Convergence at Prominent Agents: A Non-Flat Synchronization Model of Situated Multi-Agents (Short Paper)

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ABSTRACT

This paper presents a novel *non-flat* synchronization model where the synchronization capacity of each agent is different regarding its social rank and strategy dominance. In the presented model, the prominent agents may have higher synchronization forces, and finally the collective synchronization results may incline to converge at such prominent agents' strategies, which is called *prominence convergence in collective synchronization* and proved by our experimental results. The presented model can well match the peculiarities of real multi-agent societies where each agent plays a different role in the synchronization, and make up the restrictions of related benchmark works that only concerned about the *flat* synchronization.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent Systems.

General Terms

Theory, Design, Performance.

Keywords

Multiagents, Collective Synchronization, Convergence, Prominence, Field Situated Agents.

1. INTRODUCTION

The collective motion of multi-agents has been achieving much attention in many research fields [1][2][3][4][5][6][7]. In the collective motion, each agent can select any arbitrary initial strategies to behave; but with the time going, there always emerges a popular phenomenon that most agents may converge on certain behavior strategy finally, which is called *collective synchronization*.

The related works about the collective synchronization of multi-agents always follow several assumptions. First, the collective synchronization is flat, i.e., the effects of all agents in the synchronization are identical and all agents have the same synchronization capacity, and no preferred agent strategy is picked out a priori in the model [4]; second, the collective synchronization is implemented by locally neighboring imitation of individual agents: each agent acts solely on the basis of its own local perception of the world and imitate the average strategy of its neighbors [1][3][6][7]; third, the synchronization result is the convergence on a common average strategy: at last all agents' strategies will always converge to a common average strategy of the system [7].

However, in many circumstances the above assumptions do not match the peculiarities of real multi-agent societies. First, the social ranks of agents and the performances of agent strategies are always different from each other in real multi-agent community, so different agents may have different synchronization capacities and some agent strategies may be preferred due to their characteristics or their adopters' rankings in the collective synchronization [8][9]; second, in the collective synchronization, the individual agents may sense the influences from the agents in the global contexts as well as the local neighbors, so agents will make trade-off between the influences of the local neighbors and the ones of the global counterparts [10]; third, in reality, the agents sometimes may not converge to the common average strategy of community, e.g., the collective synchronization results may converge at more than one special strategy since those strategies are dominant and influential [8].

To make up the restrictions of three assumptions in the related work about collective synchronization, we present the concept of *non-flat collective synchronization* in this paper, i.e., the effects of all agents and strategies are different in synchronization, and the synchronization result does not merely converge on a common average strategy simply. In our model, the synchronization capacity of each agent is determined by its social rank and its strategy prominence; an agent may sense the synchronization forces not only from its neighbors but also from other agents in the synchronization field.

Cite as: Convergence at Prominent Agents: A Non-Flat Synchronization Model of Situated Multi-Agents (Short Paper), Jiuchuan Jiang, Yichuan Jiang, Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008), Padgham, Parkes, Mueller and Parsons (eds.), May, 12-16., 2008, Estoril, Portugal, pp. 1493-1496

Moreover, with our model, we find an interesting phenomenon that is always seen in real multi-agent societies: if some agents' social ranks are higher than the ones of other ordinary agents, or their behavior strategies are more dominant than the ones of other ordinary agents, then the collective synchronization results may converge at such prominent agents' strategies, which is called *prominence convergence* phenomenon in this paper.

2. MULTI-AGENTS SITUATED IN A SYNCHRONIZATION FIELD

In this paper, we let all agents be situated in a collective synchronization field by referring the idea of field-based coordination [11][12.

A strategy is the action that agent adopts to behave in the multi-agent society. For example, in a flock of birds, the flying direction and velocity is the strategy of a bird. In this paper, for the reason of simplicity, we define the strategy as a simple natural number; moreover, we assume that the higher a strategy value is, then the more dominant such strategy is in the collective synchronization.

In the community, to achieve a harmonious collective motion, the agents will coordinate to synchronize their strategies. In this paper, we let the collective synchronized agents be situated in a synchronization field.

Definition 1. *A collective synchronization field of multi-agents* is a tuple $<Z, A, D, C, U>$, where:

1). Z denotes a two-dimensional geographical zone where the multi-agents are situated. $Z=\{(x,y)\}|\delta_1\le x\le\delta_2,\ \gamma_1\le y\le\gamma_2\}$, where δ_1, δ_2, γ_1, γ_2 prescribe the scope of agent locations.

2). $A=\{a_1, a_2,\cdots, a_n\}$ denotes the set of agents, where n is the number of agents.

