Using Agent Based Simulation and Game Theory Analysis to Study Information Sharing in Organizations – The InfoScape

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Abstract

Information sharing in organizations, especially the impact of sharing freely versus not sharing, was studied using game theory and agent based simulation. A game theoretic analysis was performed, and Netlogo simulations were carried out wherein some agents hoarded information while others shared information. As expected, sharing was found to greatly increase the overall amount of information within the organization. Unexpectedly, agents who share acquire more information than hoarders. This is due to the synergy that develops between groups of agents who are sharing with each other. The density of the agents is important--as the density increases, the probability increases that an agent with a large amount of information to share is located nearby. The implications are that organizations should actively encourage information sharing; and agent based simulation was shown to be a useful tool for studying organizational phenomena.

1. Introduction

In 1988 Peter Drucker [1] predicted a fundamental shift in corporations towards a knowledge base. The management of knowledge became a prime concern, and has been the topic of many academic studies and organizational projects (c.f. [2, 3]). But, even at this advanced stage, knowledge management (KM) endeavors can run into unforeseen problems as described in accounts of KM projects (c.f. [4-6]).

Invariably, these studies indicate the problems are due to unforeseen side effects manifested by the *system* being manipulated – namely the organization. Sterman [7] argues, however, that there is no such thing as a side effect; only effects. This is the domain of systems science and complexity science [8-10]. This paper applies tools from these fields to the study of information sharing in order to gain new insights into KM.

1.1 Problem statement

Above all, a KM project requires members of the organization to share their information and knowledge. This may be making their explicit knowledge accessible to others or by transforming their tacit knowledge into explicit knowledge for sharing. Brown and Duguid [11] argue for the importance of this process and its critical dependence on the environment such as the social work situation. Studies have shown that individuals may be motivated to share information in some cases and not share in other cases [12]. What are the dynamics of a situation where there is a mix of individuals with different motivations within an organization? What might management be able to do in order to enhance information sharing?

1.2 The Present Study

The present study begins by applying a game theoretic approach to examine the result of interactions between individuals in the organization with different preferences regarding information sharing. Given this basic framework, agent based simulation is used to model these interactions in an artificial organization made up of individuals (agents) that either share information or do not share (hoard) information. The information properties of the organization as a whole *emerge* from the interactions of the individuals.

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2. Theoretical Background

2.1. Motivations to Share Information – or Not to Share

There are a number of reasons an individual may be willing to share their information or knowledge including [12, 13]:

- The desire to be viewed as an expert
- The desire for recognition and credit
- Viewing their information as a public good (which does not belong to them individually)
- Feeling a moral obligation to share
- "Generalized reciprocity" - That is, sharing with one in the community while expecting to be reciprocated by another in the future.

However, in other cases, individuals may not be willing to share their information [14]. There are a number of potential reasons for this [15, 16]:

- Individuals may feel their *proprietary* knowledge is a competitive advantage against their fellow employees
- They may fear loss of power or control
- They may fear ridicule or criticism

In some cases the relative *fairness* of the transaction may determine the specific response as described by experimental economics research [17]. In any case, organizational culture is an important factor in these tendencies [18].

2.2. The Request to Share – A Game theory analysis

Consider two employees who have the outlook that controlling their own information and not sharing is in their own best interest. The attempt to share information represents a prisoner's dilemma. To see this, examine the payoff table of the 2 player version of the game below

	Share	Don't Share
Share	***3***,3	***1***,4
Don't Share	***4***,1	***2***,2

Take the position of the row player who is shown in bold italics. Looking at the four payoffs (shown in utiles – the basic unit of utility value):

- Row Player Doesn't Share but Column player shares: The payoff is 4 utiles. This affords the highest payoff. The row player has the column player's knowledge and also keeps their own knowledge private
- Neither player shares: The payoff is 2 utiles. The row player is worse off than in the last situation described because he does not have the column player's knowledge.
- The row player shares, but the column player doesn't share: The payoff is 1 utile. Here the row player gets his lowest payoff. He doesn't control his own knowledge anymore, but the column player does.
- Both players share their knowledge: The payoff is 3. The reason the corporation is trying to promote the sharing of knowledge is the organizational benefit from both employees having more knowledge. The sharing of knowledge helps the entire corporation in its business goals. This in turn, helps the row player and increases the payoff from the Don't Share/Don't Share cell.

