

# A Novel Diagnostic Framework: The Application of Soft Computing Technology.

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## ABSTRACT

The emergence of information technology (IT) has opened unprecedented opportunities in health care delivery as the demands for intelligent and knowledge-based systems have increased as technology enabled medical practices advance. The complexity of medical practices makes traditional approaches of diagnosis inappropriate. In this paper, we developed a novel diagnostic framework for malaria using Fuzzy Cognitive Maps (FCMs).

FCMs provide a simple way to arrive at a definite conclusion from vague, imprecise and ambiguous medical data. In order to achieve this, a study of the knowledge base system of malaria was undertaken. A novel fuzzy diagnostic algorithm was developed. Fuzzy decision tree was used for knowledge extraction to assist the domain experts to generate linguistic weights that describe the cause-effect relationships among the concepts in the developed FCM model. Sigmoid function was used as the threshold function. The diagnostic framework was implemented using MATLAB<sup>®</sup> 7.10.0. Diagnostic data from 15 patients with confirmed diagnosis of malaria were evaluated and the computed results were in the range of the predefined limits by the domain experts.

(Keywords: medical diagnosis, knowledge-base, tropical diseases, fuzzy decision tree, fuzzy cognitive maps, medical expert system)

## INTRODUCTION

The emergence of information technology (IT) has opened unprecedented opportunities in health care delivery as the demand for intelligent and knowledge-based systems has

increased as technology enabled medical practices advance (Djam and Kimbi, 2011a).

As a result of this, there is a greater need for an easy and automatic procedure for diagnosing tropical disease in order to reduce the rate of mortality. In recent times, Artificial Intelligence (AI) methods have significantly been used in medical applications and research efforts have concentrated on medical expert systems as complementary solution to conventional techniques for finding solution to medical problems. However, advanced diagnostics systems have been lacking.

The feasibility and sustainability of a country's economic and social growth depend largely on a vibrant healthcare sector of that nation and no country can maintain a steady economic growth in the absence of an adequate healthcare system. The adages "A healthy nation is a wealthy" and "Prevention is better than cure" are still valid today because it is only with good health a man can make wealth. However, in a case where a person is already sick, diagnosis and treatment are inevitable to avoid untimely death and both proper diagnosis and quality treatment are feasible when there is a vibrant healthcare sector.

The need to arrive at the most accurate medical diagnosis in very timely manner is heightened in the case of malaria and other tropical diseases, as it is understood that accurate diagnosis and timely initiation of treatment is sine-qua-non to the reduction of complication (Djam and Kimbi, 2011b). Fuzzy Cognitive Map (FCM) is a Soft Computing technique that combines the elements of Fuzzy Logic and Neural Network to represent causal relationship between concepts. FCM can be effectively used to manage uncertainty

in medical data. FCM was adopted in this research because of the nature of the application problem. The adoption of FCM in this research was because; it is a powerful tool for dealing with the problem of knowledge representation in an environment of uncertainty and imprecision.

This paper seeks to present a novel diagnostic framework for tropical diseases management using malaria as a case Study. The developed Medical Expert System can provide a decision support platform to malaria researchers, physicians and other healthcare practitioners in the tropics through the design of knowledge representation and reasoning with FCMs.

### FUZZY COGNITIVE MAPS AND KNOWLEDGE REPRESENTATION

FCM is a graphical representation of the knowledge about the perception of a given system. FCMs, which were introduced by (Kosko, 1986) as an extension of Cognitive Maps, are powerful tools for modeling dynamic systems. A FCM, a branch of fuzzy logic, is a causal knowledge-driven methodology for modeling complex decision systems (Kosko, 1986). Concepts and causal relations constitute the fundamental elements of a FCM. Kosko (1986) introduced FCMs by suggesting the use of fuzzy causal relationships taking the interval  $[-1, 1]$  and the concepts taking interval  $[0,1]$ . Figure 1 illustrates a simple Fuzzy Cognitive Map.

FCMs have emerged as a tool to deal with uncertainty, imprecision and partial truth in medical practices. Fuzzy logic and FCMs are methods to render precise what is imprecise in the world of medicine using natural language. FCMs as branch of Fuzzy Logic, offer an alternative to knowledge integration scheme leading to proper decision making. In view of this, some research work FCMs and Fuzzy Logic have been investigated to handle the task of medical decision making (Djam et al., 2011, Djam and Kimbi, 2011a, Djam and Kimbi, 2011b, Djam et al., 2011,

Papageorgiou et al., 2002, Papageorgiou et al., 2003).

## MATERIALS AND METHODS

### Data

For data gathering, patients' medical records on Malaria were sourced from University of Benin Teaching Hospital (UBTH), Benin City, Nigeria. Personal interview was conducted with domain experts (Physicians) and a LIKERT type questionnaire was prepared and administered to physicians who are experts in tropical medicine in order to get the necessary data for this study. We sampled a total of 100 patients' medical records. The method of sampling strategy adopted was systematic sampling method. In this sequel, we made an honest attempt to incorporate FCM as a knowledge-based modeling technique and a novel diagnostic framework for the management of tropical diseases was developed and implemented using MATLAB<sup>®</sup> 7.10.