3). D: $Z\times A\rightarrow\{true, false\}$ is a mapping from the geographical localities to the agents, which denotes the geographical distribution of the agents, e.g., if the mapping value from (x_i,y_i) to a_i is true, then it shows that there is an agent, a_i, which locates at the place of (x_i,y_i).

4). C: $A\rightarrow\mathbb{R}$ is the set of agent synchronization capacities, $C=\{c_1, c_2,\cdots, c_n\}$, where c_i denotes the synchronization capacity of agent a_i in the field, which is a real number.

5). U: $A\times Z\rightarrow\mathbb{R}$ is the agent synchronizations force function, which denotes the synchronization force of each agent at different place of the field, which is a real number.

In the system, each agent has different social rank. The agents with different social ranks in the system may take different effects; the superior agents may easily influence the strategies of junior agents.

Definition 2. *Social ranking of agent* a_i can be a function: $p_i\rightarrow\mathbb{R}$, $p_i\ge p_j$ denotes that a_i has superior rank to a_j. The set of the social ranks of all agents in the system can be denoted as: $P=[p_i]$, where $1\le i\le n$, and n denotes the number of agents in the system.

Definition 3. *Synchronization capacity of individual agents*. Obviously, the higher an agent's social rank is, then the more capable that such agent will take effect in the collective synchronization; on the other hand, according to our assumption in this paper, the higher a strategy value is, then the more dominant such strategy is in the collective synchronization. Therefore, the synchronization capacity of an agent is determined by its social rank and strategy together. Let s_i denote the strategy of agent a_i, p_i denote the social rank of a_i, A denote the set of agents in the field, then the synchronization capacity of a_i, c_i, can be defined as:

$$c_i = p_i \cdot \frac{s_i}{\frac{1}{|A|}\sum_{j\in A} s_j} \qquad (1)$$

Where $|A|$ denotes the total number of all agents in the synchronization field.

Therefore, if an agent's strategy value is higher than the average one in the field, then such agent will have higher synchronization capacity; high value of c_i indicates that agent a_i will take more effects in the strategy convergence of collective synchronization.

Definition 4. *Synchronization force between two agents*. In the collective synchronization field, the synchronization force of an agent is determined by its influencing distance d, which can be chosen according to an power-law distribution $P(d)\sim d^{-2}$. Therefore, each agent may endow synchronization forces on other agents; such force is determined by the synchronization capacity comparison between the subject agent and object one, and the distance between them. Let the locality of agent a_i in the field be (x_i,y_i), the locality of agent a_j in the field be (x_j,y_j), the distance between a_i and a_j be d_{ij}, the synchronization capacity of agent a_i be c_i, the synchronization capacity of agent a_j be c_j, then the synchronization force of a_i to a_j is:

$$\begin{aligned} f(a_i \rightarrow a_j) &= \frac{c_i}{c_j}\cdot\frac{1}{d_{ij}^2} = \frac{c_i}{c_j}\cdot\frac{1}{(x_i-x_j)^2+(y_i-y_j)^2} \\ &= \frac{p_i\cdot s_i}{p_j\cdot s_j}\cdot\frac{1}{(x_i-x_j)^2+(y_i-y_j)^2} \end{aligned} \qquad (2)$$

Obviously, higher value of $f(a_i\rightarrow a_j)$ denotes that the more probably agent a_i will influence the strategy of agent a_j.

Therefore, a collective synchronization field includes a set of situated agents with different synchronization capacities; the agents may endow different synchronization forces on other agents within the field; in the synchronization process, each agent will adjust its strategy value according to the collective synchronization forces from other agents within the field.

3. THE MODEL

3.1 Definitions for Prominence and Convergence

As said in the above section, it is assumed that higher strategy value represents higher dominance. Therefore, we think that an agent' strategy is prominent if it is higher than the average one in the synchronization field.

Definition 5. *Prominence degree of agent strategy*. Let A

denote the set of agents in the field and s_i be the strategy of agent a_i, then the strategy prominence degree of agent a_i is defined as:

$$\lambda_i = \frac{1}{\frac{1}{|A|}\sum_{j \in A} s_j}(s_i - \frac{1}{|A|}\sum_{j \in A} s_j) \quad (3)$$

Therefore, we can consider that the *ordinary agents* are those whose strategies are distributed in a limited scope, but the *prominent agents* are those whose strategies are out of such limited scope.

With the collective synchronization, the agent strategies will converge on one or some strategies finally. By referring the related concepts in [13], now we formalize our notion of strategy convergence degree in the collective synchronization.