This payoff matrix represents the classic prisoner's dilemma (see for example [19]). Both players have dominant strategies – 'Don't Share.' So, it is individually rational for each player to choose this strategy. However, as is the classic attribute of the prisoner's dilemma, the individually rational choices leads to collective irrationality – that is, the organization, overall, is worse off.

Now consider the interaction between two employees whose tendency is to share. Further, consider that their motivation is to be viewed as an expert. The payoff table is shown below:

	Share	Don't Share
Share	***3***,3	***4***,1
Don't Share	***1***,4	***2***,2

In this case the row player sharing while the column agent does not share affords the highest number of utiles because the row player is seen as the expert and the column player is not. The rest of the payoff matrix is completed in a similar analysis. This is game 9 in Rappaport's [20] taxonomy and has a dominant strategy for both players and a stable equilibrium - both will share.

Finally, what if a non-sharer meets a sharer? The game's payoff will be as shown below

		Non-Sharer	
		Share	Don't Share
Sharer	***Share***	***3***,3	***4***,4
	Don't Share	***1***,1	***2***,2

This is a no-conflict game with both players having dominant strategies. The Sharer will share his information, the information hoarder will keep his information and both will be happy about it.

3. Method

3.1. Agent based simulation

Agent based simulation (ABS) employs autonomous agents operating within a spatial grid that represents the agents' environment. Each cell (patch) in the grid, and each agent, run a particular set of rules / algorithms / procedures that describe how it interacts with other cells or agents. The macro behavior of the system may look very different from what one might assume by inspecting the local rules. See [21] for a more complete description.

ABS is a good choice for the present research because the information sharing process being studied takes place between individual people (agents), and it is easy to see the spatial grid as representing the agent's location within the organization. Rules can be used to describe how employees decide whether or not to share information, and the outcomes of interactions between agents.

Epstein and Axtell argue that ABS provides a different way to explain social phenomenon [22]. They argue that being able to explain a phenomenon is equivalent to asking if one can grow it in an artificial environment. They express this process as "a generative kind of social science."

3.2 The landscape for sharing – the InfoScape

The authors took an approach similar to that chosen by Epstein and Axtell in the development of Sugarscape [22]. To that end, we have aptly named the landscape for our simulation as the InfoScape. Organizational members exist in a two dimensional space. The proximity of two agents represents organizational distance. Being close together on the InfoScape represents a combination of close physical proximity, close reporting relationships, common work groups, virtual sharing opportunities and so on. For example, Allen [23] has shown that physical proximity has a direct relationship on the probability of organization members communicating. Agents who are close together are more likely to interact. The grid is wrapped into a torus to eliminate boundary effects.

On each clock tick, new information is grown on each patch. This process represents the constant availability of new information - whether it be company (e.g. manufacturing process information) or environmental (e.g. customer or competitor information) data. The amount is randomly distributed between 0 and a maximum value set at the start of the simulation.

3.3 Organization Members – The Agents

Organizational members are modeled as agents. The agents are assigned to be one of two breeds at the beginning of the simulation – either InfoSharers or InfoHoarders – and are randomly distributed across the InfoScape in a ratio set at the outset of the simulation

This point represents the first major simplifying assumption - that an agent is solely one of two breeds and acts that way consistently through the lifetime of the simulation. There are probably some organization members who do fall in this category; however it is likely that someone exhibits both tendencies depending on the context of the individual request for information sharing (e.g. who is asking, what is being asked for, the current organizational environment, etc. [15]).

Agents have an ability to detect information in their surrounding environment and within other agents – which we call their *information vision*. As in the SugarScape example, we limited the agent's vision to their von Neumann extended neighborhood (that is, north, south, east and west, but not diagonally). Each agent's vision range is randomly distributed between 0 and a maximum value set at the start of the simulation.

In this model agents are able to assess another agent's breed. Having the neighbor agent's breed being initially unknown would be another valid approach that could be investigated in future simulations. However, the author's used the first approach staying consistent with the idea that agents have good information about their neighbor's information levels and tendencies.

3.4 Model Dynamics – Collecting and Sharing Information

First, on each clock tick agents are able to harvest the new information from the environment. Each agent can harvest the information from a single patch - the patch with the largest information value within their vision range.

Next, agents request to share information with the nearby organizational member with the most information within their vision range that is willing to share. Only agents with the InfoSharer breed share information. Sharing is implemented as the requesting agent's information being increased by a percentage of the sharing agent's information (this percent is also a variable value).

On each clock tick, some of the agent's information *evaporates*. This represents two effects: actual loss of information from human memory or perhaps files being deleted due to their age; and, information is perishable - the older information gets the less valuable it is. The amount of evaporation is set at the start of the simulation.

