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The Complex Agent Artificial Social Network based on Sugarscape —CASugarscape

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Abstract

We present an artificial social model of complex agent network, CASugarscape, to study the interaction between social network and social wealth. In the space of Sugarscape, agents survive by constantly looking for wealth within their own social circle taking their own field of vision as radius. However, agents survive by looking for wealth within the social network of friends who share wealth each other in the space of CASugarscape. In the proposed CASugarscape model, agents have different social radius based on social circle theory, which form acquaintance networks through social radius and build friendship networks through the rules of matching social wealth. Individual takes advantage of the distribution information of wealth, which comes from friend network, to look for wealth. The change of agents' wealth distribution will affect their own acquaintance and friendship networks. Eventually it forms the social wealth and social network co-evolution mechanism. We analyze the impacts of different friend networks built through different rules of matching social wealth on social networks and social wealth distribution.

Keywords: *Sugarscape, social networks, agent, artificial society, distribution of wealth*

1. Introduction

The relationship among the people consist of a social network in human society, Personal wealth acquisition activities happen in social networks, And personal wealth acquisition further affect the evolution of the social network. Therefore, the connection between the distribution of social network and social wealth usually affect and promote each other. Researching the collaborative evolutionary dynamics theory between the network and the distribution of wealth in human society can provide the regulation reference and inspiration of social wealth distribution and social relations.

A social network is a system, which is a group of people or organizations linked together by a relationship. Social wealth acquisition and social networking interaction mechanisms occurred in social networks can be employed to study the complex network model. In recent decades, computer simulation technology has been drawn increasing attention in the field of social sciences [1]. To study the complex network model, many classic network models has been produced. Watts and Strogtz proposed a small-world network model in 1998 [2]. This model reflects a characteristic of social networks, that is to say, the relationship of the majority of people are more close to neighbors or colleagues in a unit. However, a small number of people are inclined to stay away from their friends. Small world social networks have relatively short distances and relatively large average clustering coefficient. Barabási and Albert proposed BA network model in 1999 [3]. BA scale-free network is combined by "growth" and "merit" characteristics. "Growth"

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character denotes that the size of the network is not static but increasing at the same time, each network derives from a small nucleus, and by adding new nodes to grow. "Merit-based" approach determines these new nodes connected where, and will tend to choose those nodes link more with others. BA model is very concise, but the "Merit-based" approach is more reasonable, the probability of connection between the new node and the old node is determined only by the size of the existing nodes, So the older node in BA model has the higher degree compared with the new one, the latecomers cannot surpass the formers, which disagrees with the social phenomenon. Individual competitiveness should not only relate to its duration time, while related to individual ability and fitness. To make the model more realistic, researchers proposed some improved model based on the BA. Bianconni and Barabási proposed BA fitness model [4]. At the initial time, this model assumes that each node has a fixed fitness value. Preferential attachment probability made Proportional with the product of the fitness and degree of the nodes, and the more fit the richer, rather than proportional to the degree of nodes. The model mainly focus on a social network evolves, network nodes with high fitness usually have higher connectivity, and therefore, it has a wide network of social relations. However, the adaptation of the model is set in advance based on a random distribution, and cannot be determined by the characteristics of the node itself from adaptation, while the actual social network nodes in the fitness of dynamic change is according to the change of the social network. Determine nodes fitness affected by individual factors such as social wealth to need further study. Human social economic system is a complex adaptive system. Using the agent-based micro-modeling approach to study the evolution of the mechanism of social economic system of wealth has obtained a lot of attention. Robert Axtell [5] proposed Sugarscape artificial social model to address the demographic, social wealth and cultural transmission and other problems. But the model does not take into considering of the effects of social networks. Social and economic networks have a direct impact on individual wealth. It’s a powerful tool to solve this problem based on the distribution of wealth and wealth evolution analysis of complex networks. Computer simulation method has summed up the dynamic evolution of the different networks [6]. Lulan, *et al.*, studied the impact of social network structure of wealth distribution [7], furthermore, they also studied the evolution of a dynamic network model based on information asymmetry and add the marginal effect of wealth exchange mechanism, and proposed the law of the distribution of wealth [8]. Their research mainly focused on the distribution of social wealth from the social aspects of the relationship between the structures of dynamic; however, the impact of social wealth on the internet relationship was not involved.

In the realistic society, the social network and the wealth of the people is a process of mutual influence. This paper proposes a complex artificial social network model between a social network and social wealth co-evolution on the basis of the Sugarscace artificial social model. A circle of acquaintances-network with dynamic characteristics based on the Agent-based social circles network is produced which structure is closer to the actual social network structure. Then adopting fortune sharing rules to choose friends from acquaintance-network generated the friend- network, agents obtain wealth distribution information from friend- network, and Use this information to find wealth. The change of the distribution of wealth will affect acquaintance-network and friend- network, eventually construct the social wealth and social network co-evolution mechanism.

2. Sugarscape Model and Artificial Society Network Model

2.1 Sugarscape Model Sugarscape

In Robert Axtell [5] proposed Sugarscape model, which has a 50×50 two-dimensional spatial about distribution of the amount of sugar. Each point (x, y) in space has amount of

sugar and hold the space of sugar (Hereinafter referred to as "Patch"). Accommodate the amount of sugar on each patch is different. The minimum is o and the maximum is 4 of sugar, the change of colors represents different amounts of sugar. As shown in Figure 1 is the amount of sugar used in the model distribution, the lower left and upper right of the deepest color, represents the largest amount of sugar, White area on behalf of the amount of sugar is 0.

