Modeling of multi-agent virtual expert competition for the use of expert virtual resource

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Abstract:

One of the current areas of research in the field of corporate systems management is the use of expert and virtual resource (EVR), intended for intellectualization of decision-making support in cases where knowledge corporate environment is poorly structured and it has obscure connections and a multi-level subordination hierarchy. The main components of EVR are real and virtual experts, one of the variations of which is the multi-agent virtual expert (MAVE). In this case, interaction of agents with expert and virtual resource is carried out in a challenge-response mode, and on a certain number of requests, the competition for the use of expert and virtual resource arises. To simulate the competition for resources, an approach based on the use of standard integration logistic mapping, generalized in case of the two interacting MAVE competing for the use of expert and virtual resource, is introduced. The results of numerical calculations confirmed the proposed model effectiveness. It is proved that the cases of stable, non-zero system solutions, i.e. Quantity stabilization of both MAVES, have practical importance.

Key words:

Modeling, numerical methods, expert and virtual resource, multi-agent virtual expert, corporate information system.

ACM Computing Classification System:

User models, User studies, Usability testing, Heuristic evaluations, Walkthrough evaluations, Laboratory experiments, Field studies.

Introduction

When making rational managerial decisions in modern corporate structure, the accumulated intellectual resource and the corporate intellectual capital play an important role. Developing the intellectual resource in modern corporate structures occurs in a common information environment formed by networks of information users within the scope of corporate information systems (CIS) [1]. When considering the intellectual resource from the standpoint of its development in the corporate information environment one needs to treat separately expert and virtual components in the structure of intellectual capital and multi-alternative presentation of its elements in the course of managerial decision making [2].

1. The concept of expert and virtual resource

By ‘decision making’ we mean a three-stage procedure that includes analyzing the initial information, preparing to make decision and selecting a decision generated in the course of interaction between the expert (experts) and a computer system. At that we shall call the combination of expert and computer resources ‘the virtual expert resource for decision making’ and treat it as a component optimizing the management of corporate social (economic) system [3-6].

Provision of expert and virtual resource of knowledge and procedure type, is proposed. Knowledge expert and virtual resource provides intelligent decision making support.

Virtual expert resource of procedural type is meant to intellectualize support for managerial decision making in cases when the corporate knowledge environment is weakly structured, features fuzzy links and a multi-level subordination hierarchy.

The basic components of virtual expert resource are real and virtual experts, the basic principles of their interaction proposed in studies [7].

In their turn, virtual experts may be divided into the following types according to the functions they execute during decision making: imitational prognostic virtual expert (IPVE); multi-alternative virtual expert (MVE); multi-agent virtual expert (MAVE).

2. Characteristics of the multi-agent expert and virtual resource

Let us expand on the description of multi-agent virtual resource (MAVR) as the issues related to IPVE and MVE were covered in sufficient detail in a number of published works [3-6].

The classical techniques for studying competition are the theory of utility and the game theory. In particular, they yield the well-known models and conditions of optimality, expressed as the equilibrium principle. Managing hierarchic structures in organizational economic systems is modeled in the theory of active systems [8, 9].

The basic weakness of the standard model in the theory of active systems is its static character. In contrast to theoretical game models, decisions in multi-agent systems are taken sequentially, which helps the agents to obtain missing information needed to take decisions. Agents interact with virtual expert resource in the question-answer mode as shown (fig. 1).

