Agent Simulation Based on Perceptual Balance

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Summary

Harary's structural balance theory based on the idea of Heider explains social processes and is used to account for social actor's attitudes toward another. We propose a social value emergence model in the form of an agent-based simulation model. In this model, the structural balance theory is used to explain the feelings, attitudes and beliefs. Each agent is in effort to reach balanced states and communicates with each other. We analyze the effects between a social value emergence and agents' knowledge by using the proposed model.

Key words:

Agent-based simulation, Communication networks, Emergence system and Perceptual Balance

Introduction

Heider's balance theory [1] is regarded as a general motivational theory and provides a framework for conducting empirical work. Empirical field studies elucidated the human internal consistency which was represented by the balance of triangular system. Harary's structural balance based on the idea of Heider has been posited as a fundamental social process.

Hummon and Doreian proposed an agent-based approach based on these theories [2] which deal with dynamics of social balance processes. However, we examine the dynamics of "social value emergence" by using the agent-based computer simulation without "macro level mechanism." Based on Harary's structural balance, agent's micro-balancing process provides a macro-structure as agent's groups in our agent based computer simulation.

Perceptual Balance

To apply our simulation, we need a method of analyzing the notions and the interrelationships among them [3]. For this purpose, we refer to the naive psychology or commonsense psychology proposed by F. Heider [1]. He is a well-known founder of the theory of perceptual balance or cognitive balance, which is usually referred to as P-O-X Theory.

Heider analyzed words that express a person's situation ("Word analysis") as well as the situation itself ("situation analysis") based on naive psychology. He arrived at the notion of "relation types" that underlie various situations as follows:

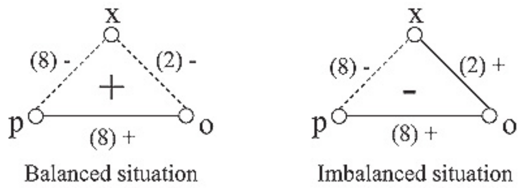

Fig. 1 Heider's perceptually balanced and imbalanced situations

1) Relations of "experiencing or being affected"
2) Relations of "causing"
3) Relations of "can (being able to)"
4) Relations of "trying"
5) Relations of "wanting"
6) Relations of "belonging"
7) Relations of "ought to and may"
8) "Sentiment" relations

Relations 1)-7), (excluding sentiment relations 8)), are called "unit formation relations". All these relations are categorized as being either positive or negative, i.e.,
(1)+, (1)−, (2)+, (2)−, . . . , (8)+ and (8)−.

Heider focused on the "consistency" of these relations in a much localized situation settings, that is, "the perceptual or cognitive balance" of a person (noted as "P") with another person ("O") with regard to an entity ("X"). For example, let us consider the case where

- P likes O ((8) +: positive sentiment relation),
- O makes a record cabinet X ((2) +: positive unit formation relation),
- P thinks that the record cabinet is poorly made ((8) -: negative sentiment relation).

These situations are illustrated in the right of Fig. 1 and are regarded as being "imbalanced" or "unbalanced." Positive relations are in full line and Negative relations are in broken line. The balance of this triangular system is defined as the sign of the product of these three arcs, being (+). In the case shown on the right-hand in Fig. 1, we have $(+)\times(+)\times(-)=(-)$, so the situation is imbalanced. The balanced situation can be accepted by P without "stress", while the imbalanced or unbalanced situation makes P feel stressful and uncomfortable.

Manuscript received December 5, 2006.
Manuscript revised December 25, 2006.

Heider's theory of perceptual balance says that an imbalanced state (situation) is altered to restore the balance of the system (situation). Fig. 2 depicts several possible relationships among the three entities P, O and X, used to restore balance.

