Integrated Approach for Developing Timed Fuzzy Cognitive Maps

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Abstract. Time is a basic aspect in any field, as factors evolve over time and influence the progression of any procedure. This work proposes an integrated approach to developing Timed Fuzzy Cognitive Maps (T-FCMs), an extension of FCMs that can handle uncertainty to infer a result. TFCMs take into consideration the time evolution of any procedure and permit the production of intermediate results and the influence of exterior parameters. It described the proposed method to develop T-FCM and then T-FCM is applied to develop a Medical Decision Support System.

Keywords: Fuzzy Cognitive Map, Time Evolution, Soft Computing, Medical Decision Support Systems.

1 Introduction

Nowadays systems are characterized by high complexity and it is essential to take into consideration various and complementary factors and reengineering alternatives before concluding to a final decision. Decision making needs exist in almost any field, while immediate and reliable decisions may be necessary in an emergent case. Decision Support Systems (DSS) can provide assistance during the process of decision making, which involves the comparison and selection of the best (or optimal) decision. Fuzzy Cognitive Maps (FCMs) have been used successfully to develop DSS because they can handle even incomplete or conflicting information.

In this work, we insert the time unit in FCMs for cases that time determines and changes the route of progression and so the final result. Intermediate results illustrate the progression of a case, while influences during the runtime can provoke concept triggering and/or deactivation, as well as changing the decision. An example from the medical domain illustrates the proposed procedure. Alternative models have been developed that insert temporal concepts into FCM. Hagiwara proposed the extended FCM (e-FCM) , introducing the need for non-linear weights, conditional weights and

P. Angelov et al. (eds.), *Intelligent Systems'2014*,
Advances in Intelligent Systems and Computing 322, DOI: 10.1007/978-3-319-11313-5_19

time delays weights. Park proposed the Fuzzy Time Cognitive Maps (FTCMs) with dummy nodes for showing time lags between nodes . Carvalho et al. proposed Rule Based FCM (RB-FCM) where a parameter called B-Time represents the highest level of temporal detail that a simulation can provide in the modeled system . Miao et al. introduced dynamic functions for the arcs to represent the dynamic and temporal effects of causal relationships . Zhong et al. proposed the Temporal FCMs (tFCM) for discrete linear temporal domain . But, some of them use only numerical weights, other fixed time lags or unique B-Time, while others are highly complicated.

2 Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCMs) is a soft computing modeling technique for complex systems. FCMs introduced as an extension to Cognitive Maps . They are a graphical representation for the description and modeling of the behavior and operation of a system. FCM supports causal knowledge reasoning process and belongs to neuro-fuzzy systems that aim at solving decision making and modeling problems. FCM resembles human reasoning; it relies on the human expert knowledge for a domain, making associations along generalized relationships between domain descriptors, concepts and conclusions. It models any real world system as a collection of concepts and causal relations between concepts [8].

FCMs are dynamical, fuzzy signed directed graphs, permitting feedback, where the weighted edge w_{ij} from causal concept C_i to affected concept C_j describes the amount by which the first concept influences the latter (Fig.1). Experts design and develop the structure of the system and the nodes that represent the key factors of the system operation. They determine the way of network's interconnections, using linguistic variables to describe the relationships among concepts, then all variables are combined and weights are determined. Learning methods and historical data have also applied .

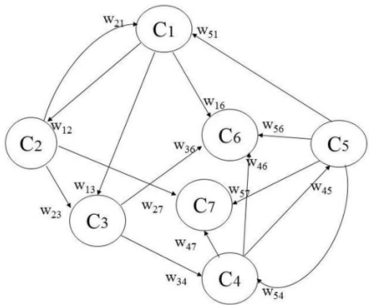

Fig. 1. The Fuzzy Cognitive Map model

Nodes of the graph are concepts, which correspond to variables, states, factors and other characteristics that are used in the model and describe the behavior of the system. A FCM is a conceptual network; the connection between the signed and weighted arcs represents the causal relationships. That is, if $w_{ji}>0$ then concept C_j increases C_i, if the weight is $w_{ji}<0$ then concept Cj decreases Ci, while if $w_{ji}=0$ concept C_j has no causal effect on C_i.

