Adaptive Fuzzy Cognitive Maps for Hyperknowledge Representation in Strategy Formation Process *

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Abstract

In [6] Carlsson demonstrated that all the pertinent conceptual constructs of strategic management theory can be represented with a knowledge based support (KBS)-system with hyperknowledge properties. Furthermore, he shows that cognitive maps can be used to trace the impact of the support and to generalize the experiences of the users. In this paper we will show that the effectiveness and usefulness of this hyperknowledge support system can be further advanced using adaptive fuzzy cognitive maps.

Keywords: hyperknowledge support system, approximate reasoning, cognitive map, error correction learning, strategic management.

1 Woodstrat project

Strategic Management is defined as a system of action programs which form sustainable competitive advantages for a corporation, its divisions and its business units in a strategic planning period. A research team of the IAMSR institute has developed a support system for strategic management, called the *Woodstrat*, in two major Finnish forest industry corporations in 1992-96. The system is modular and is built

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around the actual business logic of strategic management in the two corporations, i.e. the main modules cover the *market position* (MP), the *competitive position* (CP), the *productivity position* (PROD), the *profitability* (PROF) , the investments (INV) and the *financing of investments* (FIN). The innovation in *Woodstrat* is that these modules are linked together in a hyperknowledge fashion, i.e. when a strong market position is built in some market segment it will have an immediate impact on profitability through links running from key assumptions on expected developments to the projected income statement. There are similar links making the competitive position interact with the market position, and the productivity position interact with both the market and the competitive positions, and with the profitability and financing positions.

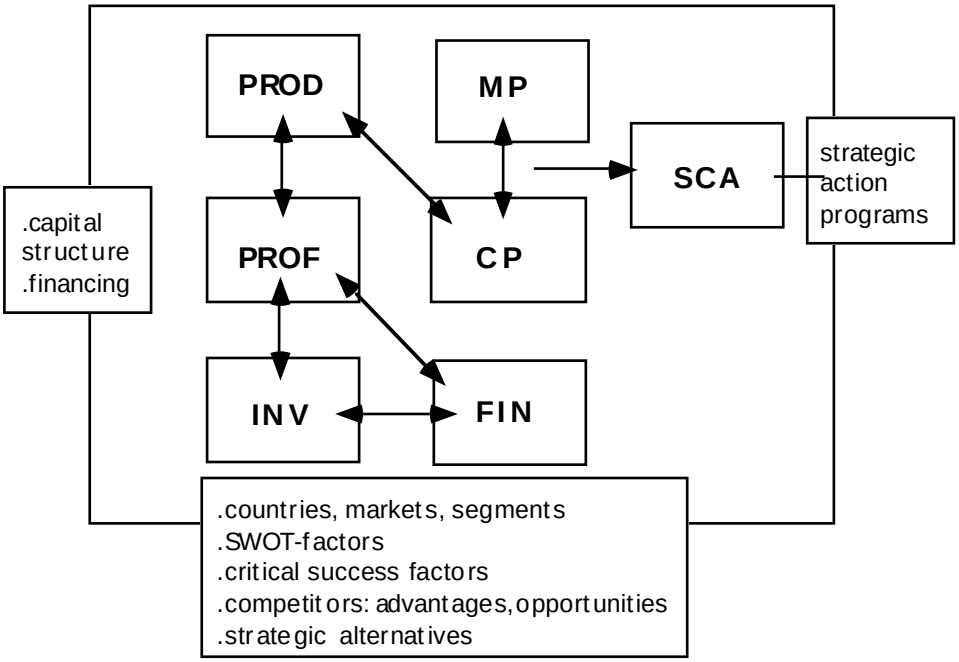

Figure 1 The framework of Woodstrat.

The *Woodstrat* offers an intuitive and effective strategic planning support with object-oriented expert systems elements and a hyperknowledge user interface. In this paper we will show that the effectiveness and usefulness of a hyperknowledge support system can be further advanced using adaptive fuzzy cognitive maps.

2 Hyperknowledge and Cognitive Maps

Hyperknowledge is formed as a system of sets of interlinked concepts [9], much in the same way as hypertext is built with interlinked text strings [16]; then hyperknowledge-functions would be constructs which link concepts/systems of concepts in some pre-determined or wanted way.