The simulation has the option for a random amount of movement – representing organizational movement. The percent of movement is set with a variable. The percentage indicates the probability that a given agent will move on that clock tick.

3.5 Simulation Implementation and Verification

Netlogo 3.1.3 was used for the simulation. Figure 1 is a screen shot of the simulation interface. All sliders and buttons are shown on the left. Two plots are displayed: a histogram of the information held by the agents; and, a plot of the total organizational information. An output window is used for the testing phases. Monitors below the grid show the key parameters. The simulation is available at http://www.sysc.pdx.edu/faculty/Wakeland/papers/InfoScape.nlogo.

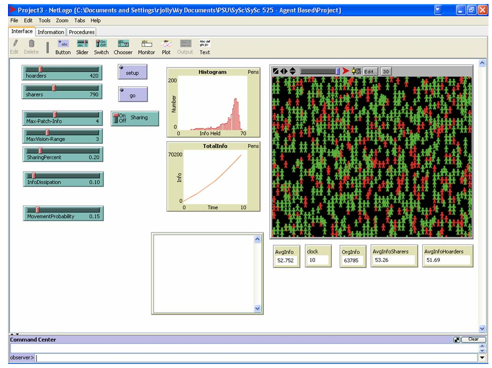

Figure 1. Screen Shot showing simulation interface

On each clock tick:

- New information is grown
- Agents harvest new information
- Agents attempt to retrieve more information from a sharing agent
- Some of the agent's information evaporates
- The agent may move to a new location on the grid.

Ticks can be repeated as many times as desired to yield a time history. Each tick represents a unit of time in the organization (e.g. a few days). As the simulation progresses the pattern of information emerges on the InfoScape.

To verify that the model's logic correctly reflected the designer's intentions, a number of activities and tests were carried out. To assure that the logic for harvesting and sharing information was correct, the attribute data for individual patches and agents was inspected, clock tick by clock tick, as the simulation proceeded. Many test displays and plots were placed on the user interface screen so that multiple aspects of the model could be viewed simultaneously. Input parameters were skewed to their extreme values to stress the logic, to ferret out unanticipated effects, and to explore the full range of possible model behaviors. Special test cases were run for which the correct behavior was known in advance. Once the model passed these tests, it was considered to be sufficiently verified to proceed with experimentation.

4. Results and Discussion

4.1. Results

Figure 2 shows a typical simulation result. In the left column all agents are InfoHoarders. In the right column all agents are InfoSharers.

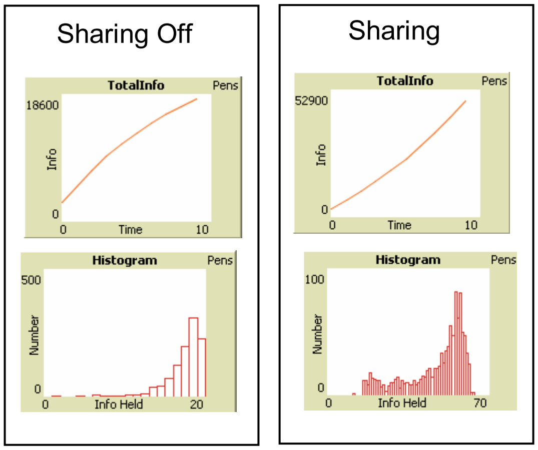

Figure 2. Simulation with sharing on and off; Note the different scales on the plots.

As expected, with sharing there is substantially more organizational information. One can also see that sharing impacts the trajectory for total organizational information over time – sharing causes the curve to bend upwards in an exponential fashion. This indicates an effect that might be considered amplification. Figure 2 also shows that sharing causes greater variance in the amount of information held by the agents. This indicates that locality is playing a role –proximity to *wealthy* InfoSharers is an important effect. These results agree with our intuition about the system.

Next the relative rate of information growth is compared across the two breeds of agents – InfoHoarders and InfoSharers. We examined this across various simulation parameters to reveal that under most conditions InfoSharers do better than InfoHoarders. However, from the prisoner's dilemma analysis, one would expect that an InfoHoarder next to an InfoSharer would create an information rich InfoHoarder and an information poor InfoSharer.