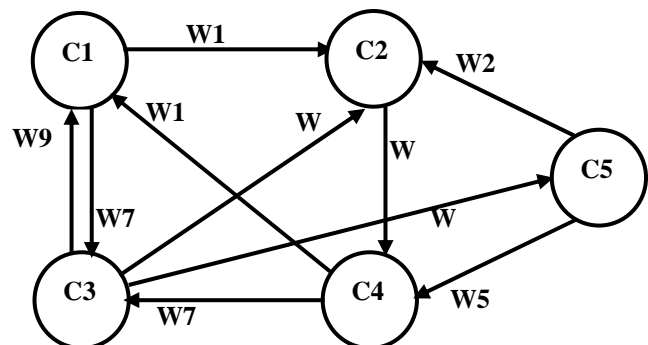


Figure 1: A Simple Fuzzy Cognitive Map.

### FUZZY COGNITIVE MAP-BASED DECISION SUPPORT TOOL

#### Fuzzy Diagnostic Algorithm

The developed algorithm for the fuzzy diagnostic process of tropical diseases is presented in Figure 2 and the flow diagram for the algorithm is presented in Figure 3.

Let  $D$  denotes the number of  $m$  tropical diseases,  $D=(d_1, d_2, \dots, d_m)$ , where each  $d_i \in D$ , represent the set of all possible diseases.

Let  $M_{InitialWeight}$  represent the Initial Weight Matrix  
 Let  $M_{OverallWeight}$  represent the Overall Weight Matrix  
 Let  $V_{Initial}$  represent the Initial Vector (Input Vector)  
 Let  $V_{New}$  represent the New Vector  
 Let  $V_{Final}$  represent the Final Vector (Decision Output Vector)

**Step 1:** For all  $N$  Domain Experts, read inputs and output parameters for  $d$ . Determine the numbers of linguistic variables associated with each input/output parameter and select an appropriate membership function.

Determine all the fuzzy sets for the system.

**Step 2:** Implementation of knowledge extraction method (Fuzzy Decision Trees) for the fuzzy rule base construction and generation of fuzzy rules from the data.

**Step 3:** For all  $N$  Domain Expert, an initial FCM each is developed.

**Step 4:** For all  $N$  Domain Experts, an Initial Weight Matrix  $M_{InitialWeight}$  is computed and an Overall

$$M_{OverallWeight} = \sum_1^N M_{InitialWeight}$$

Weight Matrix  $M_{OverallWeight}$  is computed as:

**Step 5:** Construction of an augmented FCM.

**Step 6:** Normalization of  $M_{OverallWeight}$ .

**Step 7:** Initialization the FCM model:

Initialize  $M_{OverallWeight}$  to store pattern.

Initialize  $V_{Initial}$  (Input Vector) to store pattern.

While the system has not converged, Do steps 8-9 for each Input Vector by iteration.

