1998 International Computer Symposium
Workshop on Artificial Intelligence
December 17-19, 1998, N.C.K.U., Tainan, Taiwan, R.O.C.

COOPERATING SOFTWARE AGENTS UNDER UNCERTAINLY SITUATIONS

Kimitaka Uno,, and Akira Namatame

Department of Computer Science,
National Defense Academy, Yokosuka, 239-8686, Japan
Email: {kimi, nama}@cc.nda.ac.jp

ABSTRACT

In this paper, we formulate and analyze the problem of cooperating multiple software agents under uncertainty. We show that agents cooperate in order to encounter uncertainty when acting alone by themselves, their benefits would not be as attractive, and hence cooperate to share the risk. As a specific example, we consider the model of obtaining the pieces of information from a priced Electronic Library by sharing cost. We propose the negotiation mechanism for sharing cost among agents. With that mechanism, they can learn and obtain the unbiased and fare cost distribution rule. We further examine the design of the incentive compatible cooperative protocol for multiple software agents.

1. Introduction

As the tasks in our society grow in complexity, the growing interests have been given toward methodologies that allow for cooperation among various knowledge servers. To take advantage of the growing number of knowledge servers, however, the ways must be found to process knowledge beyond their own specific domains and therefore must access other knowledge sources.. Many information systems are currently being modeled as a set of cooperating intelligent agents [1][2][7][11]. The aim of the incorporation of software agents into distributed knowledge systems is to provide the function of efficient retrieval in an open environment of those systems. The philosophy behind the agent models is that, agents must, as much as possible, make knowledge to be available to users, without knowing by whom or where they will be used. Software agents distributed within and among knowledge servers share various and heterogeneous knowledge resources. Software agents can also support that multiple users at physically distributed location and they can simultaneously access the common knowledge resources by sharing various and heterogeneous knowledge resources. To support safe cooperation and sharing of complex knowledge resources, while preserving agents' autonomy, agents should negotiate with each other on the access rights and deletion policies on distributed knowledge resources, and when necessary the rights should be also propagated.

In multi-agent problems, the tasks or functions are formulated as the interaction of software agents. When agents deal with one another, they often bring to the encounter differing goals, and the interaction process takes this conflict into account. Each agent pursues its own goals through encountering with other agents; arrangements should be made so that each individual's goal can be satisfied. Agents also may promise, threaten, and together find compromises that will satisfy all agents. The very basic question is then stated as why and how do agents should cooperate than to act independently by themselves. There can be many answers to this multi-edged question, but generally, it can be deduced that agents cooperate in order to share the common benefit or the certain load where it cannot fulfill alone. The agents benefit from the cooperative behaviors of sharing the cost or a load where they cannot fulfill alone [8][9].

In this paper, we consider the cooperating problem of multiple agents under uncertain situations. As a specific example, we consider the problem of cooperating agents in the domain of the electronic library model. In this model, two or more agents cooperate to share the cost of obtaining pieces of information as the common knowledge from a priced electronic library [6]. The agents benefit from the cooperative behavior in maximizing their utility. When acting alone by themselves, their benefits would not be as attractive, and hence they cooperates by sharing the cost. In reality, they usually do not get to see or know what the content of certain information before they acquire it. Therefore, there is always a possibility that information might not turn out to be as useful or worthy as they thought. We say, there is uncertainty involved here. In such cases, agents may acquire knowledge together to share their risk or to lower their possible cost. Cooperative behavior under uncertain can be made possible by considering their utilities while acquiring information. Cooperative behaviors under uncertainty is promoted here by, firstly satisfying each agent's individual rationality by appropriately distributing the worth and cost that could not be accepted by both or single agent incurred from acquiring the knowledge be accepted by all; and also by satisfying the agents' social rationality. The following factors like the value (worth) of information possessed by each agent, the utility through acquiring information should be considered throughout the negotiation. Similarly, conflicts occur when agents behave in such that the cost be shared accordingly to each value (worth) possessed. In this case, an efficient and unbiased sharing rule of the common cost among the agents that evens out the conflicts should be designed.