To understand the dynamics of this situation, consider Figure 3. This represents three pairs of agents located next to each other on the InfoScape. In the left two columns an InfoSharer is located next to an InfoHoarder (S and H respectively). In the middle two columns, two InfoSharers are located next to each other. In the right two columns two InfoHoarders are adjacent. The figure shows the total accumulated information level of each agent over four clock cycles. This figure assumes 2 units of information are available in the collect phase (note, this value changes at random in the simulation, but we will use a constant value here to illustrate this point) and sharing is set at 20%.

	S	H	S	S	H	H
Clock 1						
Collect	2	2	2	2	2	2
Share	2	2.4	2.4	2.4	2	2
Clock 2						
Collect	4	4.4	4.4	4.4	4	4
Share	4	5.2	5.3	5.3	4	4
Clock 3						
Collect	6	7.2	7.3	7.3	6	6
Share	6	8.4	8.8	8.8	6	6
Clock 4						
Collect	8	10.4	10.8	10.8	8	8
Share	8	12.0	13.0	13.0	8	8

Figure 3. Analysis of the synergy from sharing

First consider the left two columns – an InfoSharer next to an InfoHoarder. In the first phase of the clock tick, both agents harvest the information from the environment and their information-held account goes up to 2 units. In the second phase of clock 1 they ask each other to share. The InfoSharer gives the InfoHoarder 20% of his information (.4 units), but the InfoHoarder gives none. So, they end clock 1 with unequal amounts of information. This continues through the 4 clock phases shown until this difference has been magnified due to the unequal sharing to the point where the InfoHoarder has 50% more information than the sharer. This is consistent with the prisoner's dilemma's prediction.

Now, consider the middle two columns of Figure 3 which illustrates two InfoSharers next to each other. Through the same analysis, the InfoSharers collect the information from the environment and then proceed to share with each other. Since each is sharing, both agents' information caches are increasing. Thus, the InfoSharers have more information to share. As a result, these two adjacent InfoSharers conclude the four clock ticks with 13 units of information. That is over 8% more information that the InfoHoarder in column 1.

Finally, consider the two InfoHoarders shown in the rightmost two columns of Figure 3. They conclude the four clock ticks with only 8 units of information each.

Now if we consider the six agents in Figure 3 residing in the same InfoScape, then the three InfoSharers do better *on average* than the three InfoHoarders (the InfoSharers have 11.3 units on average while the InfoHoarders have 9.3 units on average). The *synergy* effect between the two middle InfoSharers is the key.

This makes sense on average, but shouldn't a single InfoHoarder be able to collect more information if all the others are sharing? This is the classic free rider scenario. To study this question a single InfoHoarder was simulated in a sea of InfoSharers on the InfoScape. The information of the lone InfoHoarder was compared to the average information of all the InfoSharers. The experiments were repeated 100 times to determine if any observed differences were statistical significant. Surprisingly, it was found that over most simulation conditions the InfoSharers, on average, did better than the single InfoHoarder.

Figure 4 summarizes the results of another set of simulations on the InfoScape. The numbers in the matrix represent the mean value for information held by agents, including both InfoSharers and InfoHoarders (over 100 replications). In these simulations, the density of agents on the InfoScape grid was varied as was the relative percentage of InfoSharers and InfoHoarders. Agent density represents the number of agents per unit of organizational distance as described in Section 3.2 A denser environment may result from combinations of closer physical proximity, organizational closeness (e.g. a flatter reporting hierarchy), better virtual sharing mechanisms and so on.

The chart has some unexpected characteristics. Given the earlier results, it would be natural to expect to see the largest value in the top right corner, where the density is highest, and everyone is an InfoSharer. However, the highest value for average information occurs in the *middle* of the top row. Further, notice that with 0% InfoSharers (100% InfoHoarders) the average information *decreases* as the density is increased. This can be explained by the carrying capacity of the environment. Since InfoHoarders do not share, there is no advantage to density. But, as density increases, there is a greater chance an information rich patch has already been harvested by another agent! So, in effect, we see three effects going on simultaneously in this chart:

- An increase in the average information per agent as the percentage of sharers increases. This is due to the higher probability an agent will be located near an agent who will share.
- An increase in the average information per agent as the density increases (given there are some InfoSharers). This is due to the higher probability that an agent will have a sharing agent within its vision range
- A *decrease* in the average information per agent as the density increases. This is due to the carrying capacity of the environment.

Next, the effect of random movement was studied. One might expect this to have a large effect. Networking theory (c.f. [24]) argues that occasional random links in a network substantially reduces the overall path length. However, simulations showed that the degree of random movement had a very small effect. This can be explained by again considering the synergy effect shown in Figure 3. While moving an information rich InfoSharer into a relatively information poor area will have a locally positive effect, the movement also disrupts the synergy effect between sharers that had built the information rich agent in the first place.