There are some useful characteristics of a hyperknowledge environment [9]: (i) the user can navigate through and work with diverse concepts; (ii) concepts can be different epistemologically, (iii) concepts can be organized in cognitive maps, (iv)

the concepts can be made interrelated and interdependent, (v) relations can be structured or dynamic, and (vi) relations can change with or adapt to the context.

Cognitive maps were introduced by Axelrod [1] to represent crisp cause-effect relationships which are perceived to exist among the elements of a given environment. *Fuzzy cognitive maps* (FCM) are fuzzy signed directed graphs with feedbacks, and they model the world as a collection of concepts and causal relations between concepts [12].

When addressing strategic issues cognitive maps are used as action-oriented representations of the context the managers are discussing. They are built to show and simulate the interaction and interdependences of multiple belief systems as these are described by the participants - by necessity, these belief systems are qualitative and will change with the context and the organizations in which they are developed. They represent a way to make sure, that the intuitive belief that strategic issues should have consequences and implications, that every strategy is either constrained or enhanced by a network of other strategies, can be adequately described and supported. For simplicity, in this paper we illustrate the strategy building process by the following fuzzy cognitive map with six states

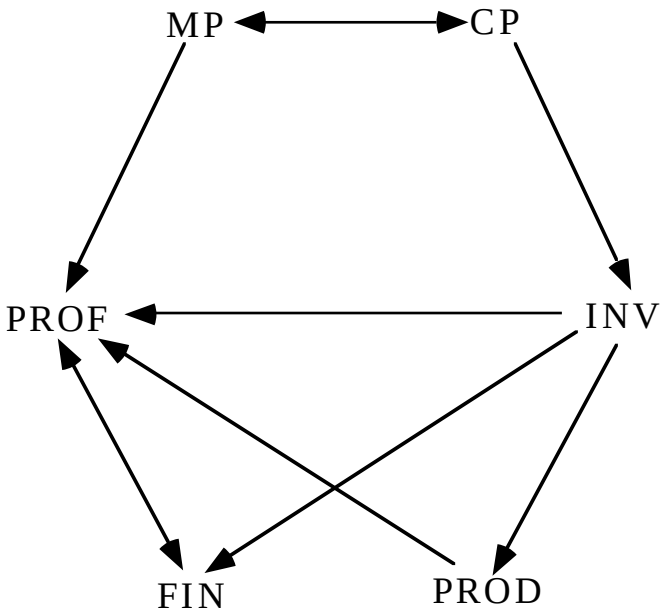

Fig. 2 Essential elements of the strategy building process.

The causal connections between the states MP (Market position), CP (Competitive position), PROF (Profitability), FIN (Financing position), PROD (Productivity position) and INV (Investments) are derived from the opinions of managers' of different Strategic Business Units.

It should be noted that the cause-effect relationships among the elements of the strategy building process may be defined otherwise (you may want to add other elements or delete some of these, or you may draw other arrows or rules or swap their signs or weight them in some new way).

3 Adaptive FCM for strategy formation

It is relatively easy to create cause-effect relationships among the elements of the strategy building process, however it is time-consuming and difficult to fine-tune them. Neural nets give a shortcut to tuning fuzzy cognitive maps. The trick is to let the fuzzy causal edges change as if they were synapses (weights) in a neural net.

Each arrow in Fig. 2 defines a fuzzy rule. We weight these rules or arrows with a number from the interval $[-1, 1]$, or alternatively we could use *word weights* like *little*, or *somewhat*, or *more or less*. The states or nodes are fuzzy too. Each state can fire to some degree from 0% to 100%. In the crisp case the nodes of the network are *on* or *off*. In a real FCM the nodes are fuzzy and fire more as more causal juice flows into them.

Adaptive fuzzy cognitive maps can learn the weights from historical data. Once the FCM is trained it lets us play what-if games (e.g. *What if demand goes up and prices remain stable? - i.e. we improve our MP*) and can predict the future.

In the following we describe a learning mechanism for the FCM of the strategy building process, and illustrate the effectiveness of the map by a simple training set.