3 A Method for Timed FCM Development

One simulation approach to approximate real situations and check results could be by resembling the human way of thinking. It includes the (represented) knowledge (concepts-factors) and the progress of a case during the time, taking into account the influence of each concept either it is clearly related or not. However, the progress of a case may be related with many concepts from various fields and for every time units that determine the final decision. This is highly difficult for the human mind but decision making models permit easier and faster decisions and/or rest any doubts to estimations. The substantial elements that define and determine the problem are: knowledge and time. Knowledge can be inferred from literature and it is combined with all aspects that a decision maker has adopted from his/her experience, observing data, etc. Time insertion is imperative as it can determine the evolution of a case, influence and change the dependence and interconnections of the initial weights. Here, a methodology is proposed to suggest the concepts and the weights per time, simulate and take the final results for an under investigation case. The overall procedure is illustrated with a flow chart of Fig.2. Specifically, each step includes the following actions:

- *Concepts*

Step 1: Determination of concepts and categorizing as factor and decision concepts.
Step 2: Grouping factor-concepts into areas with respect to their origin (concepts that come from experts, literature, observation data, questionnaires etc.). So every aspect of a problem is taken into consideration, while every possibility, even the rarest can be included as the more diversity there is the more complete and closer to a real problem will be, taking every possible circumstance into consideration.
Step 3: After grouping, a credibility value can be assigned by the experts for each group, judging the source and its reliability.
Step 4: Experts define the time span. This time unit depends on the field and the represented knowledge. There are cases that a long-term supervision is needed or in others the time unit is shorter. The ideal time unit will be the exact time that an important change can affect and provoke a change to the weight dependencies.
Step 5: Additional parameters definition. These parameters are characteristics that are significant and basic to the progression of a case as they can change completely the route of progression and as a result the final decision. Literature and experts define these parameters and the direction of their influence to the overall procedure.

- *Weights per time unit*

Step 6: Weight definition. Experts define the weights that take various values according to each time unit. That is, weights of each interconnection for each time unit are defined linguistically, using either the conclusions of related literature, studies and/or other sources as is described to the following section. This means that each interconnection between concepts takes values proportionally to the time unit. Thus, the influence can be increased or alternatively decreased, giving a detailed illustration of the change direction for each time unit.

