

Fuzzy Cognitive Map Software

Meletis Margaritis¹, Chrysostomos Stylios² and Peter Groumpos¹

¹Electrical and Computer Engineering Department, University of Patras, Greece

²Computer Science Department, University of Ioannina, Ioannina, Greece

Email: margaritis@ee.upatras.gr and stylios@cs.uoi.gr

Abstract: Fuzzy Cognitive Map (FCM) is a soft computing modelling methodology for complex systems. Beyond the mathematical formulation of the FCM theory, there was a need of developing a software tool to facilitate the implementation of FCMs. This paper describes the use of a software tool that was developed to construct FCM models. Some theoretical elements of Fuzzy Cognitive Maps are presented. Then, it is discussed how the software tool is used to develop a model and simulate the use of Fuzzy Cognitive Maps. The user interface of the software tool is described and how the FCM-Analyst is used to facilitate the implementation and simulation of Fuzzy Cognitive Maps.

1. INTRODUCTION

Modelling complex dynamic systems is a demanding task requiring many efforts and new modelling methodologies have been proposed; such as the soft computing modelling technique of Fuzzy Cognitive Maps (FCMs). In addition to the theoretical and mathematical description of any modelling methodology, the advances and availability of computer and software resources provide new potentials to facilitate the implementation and utilization of this methodology. Fuzzy Cognitive Map theory has recently introduced [1], new method for developing FCMs have been proposed and FCM have used to model systems in discipline scientific areas from organizational behaviour [2] to communication networks [3] and from failure models [4] to virtual worlds [5]. This paper presents the FCM-Analyst, a software tool that has been created to help the designer of a complex system to model it by implementing FCM technology and simulates the operation of the system.

Fuzzy Cognitive Map (FCM) is an abstract symbolic representation for the description and modelling of complex systems, based on the accumulated knowledge and experience on the operation of the system. FCM describes different aspects in the behaviour of a complex system in terms of concepts and interactions among concepts that show the dynamics of a system. Fuzzy Cognitive Maps are conceptual models of the system and human experts who

have experience on the operation of the system develop them. Experts design the fuzzy graph structure of the system, consisting of concepts-nodes that represent the key characteristics, principles and functions of the system's model and operation behaviour. The interrelationships among these concepts – main characteristics of the system - are fuzzy weighted arcs between concepts.[6].

In order to facilitate the use and implementation of FCMs there was a need for developing a specific software tool. There have been developed some software tools that simulate Fuzzy Cognitive Maps. The first attempt was a program for a very simple implementation of FCM based on C++ [7]. The second known software for FCM was an applet to draw Fuzzy Cognitive Maps based on Java through Internet [8]. Another similar tool is a virtual reality system based on VR techniques to simulate Fuzzy Cognitive Maps [9]. All these software tools are using quite simple mathematical forms of FCMs, they do not permit to the user to change and adapt the mathematical equations and the most important they do not support advanced techniques for constructing Fuzzy Cognitive Maps. For the most of these cases, Fuzzy Cognitive Map software requires crisp values for concepts and weights and the user interface is not so user friendly. Most of these drawbacks have been overcome with the FCM-Analyst that is discussed and presented here.

First of all, FCM-Analyst has been written on JAVA because there are many important advantages for this platform. JAVA is an object-oriented programming language, with great abilities to organising and developing software. It is a portable platform, thus permitting the “FCM Analyst” to run almost in any operating system. Moreover, it provides safety to the end-user, in the case of using certified applets. Additionally, it supports multi-threading programming. Finally, as far as the syntax is concerned, it is less complicated than other languages, and thus very easy to learn and update the software code.

This paper presents an overview of the Fuzzy Cognitive Maps and how the FCM-Analyst supports the various functions of FCMs. Then the FCM-Analyst user interface and functionality is described.

2. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps (FCM) is a modeling methodology for complex systems. The graphical illustration of an FCM is consisted of nodes connected with weighted interconnections. Nodes of the graph stand for concepts that are used to describe main behavioral characteristics of the system such as states, variables, inputs and outputs. Signed and weighted arcs representing the causal relationships that exist among concepts connect nodes. A graphical representation of FCMs is depicted on Figure 1.

The numerical value A_i that represents the concept value characterizes it and it results from the transformation of the real value of the system's corresponding characteristic, for which this concept stands, in the interval $[0,1]$. Causality between concepts allows degrees of causality and not the usual binary logic, so the weights of the interconnections can range in the interval $[-1,1]$.

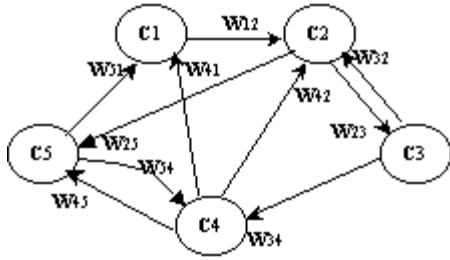


Figure 1 A simple illustration of FCM

2.1 Mathematical expressions of Fuzzy Cognitive Maps

The general calculation rule for the values of concepts of Fuzzy Cognitive Map has been proposed [10] and is supported in the FCM Analyst:

$$A_i^t = f\left(k_1 \sum_{\substack{j=1 \\ j \neq i}}^n A_j^{t-1} W_{ji} + k_2 A_i^{t-1}\right) \quad (1)$$

Namely, A_i^t is the value of concept C_i at time t , A_i^{t-1} the value of concept C_i at time $t-1$, A_j^{t-1} the value of concept C_j at time $t-1$, and the weight W_{ji} of the interconnection from concept C_j to concept C_i , and f is a threshold function which squashes the result in the desired interval. The coefficients k_1 and k_2 can take different values according to any specific case and are determined by the user of the system. The FCM Analyst supports this function, giving the ability to the user to select the coefficients.

Different kinds of threshold functions could be used in the Fuzzy Cognitive Map framework according to the mathematical justification that a researcher uses. The FCM Analyst supports the selection of different threshold functions, permitting to the researcher to comply a threshold function consisted of any known mathematical expression.

Generally, suppose that an FCM is consisted of n concepts and can be represented mathematically by a $1 \times n$ state vector \mathbf{A} , which gathers the values of the n concepts and by a $n \times n$ weight matrix \mathbf{W} . Each nondiagonal element e_{ij} of the matrix \mathbf{W} indicates the value of the weight $k_1 W_{ij}$ between concept C_i and C_j , and the diagonal elements e_{ii} of the matrix \mathbf{W} are equal to coefficient k_2 .

Equation 1 can be transformed in the following equation, which describes Fuzzy Cognitive Map operation with the compact mathematical model:

$$\mathbf{A}^{t+1} = f(\mathbf{A}^t \mathbf{W}) \quad (2)$$

2.2 Methods for constructing Fuzzy Cognitive Maps

The method that is used to construct a Fuzzy Cognitive Map have great importance for the FCM utilization in modeling complex systems. Fuzzy Cognitive Map represents the human knowledge on the operation of the system and experts develop FCMs using their experience and knowledge on the system [10].

Experts determine the number and kind of concepts of the FCMs and the interrelationships among concepts. Experts and engineers know the main factors and characteristics that determine the behavior of the system; and they describe each one of these factors with a concept. Experts know how elements and devises of the system influence each other and for the corresponding concepts they determine the negative or positive effect of one concept on the others along with a fuzzy weight describing the degree of causation.

There are two methodologies for the determination of the degree of causal relationship among concepts. The first one requires experts to assign numerical weights for each one interconnection. The second methodology for the development of Fuzzy Cognitive Maps is based on fuzzy logic approach. Experts describe the causality among concepts using linguistic weights.

