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Evolutionary Fuzzy Cognitive Maps: A Hybrid System for Crisis Management and Political Decision Making

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Abstract

This paper proposes an extension of Certainty Neuron Fuzzy Cognitive Maps (CNFCMs) used in crisis management and decision-making, aiming at increasing their reliability. The objective of the Genetically Evolved Certainty Neuron Fuzzy Cognitive Map (GECNFCM) as it is introduced here is to overcome the main weakness of CNFCMs, which lies with the recalculation of the weights corresponding to each concept every time a new strategy is adopted. The problem is overcome through the introduction of a Genetic Algorithm (GA), which produces a set of solutions and new weights following a strategy change. The GA concepts are very appealing since they offer the optimal solution without a problem-solving strategy, once the requirements are defined. It is interesting to point out that the hybrid approach is reflected in both the implementation of the GA and in the methodology applied for solving the problem. In fact, the reasoning behind this hybrid methodology is to use it for obtaining the optimal values of the weights corresponding to the variables of the model rather than the optimal values of the variables themselves.

1 Introduction

A Cognitive Map (CM) uses a technique based on qualitative reasoning and can be used to cope with knowledge that generally involves many interacting concepts. CM models were introduced by Axelrod [1] in the late 1970 and were mainly used to support political decisions in international relations. Generally, the basic elements of a CM are simple: The concepts used by an individual decision-maker are represented as nodes, and the causal relationships between these concepts are represented as directed arrows. Each arrow is characterized by a weight, a real value that indicates the effect of the causal relationship between nodes. This representation gives a figure of nodes and arrows called cognitive map in which the various concepts are considered as variables of the system. To indicate, in addition, the intensity of the relationships between these variables one needs to employ a FCM which has been developed by political scientists in order to analyze, predict and understand decisions imitating the cognitive process of human experts on various fields of expertise. This combination of Fuzzy Logic and Neural Networks [2] creates models that emulate reasoning and the decision-making process using fuzzy causal relationship [1,3]. The flexibility of such models is improved by allowing for a variety of activation levels of each concept thus creating Certainty Neuron Fuzzy Cognitive Maps (CNFCM) that have developed to a reliable technique used in strategy selection and evaluation of possibe solutions in view of intricate political problems [4].

Promising as they may appear, the CNFCMs have two weak points: The first involves the invariability of the weights, which leaves only the activation levels to participate in the configuration of a political problem. The second lies with the inability of the method to model a certain political situation by performing all possible computational simulations following the change of a certain weight or group of weights. This paper aims at solving these problems by combining CNFCMs with Genetic Algorithms (GAs) thus creating a hybrid model reflecting the complication of the Cyprus issue. In this context, the CNFCM part of the algorithm computes the final activation levels given the weights and relationships between concepts, while the GA part develops the weight matrix attempting to find the optimal set of weights that satisfy a predefined activation level for a specific concept. A hybrid model of this type, therefore, traces the degree of the causal relationships between the various concepts such that it can “force” them to be activated to a certain level. Hybrid models of this type are expected to contribute to the effectiveness of decision-making by defining for each concept the activation level achieved with a certain set of weights evolved by the GA. The simulations that follow retrieve the final activation levels of the rest of the concepts, as well as the strength of the causal relationship between them. The analyst is thus given the means to proceed to tactical movements in his decision-making by varying the degree of such relationships in line with the final activation levels the model has suggested.

2 The structure of a FCM model

A FCM consists of a diagram the nodes of which represent the various qualitative concepts, while the arrows stand for the links between the concepts that possess a numeric state denoting a qualitative measure of the concepts’ presence in the conceptual domain. Thus, a high numerical value indicates that the concept is strongly present while a negative or zero value reveals that the concept is not currently active or relevant to the conceptual domain. A FCM works in discrete steps. When a strong positive correlation exists between the current state of a concept and that of another concept in a preceding time-period, we say that the former positively influences the latter indicating this by a positively weighted arrow directed from the causing to the influenced concept. By contrast, when a strong negative correlation exists, it reveals the existence of a negative causal relationship indicated by an arrow charged with a negative weight. Two conceptual nodes without a direct link are, obviously, independent.