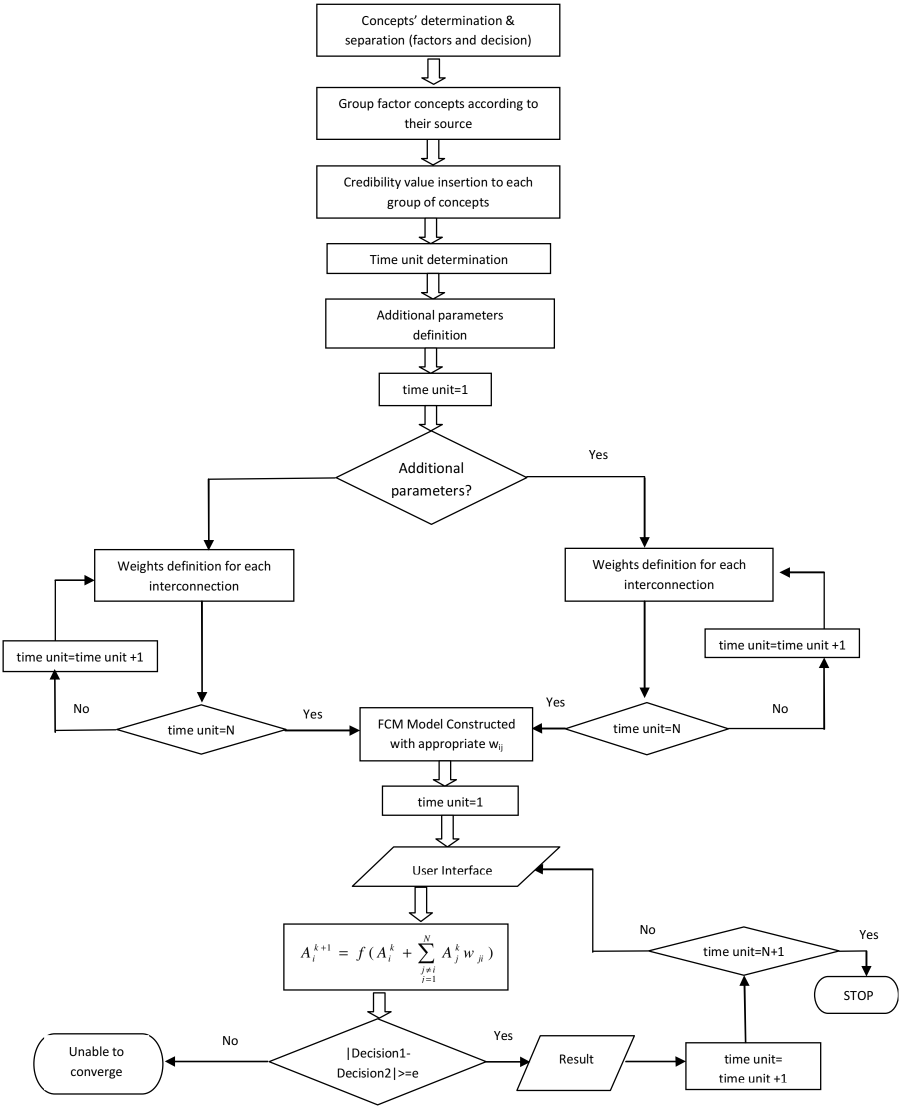

Fig. 2. Flow chart of the proposed method for developing T-FCMs

Step 7: Here the step 6 procedures are repeated until all the possible combinations are fulfilled and defined, for each additional parameter separately and combined with the other additional parameter(s), taking all the possible sub-cases into consideration. The result of this weight setting will be an array that each cell will be a matrix of the interconnections/dependencies to the correspondent time and the activated additional parameters. The final weight will represent the weight of a specific case (under the specific activated parameters and time unit), which depends both on the simulated time unit and the additional parameters. The final weight will be given by:

$$w_{\gamma,t,ij} = [w_{\gamma1,t1,ij}, w_{\gamma1,t2,ij} \dots w_{\gamma1,tn,ij}, w_{\gamma2,t1,ij}, w_{\gamma1,t2,ij} \dots w_{\gamma n,t1,ij}, w_{\gamma n,t2,ij} \dots w_{\gamma n,tn,ij}] \quad (1)$$

where γ shows the activated state of additional parameters. Table 1 defines the possible states that the parameters can take. The index n of γ shows which weight combinations are going to be used during the specific runtime. In order to calculate the final value of $w_{\gamma,t,ij}$, a process is followed to define the remaining individual variables. Table 1 presents the $p_1, p_2, \dots p_n$ that are the additional characteristics that influence completely the overall procedure. These parameters take binary values, denoting whether this characteristic is activated or not, setting the weights accordingly. The indicator *t* shows the time interval that is running each time, while the indicators *ij* show the two concepts that influence each other. Thus, weights per time unit are defined, depend and described on these three parameters: *γ, t, ij*. The γ_0 state is the case that no additional parameter is activated and the procedure will follow the basic FCM without exterior changes influencing the overall simulation. The other states are possible individual parameters that their triggering can change the route of simulation.

Table 1. Matrix of states of the activated parameters

γ_n	Activated parameters ($p_1, p_2, \dots p_n$)
γ_0	000….0
γ_1	100….0
γ_2	010….0
γ...	111.....1

Subsequently, for each state (γ) the interconnections among concepts for each time unit should be defined. This information is illustrated in the variable $d_{\gamma,t,ij}$, where *γ* and *t* will determine the state and the time unit, respectively. Table2 represents the weight dependencies ($d_{\gamma,t,ij}$) for each state.