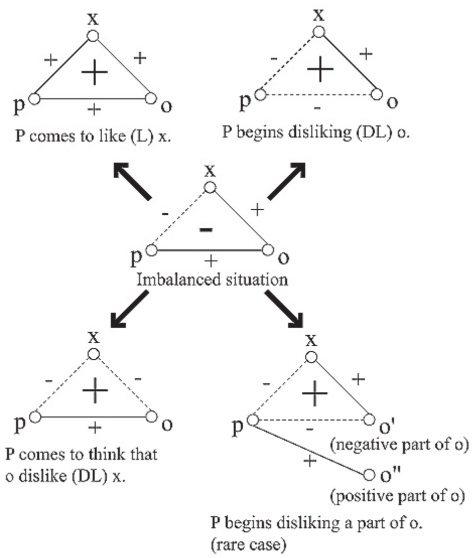

Fig. 2 Restoration of balance from an imbalanced situation

2. Minimal Balancing Processes

Moreover, perceptual balance is not localized only by these three vertices. An extension of Heider's theory was created to treat more realistic social problems. This social systems modeling uses a general signed graph, and no restriction is set on the number of members or items. Also, they do not refer to the distinction between members and items as in Heider's model [4]-[6].

2.1 Characterization of Balanced System

A graph G (balanced or imbalanced) is represented by the adjacency matrix $\boldsymbol{A}(G)=[a_{ij}]$ whose entities are stated as follows.

$$a_{ij}=\begin{cases}1 & \text{if the relation between vertices } i \text{ and } j \text{ is positive,}\\ -1 & \text{if the relation between vertices } i \text{ and } j \text{ is negative,}\\ 0 & \text{if the relation between vertices } i \text{ and } j \text{ does not exist.}\end{cases} \quad (1)$$

The structure theorem by Cartwright and Harary says that, in balanced system, the set of vertices (notions) is partitioned into two subgroups (one of which may be empty) in such a way that the relations between the vertices of the same subgroup have positive signs and relations between the vertices of different subgroups have negative signs (fig. 3). We attach $+1$ to the vertices of subgroup and -1 to those of the other subgroup given by the structure theorem. The vertices of subgroup in the balanced system is represented by a sign vector $\boldsymbol{s}=(s_1,s_2,\cdots,s_n)^T$, where

$$s_i\in\{+1,-1\},\ \text{for } i=1,2,\cdots,n. \quad (2)$$

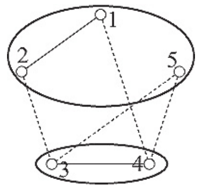

Fig. 3 Balanced graph

s^T denotes the transposed vector of $\boldsymbol{s}$ and n is the number of the vertices of G. For example, $\boldsymbol{s}=(1,1,-1,-1,1)^T$ represent the subgroups of the balanced graph shown in fig. 3.

l denotes the number of different sign relations between a graph G and a balanced graph G' as

$$\begin{aligned} l &= \sum_{i,j=1}^{n}\frac{\left|a_{ij}-s_i\cdot s_j\left|a_{ij}\right|\right|}{4},\\ &=\frac{1}{4}\left(\left(\sum_{i,j=1}^{n}\left|a_{ij}\right|\right)-\left(s_i\cdot s_j\cdot a_{ij}\right)\right),\\ &=\frac{1}{4}\left(\left(\sum_{i,j=1}^{n}\left|a_{ij}\right|\right)-\left(\boldsymbol{s}^{T}\boldsymbol{A}(G)\boldsymbol{s}\right)\right), \end{aligned}$$

(3)

where the subgroup of G' is represented by a sign vector $\boldsymbol{s}=(s_1,s_2,\cdots,s_n)^T$.

When the number of different sign relations l is minimum, a sign vector $\boldsymbol{s}^*$ (of the minimum balanced situation from graph G) satisfies the following equation.

$$\boldsymbol{s}^{*T}\boldsymbol{A}(G)\boldsymbol{s}^{*}=\max \boldsymbol{s}^{T}\boldsymbol{A}(G)\boldsymbol{s} \quad (4)$$

Considering the minimum balanced situation, it is obvious that

$$\max \boldsymbol{s}^{T}\boldsymbol{A}(G)\boldsymbol{s}\le \boldsymbol{e}^{*T}\boldsymbol{A}(G)\boldsymbol{e}^{*} \quad (5)$$

and

$$\left\|\boldsymbol{e}^{*}\right\|=n \quad (6)$$

where $\boldsymbol{e}^*$ is the eigenvector of $\boldsymbol{A}(G)$ corresponding to

the maximum eigenvalue λ^* and $\|\boldsymbol{s}\|$ is its Euclidean norm.
Therefore, approximately optimum sign vector $\boldsymbol{s}^* = \left(s^*{}_1, s^*{}_2, \cdots, s^*{}_n\right)^T$ can be given by the use of (7).

