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A Tool for Qualitative Causal Reasoning On Complex Systems

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Abstract

A cognitive map, also called a mental map, is a representation and reasoning model on causal knowledge. It is a directed, labeled and cyclic graph whose nodes represent causes or effects and whose arcs represent causal relations between these nodes such as "increases", "decreases", "supports", and "disadvantages". A cognitive map represents beliefs (knowledge) which we lay out about a given domain of discourse and is useful as a means of decision making support. There are several types of cognitive maps but the most used are fuzzy cognitive maps. This last treat the cases of existence and no nexistence of relations between nodes but does not deal with the case when these relations are indeterminate. Neutrosophic cognitive maps proposed by F. Smarandache [1] make it possible to take into account these indetermination and thus constitute an extension of fuzzy cognitive maps. This article tries to propose a modeling and reasoning tool for complex systems based on neutrosophic cognitive maps. In order to be able to evaluate our work, we applied our tool to a medical case which is the viral infection biological process.

Keywords: qualitative reasoning, fuzzy cognitive maps, neutrosophic cognitive maps, causal reasoning. Complex systems

1. Introduction

Causal reasoning is a cognitive activity that a human being practices in its everyday life to try to provide explanations to physical, social, economic and ecologic phenomena or facts. It is a qualitative and a common sense reasoning approach. In 1976, Robert Axelrod [2], researcher in political sciences, introduced the concept of a cognitive map as being a directed, labeled and a cyclic graph, whose basic relations set is {+, -, 0}, respectively representing the relations of causality or influence "increases", "decreases" and "no effect". Axelrod's cognitive maps were used to represent, predict and make decisions relating to the socio political and socio economic fields, which are considered as complex systems. In 1986, Kosko [3] proposed an extension of Axelrod's cognitive maps by introducing fuzzy logic and named its maps by fuzzy cognitive maps where the causal relations are graduated in the interval [- 1 1]. The fuzzy cognitive maps were mainly used to model complex supervision systems [4]. In 2003, F. Smarandache [1] proposed the neutrosophic cognitive maps making it possible to mitigate the limitation of fuzzy cognitive maps which cannot represent the indeterminate relations between variables. The capability of neutrosophic cognitive maps to represent indetermination makes it possible to apprehend the complexity of the systems and thus to elucidate and predict their behaviors in the absence of complete information.

Our paper will be structured in the following way. Section 2 presents related work in the field of modeling biological complex systems using cognitive maps. The section 3 presents neutrosophic cognitive maps. Section 4 will be reserved to describe the domain of discourse in fact the viral infection then to build the corresponding neutrosophic cognitive map by the recourse to a certain number of virologists. Reasoning on this cognitive map making it possible to draw the typical behaviors of the viral infection process. Section 5 is devoted to describe implementation aspects. Our objective is to automate the construction and the reasoning on the neutrosophic cognitive maps independently of the field of expertise. In order to be able to evaluate our work and to discuss the results, section 6 shows us how our developed tool is applied to the study of the viral infection process. Finally section 7, will enable us to conclude our work and to give some perspectives.

2. Related work

Fuzzy cognitive maps [3] were used in the medical domain [7][8][9] as a tool of causal reasoning, procedure often complex because multi sources data is often vague, conflicting, missing and no easy to interpret. There is a few works done on cognitive maps to model and reason about biological processes and we have only found two significant papers written by Hailin and Chenxi [10] and by Papageoriou et al. [11].

The first paper [10] introduced the qualitative reasoning technology to model and to analyze the virus penetration in the animal cell. The authors distinguish three classes of factors (See table 1) which influence the viral behavior which are: 1) Factors relating to the virus, including some situations about the virus such as its activity, its size and its structure. 2) Factors relating to the environment including the temperature, the pH and the presence of positive ions. 3) Factors relating to the cellule including permissiveness of the cellular membrane and its enzyme countenance. Each factor is affected by a degree of influence as shown in the Table 1. According to the authors of this paper, the process of entry of the virus to the cell passes by three stages:
1) Attachment of the virus to the cellular membrane, 2) Penetration of the virus inside the cell, 3) Release of the genetic inheritance of the virus inside the cell. Based on this information, a qualitative model, based on the method of T.L. Saaty proposed in 1970, was built and tested but remains an approximate model prone to improvements being the subject of future work [10].

