Knowledge Sharing in an Organization of Heterogeneous Agents

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Abstract   Cooperative work, if it is by a team of engineers, or by a group of experts, requires coordination by sharing common knowledge. We focus on knowledge transaction as the methodology of sharing knowledge. Knowledge transaction processes are formulated as knowledge trading games among selfish agents. Each agent has idiosyncratic utility function defined over his private knowledge and common knowledge. Each agent trades his knowledge with others in order to improve his own utility. In this paper, we focus on heterogeneity of agents. Agent decide whether trade or not in terms of cost and value of new knowledge. The way to decide is different from each agent. We characterize an organization of heterogeneous agents by their threshold. We investigate what characteristics of an organization promote knowledge trading or discourage sharing common knowledge.

Key words   knowledge transaction,   knowledge sharing,   heterogeneity

1. Introduction

There are many situations where interacting agents can benefit from coordinating their actions. Examples where coordination is important include trade alliance, the choice of compatible technologies or conventions such as the choice of a software or language. These situations can be modeled as coordination games, in which agents are expected to select the strategy the majority does.

Social interactions pose many coordination problems to individuals. Agents face problems of sharing and distributing limited resources in an efficient way. An interesting problem is under what circumstances will a collection of agents realizes some particular stable situations, and whether they satisfy conditions of social efficiency? Coordination problems are characterized with many equilibria, and then coordination failures occur because of their independent inductive processes. A solution to problems of this kind invokes the intervention of an authority who finds the social optimum and imposes the optimal behavior to agents. While such an optimal solution may be easy to find, the implementation may be difficult to enforce in practical situations. We also face many situations where the unique or few optimal solutions exist are rare, and we usually face the infinite number of solutions. Self-enforcing solutions, where agents achieve optimal allocation of resources while pursing their self-interests without any explicit agreement with others are great practical importance. A growing effort has given towards for understanding what conditions in a society of self-interested agents may reach optimal outcome. Many researchers address the problems of how self-interested agents learn to coordinate in a complex and non-stationary worlds. Several learning rules have been found to lead optimal outcomes when agents learn from each others.

The study of knowledge creation has begun to gain a new wave. Nonaka and his colleagues have developed a new theory of organizational knowledge creation [5]. They focus on both explicit knowledge and implicit knowledge. The key to knowledge creation lies in the mobilization and conversion of tacit knowledge. They emphasize knowledge creation in two dimensions, epistemological and ontological knowledge creation. A spiral emerges when the interaction between tacit an explicit knowledge is elevated dynamically from a lower ontological level to higher levels. The core of their theory lies in describing how such a spiral emerge. They present the four modes of knowledge conversion that are created when tacit and explicit knowledge interacts with each other. The four modes, which they refer to socialization, externalization, combination, and internalization, constitute the engine of the entire knowledge creation process. These modes consist of the individual experience. They are also the mechanisms by which individual knowledge gets articulated and amplified into and throughout the organization.

The goal of our research is to formalize an economic model of knowledge creation by focusing the quantitative aspects of the value of knowledge. We classify knowledge into two kinds, one is shared knowledge, which is common to each other. This kind of knowledge can be transmitted across agents explicitly. The other type of knowledge is private knowledge. It is personal knowledge embedded in individual experience or knowledge creation. We consider common knowledge and private knowledge as basic building blocks in an complementary relationship. More importantly, the interaction between these two forms of knowledge is the key dynamics of knowledge creation in the organization of agents. Knowledge creation both at the individual and organizational level is a spiral process in which the above interaction takes places repeatedly as shown in Fig.1. In an organization, the individual interacts with other members through knowledge transaction. Knowledge creation takes place at two levels: the individual and the organization, and knowledge creation consists of the forms of knowledge interaction and the levels of knowledge creation.

We consider an organization of heterogeneous agents, and knowledge transaction among agents constitute the basic foundation of interactions in an organization. Each member of an organization with private knowledge desires to accumulate both private knowledge and common knowledge. Agents exchange their private knowledge and the transacted knowledge is shared as common knowledge, which also accelerates agents to accumulate their private knowledge. Both private knowledge of each agent and common knowledge in an organization can be accumulated through knowledge