Definition 6. *Convergence degree of individual strategy*. Let S be the set of all strategies in the synchronization field, we denote by $likeness(s_i,\varepsilon)$ the set of agents that chose any strategies in strategy set S' , which satisfies the following situation:

$$(likeness(s_i,\varepsilon) \subseteq A) \wedge (\forall a_j \in likeness(s_i,\varepsilon) \Rightarrow W(s_j,s_i) \leq \varepsilon) \quad (4)$$

Where $W(s_i, s_j)$ denotes the difference between strategy s_j and s_i: $W(s_i, s_j)=|s_j-s_i|$, ε denotes a predefined tolerance value. Therefore, let the strategy of agent a_i be s_i, the convergence of agent a_i can be defined as:

$$conv(a_i,\varepsilon) = \frac{|likeness(s_i,\varepsilon)|}{|A|} \quad (5)$$

Where $|A|$ denotes the total number of all agents in the synchronization field.

Therefore, if the convergence degrees of prominent agents are generally higher than the ones of ordinary agents, we can say that the phenomenon of *prominence convergence* emerges.

3.2 Synchronization Measures

In the related work [1][3][6][7], each agent can only perceive the local neighbors, so it will only imitate the average strategy of its neighbors. However, in real multi-agent systems, some agents may sometimes perceive the agents in a scope more than their local neighbors. Therefore, now we define the concept of sense scope of agent in the synchronization field.

Definition 7. *Sense scope of agent in the synchronization field*. In the collective synchronization field, each agent can sense the synchronization forces from other agents within a scope which is called the sense scope. We denote by $\mathbb{Z}_i$ the set of agents that situated within the sense scope of agent a_i. Here we mainly adopt geographical distance to define the sense scope, and identify one parameter-the sensing radius of an agent, r. Therefore, we have:

$$\mathbb{Z}_i = \{a_j \mid d(a_i,a_j) \leq r\} \quad (6)$$

Where $d(a_i, a_j)$ denotes the geographical distance between agent a_i and a_j in the synchronization field. $r\in(0, \infty)$, if $r\to\infty$, then each agent can sense the synchronization forces from all other agents in the field. The sense interaction relation is symmetrical, i.e., $a_j \in \mathbb{Z}_i \Rightarrow a_i \in \mathbb{Z}_j$. Obviously, $a_i \in \mathbb{Z}_i$.

In reality, there is always a measure to adjust strategy for individual agents in the collective synchronization, which is the inclination to the strategy with the highest synchronization force.

Synchronization Measure. *Inclination to the strategy of the agent with the highest synchronization force*. In the collective synchronization field, each agent will go toward to the strategy of the one with the highest synchronization force within its sense scope. We denote a_ω by the agent which endows the highest synchronization force to agent a_i within a_i's sense scope.

$$a_\omega = \arg\max_{a_j \in \mathbb{Z}_i}(f(a_j \to a_i)) \quad (7)$$

Therefore, with Synchronization Measure, agent a_i will switch to the strategy of a_ω in the collective synchronization:

$$s_i(t+1) = s_\omega(t) \quad (8)$$

Where $s_i(t+1)$ is the strategy of agent a_i at time t+1, $s_\omega(t)$ is the strategy of agent a_ω at time t.

4. TEST THE CORRECTNESS OF MODEL

In the above section, we have presented the model on the synchronization. Now we make experiments to test the prominence convergence for general situations.

In our experiments, we consider agents randomly distributed in a two-dimensional grid. The strategies of ordinary agents are randomly distributed in a limited scope $[0,\theta]$, and the strategy values of prominent agents are generally higher than θ, where θ is a natural number.

Now we test the general correctness of the model by making experiments for several random cases. Here we give a definition to rank the convergence degree of each agent in its sense scope:

Definition 8. *Rank of convergence degree for an agent in its sense scope*. Let there be an agent a_i, its sense scope is $\mathbb{Z}_i$, $|\mathbb{Z}_i|$ denotes the number of agents in $\mathbb{Z}_i$. Then we can assign an integer number Ψ_i, $\Psi_i \in [1,|\mathbb{Z}_i|]$, to a_i, which denotes the rank of convergence degree of a_i in $\mathbb{Z}_i$. In other words, let $\Psi_i = n$ ($n\in[1,|\mathbb{Z}_i|]$), then it denotes that a_i has the n^{th} rank of convergence degree in its sense scope. E.g., if $\Psi_i = 1$, it denotes that a_i has the maximum convergence degree in $\mathbb{Z}_i$; if $\Psi_i = |\mathbb{Z}_i|$, it denotes that a_i has the minimum convergence degree in $\mathbb{Z}_i$.

In our experiments, we let the agents be located in a two-dimensional grid, and the distance of each lattice in the grid is 1. Now we set the radius of sense scope of each agent is 1, thus $\mathbb{Z}_i$ is the set of agent a_i and its 8 geographically closest neighbors, shown as Fig.1. Therefore, $\Psi_i \in [1,9]$, which denotes the rank of a_i's convergence degree in $\mathbb{Z}_i$.