$$s_i^* = \begin{cases} +1 \text{ if } e_i^* \geq 0 \\ -1 \text{ if } e_i^* < 0 \end{cases} \text{for } i = 1,2,\cdots,n., \qquad (7)$$

where $\boldsymbol{e}^* = \left(e^*{}_1, e^*{}_2, \cdots, e^*{}_n\right)^T$ is the eigenvector of $\boldsymbol{A}(G)$ corresponding to the maximum eigenvalue λ^* [7], [8].

3. Agent Based Simulation

A. Agents

Each agent has its own $n \times n$ adjacency matrix $\boldsymbol{A}(G)$ which represents its own graph. Agent's feelings, attitudes and beliefs are virtually indicated by its graph. n is the number of notions. They balance their own adjacency matrix by the method using the eigenvector $\boldsymbol{e}^*$ of $\boldsymbol{A}(G)$ corresponding to the maximum eigenvalue λ^* as stated in Section 2.

- Common Sentiment Relations -

In order to analyze the effects between a social value emergence and agents' common sentiment relations, some relations can be incorporated into some agents in common. The case that some agents have common relations or the case that agents are categorized into two groups by their "opposite" common sentiment relations is able to be analyzed by suited parameters.
For example, the common sentiment relations among the agent x and the agent y are defined by

$$a(x)_{ij} = a(y)_{ij} \in \{+1,-1\}. \qquad (8)$$

where $a(x)_{ij}$ is an element of the agent x 's adjacency matrix $\boldsymbol{A}(x)$.

B. Communication

In our simulation, an agent communicates with another agent. An agent $\boldsymbol{A}(x)$ receives $a(y)_{ij}$ from another agent y. $a(y)_{ij}$ is an element of the agent y 's adjacency matrix $\boldsymbol{A}(y)$. $a(y)_{ij}$ is given by

$$a(y)_{ij} \in \{+1,-1\}, \qquad (9)$$

and

$$a(x)_{ij} \neq \cdot a(y)_{ij}. \qquad (10)$$

(New information for the agent x is the existence of a relation which is different from the relation that x previously had.)

C. Dissimilarity

We define dissimilarity between the agent x and y such that

$$r_{xy} = \frac{\sum_{ij}^{n} \left| a(x)_{ij} - a(y)_{ij} \right|}{4} \text{ for } i, j = 1,2,\cdots,n. \qquad (11)$$

D. Other Parameters

In this paper, following conditions are assumed.

- The number of agents m is 20.
- The number of notions (vertices) n which each agent has is 10.
- In each communication, up to 8 or 10 or 12 elements $a(y)_{ij}$ are chosen which satisfies (9) (10)
- Predetermined percentage of the elements in each of the initial adjacency matrices are 0.
- Other elements of 50% are 1 and the remaining are -1.

E. Simulation Methodology

step 1 Create agent's $n \times n$ adjacency matrices $\boldsymbol{A}(1), \boldsymbol{A}(2), \cdots, \boldsymbol{A}(m)$.
Each agent balances its adjacency matrix $\boldsymbol{A}$.

Fig. 4 Create agents

step 2 Select two agent's (x, y) randomly.
Selected agent x receives $a(y)_{ij}$ which are the elements of the adjacency matrix $\boldsymbol{A}(y)$ of another agent y.

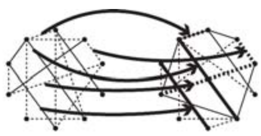

Fig. 5 Communication

The agent approximately balances its adjacency matrix $\boldsymbol{A}'$ which is replaced by received elements $a(y)_{ij}$.

step 3 Calculate the dissimilarity between $A(x)$ and $A'(x)$. (before communication and after communication)

step 4 If repetition time exceed predetermined number, then terminate, else go to step 2.

