Important Issues To Be Considered In Developing Fuzzy Cognitive Maps

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***Abstract*—The formalism of fuzzy cognitive maps as used for the modeling of various dynamical systems is presented with a critical point of view. Various issues related to terminology, concepts, sensitivities, time dependence, iteration procedures, and stability, are systematically considered with critical mind, aiming at making the overall system models be more realistic and useful, and to initiate discussions that can lead to clarifications and to uniformities. Emphasis is given to applications in social, political, economic and engineering systems.**

Keywords-fuzzy cognitive maps.

I. INTRODUCTION

Fuzzy cognitive maps (FCM) have been used to model dynamical systems in diverse fields, such as in computer science (knowledge representation, reasoning, inference, robotics, adaptation, learning, classification,) engineering (controls, robotics, adaptation), production systems (planning), management (decision making, game theory, logistics), medical/health systems (diagnostics, classification), economic/financial systems, education, environment/ecology, social/political/military systems (policy making, social dynamics, conflict resolution) [1-11].

An FCM is a system of interrelated (interconnected) concepts, also found in literature with many other names such as characteristics, factors, parameters, attributes, states, events, actions, values, goals, trends, components, resources. These concepts embed the dynamical cause-effect relationships that model a specific domain of interest.

The strength (or degree of effectiveness) of the interconnecting relations among the various concepts is governed by the degree that a concept *i* affects a concept *j*. These are called by different names in the literature such as sensitivity, weights, causality, etc. Many a times, for better appraisal of the relevant dynamics, they are graphically represented. In this formalism, the concepts are connected through directed graphs. The intensity of the interrelationships is not clearly known, and not agreed by all concerned. Thus, suitable membership functions may be used. By using appropriate systematic process it is possible to estimate the effect of a change in a specific state (concept) on any other concept (or set of concepts) of the system.

Once the parameters have been identified and initialized, the system is allowed to evolve through appropriate simulation procedures. When and if ultimately the system settles, a researcher/user can observe the effects of a change of one factor on the intensity of another. It is pointed that a modeled system may not quasi-settle to finite states, but rather may go through a limit cycle, or even exhibit chaotic behaviour [12, 13].

The work reported here is mainly involved with a critical examination of some various issues related to terminology, concepts, sensitivities, time dependence, iteration procedures, and stability, in relation to proper functioning of the FCMs, aiming at making the overall system models be more realistic and useful. Ultimately, it is hoped to initiate discussions that can lead to clarifications and to uniformities.

Emphasis is given to applications in social, political, economic and engineering systems.

II. THE FCM SYSTEM

An FCM system of *n* interrelated concepts, which are connected by causal relations, here called sensitivities, may be represented with the following system of equations.

Let the sensitivity relating the changes in the activation of a concept C_j to changes in the activation of a concept C_i be defined by:

$$s_{ij} \equiv \frac{\partial C_j}{\partial C_i} \quad (1)$$

The total accumulated change in the activation of concept C_j due to changes in concepts C_i is then given by:

$$\delta C_j = \sum_{i,i\neq j}^{n} \frac{\partial C_j}{\partial C_i}\delta C_i = \sum_{i,i\neq j}^{n} s_{ij}\delta C_i \tag{2}$$

where,

C is the activation strength of the concept of interest.

s_{ij} is the sensitivity (weight) as defined in equation 1.

The way sensitivity is defined here, it implies that it is a measure on how much a change in the current standing of concept C_i affects the changes in the standing of concept C_j.

In discrete time form the above equation becomes:

$$C_j(t+\delta t) = C_j(t) + \delta C_j = C_j(t) + \sum_{i=1}^{n} s_{ij}\left(\delta C_i\right) \tag{3}$$

and in iterative form can be implemented by:

$$C_j(k+1) = C_j(k) + \sum_{i,i\neq j}^{n} s_{ij}\left(C_i(k) - C_i(k-1)\right) \tag{4}$$

where k is the iteration counter.

In most of the published literature, it is more common to represent the FCM systems in a different form, as shown in equation 5.

$$A_j(k+1) = f\left(A_j(k) + \sum_{i,i\neq j}^{n} w_{ij}A_i(k)\right) \tag{5}$$

or,

$$A_j(k+1) = f\left(\sum_{i,i\neq j}^{n} w_{ij}A_i(k)\right) + A_j(k) \tag{6}$$

where,

A is the activation strength of the concept C.

w_{ij} is the weight (sensitivity)

f is a transformation (smoothening) function, usually of sigmoid form.

The above equation is also found in different variants, such as [5]:

$$A_j(k+1) = f\left(A_j(k)\sum_{i,i\neq j}^{n} w_{ij}A_i(k)\right) - d_j A_j(k) \tag{7}$$

where d_j is a decay factor.

It is pointed here that the suggested approach of equation 4 is different than the approach that is followed by most FCM implementations of equation 5 in two important respects:

i) The weights (sensitivities) are defined differently, as previously explained, and
ii) No smoothening activation function f has been used.

The updating is done quasi-statically and interactively until the system evolves to settlement specified by desired boundaries. Any changes in the various concepts affect either directly or indirectly all the other concepts of the system.

III. Important Considerations When Building FCM

The important aspects to be considered when building and implementing FCMs for systems simulations may be organized as follows:

A. Terminology/Nomenclature
B. Model dynamics
C. Concept identification and initial values
D. Sensitivity identification
E. Smoothening functions
F. Time dependence

In the following exposition, these areas are critically examined. Suggestions for improved FCMs are made wherever possible. The various points that are raise are clarified with appropriate examples. It is hoped that discussions will be initiated that can lead to clarifications and to uniformities.