In 1997, the introduction of the Certainty Neuron Fuzzy Cognitive Maps (CNFCMs) [5,6] provided additional fuzzification to FCMs, by allowing for various activation levels of each concept between the two extreme cases, i.e. activation or not. More specifically, a function *f()* coming from the area of expert systems [7] was used to return the new certainty factor of a fact after receiving new evidence for, or against previous beliefs based on the present certainty factor. The updating function of a CNFCM is the following:

$$A_i^{t+1} = f\left(S_i^t A_i^t\right) - d_i \ A_i^t \tag{1}$$

where

$$S_i^t = \sum_{\substack{j=1 \\ j \neq i}}^{n} A_j^t w_{ij} \ , \tag{2}$$

A_i is the activation level of concept C_i at some time $(t+1)$ or (t), equation (2) is the sum of the weighted influences that concept C_i receives at time step t from all other concepts, d_i is a decay factor [8], and

$$f_m(A_i^t, S_i^t) = \begin{cases} A_i^t + S_i^t(1 - A_i^t) = A_i^t + S_i^t - S_i^t A_i^t, if \ A_i^t \geq 0, S_i^t \geq 0 \\ A_i^t + S_i^t(1 + A_i^t) = A_i^t + S_i^t - S_i^t A_i^t, if \ A_i^t < 0, S_i^t < 0, |A_i^t|, |S_i^t| \leq 1 \\ A_i^t + S_i^t \Big/ \left(1 - \min\left(\left|A_i^t\right|, \left|S_i^t\right|\right)\right), otherwise \end{cases} \tag{3}$$

is the function used for the aggregation of certainty factors [5]. The meaning of the above function is that the external influence can affect the activation of a concept just to a certain degree. We propose the following modification to the third case of equity in (3) as follows:

$$A_i^t + S_i^t \big/ (1 - \min(A_i^t, S_i^t)), otherwise \tag{4}$$

to cover the undesired situation in which one of A_i^t and S_i^t equals to 1 and the other to –1 leading the denominator to zero.

3 Developing a CNFCM model for the Cyprus issue

Using a CNFCM we attempted to depict the unstable framework prevailing in Cyprus as this intricate political issue remains yet unsettled. The invasion launched by Turkey "to restore constitutional order" in 1974 following an abortive coup against the president Archbishop Makarios in 1974 has set 38% of the island under Turkish occupation. The United Nations have repeatedly expressed their concern regarding all arbitrary actions by the Turkish side on such a major issue. In fact, the U.N. has been continuously involved in the Cyprus problem since 1964, both in the Security Council and in the General Assembly, and is concerned about the Turkish threat to Cyprus' sovereignty and independence. The Cyprus Government, in its turn, making use of extensive support from the part of Greece, has invested a great deal in the course of the Cyprus full membership in the European Union hoping that this will provide the dynamics for the resolution of the Cyprus problem. The Turkish authorities, however, have declared through reports as well as open statements in the press that their reaction to the Cyprus full EU membership will be "limitless", an expression which is taken to imply, among other things, annexing the occupied part of the island to Turkey. Such developments, however, are far from being promising as regards a solution to the problem, something which promotes a climate of instability and uncertainty.

The development of our model depicting the situation as described above was based on the method of questionnaires and interviews [9] with a team of domain experts who have been asked to identify the important concepts that influence the Cyprus problem and which contribute to sustaining instability and intensity on the island. The general model was then built (Figure 1) in which the various concepts appear to interact with one another, to affect the central concept which is the instability/intensity in Cyprus (C1). On the right side of Figure 1 the weights are presented in a form that indicates the link from the starting concept to the ending concept, concepts separated with comma. The sixteen concepts that influence the instability in Cyprus appear in Table 1. The weight values are given in Table 2.

Table 1. The Cyprus issue: Model concepts and their description

C1	Instability /Intensity in Cyprus	C9	Support to the Greek-Cypriot army
C2	Turkish forces actions in Cyprus	C10	Strengthening of the Greek army
C3	Turkish threats	C11	Strengthening of the Turkish army
C4	Solution of the Cyprus problem	C12	Stability of the Greek government
C5	Greek political support	C13	Stability of the Turkish government
C6	UN talks for the Cyprus problem	C14	EU/NATO economic, military and political support
C7	Stability of the Cyprus government	C15	International influence
C8	Support to the Turkish forces	C16	Turkish-Cypriot reactions

4 The GECNFCM Hybrid Model

Genetic Algorithms constitute a class of optimisation algorithms that is capable of exploring efficiently a large and complex solution space for a given problem and resulting solutions close to the global optimum [10]. A genetic algorithm (GA) provides a search procedure, which optimises an objective function *f()* by maintaining and evolving a population *P* of candidate solutions. The population is evolved through crossover and mutation operations employed to generate new individuals. The computation procedure of the GA starts with random initialisation of the individuals forming the first generation of the population. The objective function is then evaluated for every individual and according to the fitness of each individual some members are selected for the next generation. The selected individuals undergo mutation and/or crossover transformations according to some probability and the fitness function is applied on the members of the new generation. The GA procedure is then repeated for a certain number of iterations called epochs or generations. The algorithm terminates if a predefined condition is met or if a maximum number of epochs is reached. The individual that has yielded the best fitness value throughout all generations gives the optimal solution.