Every expert describes the influence of one concept to the other using the linguistic variable of *Influence* [10]. *Influence* of one concept on another, is interpreted as a linguistic variable taking values in the universe $U = [-1,1]$ and its term

set $T(\text{influence})$ is determined by the designer of the system using a membership function. FCM-Analyst suggests to the user different kinds of membership functions with different characteristics to choose the most appropriate. So, three experts describe the influence of one concept to another with the linguistic variables: “zero”, “positive weak” and “positive medium” that correspond to the gaussian membership functions as illustrated in the figure 2.

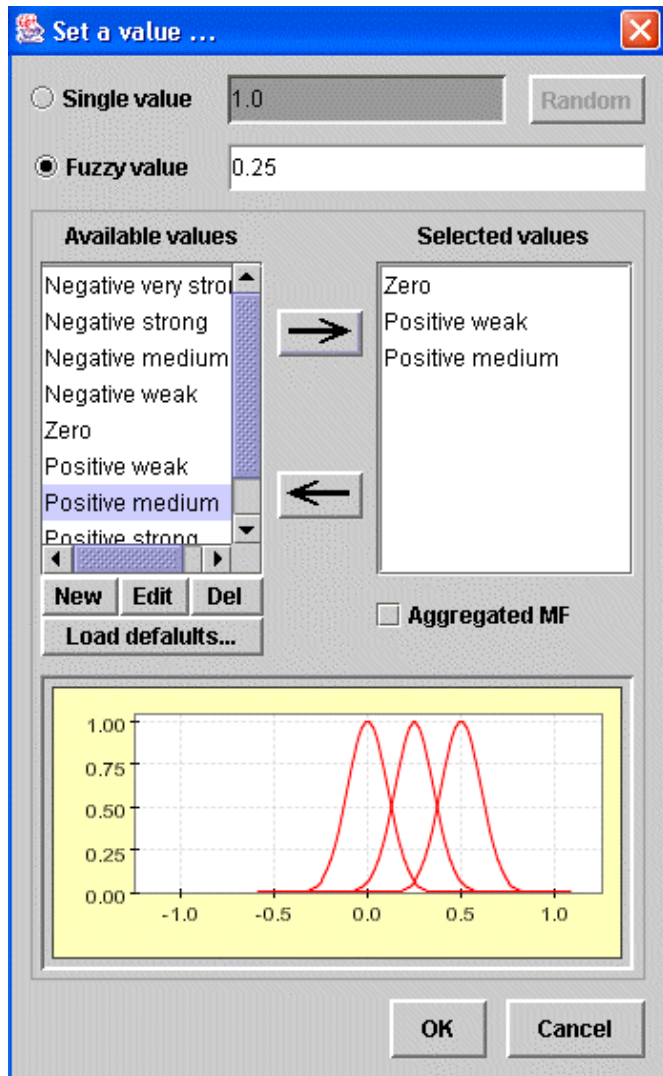


Figure 2. Selection of three fuzzy values with gaussian membership functions

The linguistic variables that are assigned to each interconnection are aggregated and combined using a fuzzy logic technique in order to calculate the overall linguistic weight for one interconnection. The FCM-Analyst suggests to the user to choose between the aggregation method of SUM or MAX. The produced overall linguistic weight will be transformed in a numerical weight for each interconnection using a defuzzification method and so the crisp weight is produced. FCM-Analyst suggests to the user to choose between the defuzzification method of Center of Gravity and the Bisector method.

The three linguistic weights described with gaussian membership functions as shown in the bottom part of figure 2, that are assigned to one interconnection by three experts are aggregated. Figure 3 shows the three memberships function, and the scheme of the outcome of the aggregation of these three membership functions using the method of SUM. Then, the overall produced linguistic weight is defuzzified and the calculated numerical value is the 0.25 for this example.