Figure 1. Distribution of Sugar

The Attributes of Agents

The attributes of Agent include, coordinate position (x, y), the amount of sugar (W), metabolism (V), visual range (r).

(1) Coordinate position (x, y)

Initial time nofagent agents randomly distributed in the different coordinate positions (x, y). Different Agents can change any position at different times, and two agents cannot occupy the same coordinates. The spatial distribution of agents is shown in Figure 2.

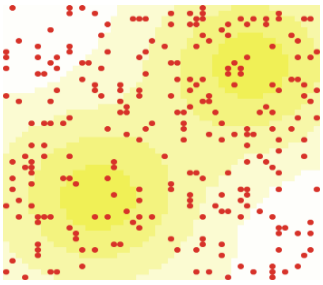


Figure 2. Agent's Spatial Distribution

(2) Metabolism (V)

Metabolism (V) refers to the amount of sugar consumption every time step or a cyclic process. Since each agent's mettle is different, so the metabolic rate is not identical. In order to reflect the difference, define V as a random value 1-4.

(3) Visual Range (r)

Visual range (r) is also a random value, with r to represent. The agents have the vision are able to see the range of units in the four directions of East West North South. In the Sugarscape model, the agent's range of vision is defined as a random value 1-6.

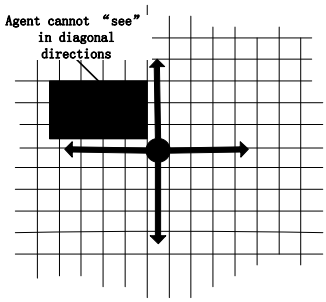


Figure 3. Agent's Field of Vision

(4) Amount of Sugar (W)

In the model, agents live in two-dimensional space to keep the collection and consumption of sugar (Agent will transfer the sugar into their own resources and defined as "sugar"; the sugar on the patches are defined as "Psugar").

Initial time, Agent was given a certain initial amount of sugar W_i. Robert Axtell [] Set the initial value of the sugar as a random value. In order to accord with social rules, this article defines Initialization of the way as rules E

Given initial rules E

- ***All agents are randomly distributed into two-dimensional space, Let each agent eat of sugar where were occupied to the power of minus three and then add eight.*** $W_i = (psugar)^3 + 8$

Because after the sugar is eaten will immediately recover the original volume, therefore the amount of sugar will continue to accumulate. Because of metabolism, agent completes the mobile as well as a certain units of energy will be consumed. The accumulation of sugar quantity decrease amount of sugar metabolism is the final amount of sugar.

Behavior Rules of Agent

The behavior rules of agent include as follows: Agents move rule $\{M\}$, birth death rule $\{B\}$, Sugarscape recovery rules $\{G_\alpha\}$

(1) Move Rule $\{M\}$

Agents were given a move rule. Each agent will find the best positions around by judge the information of Sugarscape, According to a certain standard to collect sugar so that the amount of sugar will be increased gradually.

The best positions refer to the position of the maximum amount of sugar where within the agent range of vision around.

Agents move rule $\{M\}$

- ***In the four directions within its field of view to identify the position of the maximum amount of sugar. Determine if this position is not occupied by other agent.***
- ***If both appear several equal maximum amount of sugar, choose from their recent.***
- ***Moved to this position.***
- ***In this new position, eat sugar.***

Simply, the rule $\{M\}$ can be defined this way: From all locations within the scope of vision and contain maximum amount of sugar to find the nearest position and make sure it was not occupied, moved to this position and eat sugar.

(2) Birth Death Rules $\{B\}$

Through move rule $\{M\}$, most individuals will move to the position where contain more quantity of sugar. As shown in Figure4, almost the entire agents concentrated on the

position where contain more quantity of sugar. The sugar of agent increasing, at the same time due to metabolism, every step the sugar of agent will be reduced corresponding. If at a certain moment, sugar becomes 0 or less than 0, this agent is considered to be starved to death, will be removed Sugarscape. Otherwise it will always survive. Each agent also has its own age limit. Social reality, the individual cannot be infinitely alive. If the agent up to their maximum age, it will be considered death and removed Sugarscape. This paper defines birth death as rules B

Birth Death Rules B ：

- ***If the amount of sugar of agent is less than 0 or equal to 0, dead, at the same time, born a new agent. Set the age of new agent 0, and the wealth is 4; other properties keep the same with parents.***
- ***If the agent older than the maximum age (Large age between 60 and 100), dead, at the same time, born a new agent. Set the age of new agent 0; other properties keep the same with parents.***

This rule can be understood as follows: If the amount of sugar of agent is less than 0 or equal to 0 or it older than the maximum age, then dead and born an agent to keep the number of agents unchanged. The new-born individuals cannot fully inherit all the properties of their fathers. If the agent dead because of its amount of the sugar, we need to re-assign to new initial wealth value; If the agent dead because of its age, it can inherit all property of its parents**.**

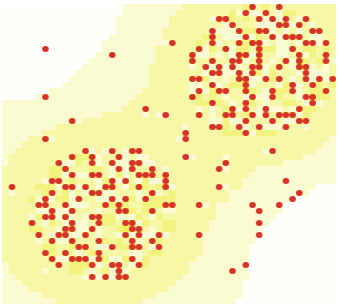


Figure 4. Agent Mobile Trends

(2) Sugarscape Recovery Rules G_α

In the model, agents live in the two-dimensional space, and can automatically continue to collect and consume sugar. And after the sugar is consumed can be restored. Robert Axtell [4] tried to recover the amount of sugar in the different rules and define this rule for $\{G_\alpha\}$. If α made different value said the rules are different. We make $\alpha = \infty$.