Table 2. The Cyprus issue: Weight matrix

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
0.10	0.29	0.03	0.32	-0.06	0.10	-0.16	0.13	0.21	0.21	-0.23	-0.21
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
0.34	0.29	0.06	0.10	0.13	0.23	0.26	0.34	-0.19	0.26	0.23	0.19
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
0.19	0.06	0.10	0.10	0.16	0.10	0.19	0.13	0.23	0.16	0.16	0.13
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.23	-0.19	0.23	0.26	0.19	0.13	0.13	-0.03	-0.03			

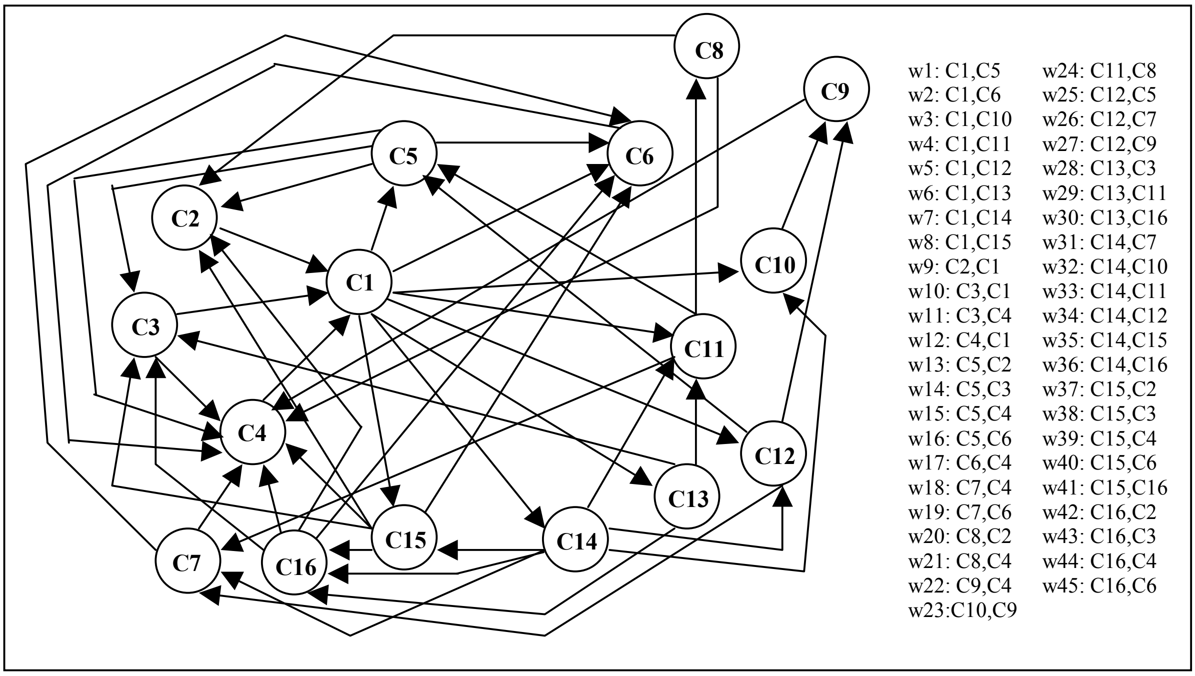

Figure 1. The Cyprus issue CNFCM model

The essence of the Genetically Evolved Certainty Neuron Fuzzy Cognitive Map (GECNFCM) model proposed in this paper lies with tracing the optimal weight matrix corresponding to a desired activation level for a given concept as computed by a simple CNFCM model. More specifically, the GA evolves a population of individuals each of which consists of a weight matrix describing the degree of causal relationships between the concepts of Figure 1. The initial generation contains weights matrices with random values. The evolution of the individuals is performed with the help of the CNFCM model, which computes the final activation levels of the concepts using equations (1) to (4). The activation level of a certain concept in focus denoted by $AL_{d,i}$ is used to calculate the fitness of each individual-weight matrix WM_i according to the following function:

$$\text{fitness}(WM_i)=1/(1-\text{abs}(AL_{d,i} - \text{mean}_{50}(AL_{a,i})) \quad (5)$$

where $AL_{d,i}$ is the target (desired) value of the activation level for the concept in focus C_i and $\text{mean}_{50}(AL_{a,i})$ is the mean value of the last fifty actual activation levels of concept C_i as these are computed by the CNFCM (*t* variable in equation (1)). It is clear from equation (5) that the closer to the target value this mean is, the more appropriate the weight matrix. In fact, the fitness function uses the average of the last fifty activation levels to take into consideration a possible final state of the model which presents limit-cycles, that is, a state in which the $AL_{d,i}$ exhibit periodic fluctuations and do not stabilize at equilibrium values. Thus, if the activation level of the concept in focus reaches equilibrium then the corresponding weight matrix in this case can be considered more appropriate compared to another individual-matrix that has resulted to limit cycle.