Table 2. Correspondent interconnections between time and additional parameters

γ_n / time unit	γ_0	γ_1	…	γ_n
t_1	$d_{\gamma0,t1,ij}$	$d_{\gamma1,t1,\ ,ij}$	$d_{\gamma\dots,t1,ij}$	$d_{\gamma n,t1,ij}$
t_2	$d_{\gamma0,t2,ij}$	$d_{\gamma1,t2,ij}$	$d_{\gamma\dots,t2,ij}$	$d_{\gamma n,t2,ij}$
….	$d_{\gamma0,t\dots,\ ,ij}$	$d_{\gamma1,t\dots\ ,ij}$	$d_{\gamma\dots,t..\ ,ij}$	$d_{\gamma n,t\dots\ ,ij}$
t_n	$d_{\gamma0,tn,ij}$	$d_{\gamma1,tn,ij}$	$d_{\gamma\dots,t.n,ij}$	$d_{\gamma n,tn,ij}$

Particularly, $d_{\gamma,t,ij}$ is an array whose dimensions are depending to the number of variables *γ* and *t*. Each cell of this array will be a matrix and the dimensions of this matrix will be defined as follows: if the number of concepts is m, then the $d_{\gamma,t,ij}$ will be an *m*x*m* matrix that will contain all the weights among the concepts, for the corresponding time unit and for each additional parameters combination (each state).

Table 3 contains the values of $d_{\gamma,t,\mathrm{ij}}$ for a specific time unit (t_1). C_1 to C_n are the numbered concepts of the FCM model that characterize the simulated model and are determined in step 1.

Thus, $w_{\gamma,t,ij}$ refers to the value of weight of a particular case. These values will represent the direction of change compared to the originally constructed FCM (default FCM) with no additional parameters activated. For example, the weight $w_{\gamma 1,t2,23}$ is referring to the weight between concepts C_2 and C_3 at time unit t_2 for the case when only p_1 parameter is activated. Table 3 contains just the values of γ_1 case and time unit 1 i.e. t_1. In the same way, the whole array should be completed.

Table 3. Weights for each interconnection and time unit t_1

	C_1	C_2	.....	C_n
C_1	$w_{\gamma 1,t1,11}$	$w_{\gamma 1,t1,12}$	.....	$w_{\gamma 1,t1,1n}$
C_2	$w_{\gamma 1,t1,21}$	$w_{\gamma 1,t1,22}$	.....	$w_{\gamma 1,t1,2n}$
....	....	...	....	...
C_n	$w_{\gamma 1,t1,n1}$	$w_{\gamma 1,t1,n2}$	.....	$w_{\gamma 1,t1,nn}$

- Simulation and Results

Step 8: Run per time unit giving the result for each time span. The time unit is characteristic for each application and field. Thus, the results per time unit are adaptable on each change and influence, reducing the possibility of an erroneous decision.
Step 9: The simulation will stop when the possible decisions will have sufficient difference among them. This difference depends on the nature of problem and the field that decision support system is used. In the case of no convergence, redesigning of the T-FCM model is needed.

3.1 Defining the interconnection dependencies (weights)

In order to define the weights between each interconnection and each time unit, experts need to recall the progression of the phenomenon during the time. They should define the initial weights, denoting which concepts' dependencies (weights) have lower or higher influence during the progression of the case. The direction of this change depends on the contribution of the additional parameters. During the time the interdependencies among some factors have different degrees of influence compared to others and this change depends on both time and the additional parameters; interconnections can become weaker or stronger, while some concepts may be deactivated and others activated.

Initially, experts determine the interconnections using fuzzy rules; a linguistic variable that describes the relationship between two concepts is inferred according to each expert who also determines the grade of causality between the two concepts. After the collecting and definition of concepts, experts are asked to propose the degree of influence among all the concepts, using IF- THEN rules. Their answers will be influenced by their knowledge, experience and etc.