Now we set some agents to be prominent ones, and make the synchronization for the whole agent societies, then the resulted ranks of convergence degrees for prominent agents are seen in Fig 2. From Fig 2, we can see that the prominent agents generally have the relatively higher convergence degrees than other ordinary agents after the synchronization; thus the ordinary agents always incline to imitate the strategies of prominent agents, and the prominence convergence phenomenon emerges finally.

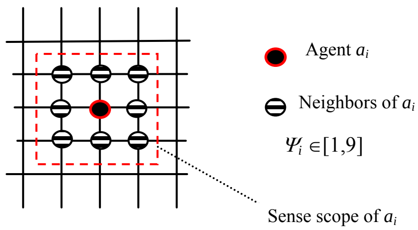

Figure 1. The sense scope of agent while sense radius is 1

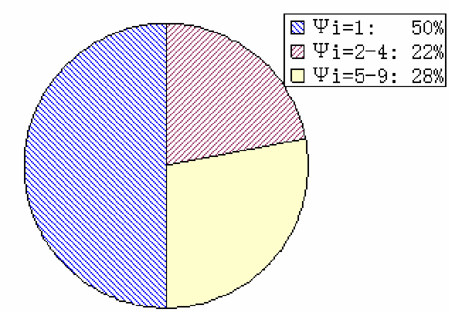

Figure 2. The ranks of convergence degrees for prominent agents in the sense scopes

5. CONCLUSION

This paper presents a non-flat collective synchronization model for multi-agents, which can make up the restrictions of the related works: 1). Each agent may have different synchronization capacity regarding its social rank and strategy; 2). Each agent may sense the synchronization forces from the scope more than the closest neighbors; 3). With the synchronization, more than one final strategy value may be converged. With our presented model, the agents always incline to converge on the prominent agents' strategies in the collective synchronization, which is called prominence convergence phenomenon.

The experimental results prove the correctness of our model; through the experimental results, we can see that the prominent agents generally have higher convergence degrees than other ordinary agents.

6. REFERENCES

[1] Reynolds. C. W. Flocks, herds, and schools: a distributed behavioral model. *Computer Graphics*, 4(21): 25-34, 1987.

[2] Toner. J and Tu. Y. H. Long-range order in a two-dimensional dynamical XY model: how birds fly together. *Physical Review Letters*, 23(75): 4326-4329, 1995.

[3] Vicsek. T, Czirok. A, Jacob. E. B, and Schochet. Novel type of phase transitions in a system of self-driven particles. *Physics Review Letter*, 6(75): 1226-1229, 1995.

[4] Toner. J and Tu. Y. H. Flocks, herds, and schools: a quantitative theory of flocking. *Physical Review E*, 4(48): 4828-4858, 1998.

[5] Mikhailov. A. S and Zanette. D. H. Noise-induced breakdown of coherent collective motion in swarms. *Physical Review E*, 4(60): 4571-4575, 1999.

[6] Jadbabaie. A, Lin. J, and Morese, A. S. Coordination of groups of mo-bile autonomous agents using nearest neighbor rules. *IEEE Transactions on Automatic Control*, 6(48): 988-1001, 2003.

[7] Lin. Z, Broucke. M and Francis. B. Local control strategies for groups of mobile autonomous agents. *IEEE Transactions on Automatic Control*, 4(49): 622-629, 2004.

[8] Jiang. Y and Ishida. T. A model for collective strategy diffusion in agent social law evolution. *Proceedings of the 20th International Joint Conference on Artificial Intelligence (IJCAI-07)*, pp.1353-1358, Hyderabad, India, Jan 6-12, 2007.

[9] Yang. W, Cao. L, Wang. X. F, and Li. X. Consensus in a heterogeneous influence network. *Physical Review E*, 3(74), 037101, 2006.

[10] Jiang. Y, Jiang. J. and Ishida. T. Agent coordination by trade-off between locally diffusion effects and socially structural influences. *Proceedings of the Sixth International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS-07)*, pp.520-522, Honolulu, Hawaii, U.S.A., May 14-18, 2007.

[11] Mamei. M and Zambonelli. F, *Field-based Coordination for Pervasive Multiagent Systems*, Heidelberg: Springer-Verlag, 2006.

[12] Weyns. D and Holvoet. T. A formal model for situated multi-agent systems. *Fundamenta Informaticae*, 2-3(63): 125-158, 2004.

[13] Walker. A and Wooldridge. M. Understanding the emergence of conventions in multi-agent systems. *Proceedings of the First International Conference on Multi-Agent Systems (ICMAS-95)*, pp.384-389, San Francisco, California, U.S.A., Jun 12-14, 1995.