19

A MULTIAGENT-BASED COMPLEX SYSTEMS APPROACH FOR EFFICIENT PARTNERING IN VIRTUAL ENTERPRISE

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Nowadays a sophisticated match-making mechanism is necessarily for appropriate collations in virtual enterprise (VE). Virtual market based match-making operation enables effective partner search in terms of products allocation by distributing the scheduled resources according to the market prices, which define common scale of value across the various products. We formulate the VE match-making model as discrete resource allocation problem, and propose a complex market-oriented programming framework based on the economics of complex systems. Three types of heterogeneous agents are defined in the complex virtual market. It is described that their interactions with micro behaviour emerge a macro order of the virtual market, and the clearing price dynamism can be analysed in economic terms. The applicability of the framework into resource allocation problem for VE is also discussed.

1. INTRODUCTION

In recent years consumers' demands have turned to be diversified, and enterprises must produce appropriate quantity of goods with reasonable price considering consumers' needs, such as fashions, quality, lead time, and so on. The introduction of information & telecommunications technologies and more recently, distributed object computing technology has enabled the creation of functioning Virtual Enterprises (VE), that do not have the geographic and structural restrictions that have traditionally constrained conventional enterprises. These technologies have enabled people to interact and collaborate effectively over distance as part of VE [1].

Traditionally, marketing, distribution, planning, manufacturing, and the purchasing organizations operated independently. These organizations have their own objectives and these are often conflicting. The result of these factors is that there is not a single, integrated plan for the organization - there were as many plans as businesses. Clearly, there is a need for a mechanism through which these different functions can be integrated together. Although cooperation is the fundamental characteristic of VE concept, due to its distributed environment and the autonomous and heterogeneous nature of the VE members, cooperation can only be succeed if a proper management of dependencies between activities is in place just like Supply Chain Management [2][3].

On the other hand, market price systems constitute a well-understood class of mechanisms that provide effective decentralisation of decision making with minimal communication overhead. In a market-oriented programming approach to distributed problem solving, the optimal resource allocation for a set of computational agents is derived by computing general equilibrium of an artificial economy [4] [5]. Market mechanism can provide several advantages in the partnering process in VE.

So as to facilitate the optimised VE management with e-Commerce infrastructure, a sophisticated business matching mechanism is required to manage such a large-scaled environment. Since the matchmaking place is a kind of pure market in terms of its structure, the idea of VE combined with virtual market (VM) must be promising [3] [6].

In e-commerce et al., the diversification of consumers' needs makes it difficult for traders to make appropriate decision makings. So, in this study, we focus on subjects about how prices of the goods are decided and how the goods are dealt in among the enterprises that compose VE. Then we try to construct a VM based on the model of `Economics of Complex Systems` [7]. Economics of Complex Systems has several features: increasing returns to scale, bounded rationality, self-organization, one-to-one trading, and so on.

2. ECONOMICS OF COMPLEX SYSTEMS

Economics of complex systems is new approach in economics to combine economics and complex systems [7]. Within this framework it is possible to construct an economic system starting, bottom-up, by its most elementary ingredients. An economic system is visualised as a large number of interacting agents whose individual actions as well as the interactions among them are explicit enough to be put into algorithmic terms. Although this approach bears the advantage of imposing weaker restrictions than a purely mathematical one, it is still necessary to greatly simplify the real situations. The challenge is that the essential features that are responsible for the emergent behaviours of the system, do not get lost. A successful model, in spite of being a heavy abstraction of real economic systems, allows discussing basic, stylised facts and working as true laboratories in which extreme conditions can easily be simulated and studied.

The main motivation of the economics of complex systems is to study the self organizing driving forces that act within an economic system. The hope is that learning about them can also provide information about the mechanisms that drive economic systems towards or away a stationary situation. The search of a global stable configuration and the process of self organisation are the two main emergent properties to clear about. A particularly relevant ingredient to model the relaxation of an economic system off equilibrium is both, the expectations and the adaptive capacity of its economic agents. Most of the robustness of the system as a whole can certainly be attributed to the memory that agents have of their previous experiences in deciding their future attitudes in their economic transactions. Adaptation on the other hand provides the necessary plasticity and change of individual behaviours to absorb changes and shocks. Learning and adaptation may therefore be considered as the basic element to model the self-organizing features of an economic system, as well as its robustness - or equivalently - its bounded homeostasis.

We formulate VE model as discrete resource allocation problem based on negotiated transaction, and propose a complex VM framework based on the economics of complex systems in this paper.

3. AGENT FORMULATION

3.1 VM structure with complex systems

VM consists of three types of agents in this study, such as producer agent, customer agent, and intermediate agent, because the VM provides auction environment for enterprises in VE.