All simulations conducted in the next section were based on the following constant values for the variables involved: The population size has been set equal to 100 and the number of generations equal to 400. The weight values were initialized in the range [-1.0,1.0] while the probability of applying the genetic operator of crossover was set to 0.25 and that of mutation to 0.01.

5 Experimental results

Simulations were performed as follows: The first step involved calculating the activation levels by the CNFCM model (Table 3) at equilibrium using the initial weight matrix shown in Table 2. The next step was to simulate different scenarios by asking the model to reach a desirable activation level for a certain concept the policy–maker focuses on. The GECNFCM model calculated the new optimal weight matrix, which was then used by the CNFCM model to recalculate the new activation levels of the 16 concepts. The recalculation of all weights that participate in the simulation process constitutes the most important difference between the GECNFCM and the simple CNFCM models. Its importance to the decision-makers is underlined by the fact that they will not base their decision only on the experts' evaluation, but also on the optimal weights that lead a concept to be activated to a certain predefined degree. Thus, decision-makers are able to introduce hypothetical cases reflected through a target activation level for a certain concept in the model and study the corresponding weights and activation levels for the rest of the concepts compatible with the predetermined target activation level. Based on this information, the policy maker is then able to take decisions leading to the desired simulated solution.

Table 3. Activation levels (A_i) calculated by the CNFCM model

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.69	0.59	0.75	-0.59	0.79	-0.44	-0.74	0.78	-0.65	-0.62	0.60	0.30	0.67	0.56	-0.81	0.54

5.1 Scenario 1: An environment of increased instability

In this scenario the model calculates the new weight matrix provided that instability in Cyprus rises. This possibility is introduced in the model by increasing A_1 from 0.69 to 0.95.

Using the optimal weights calculated by the GECNFCM indicated in Table 4 the final activation levels of Table 5 were obtained. As depicted in Figures 2 and 3, the model has reached equilibrium showing reliable fitness. The cause of the increased instability in Cyprus (A_1=0.88) has been traced to the combined result of an increase in influence terms of concepts C2 and C3, representing the Turkish provocative actions (w9=-0.75; A_2=-0.75) and the Turkish threats (w10=-0.53; A_3 =-0.59) respectively. The unstable environment is further aggravated given the combination of the negative activation levels of C2 and C3 to the weights that link them with C1 which have turned from positive (Table 2), to negative (Table 4). The activation level of 0.76 which concept C4 (solution of the Cyprus problem) has assumed can only contribute to this instability.

Table 4. Increased instability (A_1=0.95): GECNFCM optimal weight matrix

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
0.89	0.90	0.98	-0.03	-0.19	-0.21	0.02	-0.15	-0.75	-0.53	0.18	0.81
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
0.05	-0.33	0.91	0.42	0.89	0.39	0.28	0.73	0.11	-0.59	-0.24	0.88
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
-0.76	-0.68	-0.37	-0.28	-0.40	0.32	-0.78	0.07	-0.84	-0.78	-0.69	0.35
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.52	-0.49	0.71	-0.01	-0.50	-0.02	0.07	0.34	-0.004			

Table 5. Increased instability (A_1=0.95): Activation levels calculated with GECNFCM's optimal weights

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
0.88	-0.75	-0.59	0.76	0.84	0.75	0.69	-0.67	-0.67	0.41	-0.72	-0.79	0.73	0.63	0.81	0.50

