Scenario Planning Using Fuzzy Cognitive Maps

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Abstract

A fuzzy cognitive map (FCM) is a directed graph representing concepts and their causal relationships in a given scenario. Application of FCMs as a simulation tool in scenario planning can aid in the visualisation and evaluation of possible scenarios in a problem domain.

Evaluation of a scenario is facilitated through the analysis of state changes that the factors undergo in the corresponding FCM at each time step. Its ability to learn from past experience enables an FCM to discover any missing causal links between factors in the scenario.

Keywords

Fuzzy cognitive map, scenario planning, strategic planning, scenario building system.

I. Introduction

The fuzzy cognitive map (FCM) was introduced by Kosko for modelling the causal relationship between concepts and analysing inference patterns [1]. An FCM is a directed graph representing concepts and their causal relationships in a given scenario. It has been used for decision-support and causal discovery in an environment of uncertainty and incomplete information, and for making predictions in different spheres of human life such as economy, politics sociology, and virtual reality simulation [2-4]. It has been also proposed as an alternative to knowledge-based expert systems for representing and analysing complex systems [5-7]. The attractiveness of the FCM lies in its relatively simple structure and operations, ease of implementation, and its adaptability in incorporating additional knowledge through Hebbian learning or merging with other FCMs. With the recent increase in global uncertainty, and turbulence in the business world, scenario simulations have become an important tool for identifying goals as well as threats, and for formulating counter measures. .

This paper proposes a methodology for effective scenario planning incorporating the use of FCMs for simulating and evaluating alternative scenarios. We explore how the likelihood of certain events as perceived by individual strategists (scenario planners) can be adopted for the whole organisation by augmenting and combining these individual strategies.

2. Scenario planning

Scenario planning has a proven track record in tapping the knowledge of a group of people with diverse perspectives to provide breakthrough insights and innovations. As a methodology, it has long been used by the military. Many people have ideas about where the future may be heading, but there is generally no established process for gathering such knowledge and putting it to good use. Scenario planning provides a concrete framework for sharing the insights of a broad cross-section of people in a way that often leads to fresh, new insights. The concrete outcome from scenario planning is a set of plausible future scenarios that can be used to evaluate opportunities and directions. With the identification of key external metrics, monitoring for early warning signs of changes is possible.

In a volatile situation, the future is often highly unpredictable and we are working from a limited range of expectations, our expectations will frequently be proved wrong. Scenario planning offers a framework for developing more resilient ecological policies to counter such situations where there is uncontrollable, irreducible uncertainty.

Scenario planning is especially useful in situations where, a high level of participation is required to create a common goal, such as in highly modernised military command and control structure where a large number of personnel are required to make collective strategic decisions, and in the competitive commercial world. It provides a useful process for pulling together all the major stakeholders in a strategic conversation that ultimately leads to shared vision and action. It is also extensively used in business organisations.

Herman Kahn [8] was an early founder of scenario-based planning in his work related to the possible scenarios associated with thermonuclear war. Interested readers are referred to books such as [9, 10] for further information on scenario planning.

2.1. Drawbacks of conventional scenario planning

Despite its merits and significance, little advance has been made in scenario planning. The following three significant facts may be observed:

- Most scenario planning practices lack time variant component, which is essential for yielding a more realistic scenario.
- Scenario planning is a time-consuming process. With world events spinning faster than ever before [11], the conventional scenario planning practice is lagging behind.
- Strategists rely heavily on the skills of the individuals to visualise how the different and often complex scenarios unfold. It is hard to imagine the inter-plays of the different factors at different time periods in the scenario.

The conventional scenario planning process relies very much on 'paper and pencil' to draft out the various scenarios. It is therefore very hard to visualise multiple time scales in the scenario models. However, such a time-variant capability is essential in decision-making because of fast changing, turbulent environments in recent times. Within the short time frames, the competitor's strategic activity may have changed.

Fuzzy cognitive map (FCM) simulation can intrinsically accommodate the time constraint. Instead of a static snap-shot of a time step, we are able to view the scenario over the entire time span as well as at any particular time step.

FCM aids the individual strategists in visualisation as the scenario unfolds and the states at each time step can be assessed and evaluated.