- Producer agent: players who produce and supply exchanging resources in VM
- Customer agent: players who buy and consume the resources in VM
- Intermediate agent: players who provide auction field, and intermediate the trades between producer and customer agents. As a consequence, individual match makings are established between a set of producer and customer agents. As a basic study, the Intermediate agents are assumed never to try to gain profit during the matching process in this study.

Negotiations are occurred just between producer agent and intermediate agent, or customer agent and intermediate agent in this study. Thus all the tradings in the VM are based on negotiated transaction, which is completely different from the intensive transaction in stock exchange market proposed in micro economics.

An example of the proposed VM structure is shown in Fig.1. Market environment is divided into finite number of small grids where only one agent is located inside. Initially all the agents are located randomly, and they are assumed not to move their locations as a basic study. Both the producer agent and the customer agent behave individually without any contact to other agents except the intermediate agent. Only the intermediate agent has a transactional scope, and the intermediate agent is able to make communications or negotiations with other agents inside the scope. The negotiation is carried out in one to one relationship between producer agent and intermediate agent, or customer agent and intermediate agent as negotiated transactions. The scope corresponds to information transmission space, i.e. information distance, in practical situations.

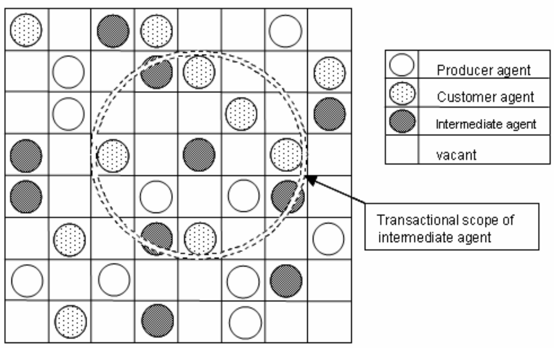

Figure 1 – An example of complex VM

3.2 Producer agent

Producer agent tries to pursue its profit by producing and selling goods x from its own capital. We formulate the producer agent (s) as follows:

(a) Objectives: maximise its capital (M_s^t) at present (t)

$$M_s^t \rightarrow max \tag{1}$$

(b) Behaviour

Step 1: Produce goods x by the amount O_{sx}^t, that calculated previous Step 5, and increase its capital (G_{sx}^t).

$$G_{sx}^t = G_{sx}^{t-1} + O_{sx}^t \tag{2}$$

Step 2: If the estimated profit ($EPro_{sx}^t$) is not negative, decide to sell all the stock and go to Step3 (Case 1). Otherwise give up to sell and go to Step 4 (Case 2).

$$EPro_{sx}^t = P_{sx}^t - Co_{sx} \tag{3}$$

where P_{sx}^t : recommended price, Co_{sx} : cost price

Step 3: Carry out transactions with the intermediate agent, and modify its capital (M_s^t) according to the transactions. The details are described in 3.4.

$$SL_{sx}^t = \sum_d \{(MP_{sxd}^t - Co_{sx}) \times n_{sxd}^t\} \tag{4}$$

$$M_s^{t+1} = M_s^t + \sum_x SL_{sx}^t \tag{5}$$

$$G_s^{t+1} = G_s^t - \sum_d n_{sxd}^t \tag{6}$$

where SL_{sx}^t : total sales, MP_{sxd}^t : clearing price, n_{sxd}^t : amount of trade

Step 4: Calculate the recommended price for the next step.

$$P_{sx}^{t+1} = \begin{cases} P_{sx}^t \times \alpha_{sx} & : Case1 \\ P_{sx}^t + \pi & : Case2 \end{cases} \tag{7}$$

where α_{sx} : price modify parameter, π : price increase parameter

■ α_{sx} : producer agent modifies this parameter according to the amount of trade. If the total amount of trade is equivalent to the prepared stock, the agent increases the price for expecting higher profit at the next step. On the contrary, if it has no offer from intermediate agent, it decreases the price.

Step 5: Calculate the production amount so as to maximise its profit by solving NLP problem as follows:

$$maximise: \Pi = P_{sx}^{t+1} \times O_{sx}^{t+1} - (Co_{sx} \times R_{sx}^{t+1} + C_s) \tag{8}$$

$$s.t.\ O_{sx}^{t+1} \leq f(R_{sx}^{t+1}) \tag{9}$$

where R_{sx}^{t+1} : material amount, C_s : fixed cost

The parameter Π means profit, and f is the production function. Producer agent is formulated to maximise its profit locally by solving the above NLP.