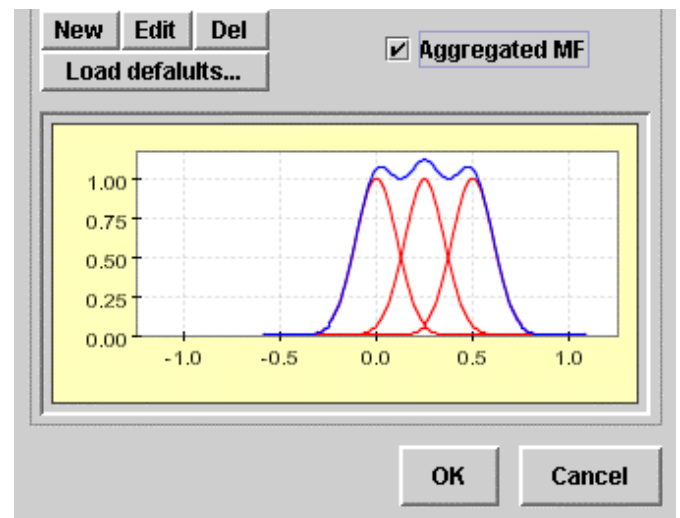


Figure 3. The aggregated weight

3. “FCM ANALYST”

This section will describe the user interface of the FCM-Analyst and will present the advantages of the FCM-Analyst and how can facilitate the simulation and implementation of FCMs in modelling a system.

FCM-Analyst has many capabilities and help the designing and developing of the FCM model for a system. When the

user run the FCM-Analyst an empty drawing area is appeared. User with mouse double click introduces a concept and he draws an interconnection between two concepts by drag and drop an arc from one concept to another. Utilising this graphical way of direct manipulation, the user can insert any node of the FCM in the position that he wants. The user provides names and descriptions to both nodes and arcs; he also assigns the initial values to the nodes. The FCM-Analyst provides various facilities at this design phase, such as deleting, moving and repositioning the nodes and zooming in and out the whole model. Figure 4 illustrates a simple FCM that has been developed. At the right-down corner at the working area, the relative information of the active node is shown (the active node has a different colour).

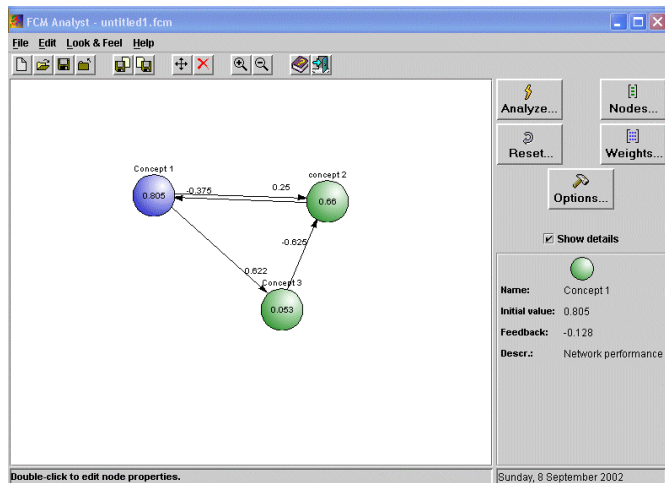


Figure 4. The FCM-Analyst drawing area with a simple FCM

On the FCM-Analyst window are illustrated the following buttons. The “Weights” button when is pressed it picks up the weight matrix W of the Fuzzy Cognitive Map, which is illustrated on the left part of the window. The user can edit on the matrix and change some weight values, add new weights or delete some (Figure 5). The changes on the weight matrix affect the graphical illustration of the FCM by adding or deleting interconnections for nonzero or zero weights correspondingly. For complex FCMs with many nodes is preferable to insert the values of in the weight matrix and the FCM-Analyst will draw the interconnections for the user.

The weight matrix contains the values of the weighted interconnections as well as the feedback values of the nodes at the diagonal. Some of these values might have been directly inserted numerically and some might have been the values that came out after defuzzification of one or more fuzzy values.