2. The problem of knowledge transaction among software agents

In this section, we formulate the cooperating problem of agents for the acquisition of knowledge from the electronic library as described in Fig.1. The agents may attain a certain worth when acquiring knowledge, however, the agents are required to pay the cost for every knowledge acquired. Whereas if they take the cooperative behavior in acquiring the knowledge, the cost will be shared among agents satisfying the condition, $c_A + c_B = C$; and the agents' benefits in acquiring the knowledge will be denoted as:

$$x_B = w_B - c_B,$$
$$x_A = w_A - c_A. \tag{2.1}$$

Fig.2 shows the boundaries of the agent's acceptance and rejection of participation in the cooperative behavior. Agent A's acceptance and rejection boundary line is represented by $c_A(w)$, and agent B's acceptance and rejection boundary line is represented at $c_B(w)$. In Fig.2, the cooperative behavior that are brought about by the worth and shared cost of $a\ (w_1,c_1)$ is not acceptable by both agents. That is each agent does not attempt to acquire the knowledge. The cooperative behavior is also not emerged at $g(w_3,c_3)$, since they may behave by themselves. On another hand, at $b(w_2,c_2)$, the cooperative behavior that are brought about by the worth and shared, where it is not acceptable to agent A, whereas it is acceptable to agent B. The promotion of cooperation through cost sharing refers to when two agents of different level of risk avoidance cooperate to share their worth and cost with each other. The benefit attainable from cooperative behavior in acquiring the knowledge should be always greater than from the status of quo.

Generally, when an agent finds high risk in acquiring the knowledge, it will tend to cooperate with another agent of low risk, hence, its risk avoidance is said to be low. Likewise, when an agent finds low risk in acquiring the knowledge, it will most likely to avoid or lower any possible risk when cooperating with other agents, hence, its risk avoidance is said to be high.

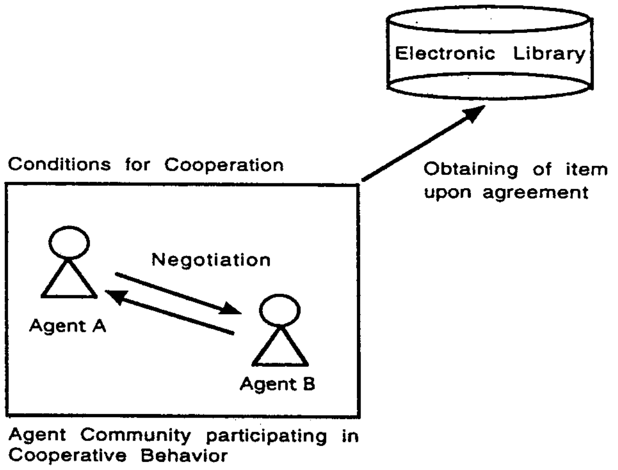

Figure 1: An illustration of the electronic library model

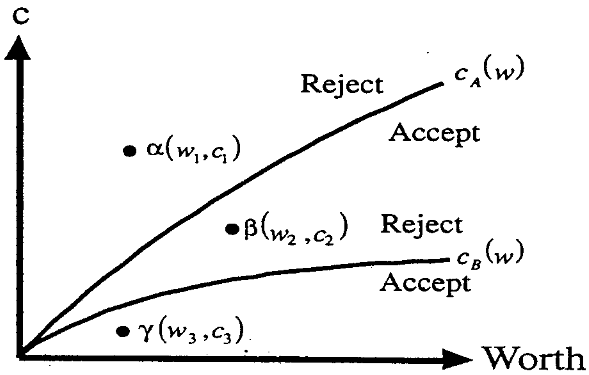

Figure 2: Boundaries of acceptance and rejection

If all agent agrees on splitting the cost evenly, the cooperative behavior will thus end here and no further negotiation is required. However, conflicts occur when these agents behave in such that the cost be shared accordingly to each value (worth) possessed. In this case, an unbiased negotiation algorithm is thus required to evaluate the best distribution rule of the common cost among the agents to even out the conflicts. The factors of each agent's individual rationality and the social rationality should be considered throughout the negotiation. We will also need to attempt to solve the problem on how an unbiased and fare cost distribution rule can be derived and further examining the negotiation algorithm of deriving at this unbiased cost distribution rule. The following factors such as the worth and cost in acquiring the knowledge, utility possessed by each agent and any risk induced in acquiring the knowledge are considered.