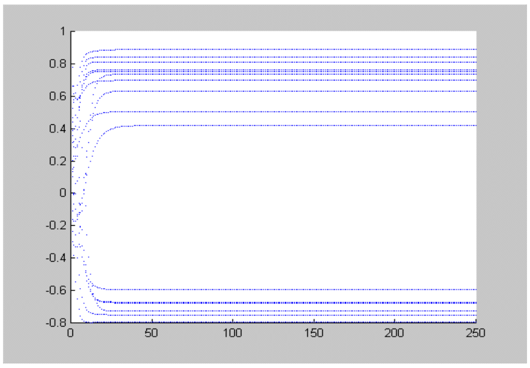

Figure 2. Equilibrium for concept A_1 = 0.95

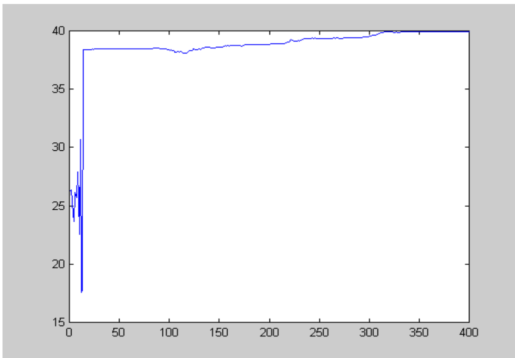

Figure 3. Fitness evolution over generations for A_1=0.95

A further interesting point regards the consequences of a reduction to the support offered to the Turkish forces on the island, a possibility which is introduced by reducing the appropriate activation level down to A_8=-0.67 from A_8=0.78 and results to a reduction of the provocative statements, threats and actions from the part of Turkey. In addition, the effectiveness of reducing the support to the Turkish forces is revealed by the increase of the corresponding weight (w20) to twice its original value due to the reduction of the Turkish forces, as indicated by the relevant weights and activation levels. Concluding the experiments involving an environment of instability we have noticed that the pronounced activation level of the international influence (C15) has turned from negative to positive, while its impact upon solving the Cyprus problem (w39), has risen to three times as much as its baseline value, underlining the importance of the pressure exercised by international organizations or superpowers.

5.2 Scenario 2: How to solve the Cyprus problem

This scenario examines the solution of the Cyprus problem in two ways: The first involves simulating the situation under which the potential of a solution to the problem is decreased, while the second investigates the scenery in case this potential is marginally increased. In the former case the simulations were performed with a targeted activation level A_4=-0.9, while in the latter case this level was A_4=-0.2.

Table 6. Solving the Cyprus problem: GECNFCM optimal weight matrix for targeted A_4=-0.9

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
0.43	-0.85	-0.98	0.98	-0.04	-0.82	0.63	-0.98	-0.81	-0.61	-0.70	-0.93
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
-0.23	-0.94	-0.44	-0.90	0.76	-0.79	-0.73	0.33	0.55	0.30	-0.81	-0.43
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
0.57	-0.41	-0.58	-0.28	0.55	0.90	-0.40	0.39	-0.64	-0.96	-0.20	-0.76
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.09	-0.21	0.81	0.63	0.20	0.99	-0.76	0.01	-0.22			

Table 7. Solving the Cyprus problem: GECNFCM activation levels for targeted A_4=-0.9

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
0.93	-0.84	0.18	-0.86	0.89	-0.83	0.90	-0.84	-0.66	0.79	0.73	0.79	-0.75	-0.77	-0.83	-0.85

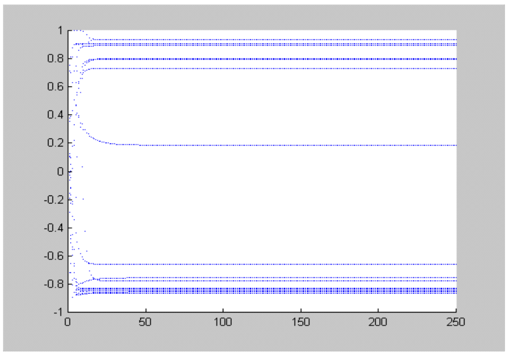

Figure 4. Equilibrium for target A_4=-0.9

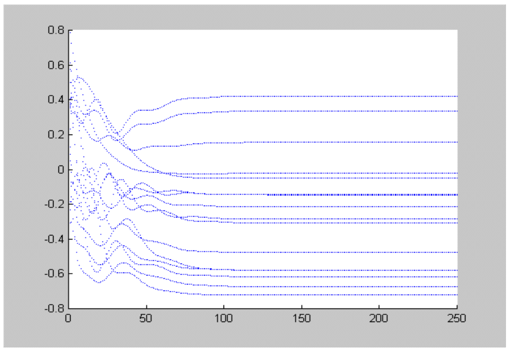

Figure 5. Equilibrium for target A_4=-0.2

Table 8. Solving the Cyprus problem: GECNFCM weight matrix for targeted A_4=-0.2

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
-0.81	0.27	0.76	0.27	-0.86	0.15	-0.09	0.96	0.75	-0.57	0.95	0.52
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
0.58	-0.15	0.41	-0.70	-0.64	-0.60	-0.52	0.33	-0.40	-0.93	-0.89	0.62
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
-0.10	-0.12	-0.79	0.69	0.53	-0.91	0.55	0.57	0.25	0.02	0.65	0.68
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
0.01	0.45	0.57	-0.62	-0.60	-0.12	-0.01	0.52	0.37			