Fig. 3 shows the structure of the FCM of the strategy building process.

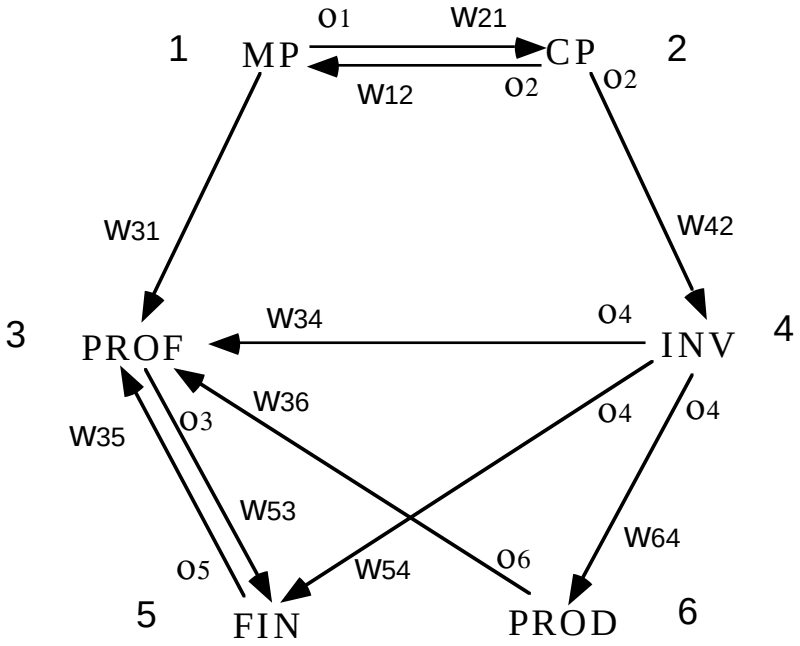

Fig. 3 Adaptive fuzzy cognitive map for the strategy formation process.

Inputs of states are computed as the weighted sum of the outputs of its causing states

$$net = Wo$$

where W denotes the matrix of weights, o is the vector of computed outputs, and

net is the vector of inputs to the states. In our case the weight matrix is given by

$$W = \begin{pmatrix} 0 & w_{12} & 0 & 0 & 0 & 0 \\ w_{21} & 0 & 0 & 0 & 0 & 0 \\ w_{31} & 0 & 0 & w_{34} & w_{35} & w_{36} \\ 0 & w_{42} & 0 & 0 & 0 & 0 \\ 0 & 0 & w_{53} & w_{54} & 0 & 0 \\ 0 & 0 & 0 & w_{64} & 0 & 0 \end{pmatrix}$$

where the zero elements denote no causal link between the states, and

$$net = \begin{bmatrix} net_1 \\ net_2 \\ net_3 \\ net_4 \\ net_5 \\ net_6 \end{bmatrix} = \begin{bmatrix} net(MP) \\ net(CP) \\ net(PROF) \\ net(INV) \\ net(FIN) \\ net(PROD) \end{bmatrix} \qquad o = \begin{bmatrix} o_1 \\ o_2 \\ o_3 \\ o_4 \\ o_5 \\ o_6 \end{bmatrix} = \begin{bmatrix} o(MP) \\ o(CP) \\ o(PROF) \\ o(INV) \\ o(FIN) \\ o(PROD) \end{bmatrix}$$

That is,

$$net_1 = net(MP) = w_{12}o_2,\ net_2 = net(CP) = w_{21}o_1,$$
$$net_3 = net(PROF) = w_{31}o_1 + w_{34}o_4 + w_{35}o_5 + w_{36}o_6,\ net_4 = net(INV) = w_{42}o_2,$$
$$net_5 = net(FIN) = w_{54}o_4 + w_{53}o_3,\ net_6 = net(PROD) = w_{64}o_4$$