F. Simulation Conclusion

Figs. 6 and 7 show that an agent's graph structure G after 0 and 2000 communications. The graph structure G becomes complicated along with the number of communications.

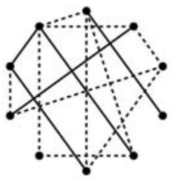

Fig. 6 An agent's graph structure at first

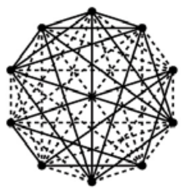

Fig. 7 An agent's graph structure *G* after 2000 communications

In figs. 8-10 3D-graphs, vertical axes show mean of dissimilarity between agent x before communication and agent x after communication (200 iterations). Horizontal axes are related to number of communications and percentages of relations which agents have at first.

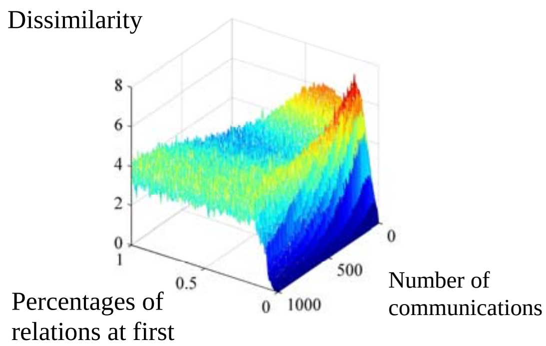

Fig. 8 8 elements $a(y)_{ij}$ are chosen for communication

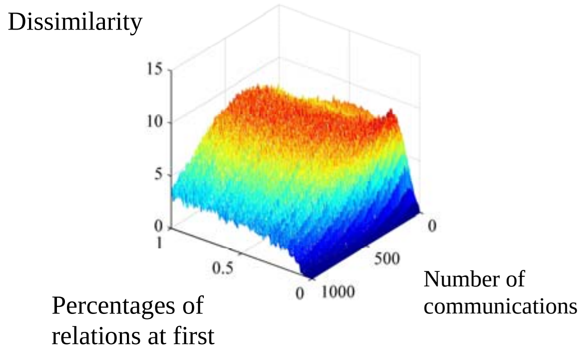

Fig. 9 10 elements $a(y)_{ij}$ are chosen for communication

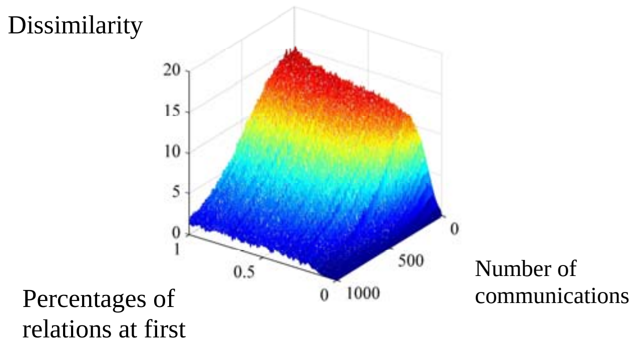

Fig. 10 12 elements $a(y)_{ij}$ are chosen for communication

These figures show us that social values emerge gradually. At first, there are no groups in the agent's society. In figs.9 and 10, dissimilarity decrease along the number of communications. After 1000 communications, there is no change of agent's graph structure approximately and they have many common sentiment relations. And these figures also show us that percentages of relations have important aspects of efficient and safe group management, because vertical axis is also regarded as "agent stress." Especially, we can see that number of communications not always reduce agents stress.

4. Conclusions and Future Works

We proposed the agent-based computer simulation based on Harary's structural balance. The micro-level agent's balancing process derives the emergence of some agent groups which cause no more change of agents' graphs. While structural balance deals with small groups and psychological situations, it can be adapted to different situations. Various societies are also virtually simulated by the suited parameter settings. The effect of the incorporation of common knowledge into the simulation can also be analyzed.

In this paper, we proposed the basic tools for the simulation based on structural balance. We need to develop a way for choosing parameter values suited for situations which involves a number of notions, new notions and buried notions, new agents and retire agents.

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