Table 9. Solving the Cyprus problem: GECNFCM final activation levels for targeted A_4=-0.2

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
-0.14	-0.28	-0.30	-0.21	-0.61	0.33	-0.14	-0.02	0.42	-0.57	-0.04	-0.47	-0.58	-0.72	-0.27	0.15

Decreasing the activation level of C4 to –0.9 the GECNFCM yields the optimal weight matrix depicted in Table 6 which activates the concept almost to its equilibrium target value (–0.86; Table 7, Figure 4). The concept interaction in this case is the following: Intensity in Cyprus climbs to A_1=0.93, while the Turkish actions decrease to A_2=-0.84 and the Turkish threats are almost neutralized. This high level of intensity comes as a result of the negative A_2 and the negative w9 linking C2 with C1, the multiplication of which contributes positively to increasing A_1. The same holds for A_4 and w12, linking C4 with C1, while the international influence (C15) is negatively activated (A_{15}=-0.83), thus affecting the solution to the Cyprus problem adversely given its positive link to C4. The Turkish government appears quite unstable (A_{13}=-0.75), while the strengthening of the Turkish army is highly activated (A_{11}=0.73). These are certainly expected to contribute to raising tension in the area, given the tendency of the Turkish authorities to "export" their domestic economic, political and social problems in crises form.

Turning to our second alternative used to attain a solution to the Cyprus problem, setting the target A_4=-0.2 seems to be more fruitful as the equilibrium values of the results indicate (Tables 8 and 9, Figure 5). While A_4 rises to –0.21, intensity appears to be significantly decreased to the value of A_1=-0.14, unlike the previous case, given the drop of both the level of the Turkish forces actions in Cyprus and that of the Turkish threats. A comparison of these results to those calculated by the CNFCM (Table 3) shows that the level of the negotiations for a solution is reactivated while the support to the Turkish forces on the island is neutralized.

5.3 Scenario 3: Rise of the Turkish threats

This scenario is involved with the hypothetical situation in which the Turkish threats are increased (e.g. in quantity and severity) in an attempt to examine the corresponding impact on intensity and on the potential of a solution to the Cyprus problem. Simulations were performed with a targeted activation level A_3=0.9.

Table 10. Rise of Turkish threats: GECNFCM optimal weight matrix for targeted A_3=0.9

w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12
-0.05	0.84	0.75	-0.78	0.31	-0.69	0.86	0.02	0.78	0.39	0.64	0.63
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
-0.23	-0.32	0.26	0.49	0.31	-0.40	0.52	0.45	0.02	-0.22	-0.12	-0.88
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
-0.27	-0.15	0.03	-0.84	-0.85	0.01	-0.74	-0.42	-0.83	0.37	0.40	0.61
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.69	0.52	0.68	0.22	0.35	-0.16	-1.00	-0.54	-0.47			

Table 11. Rise of Turkish threats: GECNFCM activation levels for targeted A_3=0.9

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.86	0.84	0.87	0.81	0.34	0.67	0.13	0.76	-0.59	0.36	-0.84	-0.51	-0.10	-0.71	0.68	–0.85

Increasing the activation level of C3 yields the optimal weight matrix presented in Table 10, which activates the sixteen concepts as shown in Table 11 and Figure 7. Here we can see that the rise of the Turkish threats cause an increase in the intensity in Cyprus and the Turkish forces actions (A_1=0.86, A_2=0.84) as one might have expected. In addition, the potential of a solution to the Cyprus problem is quite high (A_4=0.81) possibly due to the fact that when tension is observed in a certain geographical area then the international community devotes more effort to smooth it out. It is also worth noticing that stability in the three governments is low (A_7=0.13, A_{12}=-0.51, A_{13}=-0.10), something which may actually be the cause of the increase of the Turkish threats (i.e. the Turkish government may be using the Cyprus problem to increase its popularity).

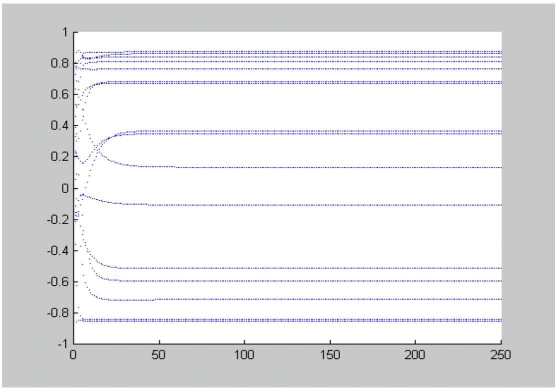

Figure 7. Equilibrium for target A_3=0.9

6 Validation of our hybrid model on a real case: The S-300 crisis

Unlike the hypothetical cases examined thus far, the hybrid model is tested in an environment of an actual incident, the one known as the S–300 crisis that occurred between January 1997 and December 1998, aiming at measuring the ability of this model to face actual crises.