##	Concept 1	concept 2	Concept 3
Concept 1	-0.128	0.25	0.622
concept 2	-0.375	1.0	0.0
Concept 3	0.0	-0.625	1.0

concept 2 affects Concept 1 with a weight that equals -0.375

Apply changes automatically
 Auto resize columns

Update OK Cancel Apply

Figure 5. The weight matrix window

Clicking on the desired cell of the weight matrix the user can edit the corresponding value, as already described in the previous paragraph. For the active cell of the weight matrix in the bottom of the window there is a description to which interconnection this weight correspond. The user can decide whether his changes would apply to his model automatically or manually, using the corresponding buttons and checkboxes.

When the Fuzzy Cognitive Map will have been developed different options for the mathematical description and simulation of the FCM can be selected (Figure 6). These options include:

- The threshold function f . The user can insert any threshold function as equation. It is inserted as a string; a special parser has been developed, by which the tool can recognize any equation, consisted of the standard mathematical functions, such as $\sin(x)$, $\cos(x)$, $\tan(x)$ and etc.
- The defuzzification method either *centroid* or *bisector*
- The aggregation method (*SUM* or *MAX*) for the aggregation of fuzzy variables
- The membership function type. The user can select either triangular, or gaussian or trapezoid (*trimf*, *gaussmf* or *trapmf*) membership function and determine the variables of these functions.
- The researcher can choose the most appropriate calculation rule for the calculation of the concept values with the selection of the corresponding parameters.

The argument of the threshold function f can be either defined as: $\sum_{j=1, j \neq i}^n A_j^{t-1} \cdot W_{ji} + \gamma \cdot A_i^{t-1}$, where γ is the feedback value of the i -node. In this case, the user is able to select the same γ value for all nodes.

As another option, the threshold function f can have as argument the value of:

$\sum_{j=1, j \neq i}^n k_1 A_j^{t-1} \cdot W_{ji} + k_2 \cdot A_i^{t-1}$, where k_1 and k_2 have the same values for all nodes and there should be that $k_1 + k_2 = 1$.

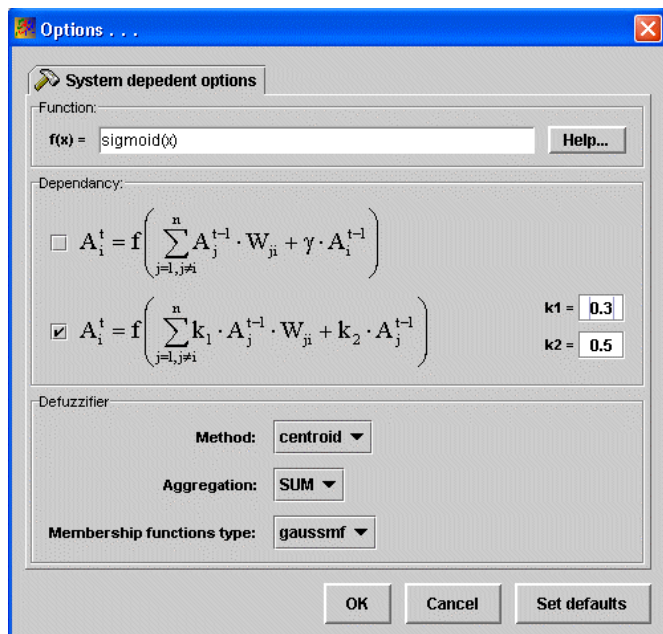


Figure 6. The system dependent options dialog

When the user has finally developed the FCM and has chosen through the option window what will be the calculation rule, the FCM-Analyst is ready to simulate the behaviour of the FCM model, by pressing the corresponding button named “Analyse” on the main window. There are available two representation of the behavioural analysis. The first one is shown on figure 7. This is a graphical chart showing the variation of the values of all the concepts for any time step. There is the possibility to expand or suppress the time range by setting different number of simulation steps.

Moreover the user can export this chart as an image to a file under the JPG standard image format.

