Concurrent Agent Social Strategy Diffusion with the Unification Trend

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Abstract. In massive agent system, there are many diffusion processes among agent social strategies which take place concurrently. A social law is a restriction on the set of strategies available to agents [1]. All agents will trend to select an identical social strategy in the agent social law evolution, which can be called as the phenomenon of *unification trend*. This paper presents a model for the concurrent social strategy diffusion with unification trend. With the model, an agent's social strategy is influenced not only by the diffusion that bear on itself, but also by concurrent diffusion processes that bear on other agents; and, an agent will incline to the average social strategy of the whole system which can make the system be more unified.

Keywords: agent, social law, social strategy, diffusion, concurrent mechanism.

1 Introduction

The concept of artificial social system provides a new way to make coordination among agents, whose basic idea is to add a mechanism, called a *social law*, into the system [2][3][4]. According to [1], social law is the set of restrictions for agents' activities which allow them enough freedom on the one hand, but at the same time constrain them so that they will not interfere with each other [5].

Each agent has its own social strategy, and those social strategies among different agents may bring out collisions. To receive the harmony of the system, we need to endow a social law to the system, and the social law is the set of the social strategies that can be accepted by all agents. If each agent obeys the social law, then the system can avoid collisions without any need for a central arbiter [1]. Moshe Tennenholtz etc. have made some benchmark researches for the construction of social law [1][2][3]. However, they have not yet made systematic research about the evolution from individual social strategies to the global social law by the agents' interactions, and they often think the design of social law is off-line [2].

Then, how can we get the global social law? One answer is to admit that agents will have individual social strategies, but the social law can be evolved from the diffusions of social strategies [6][7].

In [6], we initiated a study on how to evolve individual social strategies to the social law by the hierarchical immediate agent diffusion interaction. Our initial model

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in [6] mainly considers how the superior agents diffuse their social strategies to the junior agents, and the diffusion only take places with the hierarchical immediate form. However, in real society, there are so many collective intentions and practices [8], and the social strategies shared by many junior agents can also influence the superior agents. Therefore, we also presented a new collective diffusion model in [7]. By the model, we can see that the social strategy of a superior agent may be changed by other social strategy owned by collective agents.

Our agent social law evolution model in [6] is the diffusion form of one by one, and the model in [7] is based on the basic diffuse form from collective agents to one agent. The two models are both *sequential*, and don't consider the *concurrent* diffusion processes among many agents. In the real society, there are many diffusion processes from collective agents to collective agents which take place concurrently. Therefore, we need to explore the concurrent mechanism in the agent social law evolution.

Otherwise, in the concurrent agent social law evolution, there is an interesting phenomenon which can be called *unification trend* in this paper. When many diffusion processes take place concurrently in the agent system, the agents will try to select an identical average social strategy which can make the system more unified. Such phenomenon is also familiar in real society where people always tend to select a general social strategy which will make the community be more harmonious.

In this paper, we will mainly address the concurrent social strategy diffusion, and explore the unification trend in the diffusion. Our model is explained by the instance of people queue exercitation.

2 Illustration for Our Instance

2.1 Our Instance

As like [7], in this paper, we also take the people standing orientations in the queue exercitation as an example to explain our model. In the system, each agent can stand with its orientation, and our goal is to minimize the total number of agent orientations. In the soldiers queue exercitation, each soldier can stand with his orientation, but they will keep their unification of standing orientation while they make queue exercitation. Therefore, at the initial stage of agent system, each agent stands with its orientation, and after continuous diffusion, we will try to make the agents stand with a unique orientation. If many agents or some superior agents stand for an orientation, then the other many individuals had no choice but to fall back on the strong orientation.

In our agent system, each agent can stand with one of the 8 orientations, seen as Fig 1. Therefore, the social strategy of an agent is its orientation. Let n be the number of agents, we can use an array to denote the social strategies of agents. $L[i] \rightarrow \{1,\cdots,8\}, 1 \le i \le n$, represents social strategy of agent i, *i.e.* the standing orientation of agent i. For example, in Fig.2, the social strategies of the agent system in (a) is shown as (b).