In the second work suggested by Papageogiou and his/her colleagues [11], authors proposed a model based on the fuzzy cognitive maps to diagnose the severity of the pulmonary infection being able to have four fuzzy values: weak, moderated, average and severe. For that they connect factors having milked at the symptoms, the physical examinations, the biomedical and biochemical analyses and other factors relating to resistance to antibiotics. In total, thirty four (34) concepts are identified and connected thanks to the assistance of the experts invited to define the degree of influence between these concepts. (See Figure 1). The model builds was tested on real medical data and the simulation results showed that the reliability of the decision support system used, is dependent on the availability of sufficient information [11].

Our work consists of modeling and simulating the viral infection process by using not only the direct factors between the virus and the cell but also other factors having milked with the environment and/or the lived socio economic situation of the patient. Moreover, the model used, which is the neutrosophic cognitive map [1], is an extension of the fuzzy cognitive map model allowing to take into account of the indeterminism, significant characteristic of biological processes and of complex systems in general.

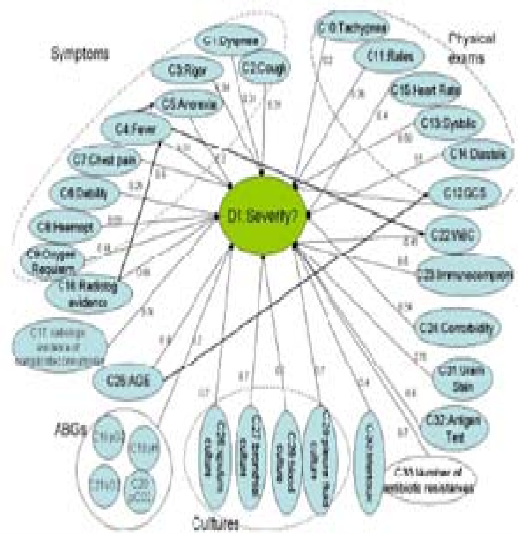

Figure 1. Fuzzy cognitive map of the viral infection according to [10]

	Factors	Influence degree
	The individual factors	
1	Virus activity	9
2	The structure of virus attachment protein	8
	The environment factors	
3	temperature	5
4	PH value	5
5	Positive ion	5
	The Cell factors	
6	Receptor site	7
7	Enzyme	5
8	The structure of cellular skeleton	6

Table 1: factors influencing the viral Infection according to [10].

3. Neutrosophic cognitive maps, representation of causal knowledge and reasoning

In this section, we will show how to represent knowledge related to a field of expertise by a Neutrosophic Cognitive Map then to explain the manner of reasoning on this latter in order to draw typical behaviors from the dynamic system which it represents.
A Neutrosophic Cognitive Map (N.C.M) is an extension of a Fuzzy Cognitive Map (F.C.M). The latter is a cyclic

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graph directed whose nodes represent the variables of the field of speech and whose arcs define causal relations between each pair of variables. These causal relations take their values in the interval [- 1 1]. N.C.M take their values of causalities in the same preceding interval but can also be indeterminate. Cognitive maps whose values of causalities belong to the set {-1,0,1, ?} is known as Simple Neutrosophic Cognitive Maps [1]. A state vector associated with a cognitive map is given by the vector: $S = (s_1, s_2, s_3 \ldots, s_N)$, where the state of node *i* could be represented by values *"1", "0" and "?"* whose significances are respectively, *active, inactive or indeterminate.* The reasoning carried out on a cognitive map makes it possible to draw all the typical behaviors from this map, i.e. the typical behaviors of the dynamic system that this cognitive map represents. Each behavior of the dynamic system is obtained by the stimulation of the adjacency matrix of the cognitive map by a suitable state vector via an iterative multiplication until we fall on a state vector which is already obtained in the preceding iterations. Before applying the K^{ieme} iteration, a thresholding function is applied to the state vector of the (K-1)^{eme} iteration defined as follows [1]:

$$N + M? = \begin{cases} ? \;, & if\ N = 0\ and\ M > 0 \\ 1 \;, & if\ N > 0\ and\ M > 0 \\ 0, & if\ \ N < 0 \end{cases}$$

A typical behavior represents an equilibrium state of the cognitive map and it is not other than a fixed point or a limit cycle. In order to illustrate this, we give the following example.