Sugarscape recovery rules G_α ：

If $\alpha = 1$***, at each grid position and according to the time, set a recovery rate.***

If α ***between 1 and*** ∞***, set different recovery rates at each grid position.***

If $\alpha = \infty$ ***at each grid position, immediately recover the original amount of sugar when sugar is consumed by agent***

Sugarscape model has a good explanation of the mutual interdependence between man and external resources. Human need survival and development, they must constantly get resources from the outside world. And maintenance resources need human intervention. Improved Sugarscape model largely explains the relationship between people and resources.

2.2 Artificial Society Network Model

Famous scholar social simulation Hamill and Gilbert [9] proposed a theory of social circles network based on agent to build a social network with a variety of practical method for generating statistical characteristics of social networks. It consists of agent's own construction and management mechanism of social relations, can be flexible to

describe the evolution of large-scale social network coupled. Social network models derived from the idea of social circles spatial and social distance. This idea was originally proposed by the Park and was later further developed by Heider [10] in 1924. Social network model can be seen as a social map that shows how people are associated with and distributed in society. Artificial Society is to study a variety of possible social [11] Individual's social circle represents its social scope, namely individual recognize other individuals within its social circle. The size of the social circle uses its social radius to describe. Social radiuses of each individual are different in the Social networks. The closer the distance between individuals refer to the social relations between them more closely. When create links between individuals, requiring both parties know each other before they think they are understanding, and produce a connection between the two, as shown in Figure 5.

(a) AB Cannot Generate Links **(b) AB Can Generate Links**

Figure 5. The Case of Contact in Individuals' Social Circles

Network model based on social circle can also set the radius to flexibly set of social exchange range between people, Due to differences in population distribution lead to social circles covering a diverse range and the range of contact between people is different. To reflect this individuals difference can set two or three individuals with different types of social radius, this paper set up three community radius. Social circles network in constructing the spatial distribution of the crowd while dynamic properties of social networks can also be achieved and through the introduction of socio-demographic movement to simulate daily flow. Social movement will cause changes in the structure of social networks, social demographic impact on individual mobile networks. Mobile population represents an individual who move a certain distance (A grade in the network) within a time step. Since the moving distance is relatively short, the individual may not change the network structure, only when the individual moves to the outer circle that the adjacent individual's community formed the circle will change the structure of the individual network. As shown in Figure 6, if A moved to B, then individual network structure of X changed; If A is moved to C, since the inner radius of the coverage of the community is still in X, so the individual network structure X unchanged.

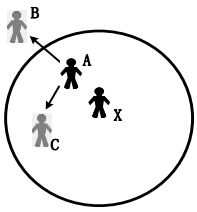


Figure 6. Social Mobile Population's Impact on Individual Network

Empirical research on complex networks shows that the social network has the following characteristics: (1) Limited size of the network and has an individual difference, the higher coefficient and the size of the cluster changes over time. 2) The overall network density is low, with the relevance of degree connection, community structure and short path length and other characteristics. Compare Social circle network with the previous four common network model-- regular networks, ER networks, small-world networks and scale-free networks, it has better performance characteristics of the actual

complex social networks. Because these four network model is flawed in aspect of embody the characteristics of social networks, causing them to not be very good social network model. Table 1 summarizes the characteristics of these four basic network models.

Table 1. The Basic Characteristics of the Four Networks [9]

Network characteristics	Rules Network	Random network	WS Network	BA Networks
The limited nature of personal networks	√	√	√	×
The individual networks of different sizes	×	Certain conditions are met	Certain conditions are met	√
Low Density	√	√	√	√
Fat-tailed distribution	×	×	×	√
Positive degree correlation	×	×	×	×
High aggregation	√	×	√	×
Can form a community	×	×	×	√
Short path length	×	√	√	×

3. Artificial Society on Sugarscape Model

The living environment of Agent keeps the same with the previous Sugarscape model which had described in section 2. Use the Sugarscape network model proposed by Robert Axtell, Join artificial social networks to study the co-evolution relationship between the social wealth and its distribution network.

3.1 Agent Property

In addition to the properties of agents on the above-mentioned coordinate position (x, y), the amount of sugar (W), metabolic (V), visual range (r), we added the population grade (Grd), social radius ($t-r$) two properties.

