# APPLYING FUZZY COGNITIVE MAPS IN SUPERVISORY CONTROL SYSTEMS

Chrysostomos D. Stylios, Voula C. Georgopoulos* and Peter P. Groumpos
Laboratory for Automation and Robotics
Department of Electrical and Computer Engineering
University of Patras,Rion 26500 Patras, GREECE
Tel. +30 61 997293 Fax. +30 61 997309
stylios@ee.upatras.gr

*School of Electrical Engineering and Computer Science
Ohio University
Athens, OH 45701, USA

ABSTRACT: Fuzzy Cognitive Maps (FCM) are presented in this paper. A short reference on their implementation in a wide field of science is provided in the introduction; then it is examined their representation and the methodology which is used to construct a FCM. In the last part of this paper a generic system is proposed to be used for the modeling and control of a plant-process, the supervisor of this system is modeled as a Fuzzy Cognitive Map.

## 1. INTRODUCTION

The use of a new theory, Fuzzy Cognitive Map (FCM) Theory, to model the upper level or supervisor of a process or plant is investigated. FCMs describe the behavior of a system in terms of concepts, they illustrate the whole system by a graph showing the cause and effect along concepts, they are a simple way to describe the system's behavior in a symbolic manner, exploiting the accumulated knowledge of the system. Fuzzy Cognitive Map (FCM) theory has been introduced recently [Kosko1986] and there is a growing interest in using this theory in a wide field of science. Fuzzy Cognitive Maps have been used for planning and making decisions in the fields of international relations, administrative science, management science and operations research, FCMs have been used to model popular political developments [Taber 1991], they have been used to analyze extend graph-theoretic behavior [Zhang 1988], FCMs have been proposed as a generic system for decision analysis [Zhang 1989], FCMs have been used to analyze electrical circuits [Styblinski 1991], they have been used to structure Virtual worlds[Dickerson 1994], FCMs have been used to model plant control [Gotoh 1989], and they have been applied to Failure Modes and Effects Analysis [Pelaez 1995] [Pelaez 1996].

The objective here is to construct a knowledge based Supervisory Control System, which will be used to exploit the knowledge and experience which has been accumulated for years on the operation of a complex plant. This can be achieved by using a FCM model for the supervisor of the control system. FCMs lie in some sense between fuzzy logic and neural networks and use knowledge representation in a symbolic manner. This methodology may increase the intelligence of the system, as the more intelligent a system becomes, the more symbolic and fuzzy the representation of the system is.

## 2. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps are a combination of Fuzzy Logic and Neural Networks. A Fuzzy Cognitive Map describes a system in terms of 'concepts' and interconnections between 'concepts'. It is a fuzzy signed directed graph with feedback, where nodes of the graph are connected by signed and weighted arcs representing the causal relationships that exist between the concepts (Figure 1). FCMs are fuzzy-graph structure which allow systematic causal propagation, in particular forward and backward chaining and also allow knowledge bases to grow by connecting different FCMs.

On the FCM each concept represents one of the key-factors and is characterized by a number $A_i$ that represents its level of activation. Another essential element on the FCM is the interconnections between concepts, there are three possible types of causal relationships between concept $C_i$ and concept $C_j$ :

1) $W_{ij} > 0$ indicates positive causality between concept $C_i$ and $C_j$. That means, an increase in the value of concept $C_i$ leads to the increase of the value of concept $C_j$, and a decrease in the value of concept $C_i$ leads to the decrease of the value of concept $C_j$.
2) $W_{ij} < 0$ indicates negative causality between concept $C_i$ and $C_j$, that is an increase in the value of concept $C_i$ leads to the decrease of the value of concept $C_j$ and vice versa.
3) $W_{ij} = 0$ indicates no relationship between concept $C_i$ and $C_j$.

The value of $W_{ij}$ indicates how strongly concept $C_i$ influences concept $C_j$. The sign of $W_{ij}$ indicates whether the relationship between concepts $C_i$ and $C_j$ is direct or inverse. The direction of causality indicates whether concept $C_i$ causes concept $C_j$, or vice versa. These three parameters have to be considered when assigning a value to $W_{ij}$.