It is briefly reminded that the installation of such an efficient long-range ground to air missile on Cyprus was considered a threat to Turkey, improving the effectiveness of the Greek and Cypriot armed forces in the context of the Integrated Defence Doctrine, while, in parallel, compelling Turkey to resort to purchasing expensive countermeasures to such an alleged threat. The Greek side, in its turn, claimed that the installation of the S-300 would not be enough to shift the balance of power in the area to its favor, given that these missiles would be exposed to a sudden blow from the part of Turkey to which they would be able to respond only if they survived. In such a case, therefore, any form of destabilizing action in the area would only come from the Turkish side, given that the role of the S-300 would have been purely defensive. The strong opposition to this purchase by the USA and Great Britain finally led to the installation of the missiles in the island of Crete and to the purchase of just a short-range ground to air system for Cyprus.

Table 12: S-300 crisis weight values defined by the experts

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
0.0	-0.1	0.0	0.0	0.0	-0.4	0.0	0.0	0.8	0.1	-0.3	-0.4
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
0.0	0.1	0.1	0.1	0.2	0.0	0.1	0.1	-0.8	-0.1	0.2	0.2
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
0.0	0.1	0.0	0.25	-0.3	0.1	0.2	0.0	0.0	0.1	0.1	0.0
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.5	-0.3	0.3	0.9	-0.3	0.3	0.1	0.4	0.1			

Table 13. S-300 crisis: CNFCM calculated activation levels

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
0.79	0.87	0.77	-0.77	-0.41	-0.63	-0.41	0.88	0.70	0.00	0.66	0.60	-0.71	0.58	-0.85	-0.27

In order to analyze the environment described above, we first simulated the S-300 incident using the CNFCM model of Figure 1 and the weight matrix presented in Table 12. The final activation levels of the sixteen concepts involved are given numerically in Table 13 and depicted graphically in Figure 8 reflecting a picture characterized by increased tension (A_1=0.79) and strong reactions and threats from the part of Turkey (A_2=0.87 and A_3=0.77 respectively). It is reminded that these threats included attacking and destroying the system once installed and were accompanied by sending F16 air fighters to the occupied airport of Lefkoniko aiming at reinforcing the Turkish position on the island [11, 12]. In short, the results obtained reproduce the atmosphere prevailing on the island during the actual crisis period, when the FIR violations, the support to the Turkish forces on the island and the intense diplomatic activity from the part of Turkey were culminating. These seem to lead to adverse repercussions as regards possibilities of a solution to the Cyprus problem (A_4=-0.77) and chances for peace talks (A_6=-0.63), while both the Cypriot and the Turkish governments suffer destabilizing effects (A_7=-0.41 and A_{13}=-0.71 respectively), results which are strongly supported by historical evidence referring to the period under study [11, 12]. The incident, however, does not appear to affect the stability of the Greek government (A_{12}=0.60), the support of which to the Greek-Cypriot army appears to be considerable (A_9=0.70), as it has been the case. The support to the Turkish forces on the island is very strong (A_8=0.88), a development sustained by the strength of the Turkish forces (A_{11}=0.66). Finally, the international influence has contributed negatively to the crisis (A_{15}=-0.85) given that, at least indirectly, it encouraged Turkish aggressiveness by opposing the purchase of the S-300 system.