The Grade of Population Group（Grd）

In order to observe the evolutionary trend of different asset classes in artificial social models, we simply divide the agents into three categories: poor, middle and rich according to agent's wealth. As shown in Figure 3, the blue represents the rich, green for medium, red for the poor. And the division manners are shown in Equation (1-5).

$$C = M / N \quad (1)$$

$$D_1 = C \cdot e \quad (2)$$

$$D_2 = C \cdot f \quad (3)$$

$$M_1 = C + D_1 \quad (4)$$

$$M_2 = C - D_2 \quad (5)$$

where, C represents the central value of the income of the whole society members, M means all members of society within a certain period of total revenue, N is all members of society in a certain period, D_1 indicates the starting point for some very rich, e

represents some extreme rich starting point coefficient, D_2 represents the starting point for some very poor, f represents some extreme poor starting point coefficient.

Social Radius ($t-r$)

In a two-dimensional space, the size of each agent's social circle is represented by social radius $t-r$. In the realistic society, the wealth people often have wider social range than the poor. Correspond, $t-r$ is divided into three categories: small community radius (small-reach), moderate social radius (middle-reach), the larger society (high-reach).

3.2 Agent Behavior Rules

In addition to Move rules $\{M\}$, Birth Death rules $\{B\}$, Sugarscape recovery rules $\{G_\alpha\}$.we added new rules: Acquaintances-circle network rules $\{S\}$, Friendship-circle network rule $\{F_p\}$, move and obtain wealth rule $\{Z\}$, and disconnect the relationship between friends rule $\{D\}$.

Generate Acquaintances-circle Network Rules $\{S\}$

Generate Acquaintances-circle network rules $\{S\}$ based on the social-circle network. If people in the community know each other, and are within their radius of society, then the connection is established, otherwise the connection is not established.

In addition, according to the amount of each person's wealth, all individuals belong to the Acquaintances-circle network are divided into three categories. They are poverty, middle and rich. In the two-dimensional, Use color red, green and blue to distinguish. The size of each individual's social circle is represented by social radius $t-r$. In the realistic society, the wealth people generally have wider social range than the poor. Correspond, $t-r$ is divided into three categories: small community radius (small-reach), moderate social radius (middle-reach), the larger society (high-reach). Use rule $\{S\}$ to establish Acquaintances-circle network which is shown in Figure 7.

Generate Acquaintances-circle network rules $\{S\}$

- ***Determine whether two agents are all in their radius.***
- ***Determine whether they know each other.***
- ***If both agents simultaneously satisfy the above two, they are acquaintances and connect with line of color gray.***

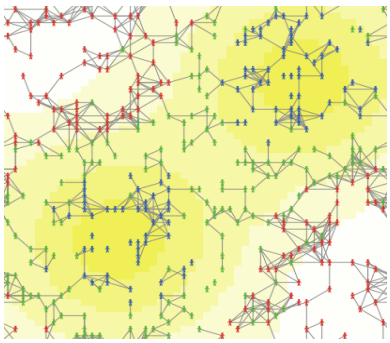


Figure 7. Acquaintances-circle networks

Generate Friendship-circle Network Rule $\{F_p\}$

Establish Friendship-circle network on the basis of the Acquaintance-circle network, which provides that individuals only the on the Friendship-circle network can achieve wealth resource information sharing. The mechanisms that exist in the actual society are

that people like connect with other people whose resources are similar with themselves. They ruled that the basis of mutual friends between people is their social status is at the same level or similar level. For this, we can study the relationship of co-evolution between the distribution of social wealth and social networks. The levels are often determined by the amount of the respective asset. Thus, we use the closeness of the amount of wealth of to define the friendship. The node of $agent_j$ who connected with $agent_i$ .If the wealth of $agent_i$ (W_i) is smaller than $agent_j$ (W_j) and satisfies the inequality. $W_i > SP \bullet W_j$ ($SP \in (0,1)$).We can establish a link between the two friends. If the wealth of $agent_i$ is larger than $agent_j$ and satisfies the inequality $W_j > SP \bullet W_i$ .We can also establish a link between the two friends. Otherwise, they cannot be established connections. The rule represents a condition that the wealth of the individuals must within the acceptable scope, otherwise not constitute friends. In the two-dimensional space, we set the links as red dotted line. As shown in Figure 8. This paper defines the process of Generate Friendship-circle as rule $\{F_p\}$.

Friendship-circle network rule $\{F_p\}$

- ***Determine whether the two individuals are acquaintances.***
- ***According to the formula*** $W_i > SP \bullet W_j$ ***or*** $W_j > SP \bullet W_i$ ***to judge the agent who has smaller wealth is in the tolerated range of who has greater wealth.***
- ***If the two individuals meet above two conditions, it is considered as friends, and connects with a red dotted line.***

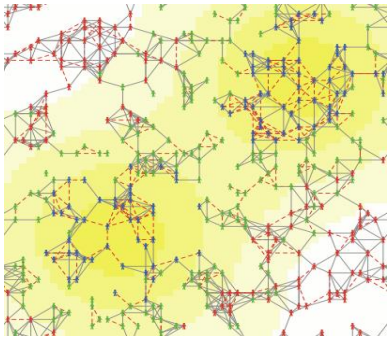


Figure 8. Friendship-circle Networks

Mobile and Acquire Wealth Rules $\{Z\}$

Unlike Sugarscape model, it is not directly through rules for resources but through the introduction of the stronger agent in the friendship-circle network to gain wealth.

In the friendship-circle network, all of the agents are friends. All of which is bound to have one strong friend at least. If these friends are willing to share information and opportunities with yourself, and you will soon be given the opportunity to earn wealth. But due to individuals who have large resources will not necessarily help all the friends, we assume that just give friends of P% help.