transaction. Agents benefit by exchanging their private knowledge if their utility will be increased. At knowledge transaction, each rational agent mutually exchanges his private knowledge so that his utility can be improved[2]. In this paper, we focus on the heterogeneity of agents. Agents may consider sharing knowledge with others is important for cooperative and joint works, or they put the high value on hiding their private knowledge from other agents. Factors such as the value (worth) of acquiring new knowledge and the cost of sharing knowledge should be considered. If many agents behave selfish and they do not transact for the cost of sharing, the society of agents can not accumulate knowledge and share the common knowledge. What circumstances accelerates the sharing of common knowledge?
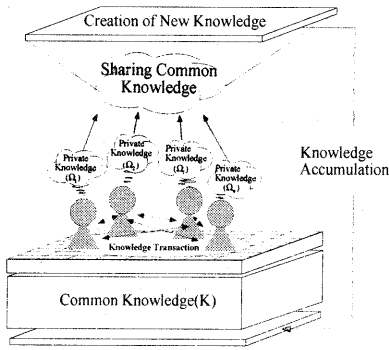

Fig 1 The knowledge creation through knowledge transactions among selfish agents

2. Concept of Knowledge Sharing in an Organization

We consider an organization of selfish agents, $G = \{A_i : 1 \le i \le N\}$ with private knowledge. This knowledge should be transacted with others. Agents can access new knowledge if other agents disclose their private knowledge. But even if he does not disclose his knowledge, and if others trade knowledge, he can access new knowledge. It's free-riding. But, if no agent trades, they can't share any knowledge. How does an agent choose strategy in order to optimizing his payoff?
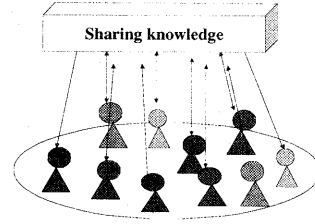

Fig 2 Knowledge trading as N-persons game

First, we show knowledge sharing can be formulated as knowledge transaction of N-persons. Each agent $A_i \in G$ has the following two trading strategies:

S_1 : Trade private knowledge

S_2 : Does not trade . (2.1)

The number of agents who choose S_1 (trade) is denoted by n $(0 \le n \le N)$. Agent A_i acquires a benefit the level of $a_i(n/N)$, which represents a fixed value a_i multiplied by the proportion of trading. If an agent trades, a cost c_i is also incurred. An agent who does not trade can get the spill-over effect of common knowledge $b_i(n/N)$ $(a_i \ge b_i)$. The payoff for each agent when he trades (S_1) or does not trade (S_2) is given as follows respectively:

$$U_i(S_1) = a_i(n/N) - c_i$$
$$U_i(S_2) = b_i(n/N) \qquad (2.2)$$

But these equations don't show the individual relationship of agent clearly. We now show that the N-persons knowledge trading game can be transformed into two persons game, and each agent trades with all other agents individually with the payoff matrix in Table 1.

Own's strategy \ The other's strategy	S_1	S_2
S_1 (Trade)	a_i-c_i	-c_i
S_2 (No trade)	b_i	0

Table 1 The payoff matrix of agent A_i

The expected payoff of each agent when he chooses S_1 or S_2 is given as:

$$U_i(S_1) = (a_i - c_i)(n/N) - c_i(1 - n/N)$$
$$= a_i(n/N) - c_i \qquad (2.3)$$
$$U_i(S_2) = b_i(n/N)$$

Since these expected payoffs become the same as (2.2). Therefore, the N-persons games can decompose two persons games.

We now obtain rational behaviors in knowledge trading games with the payoff matrix in Table 1 and characterize them.

(case1) $b_i > a_i - c_i$

In this case the expected payoffs in (2.3) are shown in Fig 3 and we obtain the relationship as follow:

$$U_i(S_2) > U_i(S_1) \quad \forall n/N \qquad (2.4)$$

Therefore, the strategy S_2 becomes to be dominant strategy and no agent trades, where no one can share knowledge. This case is known as the N-persons prisoner's dilemma game (NIPD)[1].
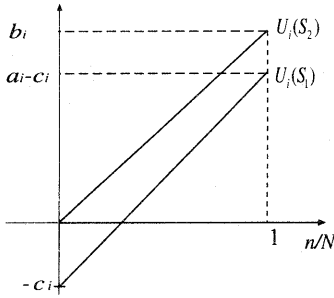

Fig 3 The expected payoffs as the function of (n/N)

(case2) $b_i < a_i - c_i$

In this case the expected payoffs in (2.3) are shown in Fig 4 and we have the following relation:

(i) $U_i(S_1) < U_i(S_2)$ if $n/N < c_i/(a_i - b_i)$

(ii) $U_i(S_1) > U_i(S_2)$

$\quad$ if $n/N > c_i/(a_i - b_i)$ $\qquad (2.5)$

The socially optimal situation is realized if all agents choose the Pareto-optimal strategy S_1. However, if the ratio of agents trading is less than $c_i/(a_i - b_i)$, the free-riding is better strategy. And nobody trades his knowledge and the situation like NIPD occurs [6].
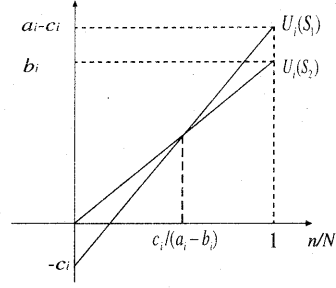

Fig 4 The expected payoffs as the function of (n/N)

3. Formalism of Knowledge Trading as 2x2 Games

In this section, we formulate knowledge transaction between two agents as the value function of knowledge. We consider an organization of agents $G = \{A_i : 1 \le i \le N\}$ with both private knowledge and common knowledge. We also define that each agent $A_i \in G$ has the following two strategies:

$\quad S_1$: Trade private knowledge

$\quad S_2$: Does not trade $\qquad (3.1)$

We define the utility function of each agent as the function both private knowledge and common knowledge. The utility function of agent A_i is defined as the semi-liner function both private knowledge Ω_i and common knowledge K, such as;

$$U_i(\Omega_i, K) = \Omega_i + v_i(K) \qquad (3.2)$$

The value $X - v_i(X)$ represents the relative value of agent A_i when he holds knowledge X as private knowledge or the common knowledge. If $X - v_i(X) > 0$, he puts a higher value on knowledge X as private knowledge. If $v_i(X) - X > 0$, he puts a higher value on knowledge X as the common knowledge
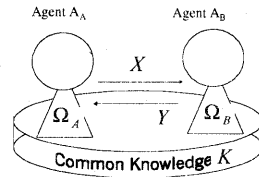

Fig 5　Knowledge trading between two agents with private knowledge

We consider a knowledge transaction between agent A_i with his private knowledge X and the trading partner

with his private knowledge Y in Fig 5. The associated payoffs of both agents in Table 2 are given as follows:

$$U_i(S_1, S_1) = \Omega_i - X + v_i(X \vee Y) \equiv U_i^1$$
$$U_i(S_1, S_2) = \Omega_i - X + v_i(X) \equiv U_i^2$$
$$U_i(S_2, S_1) = \Omega_i + v_i(Y) \equiv U_i^3$$
$$U_i(S_2, S_2) = \Omega_i \equiv U_i^4$$

(3.3)

Own's strategy \ The other's strategy	S_1	S_2
S_1 (Trade)	U_i^1	U_i^2
S_2 (No trade)	U_i^3	U_i^4

Table 2 The payoff matrix of agent A_i

The above associated payoffs can be interpreted as follows: Once they decide to trade their private knowledge, it is disclosed to the other agent, and it becomes as common knowledge. When both agents decide to trade their private knowledge, the payoffs of both agents are defined as their values of common knowledge minus their values of private knowledge. If agent A_i does not trade, and the partner trades, he receives some gain by knowing new knowledge Y. If agent A_i trades knowledge X and the trading partner does not trade, his private knowledge X becomes as common knowledge, and some value is lost because of the cost of trading. If both agents do not trade, they receive nothing.

Knowledge trading has unique features which are not found in the commodity trading. With knowledge trading, agents do not lose all the value of their traded knowledge. They also receive some gain even if they do not trade if the partner trades.

We now consider the relationship between the value function $v_i(K)$, in the payoff matrix of Table 2 and the parameters a_i, b_i, c_i, in the payoff matrix of Table 1. We assume that initial private knowledge level of agent A_i is X. Then, we obtain the following relationship.

$$a_i = v_i(X \vee Y) - v_i(X) + X$$
$$b_i = v_i(Y) + X$$
$$c_i = X - v_i(X)$$

(3.4)

This means that each agents has different payoff matrix

by his value function. We use this relationship, the threshold θ_i is given as follow.

$$\theta_i = c_i / (a_i - b_i) = \frac{X - v_i(X)}{v_i(X \vee Y) - v_i(X) - v_i(Y)} \quad (3.5)$$

The denominator of threshold in (3.5) represents the multiplier effect of sharing knowledge, and the numerator represent the cost of the trading. Equivalently, the payoff matrix in Table 1 can be transformed the payoff matrix in Table 3. This payoff matrix becomes a symmetric coordination game if $0 < \theta_i < 1$[2].