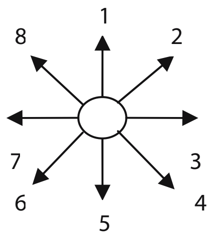


Fig. 1. 8 social strategies of agent

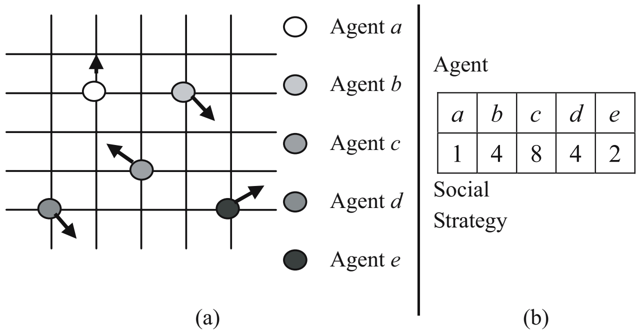


Fig. 2. An agent system and its social strategies

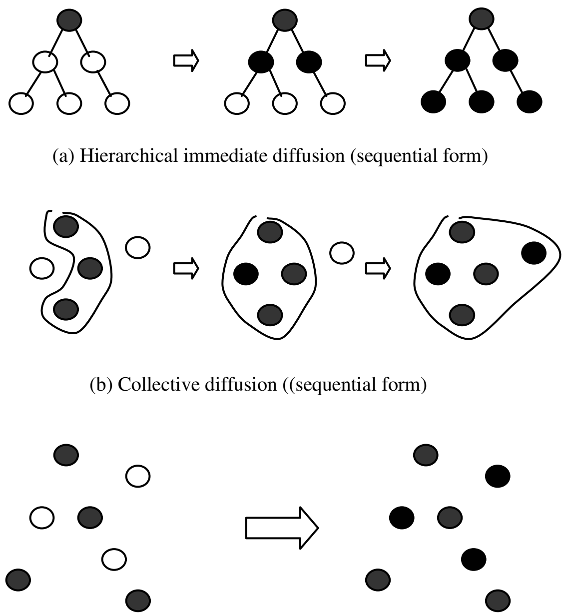
2.2 The Concurrent Mechanism and Unification Trend

In our previous works about agent social law evolution, the social strategy diffusion takes place as the sequential form. However, the diffusion is always concurrent in real society which means that many diffusion processes among agents may take place simultaneously. The concurrent mechanism of social law evolution includes the simultaneous diffusion with the form of one to one, collective to one, one to collective, and collective to collective. Fig 3 is the three forms of agent diffusion models. We mainly explored the hierarchical immediate diffusion in [6], and the collective diffusion in [7]. Now we will explore the concurrent diffusion in this paper.

From Fig.3 (c), we can see that the many diffusion processes in the system may take place concurrently. When we consider a diffusion process, we need to consider the impact of other diffusion processes that take place concurrently. Let *diffusion(i)* be the diffusion that bear on agent *i* and *A* be the agent set, the social strategy of agent *a* is not only determined by *diffusion(a)*, but also determined by $\bigcup_{b \in A-a} diffusion(b)$.

When many diffusion processes take place concurrently in the agent system, the agents will try to select an identical average social strategy, which can be called as the *unification trend*. In the society, the trend toward unification of the social strategies is obviously important in determining the evolution of the social law. With the trend to unification, the agents will incline to select the average social strategy, which can make the conflicts of the system be minimized. Finally, the social strategies within the system will go toward to unification. The evolution of social law is a collective and concurrent phenomenon, affecting by its collective and concurrent nature the way that individual agents and groups within a system think and act. In the social law evolution, the individual agents will incline to select an identical strategy which can make the system be more harmonious.