Accumulate wealth rule Z ***.***

- ***In the model, we let every*** $agent_i$ ***find the*** $agent_j$ ***that connected with itself and have the minimum wealth, if the two agents meet the condition of sharing information and then*** $agent_i$ ***move to*** $agent_j$ ***. And*** $agent_i$ ***as*** $agent_i$ ***as the center of the circle and as*** $DIS = 1$ ***as the radius, in according with rule*** $\{M\}$ ***to find the patches that contain the minimum sugar and eat it and multiply*** Mom ***(*** $MOM \in (1,10)$ ***). Then the wealth of every agent become*** $W_i = W_i + Mom * Psugar$ ***.***

- ***If don't meet the condition of sharing information,*** $agent_i$ ***will obtain wealth in accordance with rule*** $\{M\}$ ***directly.***

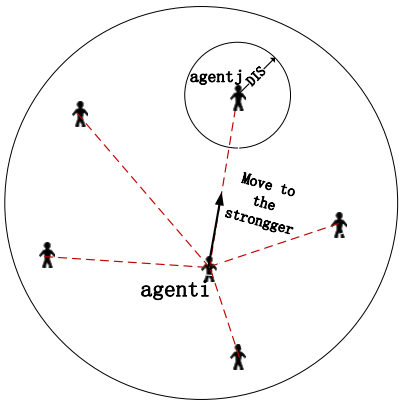


Figure 9. Mobile and Acquire Wealth

Birth Death and Network Update Rules $\{BS_F\}$

In the course of the acquisition of wealth, Because of the existence of metabolism, each time step an individual needs to consume a certain resource. Meanwhile, the rule of birth and death make the model more realistic and the rule is as same with rule $\{B\}$. The individual of death should disconnect all the links and then removed from the network. The new individuals obtain the initial wealth according to the rule E and establish new acquaintance-circle and friend-circle networks according to the rule $\{S\}$ and $\{F_p\}$

The Friendships of Maintain and Breaking Rule $\{D\}$

The Changing of Individual Wealth Value Causes the Change of Friendship. Since each person's wealth value change dynamically over time and one of the principles of establish friendship-circle network is divided by the number of wealth. Therefore, when the wealth value is changed, it may need to disconnect the existing connection and re-establish a new friendship-circle network according to the rule $\{F\}$.

More than the Individual Maximum Degree Value will Cause the Change of Relationship between Friends. In real life, everyone could not have unlimited know all the people in the world. Even within their own social range and the tolerance range of wealth, there may not be friends with each other or do not know at all. In this paper, set the number of friends of every agent is at most TK (i.e., the upper limit of the degree $TK \in (20,100)$), If any agents exceed this limit, the excessed links will replace the existing links randomly. Some occasional factors can also lead to changes in the relationship between friends. Model specifies the edges will disconnected by the probability of $DKL = 10\%$ each time step so that can reflect the random of friendship.

For these reasons, this article will define the disconnect rule as rule D .

Disconnect rule D

- ***Judge whether the wealth of friends which had been connected with red line meet the rule*** $\{F\}$ ***in the friendship-circle network. If it does not fit the rule ,then disconnect the***
- ***Determine whether the degree of each agent beyond their maximum limit. If it exceeds the n, random disconnect the original connection of n make friends relationship is not established.***
- ***By 10 percent probability of making friends randomly disconnect between friends with red dotted line connected.***

4. Artificial Network Simulation Process of Social Evolution

1. **Create and initialize agent**: Create 200 agents and randomly distributed within a range of 50 × 50-dimensional space and at the same time open the map belongs to the Sugarscape network, the map tile to the two-dimensional space.

2. **Assigned an initial value for agents:** every agent obtains the initial value of $W_i = (psugar)^3 + 8$ according to Rule $\{E\}$ Assume that each person's acquaintances are living in a radius of a circle to its own. Radius is expressed for "t-r". T-r divided into three categories: small-reach，middle-reach，high-reach. Corresponding generate three kinds of circles: Poverty, Moderate poverty, Rich. The colors are red, green, and blue in the two-dimensional, respectively. in the two-dimensional.

3. Generate the social networks: Agents establish acquaintances-circle networks according to the rule $\{S\}$; establish the friendship-circle networks according to the rule $\{F_p\}$ on the basis of acquaintances-circle networks.

4. Find resources, obtain wealth: The agents in accordance with the rule $\{Z\}$ to move and wealth accumulation, and wealth consumption.

5. Recovery resources of the patches on the map: When the resources on the patches are consumed should recover immediately to maintain the sustainability according to the rule $\{G_\infty\}$.

6. Update social-circle networks: (1) After individuals move, it is necessary to re-use the rule $\{S\}$ to update acquaintance-circle network and update friend-circle network according to the rule $\{F_p\}$. (2) Analyze the population of birth/**dead** and employ the rule $\{BS_F\}$ to update social-circle networks. (3) Since the establishment of the two circles is mainly based on the size of their wealth value, Everyone's wealth value will change after undergoing obtain wealth and we should establish the acquaintance-circle network and friend-circle network according to the rule $\{S, F_p\}$ again on the basis of their wealth value.

7. Calculate social network structure parameters: Calculate the distribution of wealth, the degree - degree correlation coefficient, clustering coefficient and degree distribution and other parameters that describe the social network features.