**Step 8:** Compute  $V_{new}$ :

$$V_{new} = V_{Initial} * M_{OverallWeight}$$

**Step 9:** Threshold and Update the resultant vector.

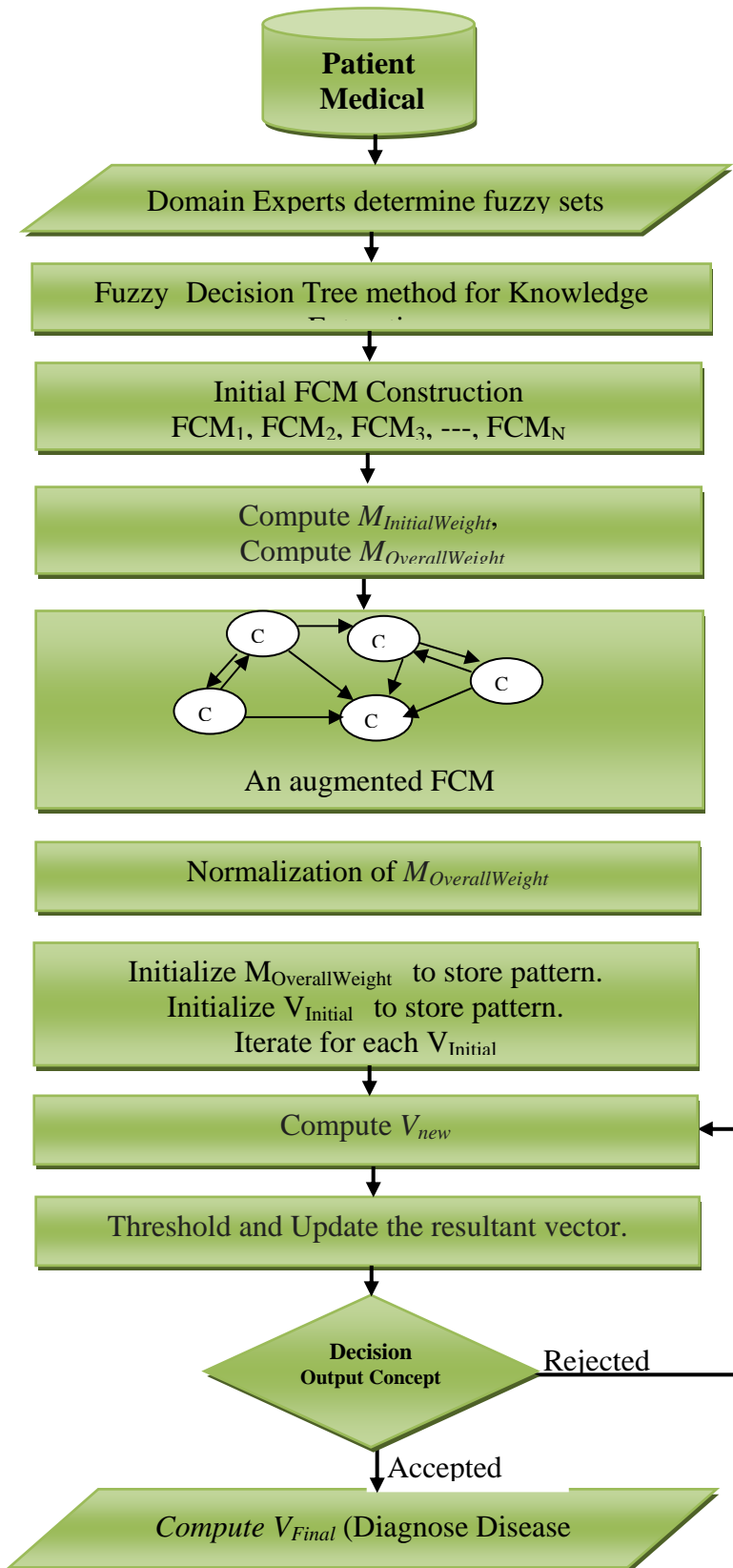
$$V_{New+1} = f(V_{New} + V_{New} * M_{OverallWeight})$$

$$V_{n+1} = (V_n + V_n * M_{OverallWeight})$$

$$V_{n+2} = (V_{n+1} + V_{n+1} * M_{OverallWeight})$$

**Step 10:** Repeat steps 8 and 9 until equilibrium is attained and the values of all the concepts no longer change. At this step, the system converges and the final value  $V_{Final}$  is gotten.

**Figure 2:** Fuzzy Diagnostic Algorithm for the Management of Tropical Diseases.



**Figure 3:** Flow Diagram for the Proposed Fuzzy Diagnostic Algorithm.

### **Algorithm to Generate Linguistic Weights in the Developed FCM Model**

A new fuzzy algorithm to generate linguistic weights that describe the cause-effect relationships among the concepts of the FCM model was developed. The algorithmic approach to assign weights on the FCMs using Fuzzy Decision Tree consists of the following steps presented in Figure 4.

- |                |  |
|----------------|--|
| <b>Step 1:</b> | For all N Domain Experts, set credibility weight in the interval [-1, 1].  |
| <b>Step 2:</b> | For all ordered pair of concepts ( $C_i$ and $C_j$ ), N Domain Experts describe the interrelationship between concepts using IT-THEN rules derived from Fuzzy Decision Tree: IF a {Mild, Moderate, Severe or Very Severe} change occurs in the value of $C_i$ THEN a {Mild, Moderate, Severe or Very Severe} change in the value of concept $C_j$ is caused. Thus the influence of concept $C_i$ on concept $C_j$ is {Negatively Strong, Negatively Moderate, Negatively Weak, Negatively Very Weak, No Relationship, Positively Weak, Positively Moderate, Positively Strong or Positively Very Strong} |
| <b>Step 3:</b> | If causality occurs, it occurs to Maximum Positive only.   |
| <b>Step 4:</b> | Using Fuzzy Ranking Values, the Fuzzy Maximum is applied and a linguistic weight is assigned between concept $C_i$ and concept $C_j$ .   |
| <b>Step 5:</b> | IF for one or more interconnections between concept $C_i$ and concept $C_j$ , more than $\frac{3N}{4}$ assigned difference linguistic weights, THEN request the Experts to GOTO step 2 and reassign weights for that particular interconnections.  |
| <b>Step 6:</b> | Aggregate all the linguistics weights proposed for every interconnection using the SUM method and construct the Weight Matrix.   |