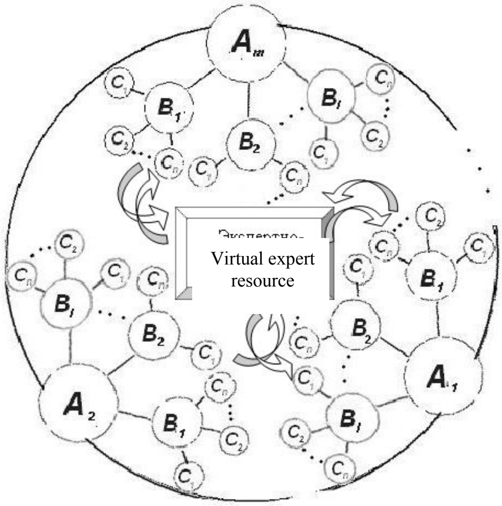

Figure 1. Interaction of multi-agent CIS with virtual expert resource

Let W be the current problem that one of MAVE agents is working on. The agent breaks the problem into a sequence of atomic works $w_1, w_2, \ldots w_n$ and starts executing them. At each step $i = \overline{1,n}$ the possibility is checked to do the work independently on the basis of available resources. As soon as the agent faces the problem of lack of data in the knowledge base of MAVE, and enquiry is formed, addressed to the virtual expert resource of the corporate system.

Having gained the lacking information, the agent proceeds to execute the works all the way to w_n. The algorithm of that execution for a single agent interacting with the virtual expert resource is shown (fig. 2).

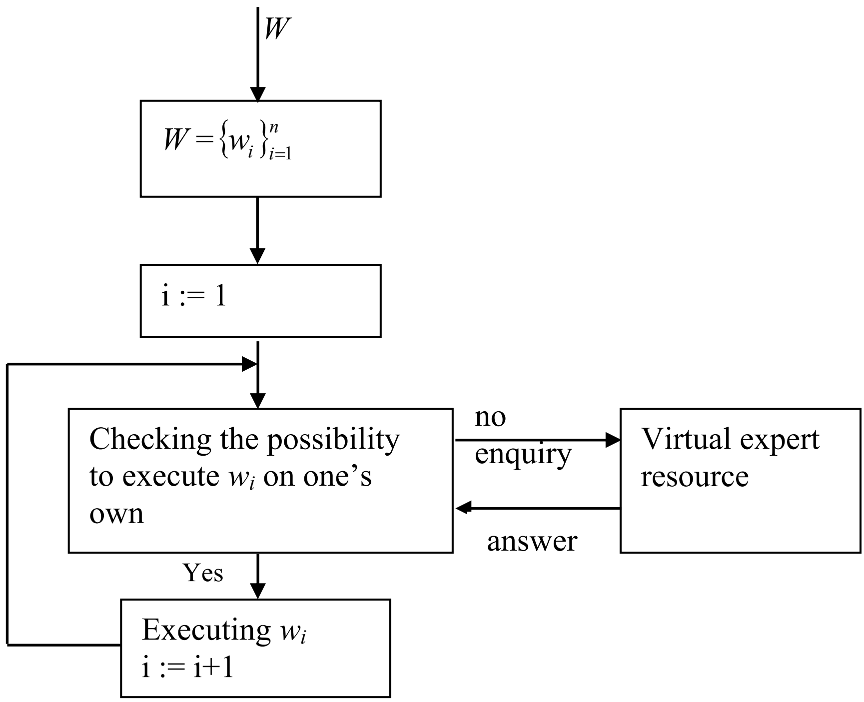

Figure 2. Algorithm of work execution with the help of virtual expert resource

Apparently, with a certain number of enquiries coming from agents of various MAVEs circulating in the common corporate network, there develops a competition for using the virtual expert resource. The agent receives no answer to his/her enquiry from the virtual expert resource within the given timeout in two cases:

a) the enquiry is formulated wrongly;

b) the virtual expert resource is overloaded with enquiries from agents of different MAVEs, which means exceeding the acceptable number of agents in the network.

Both cases mean violation of MAVE self-organization, and such an agent is blocked, i.e. a mechanism is set off to stabilize the number of agents in the corporate network. Therefore managing the number of agents is an important task in corporate systems built on using the virtual expert resource of corporate intellectual capital.