3. Formulation of the cooperating problem of software agents under uncertainty

In this section, we formulate the cooperating problem under uncertainty in which the utility attainable when acquiring the knowledge is indefinite; it varies with the change of conditions and situations. As a result, the agent not only considers about its utility derived from the cost and worth involved during the cooperative behavior, but also the new utility function deriving from the risk induced under the uncertainty. Risk is commonly defined as the degree of probability of exposure to an undesired condition or situation[4]. Usually, the risk is caused by certain unforeseen circumstances, and in the electronic library model, this uncertainty is, for instance the uncertain state of the communication route; if the lines are busy, the cost of the knowledge rises with the busyness of the lines. Similarly, the agent ay, in some cases, not be able to assess the utility of the knowledge and to the listed cost of it before acquisition.

Towards any risk induced in acquiring the knowledge, the agent possesses a risk avoidance, the tendency of avoiding risk, depending on its own worth and cost in acquiring the knowledge. Generally, when an agent finds high risk in acquiring the knowledge, it will tend to cooperate with another agent of low risk, hence, its risk avoidance is said to be low. Likewise, when an agent finds low risk in acquiring the knowledge, it will most likely to avoid or lower any possible risk when cooperating with other agents, hence, its risk avoidance is said to be high. The attitude of the agent towards risk (risk avoidance) is denoted as $r_A(r_B)$. This risk avoidance also represents the characteristic of each agent, and it differs individually. The utility function of the acquisition of knowledge with risk avoidance is denoted by the following expression:

$$\begin{gathered} U_A(x) = 1 - \exp\left(-x_A/r_A\right) \\ U_B(x) = 1 - \exp\left(-x_B/r_B\right) \\ (x_A = w_A - c_A,\quad x_B = w_B - c_B) \end{gathered} \tag{3.1}$$

Cooperative problems under uncertainty can be formulated in the following setup problem. Here, the probabilities of two phenomenons θ_1 and θ_2 occurring are denoted as *p* and 1-*p* as shown in Figure 3. In the case of phenomenon θ_1, the worth of agent A (agent B)'s worth in acquiring the knowledge is $w_{1A}(w_{1B})$, each agent's sharing cost will be $c_{1A}(c_{1B})$; and in the case of phenomenon θ_2, he worth of agent A (agent B)'s worth in acquiring the knowledge is $w_{2A}(w_{2B})$, each agent's sharing cost will be $c_{2A}(c_{2B})$. As the phenomenon occurs by probability, each agent's mean utility would be:

$$\begin{gathered} \overline{U}_A = pU_A(x_{1A}) + (1-p)U_A(x_{2A}) \\ \overline{U}_B = pU_B(x_{1B}) + (1-p)U_B(x_{2B}) \end{gathered} \tag{3.2}$$

respectively. When two agents cooperate to acquire the knowledge under uncertainty, their conditions for the social rationality is given as the combination of their sharing cost by maximizing of both's utilities. That is,

$$\begin{aligned} Max(\overline{U}_A + \overline{U}_B) = Max\ & p\{U_A(x_{1A}) + U_B(x_{1B})\} \\ & +(1-p)\{U_A(x_{2A}) + U_B(x_{2B})\} \end{aligned}$$

$$\begin{aligned} s.t.\quad & x_{1A} + x_{1B} \le x_1 \\ & x_{2A} + x_{2B} \le x_2 \\ & \begin{pmatrix} x_1 = w_{1A} + w_{1B} - (c_{1A} + c_{1B}) \\ x_2 = w_{2A} + w_{2B} - (c_{2A} + c_{2B}) \end{pmatrix} \end{aligned} \tag{3.3}$$

can be derived. The solution $(\underline{x}_{1A}, \underline{x}_{1B})$ and $(\underline{x}_{2A}, \underline{x}_{2B})$ of the above maximizing problem is also called the *pareto efficiency*. For the exponential utilities of (4.1) the problem of (4.3) is expressed as:

$$\begin{aligned} Max\ & \lambda\left\{1 - \exp\left(-(w_A - c_A)/r_A\right)\right\} \\ & +(1-\lambda)\left\{1 - \exp\left(-(w_B - C + c_A)/r_B\right)\right\} \\ & s.t.\ c_A + c_B = C \quad i = 1,2 \end{aligned} \tag{3.4}$$