**Figure 4:** Algorithm to Generate Linguistic Weights in the Developed FCM Model.

### **Logical System Design**

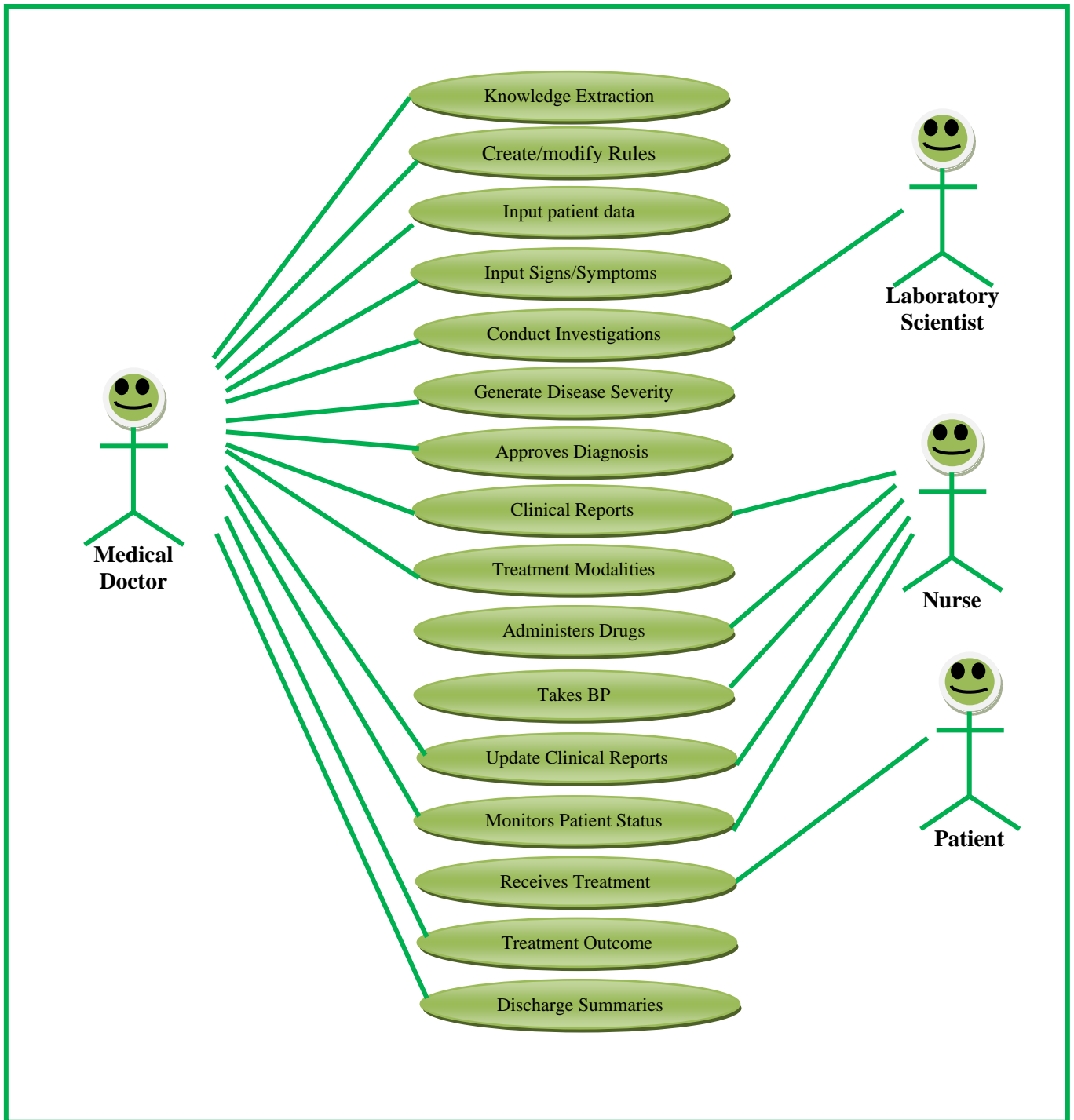
Unified Modeling Language (UML) has been used to depict the logical system view (scenarios) of the developed system. UML standardizes four types of Structural diagrams (Class Diagrams, Object Diagrams, Component Diagram, and Deployment Diagrams) and five types of Behavioral Diagrams (Use-Case Diagrams, Sequence Diagrams, Collaboration Diagram, State Diagram and Activity Diagram). For the purpose of this research, UML Use-Case Diagrams, Class Diagrams, and Activity Diagrams were used to depict the logical view of the proposed system.