The output of state i is is computed by a squashing function

$$o_i = \frac{1}{1 + \exp(-net_i)}$$

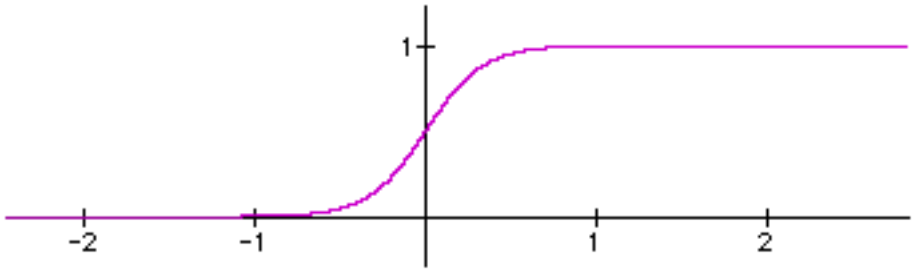

Fig. 4 Unipolar transfer function.

Suppose we are given a set of historical training data

$$(MP(t), CP(t), PROF(t), INV(t), FIN(t), PROD(t))$$

where $t = 1, \ldots, K$. Here $MP(t)$ is the observed value of the market position, $CP(t)$ is the value of the competitive position at time t, and so on.

Using an error correction learning procedure we find the weights by minimizing the overall error

$$E(W) = \frac{1}{2}\sum_{t=1}^{K} \{\ (MP(t) - o_1(t))^2 + (CP(t) - o_2(t))^2 +$$

$(PROF(t) - o_3(t))^2 + (INV(t) - o_4(t))^2 + (FIN(t) - o_5(t))^2 + (PROD(t) - o_6(t))^2\}$

where $o_i(t)$, the computed value of the i-th state at time t, is determined as

$$o_i(t) = \frac{1}{1 + \exp\left[-net_i(t-1)\right]} = \frac{1}{1 + \exp\left[-\sum_j w_{ij} o_j(t-1)\right]}$$

where j is a causing state for state i. The weights are initialized at small random values. The rule for changing the weights of the states is derived from gradient descent method.

Example 1 *Consider a simple training set of historical data shown in Table 1.*

	MP	*CP*	*PROF*	*INV*	*FIN*	*PROD*
1.	*3*	*3*	*3*	*3*	*3*	*3*
2.	*4*	*3.5*	*3.5*	*3*	*4*	*3*
3.	*4*	*4*	*3.5*	*4*	*5*	*3.5*
4.	*3*	*4*	*3.5*	*4*	*4*	*3.5*
5.	*3*	*3.5*	*4*	*4*	*3*	*4*
6.	*2*	*3*	*4*	*4*	*2*	*4*
7.	*3*	*2.5*	*4*	*5*	*1*	*4*
8.	*3*	*3*	*4*	*5*	*2*	*3.5*
9.	*4*	*3*	*4*	*5*	*3*	*3.5*
10.	*3*	*3.5*	*4*	*5*	*4*	*3*

Table 1 *A training set.*

The observed values of the states are measured from the interval $[1, 5]$*, where 1 stands for* weak*, 2 stands for* rather weak*, 3 stands for* medium*, 4 stands for* rather strong *and 5 stands for* strong*, intermediate values are denoted by* $\{1.5, 2.5, 3.5, 4.5\}$*.*

For example, at reference time 7 we have a medium market position, weak-rather weak competitive position, rather strong profitability, strong investments, weak financing and rather strong productivity position. After the training we get the following weight matrix

$$W = \begin{pmatrix} 0 & 0.65 & 0 & 0 & 0 & 0 \\ 0.46 & 0 & 0 & 0 & 0 & 0 \\ 0.54 & 0 & 0 & 0.33 & 0.14 & -0.05 \\ 0 & 0.23 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.18 & 0.31 & 0 & 0 \\ 0 & 0 & 0 & 0.27 & 0 & 0 \end{pmatrix}$$

Our findings can be interpreted as the market and competitive positions are the driving forces for the overall profitability position.

Summary 3.1 *The extensions of* Woodstrat *to a fuzzy hyperknowledge support system shown here will have the effect to*

- *support approximate reasoning schemes in linking the MP, CP, PROD, PROF, INV and FIN elements of strategic management;*
- *approximate reasoning gives us conclusions from imprecise premises;*
- *fuzzy sets and fuzzy logic support a synthesis of quantitative and qualitative concepts, which develops strategic planning to a strategy formation process.*

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