The optimal rule for cost distribution rule will be maximizing the addition of both's utility. The sharing cost of agent A is:

$$\begin{aligned} c_A = (\frac{r_A}{r_A + r_B})C + (\frac{r_B}{r_A + r_B})w_A - (\frac{r_A}{r_A + r_B})w_B \\ + \frac{r_A r_B}{r_A + r_B}\log(\frac{1-\lambda}{\lambda}\cdot\frac{r_A}{r_B}) \end{aligned} \tag{3.5}$$

and similarly for agent B,

$$\begin{aligned} c_B = (\frac{r_B}{r_A + r_B})C + (\frac{r_A}{r_A + r_B})w_B - (\frac{r_B}{r_A + r_B})w_A \\ - \frac{r_A r_B}{r_A + r_B}\log(\frac{1-\lambda}{\lambda}\cdot\frac{r_A}{r_B}) \end{aligned} \tag{3.6}$$

Furthermore, we can deduce that:

$$\delta = \frac{r_A r_B}{r_A + r_B}\log(\frac{1-\lambda}{\lambda}\cdot\frac{r_A}{r_B}) \tag{3.7}$$

where δ is a constant decided by the distribution rule λ, which is the difference between the agents' risk avoidance and is known as the *sub-payment*. This *sub-payment* δ, is the take over in cost paid to the passive agent by the active agent. With this δ, agents without their conditions of their individual rationality satisfied initially are attracted to cooperate, which makes possible the acquisition of the knowledge.

However, when the risk avoidance of two cooperative agents are equal $\left(r_A = r_B, \lambda = 1/2\right)$, the result of the distribution rule is given as:

$$c_A = \frac{w_A - w_B + C}{2}, \quad c_B = \frac{w_B - w_A + C}{2}, \tag{3.8}$$

respectively. This is equivalent to cases where uncertain conditions are not being considered, where both's social rationality are satisfied.

We will expand our problems to n (multiple) agents. Similarly, the optimal solution $x_i = \{x_{i1}, x_{i2}, \ldots, x_{im}\}$, for n agents to cooperate under the uncertain elements θ_k, $k = 1,2,\ldots,m$, can be given by:

$$Max \sum \lambda_i \sum p_k U_i(x_{ki}) = \sum p_k \sum \lambda_i U_i(x_{ki}) \tag{3.9}$$

Therefore, similar to the case of two agents, the distribution rule is independent of the occurring probability p, and x_k of the phenomenons θ_k .Under the condition $\lambda = (\lambda_1, \lambda_2, .. \lambda_n), (\sum_{i=1}^{n} \lambda_i = 1)$,

$$Max \sum \lambda_i U_i(x_{ki}) \tag{3.10}$$

$$s.t. \quad \sum x_{ki} = x_k \tag{3.11}$$

can be derived.

$$\begin{cases} (1) \ U_i'(x_i^*) = \dfrac{\rho}{\lambda_i} \\ (2) \ \sum_{i=1}^{n} x_i^* = x \end{cases} \quad i = 1,2,\ldots,n \tag{3.12}$$

Therefore, the distribution rule that satisfies (1) and (2) in expression (4.12),

$$x^* = (x_1^*, x_2^*, \ldots, x_n^*) \tag{3.13}$$

also satisfies the conditions of the social rationality. Thus, the cost distribution that satisfies social rationality is as follows:

$$c_i = \frac{1}{\sum_{i=1}^{n} r_i}\left\{ r_i C + \sum_{j \neq i} r_j W_i - r_i \sum_{j \neq i} W_j \right\} - \frac{1}{\sum_{i=1}^{n} r_i}\left\{ \sum_{j \neq i} r_i r_j \log\left(\frac{r_j}{r_i}\right) \right\} \tag{3.14}$$

As a whole, the sub-payment among the n agents is transacted underhand among the agents participating in the negotiation, in the case of:

$$r_i > r_j \tag{3.15}$$

where the risk avoidance of j is greater than that of i, agent i pays agent j the sub-payment and vice versa.