Among the system analysis and design tools, UML was chosen because it is an object-oriented tool for object modeling, in addition, the UML diagrams chosen can appropriately depict some

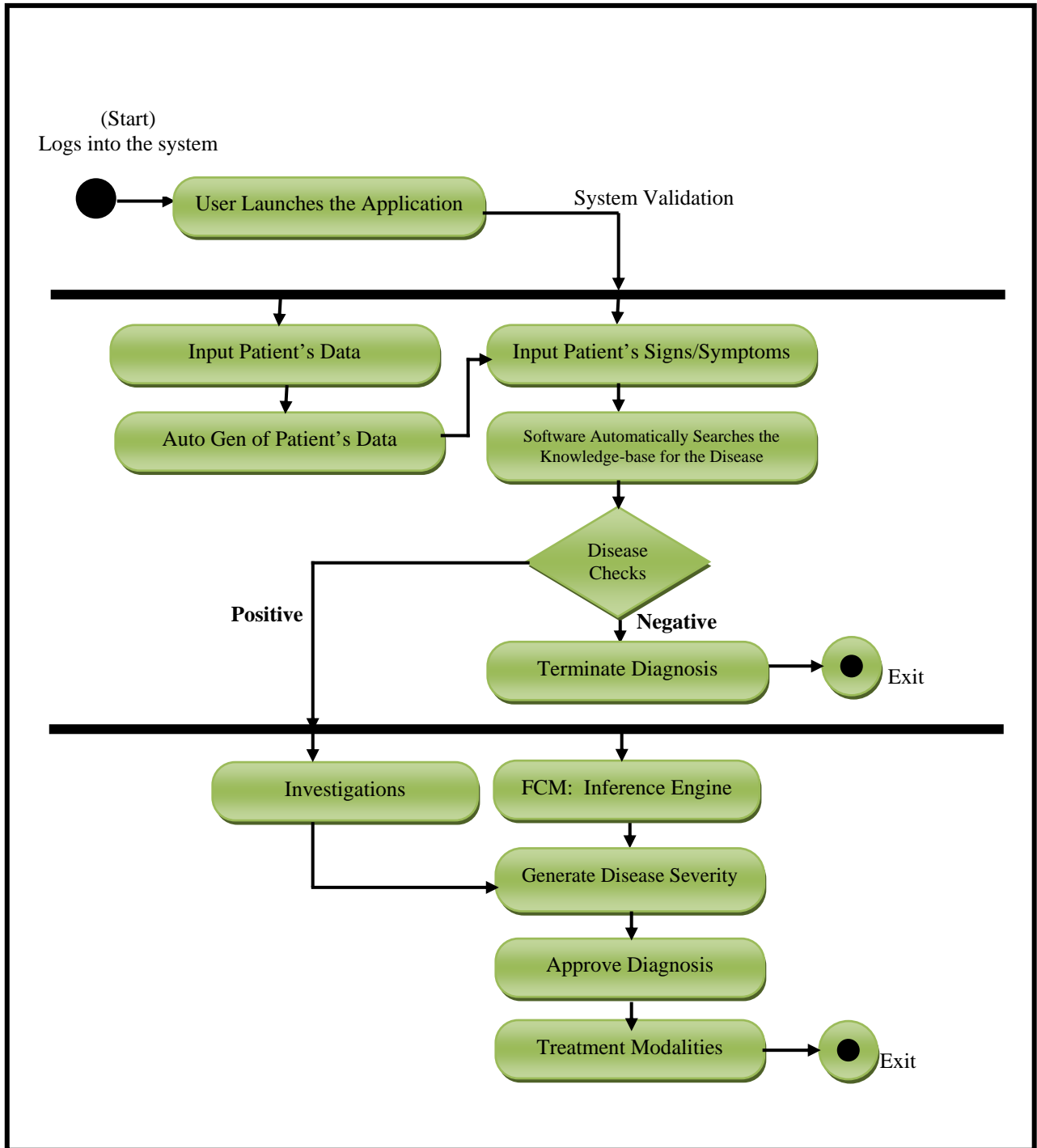
scenarios in the developed system. Figures 5, 6, and 7 below, are portions of UML diagrams derived from the analysis of the problem domain

