to be answered.
2. Expert knowledge part to include the psychiatry diagnostics information about symptoms and diseases filled in by the medical stuff, in a later stage imported form an existing database while the format is proper for import.
3. The system should work in distributed environment in order to be accessible to people working in different places; the medical stuff that should fill in the medical data and the computer science researchers. This requirement determine us to use the internet interface to make it accessible in internet, we could also use web services to expose further functions of our system to other informatics systems.
4. Maintaining a "Examination File"/(or Medical File) which to include the main characteristics of the patient
5. Making reports/ extracting results from the database regarding disease characteristics and disease correlations.
6. The system should be protected; only authorized personnel should have access to fill in the steps for establishing the diagnostic or to complete the diagnostics information and parameters.
7. The system should support collaboration from international workgroups and English will be the first language of the user interface, but will be considered a extension to Multilanguage support.

## 3.2. Knowledge Database model

The knowledge base of the system contains a few main entities: symptom with associated symptom values, disease and disease symptom value.

### 3.2.1. Symptom

A symptom in our model is not equivalent with a medical symptom; it is an independent characteristic, like temperature, pulse, etc. The symptom has associated a name, a description - attribute that will be used to formulate the questions, and a list of two or more symptom values.

### 3.2.2. Symptom value

The symptom value in conjunction with a symptom on the other hand is similar with a medical symptom e.g. temperature of 38 degrees, pulse of 80, etc. For symptom "temperature" the symptom values would be a list of values: “36 degrees”, ”37 degrees”, etc. Some of the symptom may have only the yes/no values.

### 3.2.3. Disease symptom value

A disease symptom value represents a symptom value associated to a disease.  It contains a symptom and a symptom value associated plus some other characteristics like frequency (haw often the symptom appears), duration (haw long is since the first appearance of the symptom), if the symptom value is or is not mandatory (absolutely necessary to diagnose a person with that disease) and the weight of the symptom in the disease establishment on a scale from 1 to 1000. This is the weight given by the medical specialist. Other weight, called by us the Fuzzy Weight it is computed inside the system according to a bunch of other variables. A disease symptom value has associated also a code.

### 3.2.4. Disease

The diseases are stored under a hierarchical form following the model already defined in medicine.  Important attributes are a list of disease symptom values for that disease. A patient should have most if not all the disease symptom values associated with a disease (at least all the mandatory ones) to be diagnosed with that disease.  The second important attribute of the disease is the validation formula.

### 3.2.5. Knowledge Database Model Diagram

The relations between the entities of the knowledge database, and their entities can be seen in the following database diagram. (The database has been created using Ms. SQL Server )

