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RuleML representation and simulation of Fuzzy Cognitive Maps

Athanasios Tsadiras [a,*], Nick Bassiliades [b]

[a] Department of Economics, Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece
[b] Department of Informatics, Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece

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ABSTRACT

Fuzzy Cognitive Map (FCM) technique is a combination of Fuzzy Logic and Artificial Neural Networks that is extensively used by experts and scientists of a diversity of disciplines, for strategic planning, decision making and predictions. A standardized representation of FCMs accompanied by a system that would assist decision makers to simulate their own developed Fuzzy Cognitive Maps would be highly appreciated by them, and would help the dissemination of FCMs. In this paper, (a) a RuleML representation of FCM is proposed and (b) a system is designed and implemented in Prolog programming language to assist experts to simulate their own FCMs. This system returns results in valid RuleML syntax, making them readily available to other cooperative systems. The representation capabilities and the design choices of the implemented system are discussed and a variety of examples are given to demonstrate the use of the system.

1. Introduction

Fuzzy Cognitive Map (FCM) is a formal method for making predictions and taking decisions, that is used by scientists from various disciplines. The success of the construction of an FCM is heavily depended on the degree of expertise of the domain experts involved in the FCM construction. Making decisions through FCM, requires the simulation of the FCM model, which is a hard task especially from those scientists that do not possess the necessary computer skills.

Some of the major problems that concern nowadays FCMs are the following:

(a) Although many scientists create their own FCMs there is no solid and standard representation of them that would make them easily reusable and transportable.
(b) There is not any standard software that would simulate these FCMs, so every scientist has to create his own software system.
(c) No repository of FCMs exists to assist their dissemination.

In this paper these problems are handled by developing an XML representation of FCMs, which is based on a popular rule interchange format for the web, namely RuleML (Boley, 2006), accompanied by a Prolog-based simulation system that can assist FCM authors to both create syntactically correct FCMs and simulate their scenarios in FCMs. The basic assumption that we make in this paper is that FCMs closely resemble rules, since they represent causality relations between concepts, something that matches with the logical implication semantics of rules.

This study can provide additional dissemination of the use of FCMs because:

(a) FCMs authors will have a tool to create and simulate FCM,
(b) a RuleML repository of FCMs can be created that will help the concentration and distribution of FCMs and
(c) FCMs represented in RuleML will be able to be used in RuleML projects. Additionally, the results of the FCM simulation are stored in RuleML format, making easy their use by other systems.

In this paper, a short introduction to FCMs and related literature is given in Section 2. The representation capabilities of RuleML are presented and discussed in Section 3. In Section 4, the proposed extensions to RuleML in order to be able to represent FCMs are presented. The design of the Prolog-based simulation system that simulates FCMs represented in RuleML is discussed in Section 5, followed by a section concerning the implementation and demonstration of the system's capabilities. Finally, in Section 7, a summary is presented, accompanied by a number of conclusions and recommendations for further research.

2. Fuzzy Cognitive Maps and related literature

Based on Axelord's work on Cognitive Maps (Axelrod, 1976), Kosko introduced in 1986, Fuzzy Cognitive Maps (FCMs) (Kosko,

* Corresponding author.
E-mail addresses: tsadiras@auth.gr (A. Tsadiras), nbassili@auth.gr (N. Bassiliades).

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1986, 1992). FCMs are considered a combination of fuzzy logic and artificial neural networks and many researchers have made extensive studies on their capabilities (see for example Khan, Chong, & Gedeon (2000), Khan & Quaddus (2004), Stach, Kurgan, Pedrycz, & Reformat (2005), Taber, Yager, & Helgason (2006), and Tsadiras & Margaritis (1997a, 1997b)). An example of an FCM, concerning a car industry (Eberhart & Dobbins, 1990), is given in Fig. 1.

FCMs create models as collections of concepts and the various causal relations that exist between these concepts. So in Fig. 1, the nodes represent the concepts that are involved in the model and the directed arcs between the nodes represent causal relationships between the corresponding concepts. The type of the causal relation between the two nodes is determined by the weight that each arc is accompanied. A positive (negative) causal relation between two concepts C_i and C_j means that an increase of the activation level of concept C_i will increase (decrease) C_j and also a decrease of concept C_i will decrease (increase) C_j.

The level of activation of each concept C_i at time step t is determined by number A_i^t, $i = 1, \dots, n$ with n to be the number of concepts of the FCM. We define w_{ij} as the weight of the arc that connects C_i and C_j. There is synchronous updating to the FCM system which means that A_i^{t+1}, $i = 1, \dots, n$ is calculated by one of the following formulas:

$$\text{(i) } A_i^{t+1} = f_M(A_i^t, S_i^t) - d\, A_i^t \text{ using Certainty Neurons (Tsadiras and Margaritis, 1997a) or} \quad (1)$$

$$\text{(ii) } A_i^{t+1} = f_M(w_{1i}A_1^t, f_M(w_{2i}A_2^t, f_M(\dots, f_M(w_{n-1,i}A_{n-1}^t, w_{n,i}A_n^t)))) - dA_i^t \quad (2)$$