These rules are according to the following statement and they will construct the weight matrix of the default FCM (without additional parameters): For time unit 0….N: "IF a {none, very-very low, very low, low, negatively medium, positively medium, high, very high, and very very high} change in concept value C_i occurs THEN a {none, very-very low, very low, low, negatively medium, positively medium, high, very high, and very very high} change in value C_j is caused THUS the influence of C_i to C_j is a T_{Cij}{influence}". In this way each influence is determined. The inferred fuzzy weights across experts are aggregated and deffuzzified giving an initial numerical weight in the interval [-1, 1]. Thus, the basic weights and weight matrix are defined.

However, the progression of a case depends on additional factors, which are different for each one case. These are defined from various sources as well. Taking these changes into account during the simulation process, experts need to define the direction of change for each time unit. Thus, for each interconnection influenced by the time and the additional parameters, the direction of change is determined leading to the appropriate weight change (step 6 and 7). Linguistic degrees are used to indicate the direction of change (such as none, very-very low, very low, low, negatively medium, positively medium, high, very high, and very very high). These degrees correspond to negative or positive direction. In this case the statement will be: For time unit 0 ....N: "IF (Additional Parameter 1=TRUE (AND/OR Additional Parameter 2...3 =TRUE) AND IF time has a { none, very-very low, very low, low, negatively medium, positively medium, high, very high, and very very high} change (increase or decrease) in concept value Ci THEN a { none, very-very low, very low, low, negatively medium, positively medium, high, very high, and very very high} change in value C_j is caused THUS the influence of C_i to C_j is a T'_{Cij}{influence}ELSE {keep the default value for the corresponding time unit (T_{Cij}{influence}).

The inferred new fuzzy weights, for each time unit and for each parameter are aggregated and defuzzified producing a new numerical weight in the interval [-1,1]. This procedure can better approximate real life situations, as the weights can change per time unit incorporating more elements and parameters, taking into consideration every possible situation, no matter how rare or underestimated it may be.

4 Time Varying Method for Different Fields

The described methodology is suitable for various fields and applications that time is substantial and influences the overall procedure. For every field, experts usually make decisions, control and check a process, predict the progression etc. But time should be taken into account for more realistic results. In medicine and business-management, for example, the lack of the concept of time, regarding the order and the reaction time of a change, may provoke important changes in patient state or influence the output in a strategic/economic problem. The proposed method is capable to give results for each time unit separately. This is highly important as some concepts may have been underestimated, eluded and/or emerged to a following stage.

This method lets the professionals to insert changes to the system, keeping values from the previous stages and observe the influence from the changes at the corresponding time unit, which can give a different result. Thus, expert is able to check and/or control the result provoking different changes to various time units, so different scenarios can be applied as the model follows the progression of a case and gives the possible results for long-term or short term decision cases.

Such systems that approximate real situation demands the incorporation of each possible situation coming from any related domain. Time is essential in real complex systems. Decision systems have to incorporate a high amount of data and information from interdisciplinary sources and, in addition, information may be vague, missing or not available. Such decision support complex systems involve inexact, uncertain, imprecise and ambiguous information [10]. These systems can provide assistance in crucial judgments, particularly for inexperienced professionals.

5 A Paradigm from Medicine: FCM-Medical Decision Support Tool for Differential Diagnosis

The aforementioned process can be applied to various fields. The following section describes the application of the proposed method for differential diagnosis in medicine. In medicine, professionals need to make immediate decisions, eliminating the possibility of error. Generally, medical decisions can be referred to diagnosis, treatment, prognosis etc. Some cases need a long-term while other short-term evaluation.

In this example, we apply the time varying FCM for differential diagnosis of two pulmonary diseases: Acute Bronchitis and Community-acquired pneumonia. Their symptoms are highly confused and usually their symptoms can lead to an error diagnosis [11]. This case needs short-term evaluation. The TFCM-DSS tool will lead to a daily evaluation, so that the professional will be able to judge and make a clearer decision. This is important for making immediate decisions, as when the patient visits the doctor, s/he has to decide according to the patent's symptoms and clinical examination [12],[13], [14]. For this case, an assistant tool would be valuable in order to prevent an undesirable complication. Thus, it can present a suggestion to the doctor to early estimate the patient's situation until the laboratory tests will be available. Besides, it gives to the opportunity to doctor to try various scenarios and to study how the additional parameters can influence the result. TFCM-DSS tool has the following characteristics:

Concepts: Concepts are retrieved from literature and experts. They represent the symptoms of these two diseases. They have been organized according to the nature of source; that is the activated concepts came from the patient or from the doctor. Table 4 contains these factor concepts and their separation. Doctor has a model that can handle factors from patients and from clinical findings of the under examination patient, giving the appropriate credibility to doctors' findings. The weights have a credibility value compared to those that came from patient's description of symptoms because patients' answers are influenced from fear, overestimation and/or underestimation of their symptoms. The time unit has been defined as one day, as short term progression of the disease is needed and the patient should follow a different prescription for each case. For these two diseases some additional parameters, which are individual characteristics of each patient, are defined. Table 5 contains these additional elements. Their activation in combination with the symptoms and clinical findings can lead to a different result. These parameters are important as they determine the result of the overall procedure. The age range 14-65 has been regarded as the firstly (default) constructed model with no additional parameter activated.

Table 4. Categorization of concepts

Factor Concepts		**Diagnosis Concepts**
According to patient'sanswers	**Accordingto doctor's clinical exam**	
C1:body temperature C2: cough C3:bloody sputum C4:chest pain C6:sore throat C7:nasal obstruction C8: malaise C9: rhinorrhea C10: dyspnea C15:sputum production	C5: hypoxemia C12: bronchical breath sound C13: crackles C14: beats/min C11: tachypnea C16: scatter rhonchi C17: wheezing C1:body temperature	C18:Community-acquired pneumonia C19: Acute Bronchitis

Weights per time unit: Experts define the weights, they take into consideration which concepts are influenced by time and give the proportional weight value, according to the additional parameters and the direction of weight change compared to the default one (with no additional parameters activated) (Table 3).

Simulation and Results: The simulation for each day will give a daily estimation of the disease progression, letting the doctor judge the results. In order to give the system a decision, the distance that has been determined for this case is ≥10%.

Table 5. Possible states for the medical decision support tool

γ_n	**Age:<14, Age:>65, Smoking, Co-morbidity**
γ_0	0000
γ_1	1000
…	…
γ_{15}	1111

Figure 3 illustrates the basic FCM model for the differential diagnosis of the two pulmonary diseases according to the described procedure. It should be underlined that some interconnections are omitted as the high complexity makes it unreadable.