3. Modeling of competition for resources on the basis of difference equations

Consider some aspects of modeling the competition for resources using difference equations. The proposed approach was studied assuming the existence of a sustainable equilibrium position and optimizing the management of distribution resource [10].

Currently the standard model for describing discrete dynamics is the so-called logistic map

$$y_{n+1} = 1 - \lambda y_n^2,$$

equivalent to the Verhulst-Pearl model [13]. Indeed, a substitution $x = \dfrac{y + 1/2}{\alpha/4 + 1/2}$ makes it possible to proceed from the Verhulst-Pearl model

$$x_{n+1} = \alpha x_n (1 - x_n),$$

to the logistic map with its coefficient $\lambda = \alpha(\alpha/4 - 1/2)$.

Extending the model to the case of two interacting MAVEs that compete for the use of virtual expert resource, we consider the system of iteration equations

$$\begin{cases} y_{n+1} = \alpha x_n (1 - x_n) \\ x_{n+1} = \beta y_{n+1} (1 - y_{n+1}) \end{cases} \tag{1}$$

Here x_n is the number of agents of one MAVE, y_n is that of the other MAVE during the n-th cycle of using the virtual expert resource. Let the relative number of agents y_{n+1} during (n+1)-st cycle depend on the number of agents x_n during n-th cycle ($0 \le x_n, y_n \le 1$). In its turn, x_{n+1} depends on y_{n+1}. The parabolas in the right-hand part of each equation have their maximums equal to $\alpha/4$ and $\beta/4$, respectively, at point 1/2. Due to normalization of agent population, the controlling parameters meet inequalities $0 \le \alpha, \beta \le 4$. Since the numbers of agents in both MAVEs are interdependent, their interaction may be considered antagonistic.

Monograph [7] studied the population dynamics of competing species. However the general theory, as well as its particular cases relate to equations of different type $x_n = x_n f(x_n, y_n)$, while the function $xf(x,0)$, related to the "resources" has to increase monotonously. Typical scenarios of transition to chaos via a cascade of period doublings in different nonlinear systems are presented in studies [7, 10, 11].

However, systems considered in those studies contain identical variables in both parts of their equations and are different in principle from the newly proposed system.

Despite its simple form, it is probably the particular reason why the very first study historically [2] made it possible to present the qualitative scenario of evolution of the set of system solutions. Study [2] used numerical techniques to confirm the hypothetical existence of various cyclic solutions for system (1) and the emergence of "chaos". Calculations were made using a SW application to retrieve numerically the trajectories of system solutions. These were tested continuously for uniqueness at prescribed accuracy and for emergence of cycles of varying length and chaos. The approximate resulting topography of various zones is shown (fig. 3).

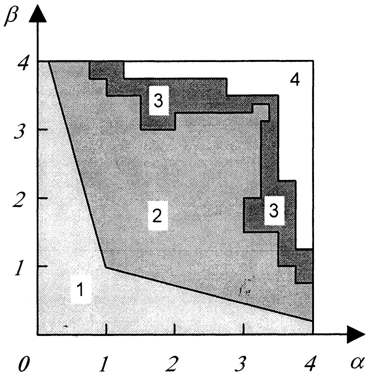

Figure 3. Results of numerical modeling of the system its parameters 0≤ α, β≤ 4 varied

Area 1 contains solutions for insufficient resource so that both MAVEs degenerate; in area 2 the number of agents in both MAVEs stabilizes; in area 3 a sustainable cycle S^2 emerges; in area 4 cycles of periods 3 and more appear and an uncertainty developing into a chaos follows. Exact boundaries of the areas remain indefinite.

Studies [3-7] defined the boundaries of these areas for the diagonal case (α=β) and obtained a new graphic presentation of the positions of immobile solutions ("the solutions ellipse"). It was found that the diagonal case yields the well-known Feigenbaum diagram (the Feigenbaum tree), except biased by a single iteration (fig. 4).