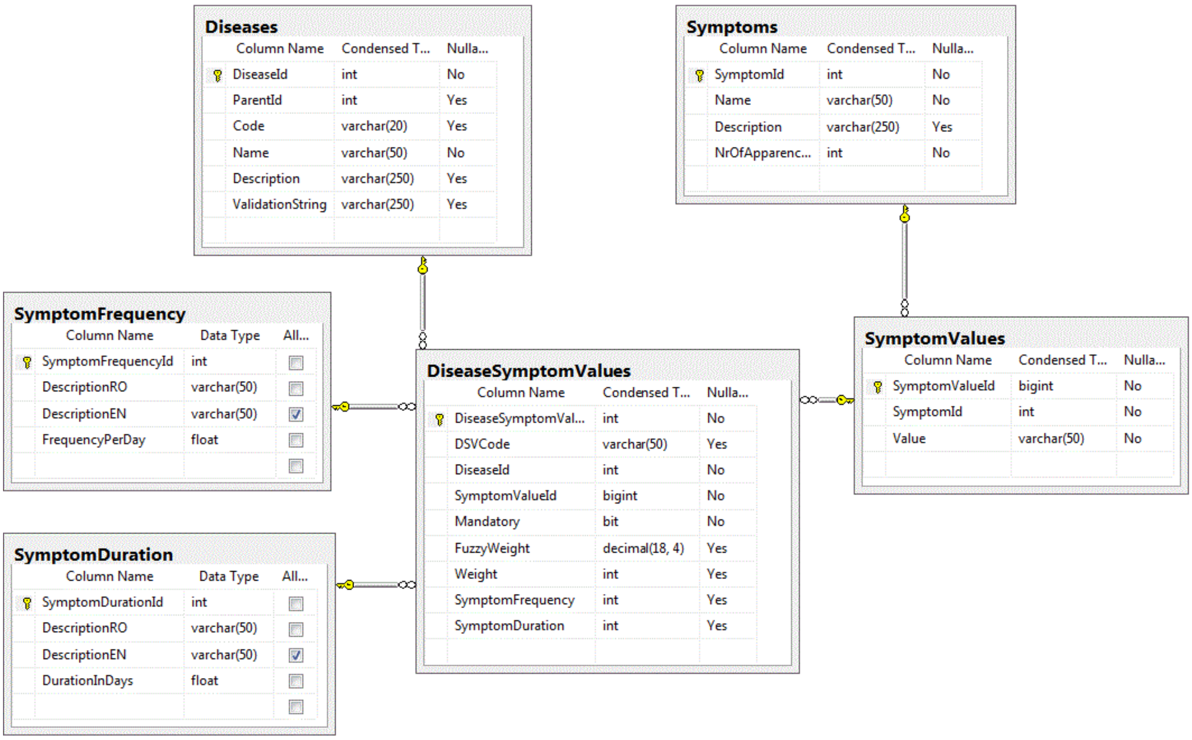


Figure 1: The Medical Disease System Data Base Diagram

### 3.3. Validation Formula

Disease establishment in the medical literature is defined as follows "Patient has disease X if it has at least three of the following symptoms S1, S2, … , S5 and if he/she also presents the symptoms S6 and S7". The disease validation string or validation formula contains this kind of constraints in order to validate a disease. To write it we use the disease symptom value codes and the following operators:

| Operator | Descriptive word | Example |
|---|---|---|
| + | And | dsv1+dsv2+dsv3 stands for "For having the current disease the patient should present disease symptom value dsv1, disease symptom value dsv2 and disease symptom value dsv3" |
| \| | Or | Dsv1 + (dsv2\|dsv3) stands for "For having the current disease the patient should present disease symptom value dsv1 and disease symptom value dsv2 or disease symptom value dsv3" |
| () | Group of symptoms | - |
| min X {s1, …, sn} | Minimum X from a list | Min2{dsv1,dsv2,dsv3,dsv4} ) stands for "For having the current disease the patient should present 2 of the following symptom value dsv1 and disease symptom value dsv2 or disease symptom values dsv1,dsv2, dsv3, dsv4" |
| max X {s1, …, sn} | Maximum X from a list | - |

Table 1 : Operators of the validation expression

# 4. Fuzzy logic approach for medical diagnostics system

### 4.1 Notations

We are considering the following notations for the Medical Diagnosis System:

d – the disease, D – the set of diseases D=[d1, d2, ..., dn]

$f_d$ – Validation formula for disease d, there is a different validation formula for each disease d, but the sub-components of the $f_d$ functions are similar.

F – all the $f_d$ validation formulas, F= [$f_{d1}$, $f_{d2}$, ..., $f_{dn}$], each disease d from D has an associated validation formula $f_d$ from F.

s – the symptom, S – the set of symptoms in the system S=[s1,s2,..., sm]

sv –the symptom value, SV – the set of symptom values in the system,

SV=[sv1, sv2, ..., svl], l >= m (there are more symptom values than symptoms)

$S_kV$ – the set of symptom values associated with the symptom $s_{k.}$, $S_KV$ =[sv1,....svr]

$S_kV$ is a subset of SK. [sv1,....svr] is included in [sv1, sv2, ..., svl] = SV, r<l

dsv – disease symptom value, DSV =the set of all disease symptom values possible

$f_d$ = function($dsv_1$, $dsv_2$, ..., $dsv_p$) – the validation formula $f_d$ contains a function whose parameters are disease symptom values dsv;

X – Examination information

$X_T$ – examination information at moment T,

$X_T$ = [$dsv_1$, $dsv_2$, ..., $dsv_k$] – examination information at moment T contains a list of disease symptom values [$dsv_1$, $dsv_2$, ..., $dsv_k$] that are know at moment T to be true for the patient condition

$X_{T+1}$ = [$dsv_1$, $dsv_2$, ..., $dsv_k$, $dsv_{k+1}$], at each iteration there will be a new disease symptom value added.