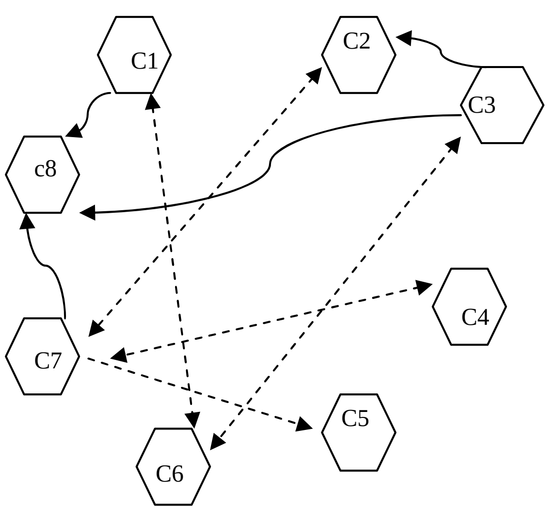

Figure 2.1: Hacking of e-mails by students

Example [1]: The simple neutrosophic cognitive map of Figure 2.1 represents causal knowledge relating to the phenomenon of e-mails hacking by students. The arcs in dotted lines represent indeterminate causal relations. Concepts of this cognitive map are: C1 (Curiosity); C2 – (Professional rivalry); C3 (Jealousy/ enmity); C4 – (Sexual satisfaction) ; C5 (Fun/pastime). C6 (To satisfy ego) ; C7 (Girl students) ; C8 (Breach of trust.). Figure 2.2 represents the corresponding adjacency matrix. Given the starting state vector S1 = (0 ? 0 0 ? 0 0 1), Inference of the N.C.M of the figure 2.1 gives the scenario depicted in figure 2.3.

$$N(E) = \begin{bmatrix} 0 & 0 & 0 & ? & 0 & ? & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & ? & 0 \\ 0 & 1 & 0 & 0 & 0 & ? & 0 & 1 \\ ? & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ ? & 0 & ? & 0 & 0 & 0 & 0 & 0 \\ 0 & ? & 0 & 0 & ? & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 2.2 The adjacency matrix of the Fig. 2.1

We reached a typical behavior, after five iterations, which can be interpreted as follows:

S1*N(E) = (0 ? 0 0 ? 0 0 1) → (0 ? 0 0 ? 0 1 1) = S2 ……. Iteration 1
S2*N(E) = (0 ? ? 0 ? 0 ? 1) → (0 ? ? 0 ? 0 1 1) = S3 … …. Iteration 2
S3*N(E) = (0 ? ? 0 ? ? ? 1+ ?) → (0 ? ? 0 ? ? 1 1) = S4 .... Iteration 3
S4*N(E) = (? ? ? 0 ? ? ? ?+1) → (? ? ? 0 ? ? 1 1) = S5 ….Iteration 4
S5*N(E) = (? ? ? 0 ? ? ? 1) → (? ? ? 0 ? ? 1 1) = S6 = S5 ….Iteration 5 .. End

Figure 2.3: A Scenario of reasoning on the cognitive map of Figure 2.1

If the "Hackers" are girl students then they act of a breach of trust and an indeterminate way of: c1, c2; c3, c5 and c6 and not for a cause of c4.

4. A case study: The viral infection

According to [10], the infection is "Invasion of an alive organism by micro pathogenic organisms (bacteria, virus, mushrooms, parasites). During an infection the pathogenic micro-organisms act while multiplying (virulence) and possibly by secreting toxins ". A virus according to [6] is defined by: "Microscopic, simple infectious agent that edge multiply only in living room cells of animals, seedlings, gold bacteria." The process of the infection passes by the seven (7) following stages [6]. a) Attachment of the virus on the surface of the host cell. b) Penetration of the virus and injection of its genetic inheritance inside the cell. c) Transcription of the viral genome to produce of A.R.N- messenger (ARNm) d) Translation of the viral RNAm to proteins. e) Reproduction of the viral genome to form virus genomes. f) Assembly of the genomes wire with proteins produced to give rise to viruses. g) Left the offspring of the virus of the host cell, and the cycle begins again to attack another cell of the same organism or another organism. Two dominating factors play their roles in the viral infection which are the pathogenic force of the virus and the immunizing force of the host cell which determines the infection or the non infection of the latter, as explained in [5]: "an infection develops when natural defenses of the organization cannot prevent some; it is the relationship between the quality of the immunizing defenses, more or less compromised during a variable time, and the pathogenic capacity, more or less marked, germ which determines the appearance or not of the infectious disease. Another significant factor which plays its role in the mechanism of the viral infection is well the environment. Indeed much viral infections are of latent type, i.e. without harmful effects on the life of the cell and the organization structurally identical to the parent virus. The actions of the virus depend both on its destructive tendencies toward a specific host cell and on environmental conditions." [6]." Viral infection does not always result in cell death or tissue injury; in fact, most viruses lie dormant in tissue without ever causing pathological effects, or they do so only under other, often environmental, provocations." [6].