In the concurrent agent social law evolution, the diffusion of social strategies takes place under the concurrent form with the trends to unification of social strategies. Therefore, the social strategy of an agent is determined not only by the diffusion



(a) Hierarchical immediate diffusion (sequential form)

(b) Collective diffusion ((sequential form)

(c) Concurrent diffusion

Fig. 3. Three forms of agent social strategy diffusion

bearing on itself, but also by other diffusions that bearing on other agents; the trend to unification of an agent is also determined not only by itself, but also the unification trend progress of other agents.

2.3 Related Concepts in Our Instance

In the agent system, each strategy has its authority. If a social strategy is accepted by many agents, its authority will be strong. However, different agents may contribute differently to the authority of a social strategy. Obviously, the superior agents will contribute to the social strategy's authority more than the junior agents. The authority of a social strategy in the system can be called its *rank*. The concept of *rank* is always used in the web search [9], which denotes the importance of web pages. Here, we use this concept to represent the authority of a social strategy.

Definition 1. Social position of agent *i* can be a function: $p_i \rightarrow [0, \vartheta]$, where ϑ is a natural number. $p_i > p_j \Rightarrow$ the position of *i* is superior to *j*. The set of the positions 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.

In this paper, we think that: if agent *a* has a social strategy *l*, *a* is implicitly conferring some importance to *l*. Then, how much importance does an agent *a* confer to its social strategy *l*? Let N_a be the number of social strategies of *a* and let p_a represent the social position of agent *a*, the agent *a* confers p_a / N_a units of rank to *l*. In our instance, the number of social strategies of an agent is only *1*, therefore, the agent *a* confers p_a units of rank to *l*.

Definition 2. We may adopt the matrix to denote the authority of each social strategy. If agent *i* has the social strategy *j*, then let the matrix entry m_{ij} have the value p_i / N_i, or else the matrix entry m_{ij} have the value *0*. Therefore, let *A* be the set of agents in the system, the authority of social strategy *j* can be defined as:

$$\forall_j Rank(j) = \sum_{i \in A} m_{ij} \tag{1}$$

A social strategy may be accepted by many agents which can be classified as a group. For example, agent *b* and *d* both have the same social strategy 4.

Definition 3. Now, we will define the *overlay group of a social strategy*. Let *G(l)* be represented as the overlay group of social strategy *l*, we have:

$$\forall_l G(l) = \{u \mid agent\ u\ adopts\ the\ social\ \ strategy\ l\} \tag{2}$$

Obviously, the authority of a social strategy is determined by the members of its overlay group. Therefore, Let *G(l)* be the overlay group of social strategy *l*, N_u be the number of social strategies of agent *u*, then the authority of social strategy *l* in Equation (1) can also be defined as:

$$\forall_l Rank(l) = \sum_{u \in G_l} p_u / N_u \tag{3}$$

Agent can only have one social strategy in our instance, so the authority of social strategy *l* can be simplified as:

$$\forall_l Rank(l) = \sum_{u \in G_l} p_u \tag{4}$$

We will use the concept of group authority to represent the social strategy authority, *i.e.* $\forall_l Rank(G(l)) = Rank(l)$.

Definition 4. The difference of two social strategies *i* and *j* can be defined as the distance of their represented standing orientation:

$$DL_{ij} = \begin{cases} |j-i|, & if\ \ |j-i| \le 4 \\ 8-|j-i|, & if\ |j-i| > 4 \end{cases} \tag{5}$$

3 Diffusion Coordination Among Inclined Social Strategies

When diffusion processes take place concurrently with the unification trend, each agent will incline to select the social strategy with strong impact strength as well as the social strategy that that will accepted by other agents. Therefore, when we decide the change probability of an agent's social strategy, we will consider the *social strategy impact strength* and the *average social strategy* of all agents together.

In the diffusion, agent will go toward to a new social strategy which can be called as *inclined social strategy*. In the following part, we will consider the impact force of different inclined social strategies to an agent by considering the concurrent mechanism and unification trend in the diffusion.

