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Benchmarking main activation functions in fuzzy cognitive maps2

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ABSTRACT

Fuzzy cognitive maps (FCM) are graph-based modeling tools. FCM can to be used for structuring and supporting decisional processes. Also, FCM allow developing what-if analysis, through the definition of scenarios. It is possible to choose among four activation functions: (1) sigmoid function, (2) hyperbolic tangent function, (3) step function and (4) threshold linear function. The use of each function can provide different alternatives. In this context, the main objective of the present study is to develop a benchmarking analysis among the mentioned functions using a same decisional model. Findings show how the sigmoid function offers significantly greater advantages than the other functions.

1. Introduction

FCM provide excellent mechanisms to support decision-makings (Koulouriotis, Diakoulakis, Emiris, & Zopounidis, 2005). Innumerable decision processes are identified in organizational projects. Some of these decisions, on which decision makers need to use different methods of analysis, i.e. brainstorming, surveys or experts' consultation, are quite complex. The different alternatives of a complex decision could cause positive or drastic consequences which depend on the evolution of its decisional factors. For this reason, in many occasion decision makers need to know all possible situations to make advisable decisions for an organization.

In this context, FCM provide decision-makers a tool with a fundamental advantage: to structure complex decision. This activity is essential for reaching successful decisions (Konar & Chakraborty, 2005; Xirogiannis & Glykas, 2007; Yu & Tzeng, 2006). In the literature about FCM application, four activation functions are identified to analyze decisions with FCM: (1) sigmoid function, (2) hyperbolic tangent function, (3) step function, (4) threshold linear function. The use of each function is conditioned to the FCM designer's preferences (Huang, Gu, & Du, 2006; Ölçer, Tuzcu, & Turan, 2006) and complexity of FCM (Xirogiannis & Glykas, 2007). Anyway, opposed opinions about the suitability for using each function can be found in the literature (Sharif & Irani, 2006; Tsadiras & Margaritis, 1997).

The four can offer benefits and limitations on each situation and decision. For this reason, decision makers can find obstacles for selecting the most suitable function (Osei-Bryson, 2004; Pajares & de la Cruz, 2006; Papageorgiou & Groumpos, 2005; Stylios & Groumpos, 1999). This paper tries to attain some evidence on the suitability of each function. Specifically, the main objective is to observe the differences between the mentioned functions. In order to complete this objective, the authors have developed a benchmarking analysis using an enterprise resource planning (ERP) tool selection as decision environment. ERP selection is a complex and unstructured decision process in a technological context (Wei, Chien, & Wang, 2005; Wei & Wang, 2004). In this case, decision makers must make an effort to understand the most relevant decisional factors in order to complete the decision-making process.

This paper is structured in five sections. In the second section, the FCM framework is defined. Next, in the third section, the authors develop an ERP selection FCM for making the proposed experimental analysis. In the fourth section, the activation functions are introduced. Then, in the fifth section, the analysis and findings are shown. Finally, the main conclusions are exposed.

2. Fuzzy cognitive maps foundations

Cognitive maps are the origin of FCM. Cognitive maps were used for the first time by Axelrod (1976) to represent the causal relationships among factors in order to outline a decision-making process. Cognitive maps and FCM have been widely applied in computing and decision sciences (Kim & Lee, 1998; Konar & Chakraborty, 2005; Osei-Bryson, 2004; Papageorgiou, Stylios, & Groumpos, 2006b; Rodriguez-Repiso, Setchi, & Salmeron, 2007; Stach, Kurgan, & Pedrycz, 2005), although other research areas have used these techniques, such as business and management (Kang, Lee, & Choi, 2004; Lee & Han, 2000; Rai & Kim, 2002), agriculture and biological sciences (Mendoza & Prabhu, 2006; Özesmi & Özesmi, 2004), engineering (Lee, Kim, & Lee, 2004; Peláez & Bowles, 1996) and medicine (Georgopoulos, Malandraki, & Stylios, 2003; Papageorgiou et al., 2006a).

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A cognitive map shows a representation of how humans think about a particular issue, by analyzing, arranging the problems and graphically mapping concepts that are interconnected (Eden & Ackermann, 2004). In addition, it identifies causes and effects and explains causal links. The cognitive maps study perceptions about the world and the way they act to reach human desires within their world. The foundation for this theory was given by Kelly (1970), based on a particular cognitive psychological body of knowledge called Personal Construct Theory.

Cognitive maps have been considered an especially useful technique in problem solving (Axelrod, 1976; Eden & Ackermann, 2004) where many decisional variables (some of which are uncontrollable on the part of the decision-makers) are causally interrelated (Kim & Lee, 1998). In the same manner, cognitive maps can also help decision-makers in analyzing the hidden causal relationships that can contribute to reaching more relevant and significant solutions.