Our work is an attempt aiming at bringing into play not only the internal factors (cell-virus) but also the external factors related to the environment in order to better understand this mechanism of the viral infection. All these factors and the relations which can exist among them are modeled graphically by a neutrosophic cognitive map on which will be carried out a causal reasoning making it possible to deduce all its possible behaviors.

5. Implementation

We developed a tool for construction and manipulation of Fuzzy and Neutrosophic Cognitive Maps allowing us to reason on complex systems. By way of application, we modeled and simulated the process of the viral infection.

With the assistance of experts, we enumerated twenty three (23) different concepts and 30 relations of influence between these concepts describing the viral infection. We give hereafter these concepts as well as the relations of influence between them.

C1. Radioactivity
C2. Smoking
C3. Socio-economic conditions
C4. Malnutrition
C5. Drug immunosuppressor
C6. Congenital disorder of immunity
C7. Chemical products
C8. Cancer
C9. Hygiene
C10. Immunodepression
C11. Viral infection
12. Bacterial infection
C13. Temperature of the body
C14. Diabetes
C15. Contagious persons
C16. Demolition of suspect animals
C17. Animal tanks
C18. Industry
C19. Globalization
C20. PH of the virus medium.
C21. Vaccination
C22. Existence of positive ions around the cell
C23. Effet of Greenhouse

The qualitative relations between these concepts are given as follows:

R1. Radioactivity (+) Cancer
R2. Smoking (+) Cancer
R3. Chemical products (+) Cancer
R4. Cancer (+) Temperature of the body
R5. Temperature of the body (+) viral Infection
R6. Bacterial infection (+) Temperature of the body
R7. Demolition of suspect animals (-) animal Tanks
R8. Animal tanks (+) viral Infection
R9. Animal tanks (+) bacterial Infection
R10. Industry (+) Chemical products
R11. Industry (+) the effect of greenhouse
R12. Globalization (+) viral Infection
R13. Hygiene (-) Smoking
R14. Hygiene (-) viral Infection
R15. Hygiene (-) Contagious persons
R16. PH of the medium of virus (+) viral Infection
R17. Vaccination (-) viral Infection
R18. Existence of positive ions around the cell (+) viral Infection.
R19. Viral infection (+) Temperature of the body
R20. The effect of greenhouse (+) viral Infection

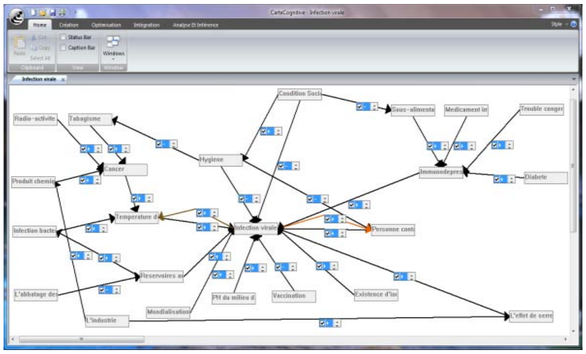

Figure 3: The cognitive map « Viral infection » created by the developed tool.

R21. Viral infection (+) Contagious persons
R22. Contagious persons (+) viral Infection
R23. Socio-economic conditions (-) viral Infection
R24. Socio-economic Conditions (-) Malnutrition
R25. Socio-economic conditions (+) Hygiene
R26. Malnutrition (+) Immunodepression
R27. Drug immunosuppressor (+) Immunodepression
R28. Congenital disorder of immunity (+) Immunodepression
R29. Diabetes (+) Immunodépression
R30. Immunodepression (+) Viral Infection.