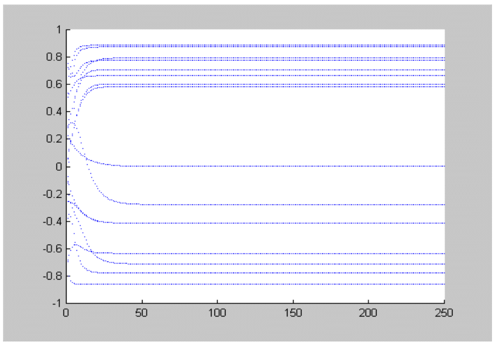

Figure 8. S-300 crisis: CNFCM equilibrium

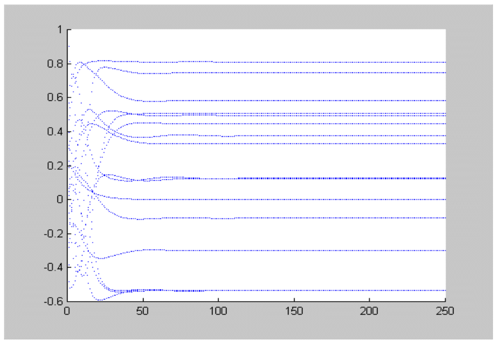

Figure 9. S-300 crisis: GECNFCM equilibrium

6.2 Coping with the S–300 crisis: Tension reduction

At this stage we requested the model to consider a 50% reduction of the intensity on the island, aiming at evaluating the extent to which it can reflect the climate prevailing on the island with the tension cooling down after December 1998. The model has indeed reached the intensity-reduction target by attaining equilibrium at A_1=0.37 (Table 15 and Figure 9). The role of the international influence, once it took initiatives, climbed from A_{15}=-0.85 to A_{15}=0.74 indicating reluctance to approve the Turkish threats and actions in Cyprus that used to support a climate of tension, while its pressure upon the Cypriot side has also considerably contributed to the same direction. The latter is introduced in the model through the weight w40=0.27 (Table 14) which links the international influence C15 to the peace talks C6. The negative weight w39=-0.50 that links C15 with C4 (solution to the Cyprus issue) implies a decrease of the international support to the solution of the problem, something which reflects the shift of emphasis placed during the crisis period from solving the Cyprus problem to resolving the S-300 crisis.

The reluctance of the Greek side to provide active military support to the installation of the S-300 on the island is reflected in the relevant zero activation level (A_{10}=0.0), unlike that of the Cypriot National Guard, the support to which had reached A_9=0.8 revealing its adherence to the S-300 project. The Cypriot government itself does not seem to be confident enough about the decision to install the missiles, since its activation level drops to A_7=-0.53, given the disagreement which took place between the military and the politicians over the issue. Finally, special attention should be drawn to w25 that links the stability of the Greek government (C12) to the Greek support to the Cyprus issue (C5), the weight linking the two assuming the impressive value of 0.99. This underlines the unanimity and confidence of the Greek side concerning the influence exercised upon Cyprus.

Table 14: Settling the S-300 crisis: GECNFCM optimal weight matrix for targeted A_l=0.4

w1	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**	**w9**	**w10**	**w11**	**w12**
0.10	0.60	-0.65	0.13	0.25	-0.24	-0.21	0.48	0.59	-0.70	-0.49	0.81
w13	**w14**	**w15**	**w16**	**w17**	**w18**	**w19**	**w20**	**w21**	**w22**	**w23**	**w24**
-0.63	-0.67	0.88	-0.41	-0.77	0.79	0.89	0.38	-0.53	-0.04	0.22	-0.32
w25	**w26**	**w27**	**w28**	**w29**	**w30**	**w31**	**w32**	**w33**	**w34**	**w35**	**w36**
0.99	-0.20	0.80	0.88	-0.52	0.01	0.05	-0.47	-0.62	-0.67	0.88	0.55
w37	**w38**	**w39**	**w40**	**w41**	**w42**	**w43**	**w44**	**w45**			
-0.73	-0.14	-0.50	0.27	-0.41	-0.13	-0.09	-0.41	-0.37			

Table 15. Settling the S-300 crisis: Final activation levels for targeted A_l=0.4

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
0.37	-0.53	-0.10	-0.29	0.44	0.49	-0.53	-0.53	0.80	0.00	0.50	0.58	0.12	0.32	0.74	0.12

7 Conclusions

Following the presentation and construction of a FCM and a CNFCM model describing the Cyprus political issue, we have introduced a hybrid model based on Genetically Evolved Certainty Neuron Fuzzy Cognitive Maps (GECNFCMs) designed to facilitate political decision-making in face of crises. The Genetic Algorithm of this model was used to find the optimal weight matrix that satisfies a predefined activation level for a certain concept. The decision-maker is thus able to introduce hypothetical scenaria through defining the target activation level of a concept in focus and study the results in weight-values terms, as well as the activation levels once the model has reached equilibrium and the target has been met. The three scenarios simulated in this context were as follows: The first involved an environment of escalating intensity on the island (C1), the second simulated the consequences in cases of decreased and increased solution possibilities (C4) respectively, and the third investigated the case of increased Turkish threats (C3). The results of these three scenaria were quite encouraging: The GECNFCM reached the targetted activation level in equilibrium state allowing the decision-maker to forecast the dynamics of a given situation and measure the variables determining the final state.

The hybrid system was then tested to face an actual crisis, namely that involving the installation of the S-300 missiles on the island. The hybrid system simulated this political situation successfully and produced results very descriptive of the actual events that lead to the defusion of the crisis. Thus, the validation process proved that the hybrid system proposed can be a reliable tool in the hands of political analysts and decision-makers aiming at managing a crisis or solving intricate politics problems.

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