2.2. Scenario building procedure

We propose the following procedures for developing the scenario planning strategy:

1. Determine the time frame for the scenarios. This largely depends on the rate of change of all factors, past volatility, and uncertainty the organization faces, and the time required to develop new technology etc to counter the influences. Define the missions and purposes of the scenario plan.
2. Each scenario planner or group of planners, uncover the decisions to be made in the future that will affect the entity (the nation or organisation), using the missions and purposes of the scenario planning as a guide. That is, set the boundaries within which the organisation must act.
3. Identify the uncontrollable environmental variables and the unpredictable external forces that will influence the decision-making processes. The uncontrollable variables are the important trends and events that are certain to happen in the future. In other words, what one already knows – e.g. increase in insurance premium, faster computers, union strikes, etc. The external forces are those that are very unpredictable or uncertain. In other words, the unknown – e.g. how will global economy change in the next 10 years, the uncertainty of organic verses GM produce, etc.
4. Select two most important driving forces that are either uncontrollable or uncertain. Formulate three or four best plausible scenarios. Given that the impossibility of knowing precisely how the future will play out, a good decision or strategy to adopt is one such that each of these scenarios diverges markedly from one another. A scenario matrix similar to Table 1 may be used. For example, we may have outcomes A1 and B1 to be of more expected (normal) types whereas outcomes A2 and B2 are of the extreme types. Scenario 1 then is one with the presence of possible future outcomes A1 and B1; Scenario 2 is the presence of A2 and B1; and so on. The scenario or scenarios that are not plausible are dropped. If necessary, the selection process may have to be revised.

Table 1: Scenario matrix

				Uncontrollability / Uncertainty	
				Low	High
				Variable A	
				Outcome A1	Outcome A2
Uncontrollability / Uncertainty	Low	Variable B	Outcome B1	Scenario 1	Scenario 2
	High		Outcome B2	Scenario 3	Scenario 4

5. Express each scenario as an FCM, where each driving force or factor is represented by a node, and each relationship between a pair of nodes is represented by an edge. This is further described in the next section.

6. Evaluate and review each scenario, using FCM simulation. Observe how the driving forces unfold over time. Identify the critical points along the path to determine under what conditions and how it unfolds. These critical points form the foundation for monitoring purposes.
7. Assess internal consistency and plausibility of each scenario.
8. Repeat steps 4 to 7 with other uncertainties and variables until all possible scenarios have been assessed.
9. Where scenarios are similar or that may be considered together, merge the FCMs.
10. Formulate strategies to counter the adversities in each scenario and encourage favourable conditions.
11. Monitor the real situation unfolding, recognise the scenario, and take necessary actions. If necessary, go back to beginning to restart the scenario planning process.

Steps 5, 6, and 9 are further described in Section 3.

Fig. 1 shows a schematic diagram of the proposed system.

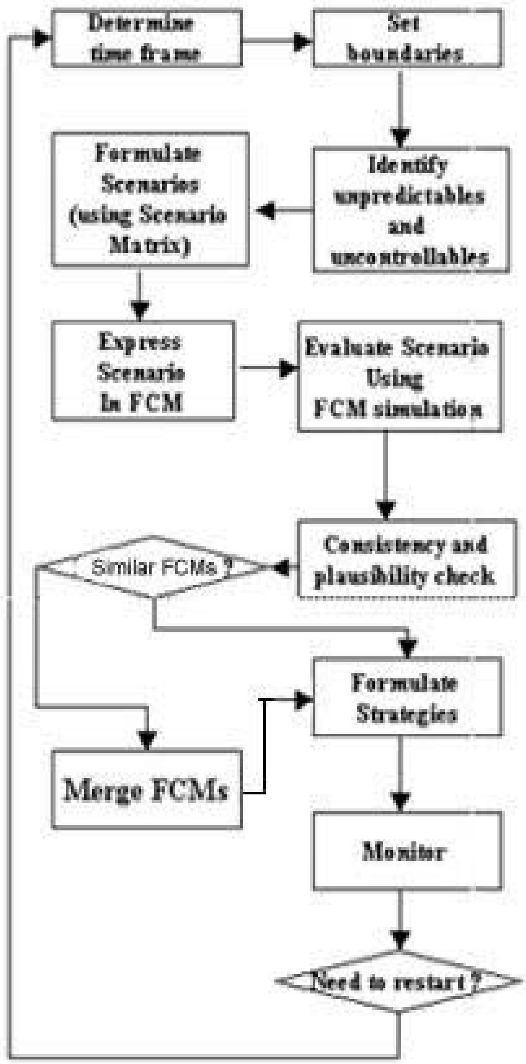

Figure 1: Proposed scenario planning system

3. Fuzzy Cognitive Map

In the scenario planning steps, there are a lot of "what if" questions being asked. A Fuzzy cognitive map (FCM) can play an important role in this respect. FCM can cope with uncertainties. Each factor in a scenario can be viewed as a concept and its effects on other concepts are the edges. Concepts can be abstract or real objects. Merging of similar scenarios can be accomplished by merging of the FCMs. These are explained in sub-sections 3.2 and 3.3 below.