Now, we can build the cognitive map using the developed tool, as shown in figure 3. Using the same tool, we can also obtain all the possible scenarios, also called typical behaviors. These last constitute a subset of the research space consisting of 8388606 possible cases to consider, i.e more than 8 million cases. As an indication, the time necessary to explore all these cases is 1 hour 20 mn using a computer equipped with a Core2Duo 2GHz processor and a 2Go of RAM.

As an example, when “greenhouse effect” concept is activated, the inference of the cognitive map of the figure 4 (which shows the cognitive map of the virus infection process plus an indeterminate relation between the effect of greenhouse and diabetes) gives the following typical behavior shown in Table 2. This scenario could be interpreted as follows: If effect of greenhouse concept is positively activated then:

a) The concepts Viral infection, Temperature of the body and Contagious persons are positively activated.
b) The concepts Cancer, Immune- depression and Diabetes are activated with an indeterminate manner.
c) The remaining concepts are not activated.

6. Conclusion and future work

We developed a tool for reasoning on causal qualitative knowledge represented by neutrosophic cognitive maps. These last are an extension of fuzzy cognitive maps which make it possible to take into account the indeterminism in the study of the complex systems. Like first application, we studied the process of the viral infection. With this intention, we took into account not only factors directly dependent on the cell and the virus but also those factors relating to the environment (such as effect of greenhouse) and the socio economic reality (such as malnutrition and globalization). The tool we developed allows handling and analyzing fuzzy and neutrosophic cognitive maps and it is independent of the field of expertise.

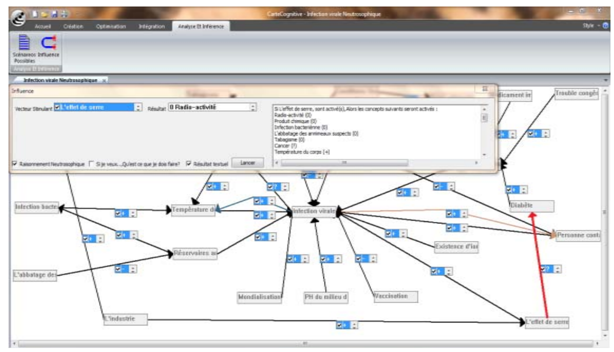

Figure 4: Neutrosophic cognitive map (indeterminate relation between « Effect of greenhouse » and « Diabetes »)

Concept	Effect
Radioactivity (0)	no effect
Chemical products (0)	no effect
Bacterial infection (0)	no effect
demolition of Suspect animals (0)	no effect
Smoking (0)	no effect
Cancer (?)	**indeterminate**
Temperature of the body (+)	**positive**
animal Tanks (0)	no effect
Globalization (0)	no effect
Industry (0)	no effect
Viral infection (+)	**positive**
Vaccination (0)	no effect
PH of the medium of virus (0)	no effect
Hygiene (0)	no effect
Socio- economic conditions (0)	no effect
Malnutrition (0)	no effect
Drug immunosuppressor (0)	no effect
Congenital disorder of immunity (0)	no effect
Immune depression (?)	**indeterminate**
Diabetes (?)	**indeterminate**
Contagious persons (+)	**positive**
Existence of pos. ions around cell (0)	no effect
greenhouse effect (+)	**positive**

Table 2: An execution scenario of the developed viral infection system.

As a future work, we plan to study the following items:

a) It was noticed that the inference on the cognitive maps consists of finding an answer to this question "what will happen if?", but in practice the decision maker wants often to know an answer to the question "if I want to …, what should I make? ". For example in our case "the viral infection", one noticed that the decision maker puts this question intuitively " If I want to decrease the viral infection, what have I to do? " With this intention, an algorithm for the "abductive" causal reasoning is to be proposed.
b) The space of research of the typical behaviors in a cognitive map increases exponentially with the number of concepts considered. It would be then very interesting to find heuristics in the aim to attenuate this problem of complexity.
c) Modeling and simulating a distributed system using neutrosophic cognitive map model (like a weather prediction system) by means of a multi agent system. This work will constitute a very good example of a collective and qualitative decision making.

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