## 4.2. Main step with IF ... THEN rules

In a diagnostic process we have a main IF-THEN rule for each disease:

IF $f_d$ ($X_T$)=true THEN Patient diagnostic is d

At a moment T in the examination we have to evaluate each $f_d$ in F, that means to make an evaluation for each d in D

EVAL[ $f_{d1}$ ($X_T$)]

EVAL[ $f_{d2}$ ($X_T$)]

........................

EVAL[$f_{dn}$ ($X_T$)]

And to check the IF...THEN Rules

IF $f_{d1}$ ($X_T$)=true THEN Patient diagnostic is d1

IF $f_{d2}$ ($X_T$)=true THEN Patient diagnostic is d2

........................

IF $f_{dn}$ ($X_T$)=true THEN Patient diagnostic is dn

Because especially in the earlier T moments in the evaluation none of the $f_d$ functions will be true, we will have to compute a “degree of truthiness”, to evaluate in which degree $f_d$ is true

Also at each moment T in the examination we have a set of disease symptom values we know for the patient: $X_T$ = [$dsv_1$, $dsv_2$, ..., $dsv_k$].

### 4.2.1. The actual evaluation

The EVAL function, EVAL[ $f_d$ ($X_T$)] is an evaluation of the $f_d$ function and is using fuzzy logic operators AND, OR, NOT and also reunion, intersection operators to compute the “degree” in which the patient has disease d at an intermediate time T. The fuzzy operators will be used over the more “linguistic” operators presented in section 3.3 Validation Formula. The EVAL function should take in consideration that not all parameters are known at the current moment T, we know only $dsv_1$, $dsv_2$, ..., $dsv_k$, not $dsv_1$, $dsv_2$, ..., $dsv_p$, p>k.

EVAL[ $f_{d2}$ ($X_T$)] = EVAL[ $f_{d2}$ ($dsv_1$, $dsv_2$, ..., $dsv_k$)]

Further testing and analysis of the EVAL function is under work.

#### 4.2.2. Optimization

In order to optimize the computation we will make the evaluation of the $f_d$ functions and check the IF ... THEN rules only for the $f_d$ functions that have as parameter(s) one or more of the disease symptom values at moment T.

That means that at moment T, having

$X_T = [dsv_1, dsv_2, ..., dsv_k]$, $D=[d1,..., dn]$, $F=[f_{d1}, ..., f_{dn}]$, $f_d = function(dsv_1, dsv_2, ..., dsv_p)$

We will compute

EVAL($f_d$), for each $f_d = function(dsv_1, dsv_2, ..., dsv_p)$ with the property that exists a $dsv_i$ in $(dsv_1, dsv_2, ..., dsv_p)$ that belongs also to $[dsv_1, dsv_2, ..., dsv_k]$, $= X_T$ .

### 4.3. Finding the next iteration

The role of the intelligent agent is to determine the next symptom to be interrogated for its value in order to obtain the next disease symptom value dsv to be added in the examination list at moment T+1.

The rules to choose the next symptom are the following:

Search for the disease d with the best scores for the EVAL($f_d$),

- $f_d = function(dsv_1, dsv_2, ..., dsv_p)$ and for which not all $(dsv_1, dsv_2, ..., dsv_p)$ are included in $X_T = [dsv_1, dsv_2, ..., dsv_k]$; exists at last one dsv that is not included.
  If there are more such diseases choose randomly one of them
- Choose the next disease symptom value $dsv_{T+1}$ needed to determine the truth of this disease with the following conditions:
  - $dsv_{T+1}$ belongs to $(dsv_1, dsv_2, ..., dsv_p)$, parameters of $f_d = function(dsv_1, dsv_2, ..., dsv_p)$ for the chosen disease d
  - $dsv_{T+1}$ does not belong to $X_T = [dsv_1, dsv_2, ..., dsv_k]$;
  - if there are more disease symptom values candidates which fulfil the above conditions choose the one that are mandatory for disease d, and if there is none mandatory choose the one that has higher weight
  - if applying the above rule none of the disease symptom values has been chosen choose one randomly
- The next symptom to be questioned will be the symptom of the chosen disease symptom value $dsv_{T+1}$

## 5. Other Approaches in CDSS

Common example of the DSS is the Clinical Decision Support System for medical diagnosis. Clinical decision support systems (CDSS) are interactive computer programs, which are designed to assist physicians and other health professionals with decision making tasks.