Own's strategy \ The other's strategy	S_1	S_2
S_1 (Trade)	$1 - \theta_i$	0
S_2 (No trade)	0	θ_i

Table 3 The payoff matrix of agent A_i

4. Characterization of an Organization of Heterogeneous Agents

Each agent has different threshold, and their behaviors depend on their threshold. Next, we characterize an organization in terms of threshold of agents

First, we can classify agents the following three types depending on his payoff matrix in Table 3:

(a) $\theta_i \approx 0$: Hard-core of trading

An agent with low threshold has the strategy S_1 as a dominant strategy. He is willing to disclose his private knowledge without regarding the other agent's strategy. Therefore, we define an agent with low thresholds is a hard-core of trading.

(b) $\theta_i \approx 0$: Hard-core of no trading

An agent with high threshold has the strategy S_2 as a dominant strategy. He does not trade his knowledge without regarding the other agent's strategy. We define an agent with high threshold is a hard-core of no trading.

(c) $0 < \theta_i < 1$: Opportunist

In this case, the optimal strategy depends on his partner's strategy. Therefore we define this type of an agent as an opportunist.

Each agent has idiosyncratic payoff matrix reflecting his own value judgments for knowledge trading. Therefore, we aggregate of the heterogeneous payoff matrices, one for each member of the organization, and

represent as the distribution of threshold.

As examples, we consider several threshold distributions in Fig 6. An organization with the threshold distribution in Fig.6(a) consists of many hard-core of trading with low threshold. There are many agents with high utility of the knowledge trading in organization. An organization with the threshold distribution in Fig.6(b) consists of many hard-core of no trading with high threshold. There are many agents with low utility of the knowledge trading in organization. An organization with the threshold distribution in Fig.6(c) consists of opportunists with intermediate thresholds. An organization with the threshold distribution in Fig.6(d) consists of hard-core of trading and hard-core of no trading.
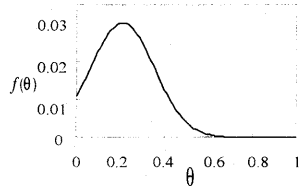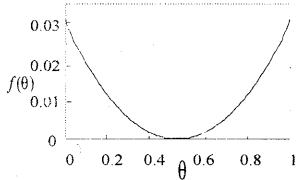

(a) Organization Type 1
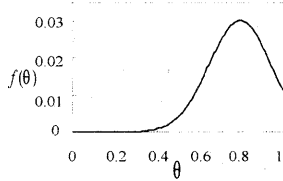
(b)Organization Type 2
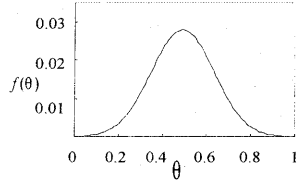
(c) Organization Type 3

(d) Organization Type 4

Fig 6 The threshold distribution in an organization

5. Characterization of Knowledge Sharing of Various Organization

In this section, we investigate knowledge trading with previous four organizations consists of heterogeneous agents. We show that knowledge trading of heterogeneous agents is different from knowledge trading of homogeneous agents [7].

In order to describe the interaction among agents, we introduce the global matching model. The approach of global matching is follows: in each time period, every agent is assumed to match (interact) with one agent drawn at random from a population as shown in Fig 7 [4]. Each agent chooses an optimal strategy based on information about what all the other agents have done in the past. And each agent can calculate his reword or other's rewords and can play the best action in a population. An important assumption of the global matching is that they receive knowledge of the current situation through global matching. The agents gradually learn the strategy in the population.

The proportion of agents to trade at time t is denoted by $p(t)$ $(0 \leq p(t) \leq 1)$, the expected utility of agent A_i when he chooses the strategy S_1 or S_2, is given as follows:

$$U_i(S_1) = p(t)(1 - \theta_i)$$
$$U_i(S_2) = (1 - p(t))\theta_i \qquad (5.1)$$

Agent A_i chooses S_1 if

$$U_i(S_1) \geq U_i(S_1) \qquad (5.2)$$

or S_2 if

$$U_i(S_1) < U_i(S_1) \qquad (5.3)$$

The optimal trading rule with global matching is obtained as the function of their threshold θ_i as follows:

If $p(t) \geq \theta_i$ then, trade S_1.