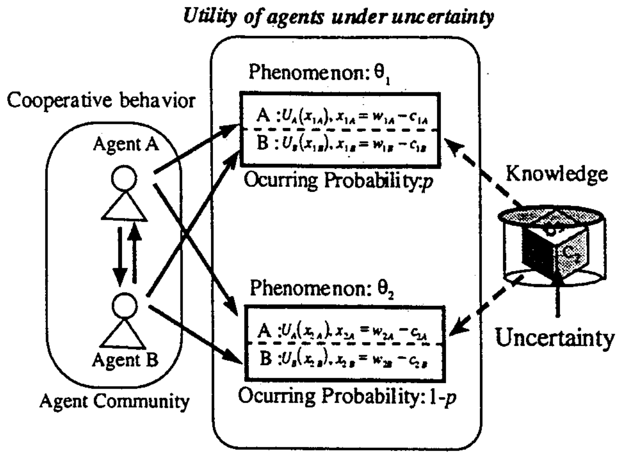

Figure 3: The Formulation of the cooperative problem under uncertainty

4. The design of the incentive compatible cooperative protocol

The problem of incentive is defined as the issue of declaring private information of each agent without false. Then the question is how to design the cooperation protocol that are compatible with incentives of each selfish agents. In this section, we develop the mutual adjustment process among agents that compatible with each individual agent and it may reveal the true cognitive states. The preceding sections explained mainly about the rationality of the agents in cooperating with each other, and the cost distribution rules that governs the cooperative behaviors. In this section, we will discuss about how negotiation is carried out to satisfy the rationalities of the agents during cooperative behaviors. In our proposed protocol, there exists a negotiation manager within the same community of the participating agents. Initially, every agent will receive a common coefficient ρ from the negotiation manager upon agreement to negotiate as illustrated in Figure 5. The agent will then compare it with its own limit utility function $U'(x_i)$, and modifies its profits x_i, accordingly, to meet the given value of ρ/λ_i, while at the negotiation manager for further judgements. The modifying rules are as follows:

$$\text{if } U_i'(x_i) < \frac{\rho}{\lambda_i} \text{ then } x_i := x_i + \Delta x$$

$$(\text{ where } x_i = w_i - c_i),$$

$$\text{if } U_i'(x_i) > \frac{\rho}{\lambda_i} \text{ then } x_i := x_i - \Delta x . \tag{4.1}$$

As shown in expressions (4.1), the agent modifies by adding or deducting Δx when the given value of ρ does not satisfies its marginal utility function. The modified new x_i is then returned back to the negotiation manager for the approval before the next round of transaction starts. On the other hand, the negotiation manager gathers the x_i collected from all the participating agents, and compare the summation with a preset value. The value of ρ is modified according to the outcome of comparison and sent back to the participating agents, to match the pre set value X closer. The modifying rule is described as follows:

$$\text{if } \sum_{i=1}^{n}(x_i) < X \text{ then } \quad \rho := \rho + \beta,$$

$$\text{if } \sum_{i=1}^{n}(x_i) > X \text{ then } \quad \rho := \rho - \beta,$$

$$\left(\because X = \sum_{i=1}^{n} w_i - C\right), \qquad (4.2)$$

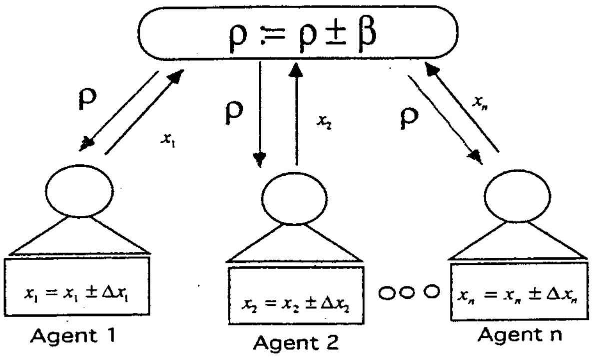

Figure 4: The negotiation the cooperation protocol

This process of exchanging the respective x_i and ρ is carried out until the specific conditions of the social and individual rationalities are met. The compromising status mentioned here refers to the state where both the conditions of the conditions of each agent's individual rationality and the social rationality are being satisfied simultaneously.

A simulation applying the above suggested protocol was performed to examine the behaviors of the agents during the negotiation process. Each of the agents possesses each of worth and risk avoidance towards the acquisition of the commonly desired knowledge. Figure 6 shows the results of the simulation. The figure consists of three graphs. Each graph is a plot of cost versus negotiation counts / times, of the respective agents. When the simulation is performed, the agents seek to stop at a compromising point, where their conditions of both rationality are satisfied. When they negotiate to distribute relatively high cost (C=950), the agent with the high avoidance (r_A=100) shares lower cost, as shown in Fig.5(a). However, when they negotiate to distribute relatively low cost (C=300), the agent with the low risk avoidance (r_C=300) shares lower cost, as shown in Fig. 5(b).