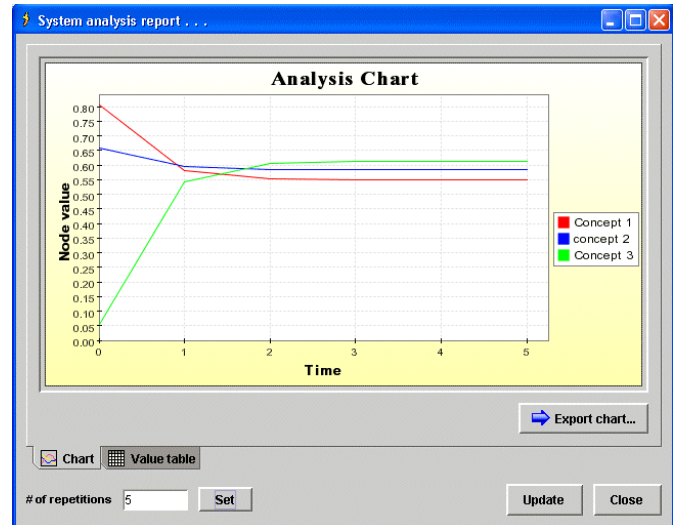


Figure 7. The FCM model behavior analysis window

The second one choice is shown on figure 8. There are illustrated the variation of the values of the concepts numerically. Using this option, there is the facility to copy the concept values to the system clipboard or to export them to a file under the Microsoft Excel format (XLS).

Time	Concept 1	concept 2	Concept 3
0	0.805	0.66	0.053
1	0.581	0.594	0.544
2	0.554	0.586	0.604
3	0.551	0.585	0.611
4	0.55	0.585	0.612
5	0.55	0.585	0.612

Figure 8. The value table for the FCM analysis report.

4. SUMMARY

Fuzzy Cognitive Map is a soft computing methodology for modeling complex systems but there was not any special software tool for this. A software tool the FCM-Analyst has been developed in order to facilitate the design and simulation of FCM of any complexity. The user interface and the operation of the FCM-Analyst has discussed in this paper.

REFERENCES

[1] Bart Kosko: "Neural Networks and Fuzzy Systems" Englewood Cliffs, N.J.: Prentice-Hall, 1992.

[2] Philip Craiger, Deborah Goodman, Jason Weiss and Adam B. Butler: "Modeling Organizational Behaviour with Fuzzy Cognitive Maps", *Int. J. of Computational Intelligence and Organizations*, (1996) Vol. 1, No. 3 pp. 120-123.

[3] Satish Jamadagni: "Object oriented Fuzzy Cognitive Maps for Network modeling" 19th International Conference of the North American Fuzzy Information Process NAFIPS' (2000), pp. 412-415

[4] Enrique Pelaez and John Bowles: "Using fuzzy Cognitive Maps as a System Model for Failure Models and Effects Analysis" *Information Sciences*, (1996), Vol. 88, pp. 177-199.

[5] Julie Dickerson and Bart Kosko: "Fuzzy Virtual Worlds" *AI Expert*, (1994) pp.25-31.

[6] Chrysostomos Stylios and Peter Groumpos: "A soft computing approach for modeling the supervisor of manufacturing systems" *Journal of Intelligent and Robotics Systems*, (1999) Vol. 26, No 3-4, pp. 389-403

[7] Josef Betancourt, September 25, 1993, <http://ourworld-top.cs.com/tcmits1/fcm.html>

[8] Stephen Mohr: "Software Design for a Fuzzy Cognitive Map Modeling Tool", Master thesis 1997, Rensselaer Polytechnic Institute.

http://www.users.voicenet.com/~smohr/fcm_white.html

[9] Pablo Arturo Von Raesfeld Porras: "Application of Fuzzy Cognitive Maps with VRML for a virtual environment" (in Spanish), Master thesis 2000, University Americas-Puebla, Mayo, Mexico.

http://mailweb.udlap.mx/~tesis/lis/von_r_pa/index.html

[10] Chrysostomos Stylios and Peter Groumpos: "Fuzzy Cognitive Maps in Modeling Supervisory Control Systems" *Journal of Intelligent & Fuzzy Systems* (2000), Vol 8. No 2. pp. 83-98.