(c) Withdrawal conditions

If the agent exhausts its capital, then it withdraws from the market.

3.3 Consumer agent

Consumer agent is assumed to try to purchase goods *x* and sell it to the market underneath in supply chain. The underneath market isn't modelled precisely in this study and it is assumed as fully stable as a basic research. We formulate the consumer agent (*d*) as follows:

(a) Objectives: maximise its capital (M_d^t) and stock (G_d^t) at present (*t*)

$$M_d^t \to max \wedge G_d^t \to max \tag{10}$$

(b) Behaviour

Step 1: Increase capital M_d^t with sales income(C_{Md}).

$$M_d^t = M_d^{t-1} + C_{Md} \tag{11}$$

Step 2: Carry out transactions with the intermediate agent, and modify its capital (M_d^t). The details are described in 3.4.

$$PY_{dx}^t = \sum_s (MP_{dxs}^t \times n_{dxs}^t) \tag{12}$$

$$M_d^{t+1} = M_d^t - \sum_x PY_{dx}^t \tag{13}$$

$$G_{dx}^{t+1} = G_{dx}^t + \sum_s n_{dxs}^t \tag{14}$$

where $\sum_x PY_{dx}^t$: total cost, $\sum_s n_{dxs}^t$: amount of purchased goods

Step 3: Calculate the desired purchase price for the next step.

$$P_{dx}^{t+1} = P_{dx}^t \times \alpha_{dx} \tag{15}$$

where α_{dx} : price modify parameter

■ α_{dx} : consumer agent modifies this parameter according to the amount of trade. If the total amount of trade is equivalent to its requirements, the agent decreases the price for lower expenditure. On the contrary, if it has no offer from intermediate agent, it increases the buying price.

Step 4: Calculate the requiring amount in the next step by solving the following simultaneous equations.

$$M_d^{t+1} = \sum_x P_{dx}^{t+1} \times H_{dx}^{t+1} \tag{16}$$

$$P_{dx1}^{t+1} \times H_{dx1}^{t+1} / P_{dx2}^{t+1} \times H_{dx2}^{t+1} = MRS_{x1,x2}^{t+1} \tag{17}$$

where MRS : marginal rate of substitute

(c) Withdrawal conditions

If the agent exhausts its capital or one of any goods, then it withdraw from the market.

3.4 Intermediate agent

Intermediate agent corresponds to auctioneer in e-market place, and provides partnering environment for the attendees. The intermediate agent has transactional scope, and the scope V_i^t is dynamically spread followed by logistic function.

$$V_i^t = (A/2) \times \{\exp(C_{Vi}t)/1 + \exp(C_{Vi}t)\} \tag{18}$$

where *A*: diagonal length of the market, C_{Vi} :constant value

All the agents inside the scope are considered as applicants for match-making algorithm. We applied 4-heap algorithm[8] for the match-making process.

The behaviour of intermediate agent is as follows:

Step 1: Call for the market to all the agents inside the scope.

Step 2: Collect the information from all the agents who attend the market by their own decision.

Step 3: Proceed the match-making based on 4-heap algorithm. Clearing price between producer agent s* and consumer agent d* is calculated as Eq. (19).

$$MP^t_{s^*xd^*}(= MP^t_{d^*XS^*}) = (P^t_{s^*x} + P^t_{d^*x})/2 \tag{19}$$

Step 4: Report the transactional results to all the applicants.

Step 5: Negotiated transactions are finally carried out in VM, based on the match-making process.

4. EXPERIMENTAL RESULTS

4.1 Experimental parameters

We constructed small but principle complex VM as a basic study to analyse distinctive characteristics. The parameters are shown in Table 1. U(min, max) and N(μ, σ^2) mean uniform distribution and normal distribution, respectively in Table 1. Simulation trial is 100 times at each result described in this chapter.

Table 1 Experimental parameters

Producer agent		Consumer agent	
M_s	10000	M_d	20000
P_s	U(400, 500)	P_d	U(450, 550)
O_{s1}	10	G_{dx}	N(50. 25)
O_{s2}	15	μ_{d1}	5
Co_{s1}	5	μ_{d2}	6
Co_{s2}	4	C_{md}	5000
π	10		
C_s	100		

4.2 Price dynamism and scope effects

Dynamic transactional price transition of producer agent in goods 1 is shown in Fig. 2. That figure shows that the converged transactional prices are emerged in the VM, although it has no positive convergence mechanism which Walras market has. The converged prices are acquired through adaptive micro-macro interactions between agents and market, and that means the complex VM successfully attains practical market mechanism in reality. There happens some autonomous selection amongst agents, and only the appropriate number of agents is able to survive in this market according to the power balance between supply and demand.