8. The network's dynamic evolution: As time updates, repeat steps 4-7.

5. Simulation Results Analysis

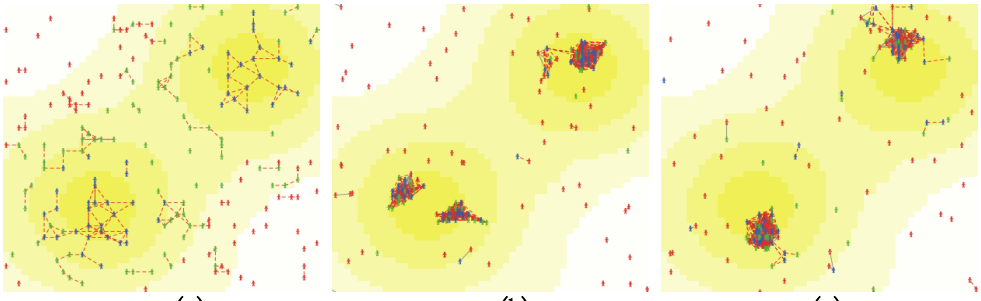
This model use NetLogo [12] as a platform, the structure parameters were discussed in the SP=20%, 50% and 90%. We get the structural parameters of SP impact on the distribution of social wealth. The environment in which the agent is set to a two-dimensional space of 50 × 50 mesh, and the specific parameters in Table 2 as below.

Table 2. Adjustable Parameters and Initial Values of Model

Parameters	Initial value	Description
nOfAgents	200	The total number of agents
small-reach	2	Social radius of the poor
middle-reach	3	Medium poor social radius
high-reach	4	The rich social radius
SP	20%	The proportion of become friends
DIS	4	The radius of finding resources which see the rich resources of nodes as the center
Max-e	0.5	The extreme rich range
Min-f	0.9	The extreme poor range
Mom	2	The proportion of obtain wealth
TL	50	The maximum degree Friendship-Network
DKL	10%	Disconnect links of friends

5.1 Analysis of Network Evolution

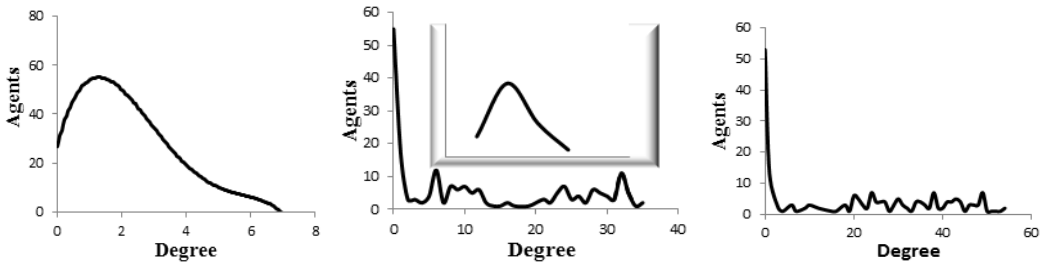
The Dynamic Evolution of the Network under SP=20%



(a) (b) (c)

Figure 10. The Dynamic Evolution of the Network under SP=20%

The system parameters are shown in Table 2 and the network evolution are shown in Fig10. At this point SP = 20%. SP = 20% said the wealth of the smaller agent account for more than 20% of large wealth agent, two agents are friends in the acquaintance network. As can be seen from Figure 10, the individuals presents the phenomenon of communities gradually, the number of divorced individuals outside the community continue to decline and eventually form two large groups and occupy the two spaces that contain larger resources respectively. All of agents are connected with each other in the communities. They are the friends. Although there are three kinds of agents: poverty, middle and wealthy, But the community structure did not appear three kinds of community. Wealth and poor hugged together to form two groups. And although many isolated individuals located in areas with fewer resources, but they are not all poor individuals, there are also a small number of middle and wealthy individuals' distribution. This shows that when the network reaches stable, some isolated individuals will be added to the community and the individual will be isolated from the community. The network is a dynamic steady state. These phenomena coincide with the social reality. At this time, the degree-degree of correlation coefficient is 0.042 and it's greater than 0.It is a positive correlation network. Corresponding to Fig. 10 (a), (b) and (c), the clustering coefficient of network is 0.494 0.623 0.818 respectively, the clustering coefficient is large when the network keep stable, which also reflects the phenomenon of visually consistent from the network diagram.



(a) **(b)** **(c)**

Figure 11. The Evolution of Degree Distribution at SP =20%

The evolution of degree distribution of the networks is shown in Figure 11. Initial time, the majority of the individual degree values is present from 1 to 3; there are also a small number of large degree values of individuals. With the change of the time and condition, small communities began to emerge among individuals, which are shown in Figure 11 (b). Distribution curves have multiple peaks, from the enlarged peak picture, we can see the small peak curve is approximate the Poisson distribution and Poisson distribution keep consistent with previous conclusions. After the network achieved stable status, forming

two big community groups, despite the curve is also exist but the number is increased, and the peak value becomes smaller. At this time the most degree value is about 55. This means that each major community is brought together by many small communities. The inner links are the strong connection in these small communities, and the links among the small communities are weak connections. The number of links of every agent almost keeps the same.