3.1 Trend to Strong Social Strategy

The impact strength of a social strategy at a place will be decided by the collective positions of the agents within its overlay group, and the geographical distribution. Let $s_l(x, y)$ denotes the impact strength of social strategy l at the place of (x,y), $i\Theta(x, y)$ denotes that agent i doesn't locate at the place of (x,y), then $s_l(x, y)$ is defined as:

$$s_l(x, y) = \sum_{i \in G(l), i\Theta(x,y)} \frac{\alpha_1 p_i}{\alpha_2 \bullet \sqrt{(x_i - x)^2 + (y_i - y)^2}} \tag{6}$$

Where α_1 and α_1 are parameters to determine the relative importance of the two factors. If agent a is located at the place of (x,y), the set of social strategies in the system is L, then the probability that a select social strategy l in the diffusion can be initially defined as:

$$prob_i^l = s_l(x, y) / \sum_{m \in L} s_m(x, y) \tag{7}$$

Obviously, the above definition for change probability in diffusion is simple, and which doesn't consider the concurrent mechanism and unification trend in the diffusion. When an agent selects a social strategy according to the above definition, it will only consider the impact strength of the social strategy, but not consider the concurrent diffusion processes of other agents, and not trend to go toward to a unified social strategy of the system.

3.2 Concurrent Trend to Current Average Social Strategy

The diffusions of all social strategies take place concurrently, and the agents tend to select an identical social strategy that will be accepted by all agents. Therefore, the agent will incline to select not only the social strategy with strong impact strength, but also the average social strategy which can satisfy the trend to unification.

Then, what is the average social strategy? Obviously, it is not the simple average value of all social strategies. Therefore, let L be the set of the social strategies in the system, the *current average social strategy of the system (CASS)* can be defined as:

$$CASS \approx \sum_{l \in L} \frac{rank(l)}{\sum_{m \in L} rank(m)} \cdot l \tag{8}$$

The inclination of an agent will compromise the two factors of *social strategy impact strength* and *current average agent social strategy* together. Now we will define the change probability by modifying the initial definition of Equation (7) as:

$$prob_i^l * = \frac{\beta_1 prob_i^l + \beta_2 (1 - DL_{l,CASS}/8)}{\sum_n (\beta_1 \bullet prob_i^n + \beta_2 \bullet (1 - DL_{n,CASS}/8))} = \frac{\beta_1 \bullet (s_l(x,y) / \sum_{m \in L} s_m(x,y)) + \beta_2 \bullet (1 - DL_{l,CASS}/8)}{\sum_{n \in L} (\beta_1 \bullet (s_n(x,y) / \sum_{m \in L} s_m(x,y)) + \beta_2 \bullet (1 - DL_{n,CASS}/8))} \tag{9}$$

Where β_1 and β_1 are parameters to determine the relative importance of the two factors. Therefore, the probability that agent *a* selects social strategy *l* is determined by not only the impact strength of *l* but also the distance between *l* and *CASL*. Obviously, the probability in Equation (9) considers the average social strategy, which can make the agents incline to the social strategy with unification trend.

3.3 Concurrent Trend to Expected Average Social Strategy

Let the current social strategy of agent *i* is l_i and its locality is (x_i, y_i), the expected social strategy (*ESS*) of agent *i* after the diffusion can be defined as:

$$ESS_i \approx \sum_{l \in L} prob_i^l * \bullet l \tag{10}$$

Let *n* be the number of agents in the system, then the expected average social strategy of the whole system can be defined as:

$$EASS = \left\lfloor \sum_{i=1}^{n} \left(\frac{p_i}{\sum_i p_i} ESS_i \right) \right\rfloor = \left\lfloor \sum_{i=1}^{n} \left(\frac{p_i}{\sum_i p_i} \sum_{l \in L} prob_i^l * \bullet l \right) \right\rfloor \tag{11}$$

With the concurrent mechanism and unification trend, each agent will incline to such *EASL*, which can make the social strategies of the system be more unified. As said above, the agent also inclines to the social strategy with strong impact strength and the *CASL*. So, we need to compromise those three inclinations together.