A. Considerations on terminology and nomenclature.

In the relevant literature there have been different names for different features of FCM. The most diversified nomenclature proposed is for the concepts. The numerous terms that have been used for the concepts are mainly reflecting the application at hand. The most common names given are the following: *Concepts, Characteristics, Factors, Parameters, Attributes, States, Events, Actions, Values, Goals, Trends, Components, Resources.* This is not surprising, and it is not a serious problem when it comes to specific applications. For the fundamental theory though, it creates unnecessary confusions, and it is better to adopt a single term. To this end, we propose the adoption of the term ACTION CONCEPTS, as this term encompasses to a large extend those listed before, and is appropriate for many applications in social sciences, engineering and medicine.

Concerning the notation used, there doesn't seem to be a serious problem by using either A for the activations or action concepts (AC), or C for the concept values. As for the interconnecting strengths, we believe that using the symbol s for sensitivity is better than using w for weights, which are more commonly used for the synaptic weights of the neural network paradigms. The term sensitivity will more easily guide the user to establish more realistic values for the interconnecting strengths.

B. Dynamical modeling.

The most commonly used formalism for describing the system dynamics for an FCM are those shown in equation 5, and the occasional variant expressed in equation 6.

We believe that the form of system dynamics as proposed in equation 4 is more appropriate for two main reasons.

i) It is more compatible with the mathematical expression for finite differentials, and
ii) It does not need to use the smoothening function f, that is quite arbitrary, and poorly or even totally unjustified. Of course if one still wants to use a squashing function with equation 4, then it should be modified as shown in equation 8.

$$C_j(k+1) = f\left(C_j(k) + \sum_{i,i\neq j}^{n} s_{ij}\left(C_i(k) - C_i(k-1)\right)\right) \tag{8}$$

C. Establishing the types of action concepts and their initial values.

With respect to this aspect, there is hardly any disagreement that the important AC that need to be incorporated in an FCM system will have to be identified by highly knowledgeable persons (experts in the field(s)). However, there are certain important issues/questions to be raised. Namely,

i) How certain are we that those AC are indeed the most influential and the most appropriate ones to capture the system dynamics? Maybe it is desirable to assign a degree of certainty (or ignorance) to each AC, that will somehow be embedded in the system. Certainly, the more the experts, the better is the realistic model.

ii) Are these AC constant during the whole period of simulation, or some vanish and others may emanate? This is a problem specific issue that needs to be tackled when a specific system is being modeled. However, the relevant equations and algorithms have to be reformulated.

iii) How independent to each other are? The FCM model to a certain extend, captures this interdependence.

Another important issue in relation to the ACs is how and in what scale to establish the initial values of the ACs in the system under study. For socio-economic-political systems, in the systems that we have simulated, we have adopted a scaling from 0 to 100%.

Thus, it seems that there is some room for improvements in this aspect. It is definitely advantageous to receive information from very many different experts, and if needed to get the weight average from their propositions.

Also, it would be most beneficial if a methodology is being developed that will enable a user to check and verify the relevance of the various ACs and their initial values.

D. Establishing the values of the sensitivities connecting the ACs.

This is one of the most crucial aspects of building FCMs. The comments made in *section C* are also valid for this issue.

In addition, there are also some important aspects such as:

i) Do all the experts have same understanding of the terms that are being used? To this end we propose that the sensitivity is defined by equation 1, that specifies the differential contribution of a change in AC *i* to a change in AC *j*. For example, for a social system, a 100% increase (doubling) say in nationalism, to how much (%) is it estimated that the risk of conflict will be?

ii) How certain/fuzzy are they, and how to fuzzify/defuzzify them?

iii) Can these relationships be learned? This can be done, provided there is available a large database of passed cases/examples, as is usually the case with some medical system applications.

iv) How to handle conflicting or even mutually exclusive values proposed by the different experts?

v) Who can be considered as an expert? On what basis? Should they be weighted? Should they be eliminated depending on how well they predict?

vi) Can the sensitivities be extracted through automated procedures, e.g. NEFCLASS?

E. Smoothening (or squashing) functions

To us, the use of squashing functions, especially in sociopolitical systems, is quite artificial and not properly justified. In the system we propose there is no such need. In certain systems though, such as in controls, they may serve the purpose that they were meant, i.e to confine the various values to manageable levels.

F. Time dependence

We think that this is one of the most important aspects that has not been given proper attention. Certain observations are being made that will enable us to find ways to tackle this issue:

i) The various AC have different time responses when they are given a certain sudden change (input). Some respond slowly, others faster. For instance, a new law that makes the learning of a foreign language imperative will affect the students' attitudes many years later. Also, there may be a dead time before a system responds to a certain input. Thus, not only is the time constant (exponential time) important, but also the dead time. Some argue that the logistic sigmoid serves this purpose, but this is not the case, because the response in the functionals f that are used for the sigmoids, is instant.

ii) How can time dependencies be incorporated in an FCM?

iii) In what kind of problems and FCM models are the time dependent issues most important?

iv) How about the problems of synchronization that may be important in real systems? How are they captured in a simplistic iterative method?

Considering the above, then for better representation of real system dynamics, each expert could give also information on the dead time and the time constant associating an AC *i* to an AC *j*. Such information will also make the understanding of the problem better, thus enabling a better model of the system of interest.

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