The Dynamic Evolution of the Network under SP=50%

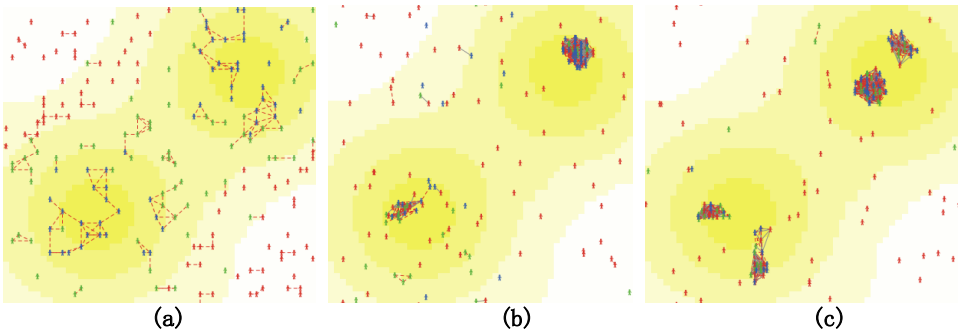


Figure 12. The Dynamic Evolution of the Network under SP=20%

Let the system parameter SP = 50%, network evolution process is shown in Figure 12. When the network keep stable, it also appeared social the phenomenon of communities, but compared with SP = 20% the community is no longer mainly concentrated in two groups but rather multiple communities. As shown in figure 12(c), the degrees-degree correlation coefficient is 0.038 and the network is positively related network. The clustering coefficient of the network is 0.795 and compared with the SP = 20% which was shown in Fig10（c）, it had declined. This shows that the strong link between community and community structure internal to the weak link close degree decreased.

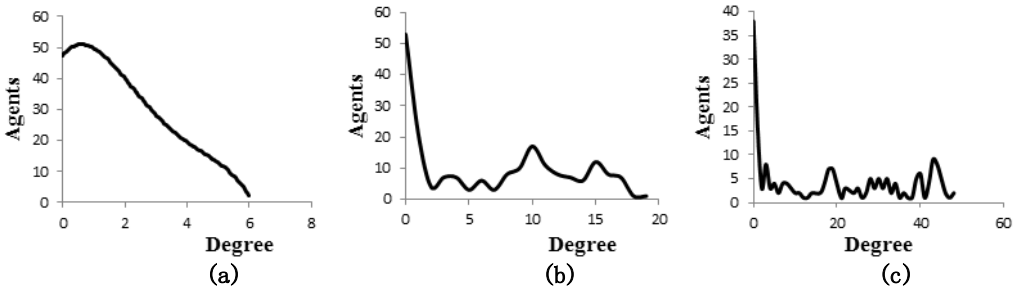
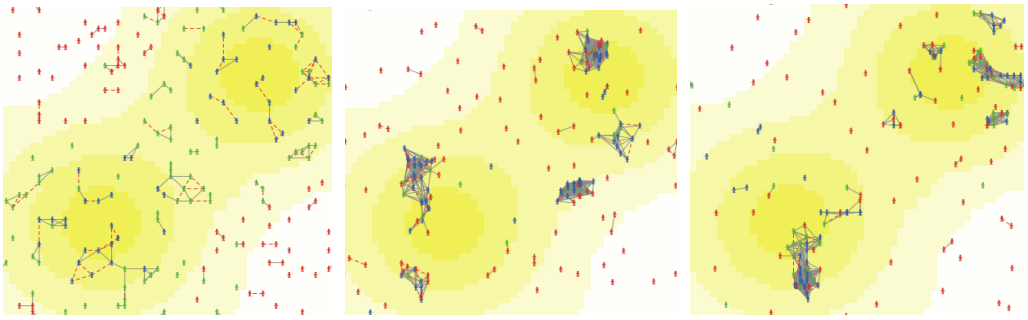


Figure 13. The evolution of degree distribution at SP =50%

As shown in Figure 13 (a), (b) and (c) for the corresponding degree distribution evolution. The degree distribution of initial time 13 (a) exhibits disparity, majority of individuals' degree keeps the smaller value and the differentiation is serious. There have been multiple peaks; each peak also follows the Poisson distribution which is shown in Figure (b). When the network reaches a dynamic steady state (Figure (c)), SP = 20% with the comparison, it is apparently to see the number of peaks in this case is further increased and a large peak appeared many places; The maximum degree value is also reduced from 55 to about 50, which shows that, Although the size of the friendship-circle network is reduced but the number continues to increase and the density decreased. The rule $\{F\}$ making wealth difference within 50% of the individual can become friends and then build friendship network and the rich connection probability increase, reinforce the trend of alliance between giants.