Therefore, the real probability that agent *i* transfers to social strategy *l* is:

$$\begin{aligned} prob_i^l ** &= \frac{\lambda_1 prob_i^l + \lambda_2 (1 - d_{l,CASS}/8) + \lambda_3 (1 - d_{l,EASS}/8)}{\sum_n (\lambda_1 \bullet prob_i^n + \lambda_2 \bullet (1 - d_{n,CASS}/8) + \lambda_3 (1 - d_{n,EASS}/8))} \\ &= \frac{\lambda_1 \bullet (s_l(x,y) / \sum_{m \in L} s_m(x,y)) + \lambda_2 \bullet (1 - d_{l,CASS}/8) + \lambda_3 (1 - d_{l,EASS}/8)}{\sum_{n \in L} (\lambda_1 \bullet (s_n(x,y) / \sum_{m \in L} s_m(x,y)) + \lambda_2 \bullet (1 - d_{n,CASS}/8) + \lambda_3 (1 - d_{n,EASS}/8))} \end{aligned} \tag{12}$$

Where λ_1, λ_2 and λ_3 are parameters to determine the relative importance of the three factors. Obviously, $\sum_l prob_i^l ** = 1$.

4 Performance Judgment and Saturation of Diffusion

4.1 Performance Judgment of the Diffusion

After the diffusion, there may be some social strategies remained in the system, and the social strategies can't diffuse to each other any more. Certainly, for the queue exercitation, the number of standing orientations ought to be minimized so as to make the queue orientations be unified. Otherwise, we should make the social strategy with high authority can overlay more number of agents, which can make such strategy more popular. Therefore, let N_L be the number of social strategies in the system after diffusion, $|G(l)|$ be the agent number in the overlay group of social strategy *l*, then the performance criterion of the diffusion can be initially defined as:

$$P_L^{'} = \frac{1}{N_L} \sum_{l \in L} (Rank(l) \bullet |G(l)|) \tag{13}$$

Otherwise, for the trend of unification, we will try to make the difference between every agent and the current average social strategy (*CASS*) after diffusion be minimized. Let the number of agents is *n*, the total difference between all agents and the *CASL* can be called as *Variation Index* (*VI*):

$$VI = \frac{1}{n} \sum_{i=1}^{n} d_{i,CASS} \tag{14}$$

Obviously, the less *VI* is, the higher the performance of the diffusion is.

Therefore, we can modify the Equation (13), and define the ultimate performance criterion of the diffusion as:

$$P_L = P_L^{'} / VI = \begin{cases} \dfrac{n \bullet \sum_{l \in L} (Rank(l) \bullet |G(l)|)}{N_L \bullet \sum_{i=1}^{n} d_{i,CASS}} & , if \ \sum_{i=1}^{n} d_{i,CASS} \neq 0 \\ \dfrac{n \bullet \sum_{l \in L} (Rank(l) \bullet |G(l)|)}{N_L}, & else \end{cases} \tag{15}$$

Obviously, the more P_L is, the higher the performance criterion of the diffusion is.

4.2 Saturation of the Diffusion

Then, how can we fix on the end of the diffusion? The end of diffusion can be called as diffusion *saturation*. In the status of diffusion saturation, the diffusion can't proceed any more. Now, the saturation of the diffusion can be defined as:

$$EASS == CASS \tag{16}$$

This means that if the expected average social strategy is equal to current average social strategy, then status of diffusion saturation is reached even though there are still changes of agent social strategies.

5 Case Studies and Test

Fig.4 is a case for testing our diffusion model, in the case there are 19 agents with different social strategies (standing orientations). From the top left to the bottom right, we can number the agent as a_1, a_2, …, a_{18}. Now we can compute the change probability of all agents respectively according to Equation (7), (9) and (12), shown in Table.1. In Table.1, the value denotes the social strategy with the highest probability.

- If we select $prob_i^l **$, then the diffusion can be finished within a step, and the diffusion result is that all agents have l_4.
- If we select $prob_i^l *$, then the diffusion result after a step is shown as Fig.5. Now we make the 2nd step diffusion for Fig.5 according to $prob_i^l *$, the change probability is shown as Table.2.
- If we select $prob_i^l$, then the diffusion result after a step is shown as Fig.6. Then, we make the 2nd step diffusion for Fig.6 according to $prob_i^l$. The change probabilities are shown as Table.3. Therefore, now the diffusion is finished.