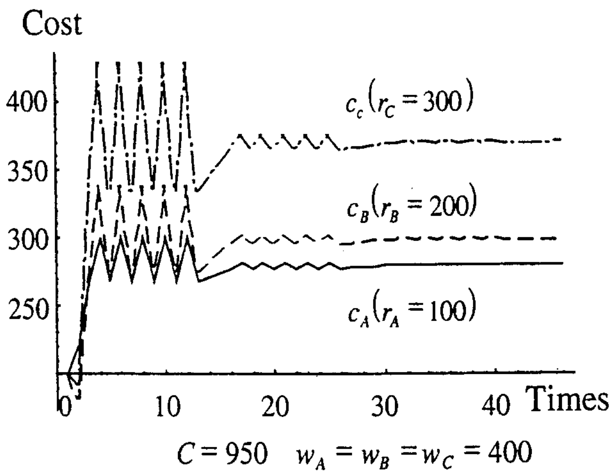

Figure5(a) Result1: the negotiation process for sharing the low cost

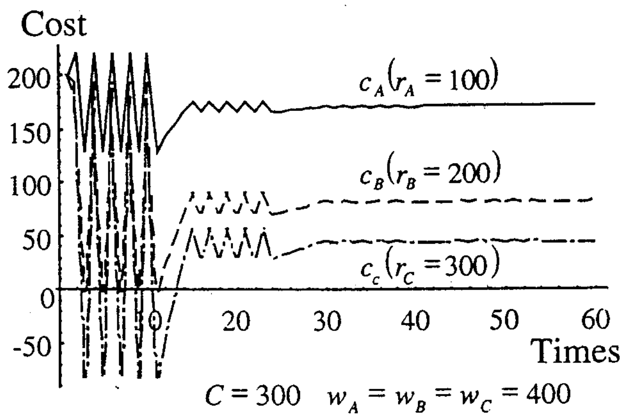

Figure5(b) Result2: the negotiation process for sharing the high cost

5. Conclusions

We discovered that agents cooperate to enhance their utilities under normal situation, but cooperate to share risk and at the same time to enhance their utilities under uncertainty. We also realized that, by an agreement to a sub-payment among the agents while sharing the risk incurred, cooperative behaviors can be promoted. However, this sub-payment is not considered as the result of social benefits, but rather a behavior that would lead to the satisfaction of each agent's individual utility or satisfaction of the conditions of individual rationality. We attempted to define risk sharing as the distribution of undesired results, and proposed a negotiation protocol that solves cooperating problem among agents under uncertainty. In this protocol, we achieved an unbiased distribution of cost among the agents through the existence of a negotiation manager, which governs the satisfaction of the participating agents' social rationality.

6. References

[1] Alan, H.B. and Gasser, L: "Readings in Distributed Artificial Intelligence", Morgan Kaufmann, 1988.

[2] Demazeau,Y. and Müller, J.P(eds) "Decentralized Artificial Intelligence", in *Decentralized AI*, Demazeau,Y & Müller,J.P(eds), Elsevier Science, pp. 3-31, 1990.

[3] Detlof von Winterfeldt, Ward Edwards, "Decision Analysis And Behavioral Research", Cambridge University Press,1986

[4] Giampiero E. G. Beroggi, William A. Wallance, "A Decision Logic for Operarional Risk Management", Computational Organization Theory, IEA,pp.289-308, 1994

[5] Howard Raiffa: "Decision Analysis, Introductory Lectures on Choices under Uncertainty", Addison-Wesley Publishing Company, July 1970.

[6] Jeffrey S. Rosenschein and Gilad Zlotkin: "Rules of Encounter, Designing Conventions for Automated Negotiation among Computers", The MIT Press, 1994.

[7] John H. Connolly and Ernest A. Edmonds (Eds.): "CSCW and Artificial Intelligence,Computer Supported Cooperative Work", Springer-Verlag, 1994.

[8] Kumon, S:" Information Civilization Theory ", NTT Press,1979

[9] Les Gasser: "Computational Organization Research", ICMAS'95 Proceedings, pp414-415,1995

[10] Sian.S.E. "The Role of Cooperation in Multi-agent Learning Systems", *Cooperative Knowledge-Based Systems*, Springer-Verlag, pp.67-84, 1990

[11]Steiner,D. and Mahiling, D.: "Collaboration of Knowledge Bases via Knowledge Based Coordination", in *Cooperating Knowledge Based Systems 1990*, Deen, S.M (Ed), Springer, pp. 113-129, 1990.