### **FUZZY COGNITIVE MAP MODEL**

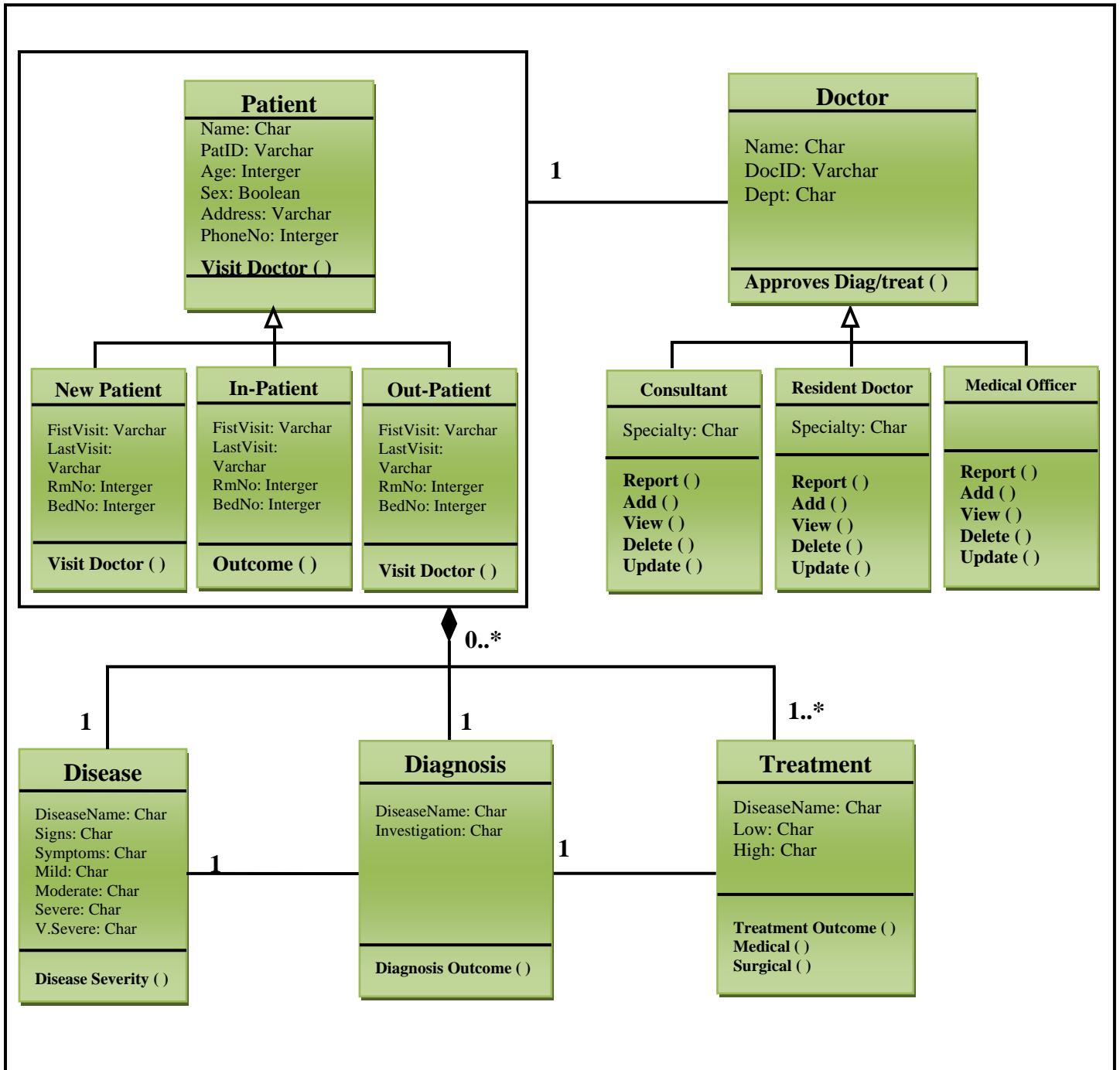
Three Physicians-Domain Experts from University of Benin Teaching Hospital, Benin City Nigeria were pooled to define the number type of parameters (Concepts) concern with malaria diagnosis. These concepts are listed in table 1 with their linguistics variables. For this application, 14 Concepts with 14 fuzzy sets were suggested by three domain experts. The Decision Concept (DS1) represents the severity of Malaria infection and takes for fuzzy values (None, Mild, Moderate, Severe, Very Severe) as shown in Table 1 below.



**Figure 5:** Use-Case Diagram for the Medical Expert System.



**Figure 6:** Activity Diagram for the Medical Expert System.



**Figure 7:** Class Diagram Showing Attributes, Generalization, and Composition Association.



**Table 1:** Concepts in the FCM Model.

Concept Symbol	Concepts	Linguistics Variable
C1	Fever	None, Mild, Severe, Very Severe
C2	Headache	None, Mild, Severe, Very Severe
C3	Abdominal Pains	None, Mild, Severe, Very Severe
C4	Vomiting	None, Mild, Severe, Very Severe
C5	General Body Weakness	None, Mild, Severe, Very Severe
C6	Loss of Appetite	None, Mild, Severe, Very Severe
C7	Diarrhea	None, Mild, Severe, Very Severe
C8	Convulsion	None, Mild, Severe, Very Severe
C9	Palour	None, Mild, Severe, Very Severe
C10	Loss of Consciousness	None, Mild, Severe, Very Severe
C11	Dehydration	None, Mild, Severe, Very Severe
C12	Jaundice	None, Mild, Severe, Very Severe
C13	Malaria Parasite Test	None, Mild, Severe, Very Severe
DS1	Diseases Severity	None, Mild, Severe, Very Severe

The 14 identified concepts with 14 fuzzy sets keep relation with each other, in other to characterize the process of diagnosing malaria. After the determination of fuzzy sets, each expert was asked to define the degree of influence among the concepts and equally describe their interrelationship using an IF-THEN rule.