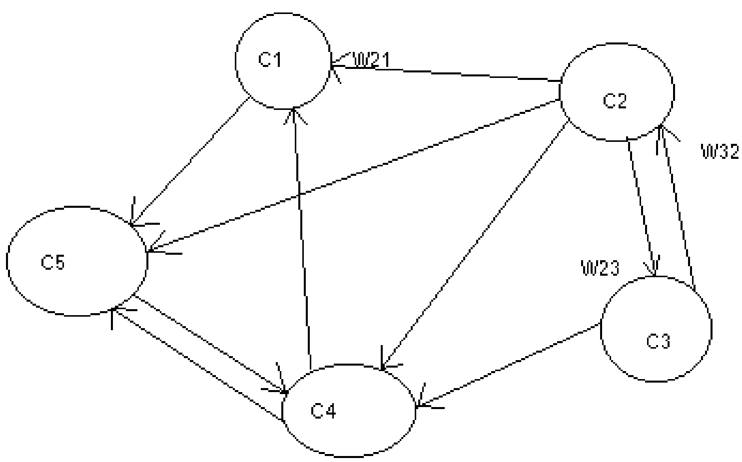


Fig.1. A Fuzzy Cognitive map

Mathematically the FCM is described by a state vector $A$ and an edge matrix $E$. The matrix $E$ is *n* by *n*, and each element $e_{ij}$ of the matrix indicates the relationship $W_{ij}$ between concept $C_i$ and $C_j$. The matrix $E$ has *n* rows and *n* columns where *n* equals the total number of distinct concepts that are depicted on the FCM; the diagonal of the matrix is zero since it is assumed that no concept causes itself. The state vector $A$ is an $1 \times n$ vector which consists of the *n* activation levels of each of the *n* concepts of the Fuzzy Cognitive Map.

The activation level $A_i$ for each concept $C_i$ is calculated by the following rule :

$$A_i = f\left(\sum_{\substack{j=1 \\ j \neq i}}^{n} W_{ji} A_j\right) \tag{1}$$

$A_i$ is the activation level of concept $C_i$ at time t+1, $A_j$ is the activation level of concept $C_j$ at time t, and $W_{ji}$ is the weighted arc from $C_j$ to $C_i$ and $f$ is a threshold function. So the new state vector $A$, which is computed by multiplying the previous state vector $A$ by the edge matrix $E$, shows the effect of the change in the activation level of one concept on the other concepts.

A Fuzzy Cognitive Map is built by experts, an expert draws a FCM according to his experience on the operation of the system; he determines the concepts, which in general stand for events, actions, goals, values, trends or any other characteristic of the system. Moreover he determines the negative or positive effect of one concept on the others, with a fuzzy degree of causation.

It is possible to be used a group of experts. First all the experts are gathered to determine the relevant factors that should be present in the cognitive map. Then, the experts are individually asked to express the relationship among these factors. In this way there will be a collection of individual FCMs that must be combined into a collective map. Experts could be thought that they have varying credibility by multiplying their factors with a nonnegative 'credibility' weight $b_i$ before combining them with other expert's opinions (equation 2). And if there is an expert who is extremely knowledgeable about certain factors and not others, it can be used differing credibility weights on different links. Generally, the whole FCM could be constructed by combing the different FCMs and its augmented matrix $E$ will be:

$$E = \sum_{1}^{N} b_i E_i \tag{2}$$

where $E$ is the whole FCM, $b_i$ is the weight for $i_{th}$ expert and $E_i$ is the expert's fuzzy cognitive map and $N$ is the number of the experts.

Fuzzy Cognitive Map can be used to simulate the operation of the system. Firstly FCM should be initialized, the activation level of each of the nodes of the system takes a value in the interval[-1,1] based on expert's opinion for the each state and then the concepts are free to interact. This interaction continues until:

i) A fixed equilibrium is reached
ii) A limited cycle is reached
iii) Chaotic behavior is exhibited

It must be mentioned that in each unit time, the activation levels of each concept are recalculated according to the equation (1).

## 3. THE GENERIC SYSTEM

Any technological process can be easily identified with Figure 2, where in the upper layer there is a storage of the World Model : an augmented FCM contains all Knowledge necessary for modeling the operation and best describes the behavior of the complex lower level system.