A cognitive map is a formal model with construction rules, which is characterized by defining a hierarchical structure for a decisional process. A cognitive map is composed of nodes which represent the most relevant factors of a decisional environment (Axelrod, 1976). Furthermore, a cognitive map allows the identifying of the type of relationship by means of incorporating plus (+) and minus (−) signs (Dikerson & Kosko, 1994). A positive relationship between two factors should be considered as stimulating, while a negative relationship should be considered as an inhibiting one between two nodes. With these rules, a cognitive map can be represented through an adjacency matrix which shows the sign of the relationship, while keeping in mind that in the case there being an absence of relationship between these two factors, the corresponding entry will be empty. The path between two factors is the sequence of all the nodes connected by arrows, but without considering their signs (Kardaras & Karakostas, 1999).

Cognitive maps possess, as their main limitation, the impossibility of quantifying relationships among variables. With the purpose of offering a solution to this weakness and enhancing cognitive maps, fuzzy numbers have been conjugated with cognitive maps. In this context, FCM were introduced by Kosko (1986), and allow the providing of fuzzy causation measures to the cognitive maps proposed by Axelrod (1976).

FCM substitute the signs (+) and (−) for a fuzzy value between -1 and 1. The zero value indicates the absence of weight. Through this range of value FCM allow the making of a wider interpretation of complex problems (Lee, Kim, Chung, & Kwon, 2002; Lee et al., 2004; Liu & Miao, 1999; Schneider, Shnaider, Kandel, & Chew, 1998), due to the possibility of applying weights to the relationships. However, it is more difficult to establish a consensus among the experts with FCM, since each expert has a greater range of answers than a cognitive map.

Also, FCM can be represented by a $n \times n$ adjacency matrix (E), since that n is the number of nodes. Each e_{ij} indicates the relationship between the i and j concepts, enabling us to obtain values between [−1,1]. Three types of relationships can be seen: (a) $e_{ij} > 0$, indicating a positive relationship, (b) $e_{ij} < 0$, indicating a negative relationship, and (c) $e_{ij} = 0$ where no relationship exists

$$E = \begin{pmatrix} e_{11} & \dots & \dots & \dots & e_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & e_{ij} & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ e_{n1} & \dots & \dots & \dots & e_{nn} \end{pmatrix}$$

Therefore, when an expert assigns a e_{ij} value, three issues exist and must be kept in mind (Schneider et al., 1998). In the first place, the e_{ij} weight to indicate how strong the i concept is on j. Secondly, the strength of the relationship is given by a fuzzy weight preceded by a positive or negative sign indicating whether that relationship is direct or inverse respectively. Lastly, the causality relationship needs to be indicated to establish if the i concept is a cause of j or vice-versa.

3. Data domain

An ERP selection FCM was defined via the opinions of ten experts. The experts had formed or form part of an ERP implementation steering committee. These experts work in both the public and private sectors, and, in some cases, they were actually consultants of an ERP vendor. Also, the number of experts finally selected is found within the recommended range (Clayton, 1997; Okoli & Pawlowski, 2004).

This group composition guarantees the experts who are finally chosen having profound knowledge of ERP selection tools. This last aspect is important because some of the chosen experts opted for developing a custom-made ERP tool after discarding the alternative to buy an ERP in the market.

The Delphi method was applied with the purpose of reaching a consensus regarding the ERP selection FCM. Delphi is widely used to structure the process of communication of a group of experts about a complex problem (Dalkey & Helmer, 1963; Linstone & Turoff, 1975). The Delphi method provides feedback reports to expert, and, hence, the opportunity to improve their own opinion based on this feedback (Akkermans, Bogerd, Yücesan, & Wassenhove, 2003; Dalkey & Helmer, 1963).

The difficulty is in reaching a consented value not only for the causal weight but for the sign between the cognitive map relationships as well. This measure will be distinct with respect to the experts who assign the fuzzy numbers to each of the relationships. The Delphi methodology application to FCM offers the possibility of reaching measures about the weight and sign of the relationship by means of the consultation of a panel of experts.

The final ERP selection FCM was defined with two rounds of questions. In the second round, the experts had information such as averages, medians or typical deviation coming from the first round. This information is essential to try to obtain consensus and get all experts to go toward the median.

The ERP selection FCM is composed of 12 selection factors (Table 1). The weight values take as fuzzy numbers the median of the values reached in round two and taking as its sign that which is used by the majority of the experts in each of the relationships (Chakravarti, Vasanta, Krishnan, & Dubash, 1998; Holzmüller & Schlüchter, 2002; Mitchell, 1991; Shin, 1998). These factors were directly obtained from interviews which made reference to basically two factor groups; on one hand those related to organizational aspects, and on the other, those related directly to the ERP tool itself.

Table 1
Selection factors

Factor	Description
X_1	ERP selection
X_2	Solution prestige
X_3	Solution services
X_4	Similar ERP to current information systems (IS)
X_5	Project investment
X_6	Implementation efficiency
X_7	Organizational flexibility
X_8	Software cost
X_9	Consulting cost
X_{10}	Maintenance cost
X_{11}	Hardware requirement
X_{12}	Specialist team requirement