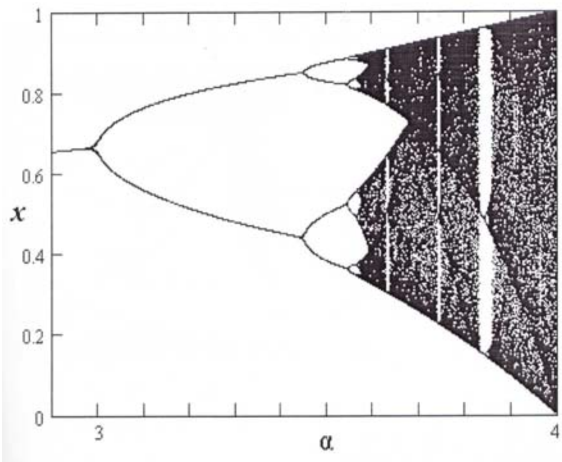

Figure 4. Bifurcation tree for a two-parameter model, α=β

The most interesting phenomena difficult to study occur in zones defined by their controlling parameters $\alpha,\beta\in(3, 4)$. Below we show the diagrams of the respective solution trajectories.

Figure 5 has one stable point in the vicinity of 1.

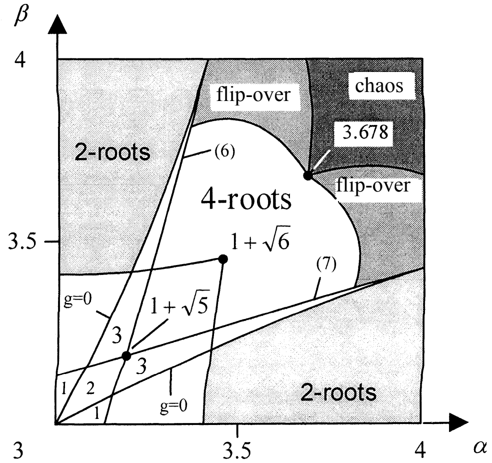

Figure 5. Areas structure for 3<α<4, 3<β<4

Curve g = 0 corresponds to those values *(α, β), for which the* system has 3 roots. Essentially, the third root is the touching point for the curves described by equations in the system:

$$\begin{cases} y = \alpha x(1-x) \\ x = \beta y(1-y) \end{cases}. \tag{2}$$

In area 2 the system has 4 different roots, the two central of them being unstable and the other two stable (fig. 6).

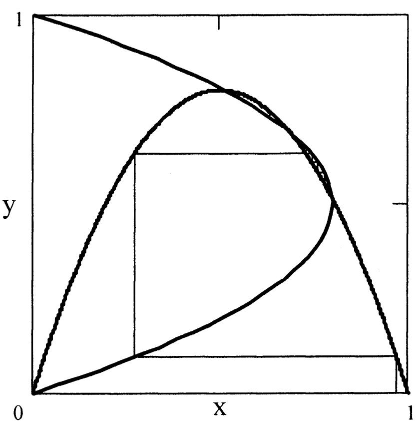

Figure 6. System evolution for $\alpha = \beta = 1 + \sqrt{5}$

That situation means that the number of both MAVEs (the number of enquiries) stabilizes with time and MAVEs stop competing for the virtual expert resource.

Area 3 (fig. 5) corresponds to one function from the equation of system (2) crossing the maximum of another equation of that system and a periodic cycle forming. In our case it means that the number of agents in both MAVEs will keep changing with a certain periodicity. In dependence of the initial conditions in the 4-root area attractors may emerge around either of the two crossing points off both sides of the diagonal, except for the zones of flip-over (fig. 7). This case is characterized by a pair of alternatives in the numbering of the two competing MAVEs.