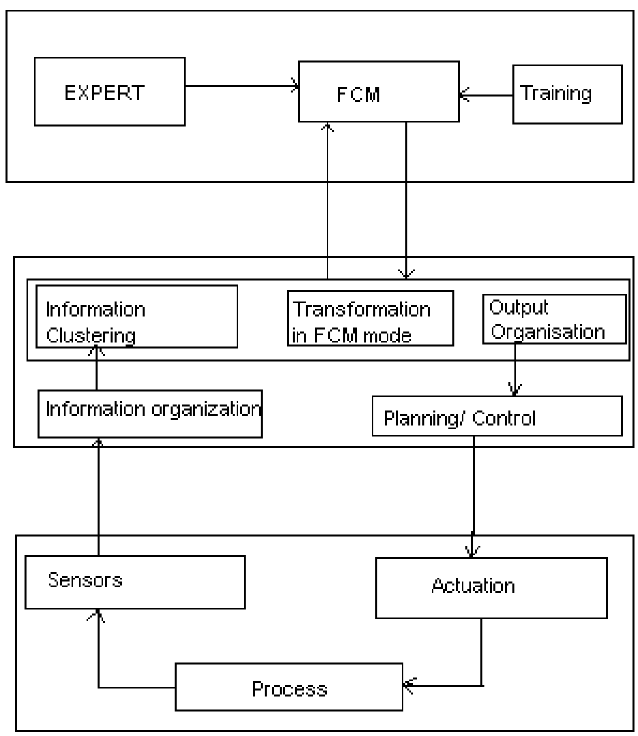


Fig. 2. A general model of the plant

This FCM is constructed after acquiring knowledge from experts. Each expert draws a map consisting of concepts which best describe the operation of the process and he determines the causality between concepts. Then using the method that is described in the previous section the various FCM are integrated into one. It must be clear that the concepts of the FCM stand for the variables, states, inputs, outputs or any other significant characteristic for the operation of the process; the weighted arcs among concepts show the dependence that exist among the variables of the process. After that, data from the real process can be used in order to train the FCM, which means having data for concepts values, the weights of the interconnections between concepts are adjusting. For this training procedure the Differential Hebbian learning method can be used as is proposed in [Kosko 1992].

When the FCM is going to be used, it must initialized, it takes the activation values for each concept that best represent the current state according to the expert's opinion. The input information from the lower level causes the change in the activation value of one or more concepts. In the lower level, sensors measure some variables of the process and these measurements must be organized and transformed into suitable information for the FCM. So, the available measures from the lower level are categorized and a cluster of measures causes change in the value of one or more concepts of the FCM in the highest level. Then the FCM runs, during this procedure the concepts interact and their values are computed according to equation (1), the running stops as soon as FCM reaches an equilibrium point where no change occur to the concepts. In this case the activation value of some concepts have changed and this information passes to the lower level and influences the process. Sometimes it is likely the activation values of the concepts to lead the FCM into a limit cycle where the activation levels of all the concepts periodically change, and in this case an external influence is needed.

If a two level structure of the whole system is considered, it should be mentioned that in the lower level there are local controllers which are responsible for the conventional operation of each one of the parts of the process. In the higher level the supervisor is thought as a Fuzzy Cognitive Map associated with other complementary methods, where the FCM is used for strategic planning and decision analysis. It is obvious that a lot of problems and limitations must be considered and overcame, especially concerning the intermediate level.

A part of the FCM could be used for Fault Diagnosis and Prediction [Pelaez 1995][Pelaez 1996]. In this FCM the concepts would be the device failure modes, their effects and causes, the system mission, and the ultimate function of the system that all are represented by a variable. So the Fuzzy Cognitive Map represents the failure modes and their effects and the relations between them that an expert uses to describe the functionality of the system and the failures.
Another useful characteristic of the FCM is its effectiveness in prediction and especially to predict what will happen if a scenario is followed, what will be the consequences for the whole process if a state change suddenly or with the addition of a new device in the process. This feature is especially useful to designers of systems to observe the influence of each device separately.

## 4. CONCLUSIONS

Fuzzy Cognitive Maps have been examined in this paper, this new theory can be used to model the behavior of complex systems, the main advantage of this approach is that best utilizes existing experience in the operation of the system. For such a complex system it is not always possible to describe the entire system by a precise mathematical model. Thus, it is more attractive and useful to represent it in symbolic manner. Fuzzy Cognitive Map is appear to be an appealing tool in the description of the supervisor of complex control systems, which teamed up with other methods will lead to new advanced methodologies in the modeling and control of complex systems and help man's effort for more intelligent control systems.

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