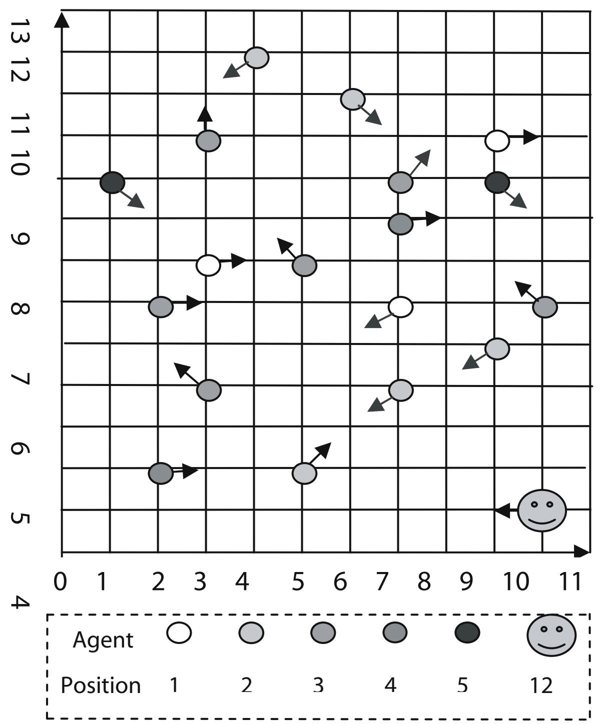


Fig. 4. The initial case, where P_L=12.9, *CASS*=5

Table 1. The inclined social strategies with the highest change probability of the initial case

Agent	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
$prob_i^l$	l_4	l_3	l_4	l_4	l_4	l_3	l_4	l_3	l_3	l_3
$prob_i^l*$	l_4	l_4	l_4	l_4	l_4	l_3	l_4	l_4	l_3	l_3
$prob_i^l**$	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4
Agent	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	
$prob_i^l$	l_3	l_3	l_6	l_6	l_3	l_6	l_3	l_3	l_3	
$prob_i^l*$	l_4	l_3	l_3	l_3	l_3	l_3	l_4	l_3	l_4	
$prob_i^l**$	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	

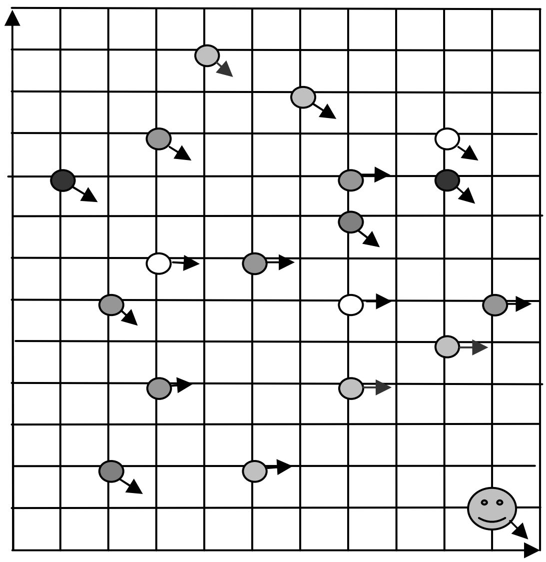


Fig. 5. The agent system after the 1st diffusion by choosing $prob_i^l*$, now *CASS*=4, P_L=622.8

Table 2. The inclined social strategies with the highest change probability $prob_i^l*$ in Fig.5

Agent	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
$prob_i^l*$	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4
Agent	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	
$prob_i^l*$	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	l_4	

Analyses for the test results:

- From the above result, we can see that it only need 1 step for the diffusion if we select $prob_i^l**$. When we select $prob_i^l**$, we consider the concurrent mechanism and the unification trend. Therefore, the social strategies of all agents can reach the status of unification shortly.