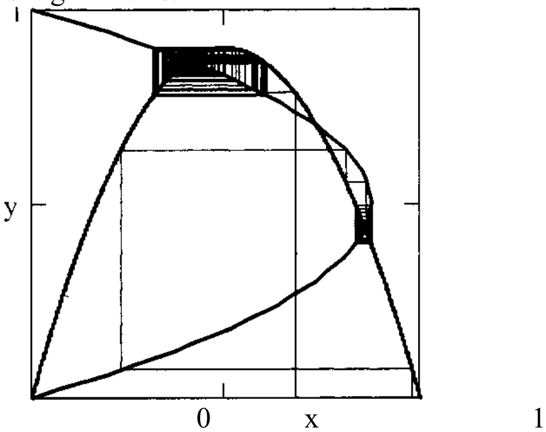

Figure 7. System evolution for $\alpha = 3.6$, $\beta = 3.5$

Most complex phenomena occur for when parameters α and β yield such wide attractors that their iteration cycles start flipping over from the area of one attractor to the other (fig. 8).

Let us consider the conditions for the occurrence of that phenomenon in more detail. Apparently, the cycle width is limited by functions' maximums. Let there be two cycles passing through the maximums of functions in the right-hand part of first and second equations of system (2) (fig. 7 and fig. 8).

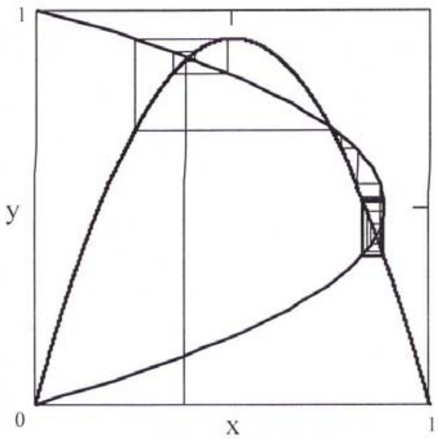

Figure 8. System evolution for $\alpha = 3.7$, $\beta = 3.55$

The initial evolution of one cycle goes through the states $0 \rightarrow 1 \rightarrow 2 \rightarrow 3$ and the evolution of the other through the states $0' \rightarrow 1' \rightarrow 2' \rightarrow 3'$ (fig. 9).

Apparently, the key role is played by point "A" where the graphs intersect. In case the attractor appears wider than the elevation of point "0" (or "0′") above point "A", the iteration cycle $0 \rightarrow 1 \rightarrow 2 \rightarrow 3$ will fail to reach its attractor and will cross to the area of the other attractor instead.

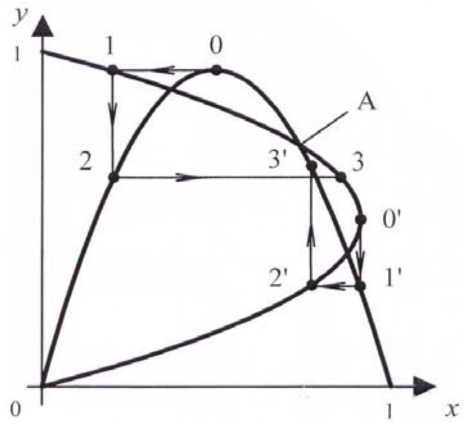

Figure 9. Cycle to cycle flip-over

We obtain an exact expression for the boundaries of that phenomenon. Consider the evolution of cycle $0 \to 1 \to 2 \to 3$. We have

$$x_0 = \frac{1}{2},$$

$$y_0 = \frac{\alpha}{4},$$

$$x_1 = \frac{\alpha\beta}{4}\left(1-\frac{\alpha}{4}\right),$$

$$y_2 = \frac{\alpha^2\beta}{4}\left(1-\frac{1}{4}\right)\left[1-\frac{\alpha\beta}{4}\left(1-\frac{\alpha}{4}\right)\right],$$

$$x_3 = \frac{\alpha^2\beta^2}{4}\left(1-\frac{\alpha}{4}\right)\left[1-\frac{\alpha\beta}{4}\left(1-\frac{\alpha}{4}\right)\right]\left\{1-\frac{\alpha^2\beta}{4}\left(1-\frac{\alpha}{4}\right)\left[1-\frac{\alpha\beta}{4}\left(1-\frac{\alpha}{4}\right)\right]\right\},$$