**FUZZY RANKING OF CONCEPTS (INPUT/OUTPUT VARIABLES) IN THE FCM MODEL**

On the basis of the three Domain Experts' knowledge used in this research, input variables selected for this research were described with five linguistic variables (None, Mild, Moderate, Severe and Very Severe) in the fuzzy interval of [0, 1] as shown in Table 2 below. According to the Domain Experts, the relationships between concepts were described with eight linguistic variables (Negatively Strong, Negatively Moderate, Negatively Weak, Negatively Very Weak, No Relationship, Positively Weak, Positively Moderate, Positively Strong, and Positively Very Strong) in the fuzzy interval as shown in Table 3.

Based on Domain Experts opinion, the Fuzzy Ranking for our system is shown in Tables 2 and 3 below (the fuzzy values were categorized and classified based on Expert Judgment).

**Table 2:** Fuzzy Ranking of Input/Output Variables (concepts) of Tropical Diseases.

Linguistic Variables	Fuzzy Values	Classification
Neutral	0	0
Mild	$0.1 \leq x < 0.3$	1
Moderate	$0.3 \leq x < 0.6$	2
Severe	$0.6 \leq x < 0.8$	3
Very Severe	$0.8 \leq x \leq 1.0$	4

**Table 3:** Fuzzy Ranking of Relationships between Concepts of Tropical Diseases.

Linguistic Variables	Fuzzy Values
Negatively Strong	$-1 \leq x < -0.8$
Negatively Moderate	$-0.8 \leq x < -0.6$
Negatively Weak	$-0.6 \leq x < -0.4$
Negatively Very Weak	$-0.4 \leq x \leq -0.1$
No Relationship	0
Positively Weak	$0.1 \leq x < 0.3$
Positively Moderate	$0.3 \leq x < 0.6$
Positively Strong	$0.6 \leq x < 0.8$
Positively Very Strong	$0.8 \leq x \leq 1.0$

## THRESHOLD ACTIVATION FUNCTION

Several formulas can be used as the threshold activation function in a FCM system. The threshold function is used to reduce unbounded weight sum to a certain range. For this application, the logistic Signal Function was used as the threshold function. The logistic signal function is a continuous function and provides true fuzzy conceptual node states. The function is:

$$f(x) = \frac{1}{1 + \exp(-cx)}$$

The constant,  $c$ , is critical in determining the degree of fuzzification of the function. We have chosen  $c = 1$  as a trade-off which favors the fuzzy interval  $[0,1]$ . Plots of this threshold function for various values of the constant  $c$  are shown in Figure 8.

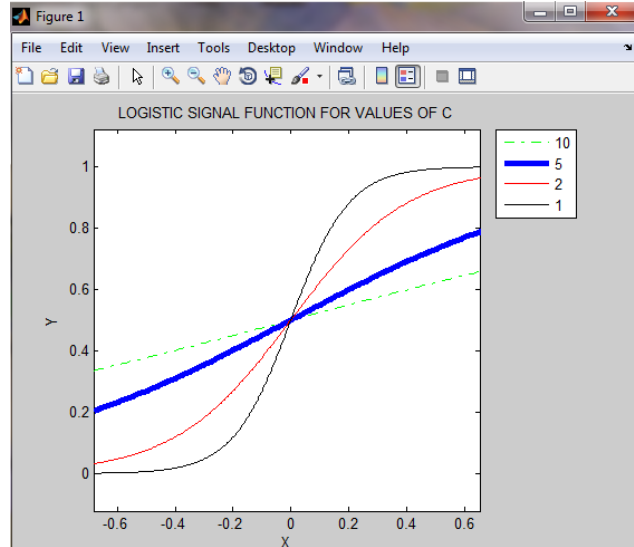


Figure 8: Logistic Signal Function for Various Values of C.

## FUZZY COGNITIVE MAP (FCM) MODEL

The developed FCM model consists of 14 concepts (Table 4). These concepts describe the behavioral characteristics of the systems with respect to malaria diagnosis.

Figure 9 is the FCM model for the diagnosis of Malaria. The weighted arcs represent the relationship between concepts and the weights were assigned by the Domain Experts based on the algorithms in Figures 2 and 3.

Table 4: Overall Weight Matrix  $M_{OverallWeight}$

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	DS1
C1	0	0.31	0.27	0.6	0.21	0.32	0	0	0	0	0	0	0.6	0.34
C2	0	0	0	0.61	0	0	0	0	0	0	0	0	0	0.75
C3	0.73	0	0	0	0	0	0	0	0	0	0	0	0	0.28
C4	0	0.63	0	0	0	0	0.78	0	0	0	0.38	0	0	0.9
C5	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0.64
C6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
C7	0	0	0.46		0.48	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
C9	0.61	0	0	0	0	0	0	0	0	0	0	0	0	0.72
C10	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0.77
C12	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.84
C13	0	0	0	0	0	0	0	0	0	0	0	0	0	0.51
DS1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