using Recursive Certainty Neurons (Tsadiras & Margaritis, 1997b) where,

- $S_i^t = \sum_j w_{ji}A_j^t$ is the sum of the weight influences that concept C_i receives at time step t from all other concepts,
- d is a decay factor and
- $$f_M(A_i^t, S_i^t) = \begin{cases} A_i^t + S_i^t(1 - A_i^t) = A_i^t + S_i^t - S_i^t A_i^t & \text{if } A_i^t \geqslant 0, S_i^t \geqslant 0 \\ A_i^t + S_i^t(1 + A_i^t) = A_i^t + S_i^t + S_i^t A_i^t & \text{if } A_i^t < 0,\ S_i^t < 0 |A_i^t|,\ |S_i^t| \leqslant 1 \\ (A_i^t + S_i^t)/(1 - \min(|A_i^t|, |S_i^t|)) & \text{if } A_i^t S_i^t < 0 \end{cases} \quad (3)$$

is the function that was used for the aggregation of certainty factors at the MYCIN expert system (Buchanan & Shortliffe, 1984).

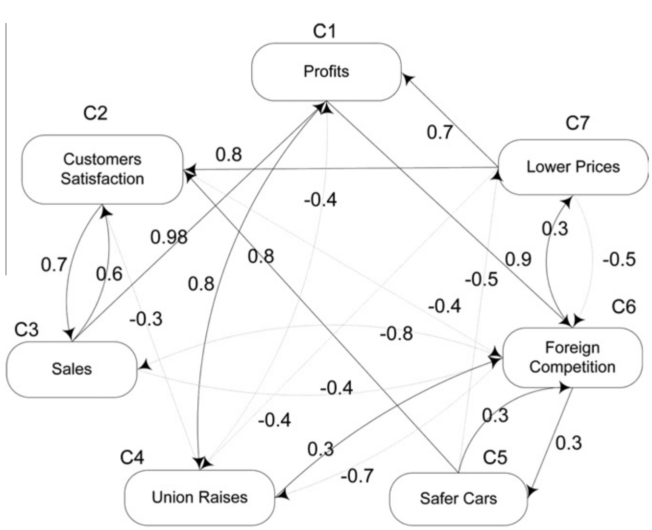

Fig. 1. An FCM concerning a car industry (modified version of original taken from Eberhart and Dobbins (1990)).

Many years have passed since the pioneering work of Taber (1991) on FCM and this technique is still an active research field (Glykas, 2010). The applications of FCMs are numerous and scientists from a wide diversity of disciplines are studying and using them. For example FCMs were developed for analyzing success factors in retail industry (Büyüközkan & Vardaloğlu, 2012) and for the design of controls in business-to-consumer e-commerce systems (Lee & Ahn, 2009). Lee, Lee, and Lee (2012) used an FCM for personalized pricing of last minute theatre tickets, while Lee and Lee (2012), studied the creation of an Internet-based stock trading system, using an FCM. Kang, Lee, and Cho (2004), created an FCM for the relationship management in airline service. The privatization of a firm was studied by Çoban and Seçme (2005) using an FCM. Trappey, Trappey, and Wu (2010), proposed the use of FCMs for RFID reverse logistic management while Kim, Kim, Hong, and Kwon (2008), used an FCM for forward–backward analysis of RFID-enabled supply chain. FCM models for the analysis in nuclear power reactors have been proposed by Espinosa-Paredes, Nuñez-Carrera, Vazquez-Rodrigue, and Espinosa-Martinez (2009), while Ghaderi, Azadeh, Nokhandan, and Fathi (2012) proposed the application of FCMs for studying the electricity markets.

FCMs are also widely used in various areas of medicine. For example, Papageorgiou and Kannappan (2012) have applied FCMs to autism identification, while Giabbanelli, Torsney-Weir, and Kumar (2012) used them for studying the psychosocial determinants of obesity. Lee, Yang, and Han (2012) used FCMs for the selection of dental implant abutments while Stylios, Georgopoulos, Malandraki, and Chouliara (2008) proposed FCMs for creating medical decision support systems. John and Innocent (2005) used FCMs for modeling uncertainty in clinical diagnosis.

Concerning political science, Andreou, Mateou, and Zombanakis (2003) and Tsadiras, Kouskouvelis, and Margaritis (2003), proposed FCMs as a decision support system for political decisions.

FCMs are also used in topics concerning ecology (Hobbs, Ludsin, Knight, Ryan, & Biberhofer, 2002; Ramsey & Veltman, 2005) while their forecasting and decision making capabilities are presented in a number of studies e.g. the forecasting of artificial emotions (Salmeron, 2012), the prediction of chaotic time series (Song et al., 2010), multicriteria analysis (Salmeron, Vidal, & Mena, 2012).

FCMs has also been used for web-mining inference (Lee, Kim, Chung, & Kwon, 2002) and for the navigation of mobile robots (Motlagh, Tang, Ismai, & Ramli, 2012).

Although there are many recent attempts toward training and learning of FCMs (Papageorgiou, 2012; Papakostas, Koulouriotis, Polydoros, & Tourassis, 2012; Stach, Pedrycz, & Kurgan, 2012), the application of FCM technique to a wide variety of scientific areas makes crucial the development of a commonly used tool that can assist the creation and simulation of FCMs. Various attempts have been done towards the creation of such a tool. For example:

- FCM constructor is a knowledge acquisition system that builds an FCM by direct knowledge acquisition (Cheah, Kim, Kim, & Yang, 2011).