A cognitive map [12] (CM) was originally used to represent knowledge in political and social sciences. It is well known for its simplicity in representing cause-effect relationships among elements in an interactive environment. It is a directed digraph with nodes representing the concepts or perceptions of the given environment and directed links or edges representing the causal relations between these nodes. FCMs were introduced to overcome the shortcomings of CMs which only allow basic symmetric and monotonic causal relations [13]. An FCM allows both the system concepts and relationships to be fuzzy. It is capable of dynamically modelling the world as a collection of concepts and causal relations between these concepts. Consider the case in Figure 2.

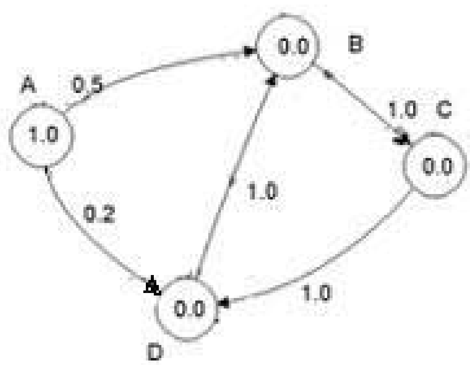

Figure 2: A simple FCM

Each node represents a concept and is linked to one or more other nodes via directed edges. As shown in Figure 2, node A has a positive causal link of strength of 0.5 leading into node B, and another positive causal link of strength of 0.2 to node D. The causal effect on a node (e.g. node D) or its output, is determined by computing the activation of the node due to other nodes influencing it, and then applying a transformation function to this activation. The output of a node C_i is given by the simple neuronal model: -

$$c_i(t+1) = S(\sum_{j=0}^{n-1} c_j(t) \bullet w_{ij}) \qquad (1$$

where *S( )* is the transformation function,
w_{ij} is the weight of the edge from node j to node i.
t is a time step in a simulation model.

Several transformation functions exist and the commonly used ones are the step and the sigmoid functions, as shown in equations 2 and 3 respectively.

$$S(x) = \begin{cases} 0 & if \quad x \leq 0 \\ 1 & if \quad x > 0 \end{cases} \qquad (2$$

where *x* is the activation of a node.

$$S(x) = \frac{1}{1+e^{-cx}} \qquad (3$$

where x is the activation of a node, and *c* is a constant which decides the slop of the function.

3.1. FCM simulation

As can be seen in Fig. 2, Node A has a state value of 1, indicating that the node is 'on'. When this happens at the start of a simulation session, the effect is similar to asking the question: *What if concept (or variable) A happens?* Observing a simulation run gives the scenario planner insights into the interactions between the various nodes. The planner may also try out with other nodes or combination of nodes turned 'on'. The results of simulation of the FCM in Fig. 2 after time step 7 are as shown in Table 2. As can be seen, the states of the nodes form a fixed pattern of cyclically turning on the three nodes B, C, and D. With hard-limiting transformation function, different scenarios may have different limit cycles, or a fixed-point attractor [14] (a limit cycle of one). Using continuous transformation function such as the sigmoid function may also give rise to a situation known as chaotic attractor [5]. After reviewing and evaluating the different scenarios, the planners will be in a better position to decide which are the best scenarios for further evaluation.

Table 2: Results after 7 iterations

Time	A	B	C	D
0	1	0	0	0
1	0	1	0	1
2	0	1	1	0
3	0	0	1	1
4	0	1	0	1
5	0	1	1	0
6	0	0	1	1
7	0	1	0	1

3.2. Differential Hebbian Learning

Sometimes the planners may not be able to decide on the degrees of the causal effects of one node on another. In such cases, it is possible to let the FCM learn the causal weights by applying Differential Hebbian Learning (or DHL) [15] using a set of training data, which represents a record of the states of the nodes at a sequence of time steps. At each time step t, the weight value w_{ij} of an edge connecting concept nodes i to j, is given by the discrete version of the HDL:

$$w_{ij}(t+1) = \begin{cases} w_{ij}(t) + \mu_t[\Delta C_i(t) \bullet \Delta C_j(t) - w_{ij}(t)] & if \quad \Delta C_i(t) \neq 0 \\ w_{ij}(t) & if \quad \Delta C_i(t) = 0 \end{cases} \qquad (4$$

where ΔC_i is the change in concept node i, $\Delta C = C_i(t) - C_i(t-1)$.