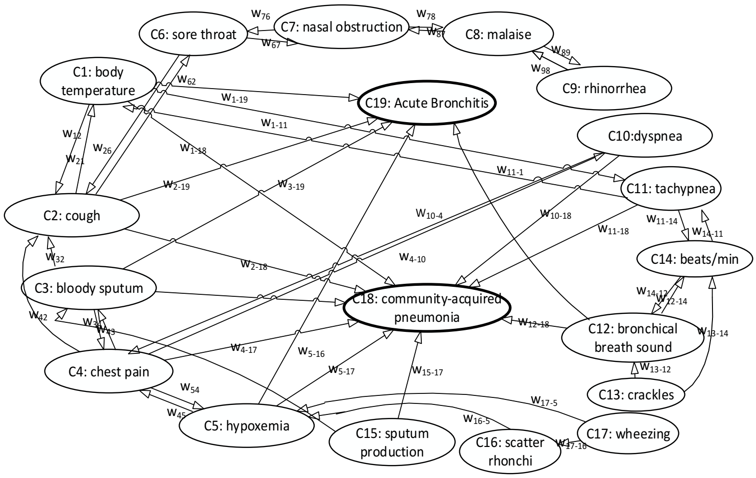

Fig. 3. T-FCM model for the pulmonary differential diagnosis

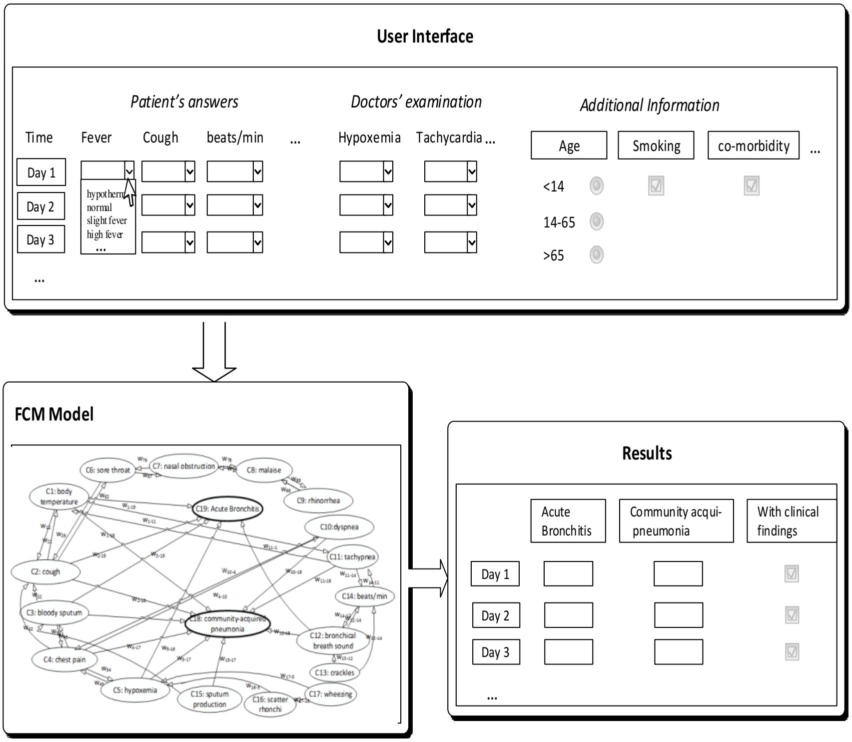

Fig. 4. An illustration of the FCM decision support system for the differential diagnosis

5.1 User Interface of the TFCM-Medical DSS Tool

The user interface contains all the possible situations that a doctor characterizes the patient's situation. The T-FCM takes into consideration all the possible degrees of a factor. For example, the body temperature factor-concept can be hypothermia (<35.6^o), normal (35.7-37.3^o), slight fever (37.4-37.8^o), high fever (37.9-39^o), very high fever (39.1-40.9^o), hyperpyrexia (>41^o). The T-FCM is able to model and handle various numbers of linguistic values and various types of values, as each concept has different characterization [15].

Fig. 4 illustrates a possible interface of the tool that the doctor would be able to set the appropriate values for each concept. The results for each simulation would appear in a window giving the decision for each day. Thus, the doctor will be able to make a decision for the patient, giving the appropriate prescription and/or laboratory tests.

6 Conclusions

The proposed method introduces the concept of time, which is essential for many problems to better approximate real situations. This procedure takes into consideration the evolution of a case, inserting additional parameters that can change the route of progression. These additional parameters are basic elements that make more particular and personalized a simulated case. The fact that concepts' values can change in proportion to the additional parameters' activation and/or deactivation which cause the change, make the model dynamic and adaptable to real situation problems. It takes each exterior factor into consideration and directs the evolution accordingly. Thus, it is suitable for observing the progression of a case and trying various scenarios by triggering and/or deactivating different concepts, achieving a better decision and better understanding of the evolution of a process. An example from the medical domain has been described for differential diagnosis among two diseases with many factors in common.

However, the process of constructing the T-FCM model is intensive for experts and other contributors, who need to determine the progression of the influenced by the time weights for each time unit. Thus, a more automated procedure is needed reducing the human intervention. The described tool is an assistant tool that will support the professional to have a general evaluation of a case progression, making faster decisions [16].

Acknowledgments. This research work was supported by the joint research project "Intelligent System for Automatic CardioTocoGraphic Data Analysis and Evaluation using State of the Art Computational Intelligence Techniques" by the programme "Greece-Czech Joint Research and Technology projects 2011-2013" of the General Secretariat for Research & Technology, Greek Ministry of Education and Religious Affairs, co-financed by Greece, National Strategic Reference Framework (NSRF) and the European Union, European Regional Development Fund.

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