- When we select $prob_i^l*$ to decide the change probability of social strategy, we need 2 steps to reach the status of unification. After the 1st step, the number of social strategies in the system is 2.
- When we select $prob_i^l$ to decide the change probability of social strategy, we also need 2 steps to reach the status of unification. The steps is equal to the one of change probability with $prob_i^l*$. However, when the 1st step is finished, the performance of the system with $prob_i^l*$ is more than the one of the system with $prob_i^l$. Therefore, the $prob_i^l*$ consider the concurrent mechanism and unification trend better than the $prob_i^l$.

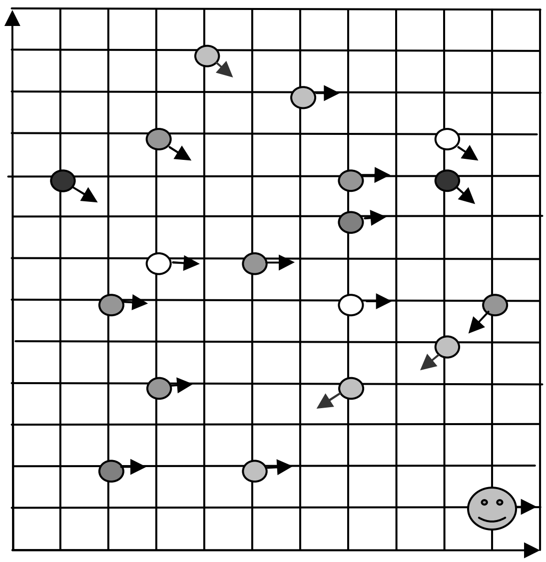


Fig. 6. The agent system after the 1st diffusion by choosing $prob_i^l$, now *CASS*=4, P_L=197.5

Table 3. The inclined social strategies with the highest change probability $prob_i^l$ in Fig.6

Agent	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
$prob_i^l$	l_3	l_3	l_3	l_3	l_3	l_3	l_3	l_3	l_3	l_3
Agent	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	
$prob_i^l$	l_3	l_3	l_3	l_3	l_3	l_3	l_3	l_3	l_3	

Summary: We can also demonstrate our model in some other cases, shown in Table 4. Therefore, from the results of all cases, we can see that our model can solve the concurrent mechanism and unification trend in the agent social strategy diffusion well. For the performance criterion, $prob_i^l ** > prob_i^l * > prob_i^l$, where '>'denotes that '*performs better than*'.

Table 4. Test results for other cases, where P_L^i denotes P_L after the i^{th} step diffusion

Case	Change Probability	*Steps*	P_L^1	P_L^2	P_L^3	P_L^4	P_L^5	P_L^6
1	$prob_i^l$	2	85	231				
	$prob_i^l *$	2	114	231				
	$prob_i^l **$	1	231					
2	$prob_i^l$	5	34	139	291	448	981	
	$prob_i^l *$	4	112	298	361	981		
	$prob_i^l **$	2	242	981				
3	$prob_i^l$	6	12	132	189	208	302	994
	$prob_i^l *$	4	34	189	245	994		
	$prob_i^l **$	2	213	994				
4	$prob_i^l$	3	24	109	341			
	$prob_i^l *$	2	98	341				
	$prob_i^l *$	1	341					
5	$prob_i^l$	6	12	45	176	221	304	981
	$prob_i^l *$	4	23	75	331	981		
	$prob_i^l **$	3	103	231	981			

6 Conclusion

There are many forms of agent social law evolution where concurrent mechanism and unification trend are often seen. This paper explores the concurrent agent social strategy diffusion with unification trend. In the concurrent diffusion, many diffusion processes will take place simultaneously, and an agent's social strategy is not only determined by the diffusion that bears on itself but also by other diffusion processes that bear on other agents. Otherwise, with the unification trend, each agent will incline to select the average social strategy of the system. This paper provided the change probability of agent social strategy by considering the concurrent mechanism and unification trend, which compromises the impacts of social strategy authority, concurrent mechanism, and unification trend.

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