The VM isn't stable system in nature, and these prices aren't always converged. A number of simulation trials showed us that the transactional scope of intermediate agent has great effects on the price stability.

The Fig. 3 shows the relationship between the scope parameter C_{Vi} and coefficient of variation of the converged transactional price (goods 1).

It is obviously shown that the price is stabilised as C_{Vi} increases, i.e. the scope enlarges rapidly. Especially C_{Vi} is around 0.1, the coefficient of variation decreases sharply, and the price stability is improved rapidly. The fact implies that the relaxation of the constraints on agent visibility draws the VM with complex systems closer to classical Walrasian market, which has positive convergence mechanism inside. It has been confirmed that the price convergence of the proposed VM is manageable by the scope factor.

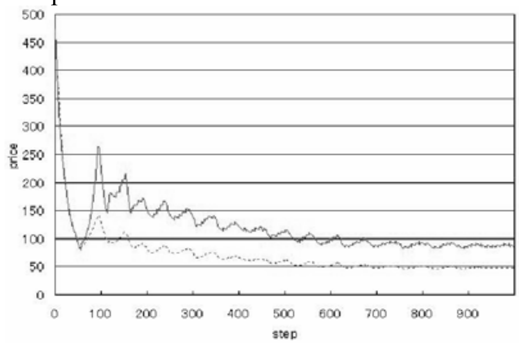

Fig.2 Price transition of producer agent (goods 1)

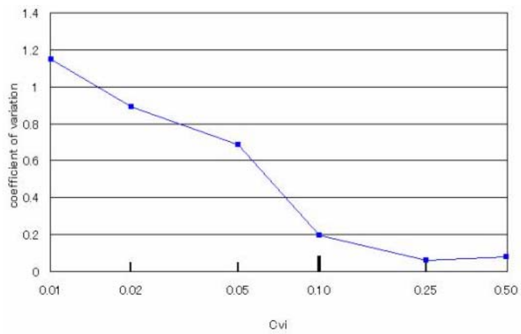

Fig.3 Scope and price convergence (goods 1)

4.3 Sensitive dependence on initial conditions

Finally we analysed the proposed market in terms of the dependency on initial conditions, which complex systems have in general.

Fig.4 illustrates the final budgets (at t=1000) of customer agents in the market. (x, y) means the existing position of each consumer agent in this figure. It has obviously observed that the budget distribution is very large, and the budget difference is deeply connected to the initial conditions of the market, such as positions, budget and price modification parameter. An accidental small difference at first emerges great diversity as the consequence of agent interactions finally. We have confirmed that our VM obtains Sensitive Dependence on Initial Conditions (SEDIC).

5. CONCLUSIONS

In this study, we focused on the subject about how prices of the goods are decided and how the goods are dealt in among the enterprises that compose the supply chain.

Then we have constructed an "Artificial Market" in computer, and the macro dynamism of the market have been analyzed from the micro point of view. The artificial market has been constructed based on the model of Economics of Complex Systems, which has several unique features compared with conventional Walras market.

At First, the basic market model, which abstracts and simplifies an actual market, has been defined and constructed, and we have simulated this model. Some distinctive characteristics of the price dynamisms have been observed in this simulation, and the decision mechanism on the market price has been analyzed by the behaviour of each agent. It has been clarified that the price is fully converged in some cases, although the market doesn't have specific mechanism for the convergence that Walras market holds. Additionally, we have found out that the spread speed of intermediate agent's view has affected market's activity and stability. And SEDIC has been observed in this model. Moreover, it has been observed that the balance of rising / lowering price parameters between supply agents and demand agents is important to stabilize market.

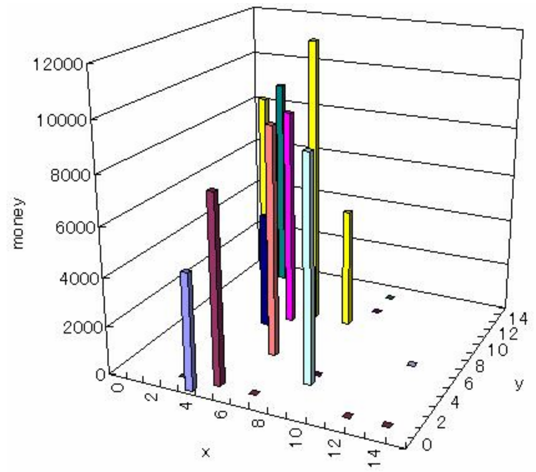

Fig.4 Final landscape of consumer agents

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