### 5.1 Iliad

Iliad was developed at the University of Utah School of Medicine, Dept. of Medical Informatics, it is an expert system and has been under development for several years. It uses Bayesian reasoning to calculate the posterior probabilities of various diagnoses under consideration, given the findings present in a case. Iliad was developed primarily for diagnosis in Internal Medicine and now covers about 1500 diagnoses in this domain, based on several thousand findings. The Iliad shell has also been used to develop knowledge bases for diagnosis in other domains.

### 5.2. TheraDoc

TheraDoc is a suite of real-time monitoring products as well as Infection prevention, mediation, and correction. TheraDoc uses a variety of standards compliant messaging taxonomies to work with currently existing software in the clinical setting to guide decision making as well as report trends in problems your institution is encountering (http://www.theradoc.com/products/). An Expert System Platform is used as a unique knowledge execution platform that concurrently utilizes TheraDoc Knowledge Modules to intelligently alert clinicians and deliver patient- and disease-specific information and treatment recommendations to the point-of-care. The TheraDoc Expert System Platform is based on a scalable n-tier architecture based on robust third party technologies.

### 5.3. Lifecom -CHAMP

Lifecom has developed the CHAMP Project(Computerized Healthcare Assistant and Management Project) which is an entirely new form of artificial intelligence technology and a supporting suite of knowledge development tools. The Lifecom technology portfolio includes novel knowledge extraction and management tools, the artificial intelligence engine , and a highly graphical user interface.( http://www.ohsu.edu/champ/ch_champ.html)[7]. The A. I. Engine - Integral Diagnostic Engine (patent pending) assesses all entered data in support of optimal decision-making.

### 5.4. VisualDx

VisualDx is a point-of-care diagnostic resource that allows clinicians to build patient-centric visual differential diagnoses based on the patient's signs, symptoms, medical history, and more. Clinicians have immediate access to more than 17,000 images as well as expert-reviewed information for nearly 1,000 visually identifiable diseases, drug reactions, and infections represented in all age ranges and skin types [8]. The system is a JAVA-based decision-support program developed by Logical Images to be used in clinical care to develop differential diagnoses based upon morphologic finding- and patient finding-driven searching. It consists of several modules, many of which are very relevant to infectious diseases specialists.

### 5.5. Auctoritas

Auctoritasis psychiatric expert system is a global database managing the newly-developed advisory system; it is appropriate for managing a complete hospital network system for the continuing individual long-distance observation of patients. It consists of four parts: administration, diagnostic decision support system, activities concerning treatment, and statistics. The diagnoses relying on the up-to-date psychiatric diagnostic systems manuals - DSM-IV and ICD-X (based on classical logic). For the construction authors used fuzzy logic and backward chaining.

## 6. Conclusions and further work

This paper presents a fuzzy CDSS - an intelligent agent using fuzzy logic. We study the possibilities of using fuzzy logic in building agent software assuming the role of an experienced medical person, which benefits of a vast medical knowledge regarding symptoms and diseases and has the role to orientate the young resident doctors in the process of diagnosis establishment.

The action this agent system should take according to the functional requirements is to generate at each iteration the next more appropriate question - whose answer will bring the diagnosis process closer to its end: the diagnostic of the patient. The question is closely related to the symptom (in DB model the question is an attribute of the symptom entity and we intend to use fuzzy set theory elements and fuzzy logic to find the more appropriate symptom that needs a value.

Further work will consist in finding possible linguistic values for the evaluation function that computes the degree of truth in a validation formula at a time T, adjustments of the fuzzy weights that are initially given and possible optimization of the next iteration choosing algorithm. We intend to make also a model based on fuzzy clustering to compare the results with the existing one or to use it for system improvement. Further research will also be done in the distributed artificial intelligence domain, specifically regarding the intelligent agents models and in indentifying the appropriate technologies to be used in such a distributed environment.

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