% Sharers	0.24	0.48	0.72	0.96	1.20
100%	48.5	55.5	57.7	57.2	56.0
75%	43.7	51.9	56.1	55.6	54.6
50%	34.1	46.6	51.0	51.3	52.2
25%	27.6	34.3	40.1	41.1	43.8
0%	18.4	17.7	16.9	16.0	14.5

Density

56-65
46-55
36-45
26-35
<26

Figure 4. Average information per agent as the percentage of sharers and the density of agents is varied

Finally, the effects of various information dissipation and sharing percentage values were also studied. While increased information dissipation impacted the information held by the agents, it didn't have a major impact on the effects discussed above. The sharing percent (per transaction) has a substantial positive effect on average agent information – as would be intuitively expected. The greater the sharing percentage, the faster the sharing synergy builds.

4.2. Conclusions

Even with the assumptions and simplifications of the model, interesting conclusions and implication can be drawn. For organizations, the results suggest that techniques to foster a culture of sharing would prove to be very beneficial.

Further, organizations should consider measures which would cluster employees to enhance the opportunity for information sharing. This pertains to organizational as well as physical nearness. For example, a flatter (higher span) reporting structure may foster sharing. In the physical realm, possibilities might be the use of cubicles versus offices. Or, organizations could foster occasions for employees to come together and network (for example, communal cafeterias, group meetings, brown bag events, etc.).

For employees located in an environment of InfoSharers and InfoHoarders, who are concerned with the no win conclusion of the prisoner's dilemma the research by Axelrod [19] outlines a potential course of action. Due to the repeated nature of the interactions, a strategy such as tit-for-tat can be employed to maximize the employee's own results as well as enhance overall cooperation. With a tit-for-tat strategy, the employee would first share with a partner. Then, if this partner reciprocates, then sharing would continue. However, if, upon request, the partner does not return the favor - then the best strategy is not to share when asked the next time.

The research also demonstrates that agent based simulation methods can be a powerful aid in the study of organizational phenomena. While these methods are not well-suited for prediction, they provide a very versatile laboratory for studying the possible effects of parameter changes and potential interventions. And, the ability to generate phenomenon can be a powerful tool in its explanation. It is vital, of course, that the processes used to develop the model, to verify and validate the model, and to carry out the experimental analysis must be well thought out and complete.

4.3. Limitations

One potential argument against the validity of the modeling of the sharing synergy is that the *same* information may be shared back and forth between neighbors over subsequent clock cycles - implying potential information double counting. This is a valid concern. While it may lead to an overstatement of the total amount of unique information in the organization, re-sharing the same information could in fact be beneficial, since an agent may have lost or forgotten a particular bit of information.

4.4. Future work

The results of this study suggest that further work is warranted. Potential next steps could include:

- Examining the possibility of a tipping point effect – that is, some critical density of sharers to trigger enhanced organizational benefits.
- Adding the simulation capability to generate a history of sharing transactions. This could be used to examine the characteristics of the sharing networks – e.g. are they random or scale-free [25].
- Examining alternative implementations to the information sharing and vision algorithms, such as having the agent look for the neighboring agent with the most information (not knowing if he is an InfoHoarder or an InfoSharer) and asking that agent to share. In the case of asking an InfoHoarder, the result would be no sharing. An agent might or might not lose his *turn* for a given clock tick after an unsuccessful attempt to share.
- One could examine a model where the agent cannot determine which of its neighbors has the most information. The current model assumes the agent has perfect information about their neighbors. This could be embellished by having the agent keep track of their neighbors (that is, once you have attempted to share with an agent, you have an idea of how much information they have and their breed). This would also allow the testing of different sharing strategies (such as the tit-for-tat strategy mentioned).

- Examining different vision algorithms – for example, implementing a radius vision which would allow the agents to see diagonally.
- Make a reciprocal sharing process – something akin to the trade algorithm in Sugarscape [22]– here agents in a group would attempt to determine who they should share with. Sharing would be a dyad between the two agents who will receive the greatest mutual benefit from the transaction.
- Making the sharing or hoarding tendency a variable – It could begin with some base tendency and modify over the course of the simulation - perhaps being based on the history of the agent's sharing transactions or with an understanding of their neighbor's state.
- Address the concerns raised earlier about information uniqueness by making the bits of information being shared unique

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