μ_t is the learning coefficient, which decreases over time, and is given by:

μ_i= 0.1(1-t(1.1N)), where t is the number of time steps, and N is a constant.

DHL thus provides a means of aiding the planner in determining the relationships between the nodes, provided the planner can provide the perceived sequence of events. However, DHL is not without problems. One major setback is that it's learning is a linear one, rather than a (biologically realistic) sigmoid learning curve. We are investigating the possibility to improve on this.

3.3. Merging of FCMs

Different scenario planners will come up with different scenarios and strategies. Merging of FCMs provides a simple yet effective means of combining the set of scenarios to give an overall picture of the possible scenario. By combining the FCMs to form a new FCM, which represents the collective experts' opinion on the particular scenario, the new FCM may be considered to have learnt from all the experts.

The FCMs are combined by summing the matrices of the edges of the FCMs [16, 17]. As not all the FCMs are having the same number of concept nodes, the missing concept nodes with default edge weight values of 0s are first appended to the respective FCMs. This is said to have the FCMs augmented to ensure conformity in the subsequent computation process. For example, we have two FCMs to be merged as depicted in Figures 3 and 4.

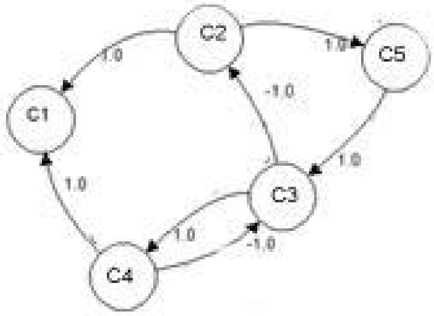

Figure 3: FCM# 1

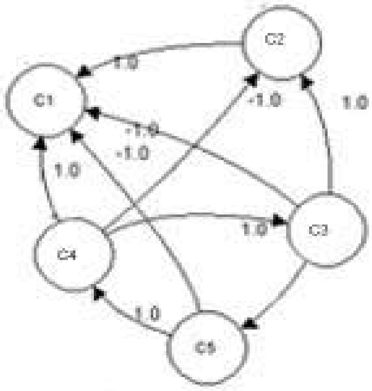

Figure 4: FCM# 2

The new FCM is given by:

$$E = \sum_{0}^{N-1} W_k E_k \qquad (5$$

where E is the newly formed FCM,
E_k is the k^{th} FCM,
W_k is the credibility weighting, assigned to FCM E_k
N is the number of FCMs to be merged.

The weights of the edges of the new FCM is then normalised by dividing the weights by W, where W is the sum of the credibility weightings, i.e. $W = W_1 + W_2 \ldots + W_k$. It is possible that different planners may be given different credibility weighting to their FCMs [18]. That is, some planners' views are more credible than others.

The new augmented FCM is shown in Fig. 5.

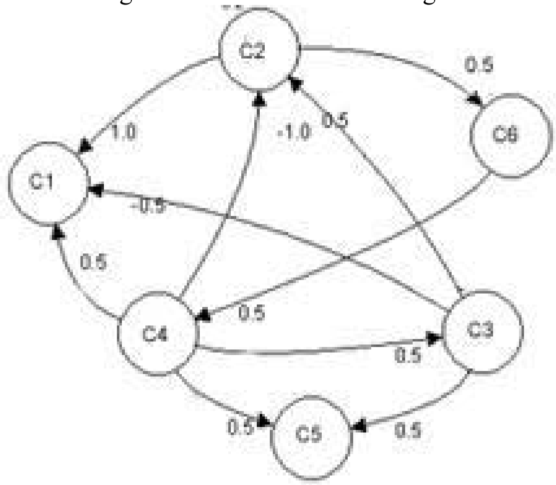

Figure 5: New augmented FCM

4. Conclusion

The Fuzzy Cognitive Map (FCM) has emerged as a powerful tool for modelling and simulation of events that are uncertain or uncontrollable. We have explored and shown how it is possible to use FCM to aid in the scenario planning process.

A system for scenario planning has been presented, with a demonstration of how FCMs can provide the essential visual aids often neglected in the past. By observing the states of each factor in an FCM at each time step, we have shown that it is possible to detect those factors that play an important role in the scenario. It is therefore possible to monitor these factors closely as the actual event unfolds.

FCMs can also be used to aid the scenario planners to discover missing causal links. However, Differential Hebbian Learning algorithm used in the FCM only provides an approximation of the causal links. We are currently investigating means of improving the algorithm.

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