While cycle $0' \to 1' \to 2' \to 3'$ yields:

$$y_{0'} = \frac{1}{2},$$

$$x_{0'} = \frac{\beta}{4},$$

$$y_{1'} = \frac{\alpha\beta}{4}(1-\frac{\beta}{4}),$$

$$x_{2'} = \frac{\alpha\beta^2}{4}(1-\frac{\beta}{4})\left[1-\frac{\alpha\beta}{4}\left(1-\frac{\beta}{4}\right)\right].$$

Equating $x_{2'} = x_3$ we get an equation for the curve where attractors start to overlap. Using the problem symmetry one may assume $x_3 = 1 - x_1$ and simplify the expression: $x_{2'} = 1 - x_1$ or

$$\frac{\alpha\beta^2}{4}\left(1-\frac{\beta}{4}\right)\left[1-\frac{\alpha\beta}{4}\left(1-\frac{\beta}{4}\right)\right] = 1-\frac{\alpha\beta}{4}\left(1-\frac{\alpha}{4}\right) \tag{3}$$

Actually we have proved the following statement describing the fine structure of the 4-root zone: ***The chaos area is limited by the two branches of equation (3).***

As its consequence this statement entails the well-know constant valid for the classical one-dimensional case that separates cycle area from that of chaos (the area of unpredictable behavior of solutions in a sense). For α=β that expression has the form:

$$\frac{\alpha^2}{4}\left(1-\frac{\alpha}{4}\right)-1=0$$

with its real solution:

$$\alpha=\frac{2}{3}\left(\sqrt{19+3\sqrt{33}}+\frac{4}{\sqrt{19+3\sqrt{33}}}+1\right)\approx 3.678$$

Therefore, a state commonly called chaos develops in the range of $\alpha,\beta \geq 3.678$ (fig. 10).

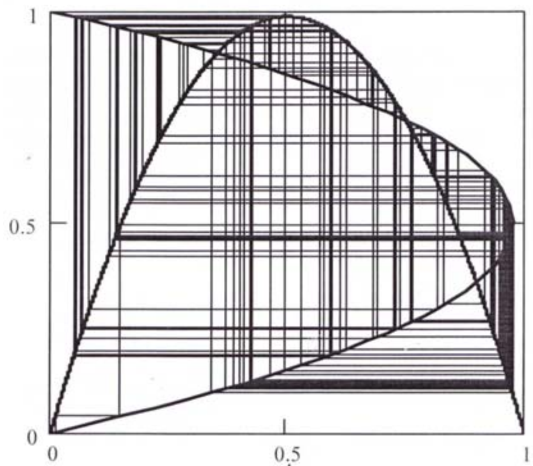

Figure 10. System evolution for $\alpha = 3.95,\ \beta = 3.9$

The last case means that self-organized MAVEs replicate their agents at a large frequency resulting in failures when addressing the virtual expert resource.

Of practical significance is the case of stable system solutions different from zero, i.e. of stabilization in the numbers of both MAVEs.

Optimizing the number of agents for more than two MAVEs is reduced to the problem of finding such controlling parameters α and β that stabilize their numbers for each pair of MAVEs.

Conclusion

The application of a modeling procedures package that allow to carry out an adequate transformation of the intellectual capital components with a focus on multi-agent experts functioning in expert and virtual environment of managerial decision-making is reasonable to use in expert intelligent systems building to provide effective teamwork of real and virtual experts when making optimal decisions. The process of interaction of agents with the expert and virtual resource on a certain number of requests results into the competition for resources, which can be simulated by using the approach proposed in the article. The results of numerical calculations have confirmed the effectiveness of the developed model, which suggests the possibility of its practical use.

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