If $p(t) < \theta_i$ then, do not trade S_2. $\qquad (5.4)$

The crucial point for dealing with heterogeneity in population is threshold. According to the threshold, agent's behavior is different from each other.
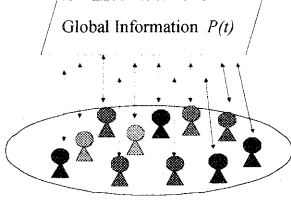
Fig 7 Global matching model

Next, we investigate the long-run knowledge trading, and we show the characteristics of knowledge trading in each organization. The heterogeneity of the organization G can be represented as the distribution function of their threshold. We denote the number of agents with the same threshold θ by $n(\theta)$ in G, which is approximated by the continuous function $f(\theta)$, defined as the density function of threshold of G. The proportion of agents whose threshold is less than θ is then given by

$$F(\theta) = \int_{\lambda \leq \theta} f(\lambda) d\lambda \qquad (5.5)$$

,which is defined as the accumulative distribution function of threshold in G.

We denote the proportion of trading by the *t-th* transaction by $p(t)$. Since the optimal transaction rule was given in (5.4), agents with the threshold satisfying $p(t) \geq \theta_i$ trade at the next time period. The proportion of agents who traded can be described by the following dynamics:

$$p(t+1) = F(p(t)) \qquad (5.6)$$

The dynamics is an equilibrium at

$$p^* = F(p^*) \qquad (5.7)$$

We consider the knowledge trading in an organization G with the threshold distribution function in Fig 6 (a)-(d). We show the dynamics of knowledge trading in Fig 8 (a)-(d). In these figures, the x-axis represents the times of knowledge trading, and y-axis represents the ratio of agents to trade at the initial stage. Fig8(a) is the result of the organization consists of many hard core of trading. All agents trade at equilibrium because many agents put high value of trading. Their optimal strategy is to trade their knowledge, and finally they trade in spite of any initial conditions. That is, they can conquer the situation such as N-persons prisoner's dilemma. On the other hands, Fig8(b) is the result of the organization consists of

many hard core of no trading. All agents do not trade at equilibrium because many agents put high value of no trading. Their optimal strategy is not to trade their knowledge, and finally they do not trade in spite of any initial conditions. That is, nobody can share the knowledge in this organization. Fig8(c) is the result of the organization consists of many opportunists. In this organization, we find that the initial ratio of trading is important to realize the optimal situation that all agents trade their knowledge. Because their strategy depends on their partners, if the initial ratio of trading is less than 0.5, they do not trade their knowledge and the situation like NIPD occurs. Fig8(d) is the result of the organization consists of both hard core of trading and hard core of no trading. In this organization, half of agents trade their knowledge and other agents do not trade at equilibrium in spite of any initial condition. Because half agents put high value of trading knowledge and other agents put high value of no trading. Only half of agents can share knowledge at equilibrium in any initial conditions.
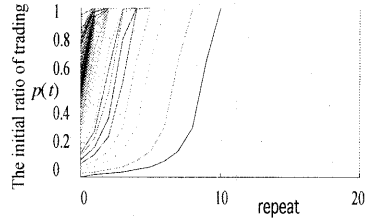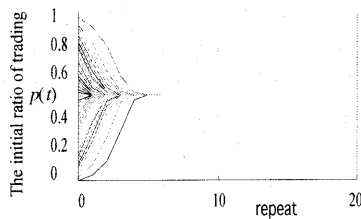

(a) Organization Type1
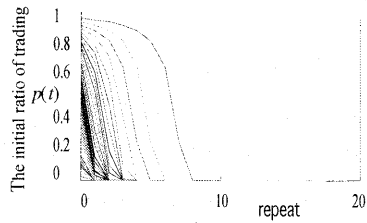
(b) Organization Type 2
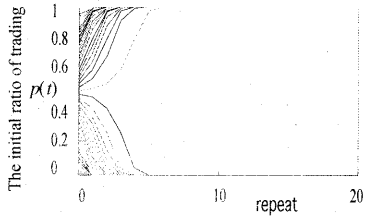
(c) Organization Type 3

(d) Organization Type 4

Fig 8 Knowledge trading with global model

6. Conclusion

We focused on heterogeneity of agents in terms of threshold. We defined that agents have different payoff matrix. That is, agents have different decision rules. We showed that knowledge trading of heterogeneous agent is different from knowledge trading of homogeneous agent. We found that agents with low threshold in an organization lead other agents to trade knowledge. And they can conquest the situation such as N-persons prisoner's dilemma. But, nobody can share knowledge at equilibrium in the organization consists of agents with high threshold even if all agents trade in the initial stage.

We obtained the completely different collective behaviors through the knowledge trading in an organization of heterogeneous agents. But if all agents trade knowledge in an organization and they realize the optimal situation, individual agent may not get enough payoff because of the cost or other factors. Next we will investigate in terms of individual level.

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