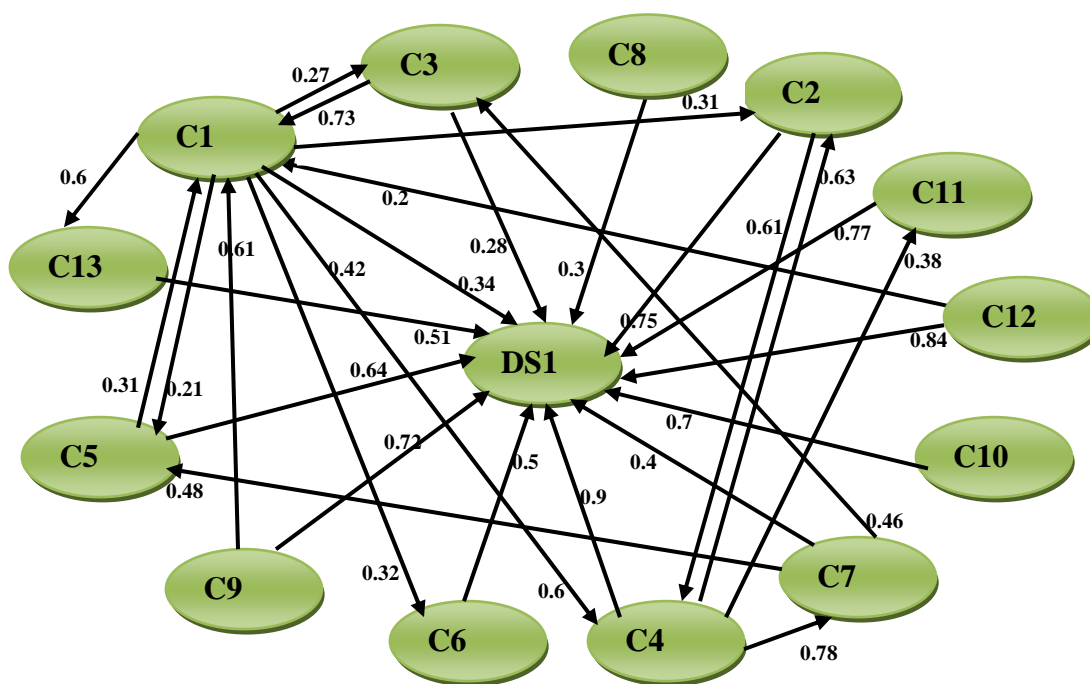


Figure 9: FCM Model for Diagnosing Malaria.

From the above FCM model, an Overall Weight Matrix ( $M_{OverallWeight}$ ) with 14 rows and 14 columns was computed as shown in Table 4.

### RESEARCH EXPERIMENT

Patients' state of health (with respect to Malaria) was evaluated by the domain experts based on signs, symptoms and investigations. The intensity of signs, symptoms and investigation was classified as mild, moderate, severe and very severe as linguistics variables. A young patient was considered with Moderate Fever (C1=0.3), Severe Headache (C2=0.67), Very Severe Loss of Appetite (C6= 1), Moderate General Body Weakness (C5= 0.3) and MP+++ Test (C13=1). Thus the initial concept (Input Vector) is:

$$V_{Initial} = \begin{bmatrix} 0.30 & 0.67 & 0 & 0 & 0 & 0 \\ 0.30 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.00 & 0 & 0 & 0 \end{bmatrix}$$

After the fuzzy inference process, the final concept vector (Decision Output Vector)  $V_{Final}$  was reached at the 9 simulation indicating that the

system converged at the 9 simulation with a fixed point.

$$V_{Final} = \begin{bmatrix} 0.50 & 0.23 & 0 & 0 & 0 & 0 \\ 0.64 & 0.80 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.7 & 0.79 & 0 & 0 \end{bmatrix}$$

The calculated value of the decision concept (DS1 = 0.79) indicates that the patient was diagnosed with 79% disease severity of malaria.

### RESULTS AND DISCUSSION

A diagnostics system for the management of tropical diseases has been developed. The developed framework based on FCMs provides an efficient way of diagnosing tropical diseases. The essence of the study was to ascertain the degree to which a knowledge-based methodology represents the exact diagnosis of the patient as compared with those of medical doctors. A young patient was diagnosed for severe malaria with 79% disease severity. The designed fuzzy expert system provides a decision support tools to medical practitioners and other health workers. Our results based on real patient data confirms that the Fuzzy Cognitive Systems can represent

the expert's thinking in a satisfactory manner in handling complex trade-offs.

Diagnostic data from 15 patients with confirmed diagnosis of malaria were evaluated and the computed results were in the range of the predefined limits by the domain experts.

## CONCLUSION

In this paper, we developed a FCM model for medical decision support for diagnosing tropical diseases. The knowledge-based approach used in this research is a powerful Soft computing technique to address the issue of uncertainty in medical data. Without sound diagnosis, medical practice is as good as guess work. The developed diagnostic tool can effectively enhance doctors' performance for quick and effective diagnosis of tropical diseases.

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