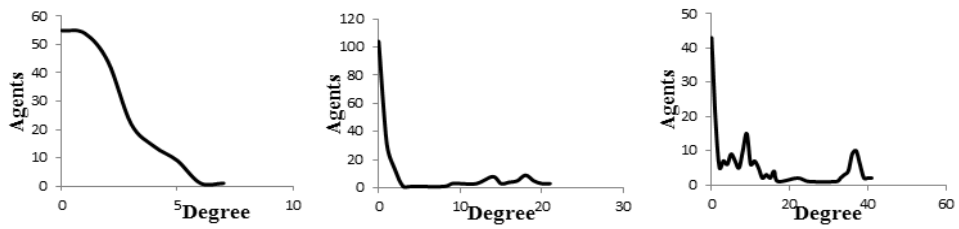
The Dynamic Evolution of the Network under SP=90%



(a) (b) (c)

Figure 14. The Dynamic Evolution of the Network under SP=90%

Let the system parameter SP = 90%, network evolution process is shown in Figure 14. The evolution of the network is similar to the previous two. When network reaches dynamic stabilization time, a further increase in the number of communities; the size is further reduced and difficult to form a larger community. At this point of the network, the correlation coefficient of degree-degree is 0.032, is also positively related network. Corresponding to Figure 14 (a), (b) and (c), the clustering coefficient is 0.746. And take Figure 14 (c) as an example, compared with the 0.818, 0.786, the value is reduced again. Tightness of the communities had decreased and the number of communities had further increased.



(a) (b) (c)

Figure 15. The Evolution of Degree Distribution at SP =90%

As shown in Figure 15 (a) (b) and (c) are the corresponding degree distribution evolution. The phenomenon of disparity of degree distribution in initial time (15 (a)) is further strengthen. When the network evolution to an intermediate time, due to the decline in the tightness of the network, although appearance the communities, but it is not very obvious. When the network reached the dynamic stability, as shown in 15 (c) the maximum degree value is about 40, compared with 50 (Figure. 11 (c))and 55(Figure. 13 (c)) respectively, the peak decreased significantly and mainly can be seen at the start and the end of the curve. This indicates that the individuals who have smaller and lager degree values appear small communities respectively. Communities present the phenomenon of further fragmentation. Only those individuals who have almost the same amount or wealth can become friends' social network. It's obvious that the trend of alliance between giants.

5.2 Wealth Analysis of the Network

The Wealth Distribution of the Value SP = 20% in the Network

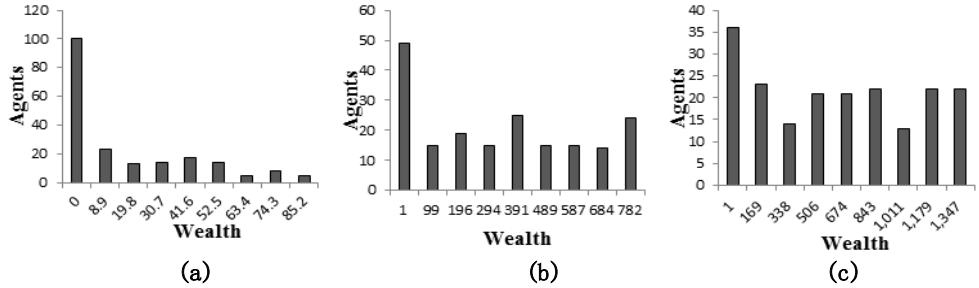


Figure 16. The Wealth Evolution of Network when SP = 20%

According to the rule $\{E\}$ of assigning an initial value, since the initial moment, affected by geographical environment and the origin, the gap between rich and poor is serious. With the passage of time, the number of the poor gradually reduces and almost all individuals got the accumulation of wealth. When the network is close to equilibrium, the number of people at all levels almost keep the same, the gap between rich and poor got much relief (It should be noted that although the network got to stabilize, but the activities of individual accumulation of wealth is still ongoing, it is a dynamic equilibrium process), and distribution of wealth of the whole network presents a phenomenon of equalization. This point can be confirmed By Lorentz curve shown in Figure 17.

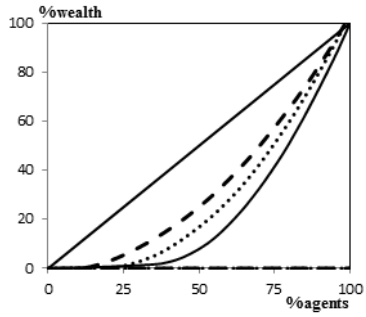
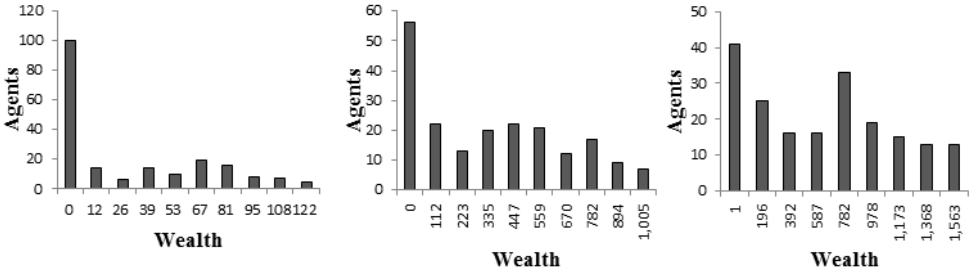


Figure 17. The Change of Lorenz Curve when SP = 20%

Figure 17 is the change of Lorenz curve for the network evolution in different periods. The Lorenz curve is used to compare and analysis the wealth inequality of a country in different time or in different countries at the same time. The curve is a convenient graphical method for summarize of income and wealth distribution.

From the Lorenz curve, we can find that a national income distribution equality or inequality conditions. As shown in Figure 17, the area between the curve and the diagonally straight line smaller and smaller (The solid, dotted and dashed line in the figure representing the simulation process of the 80th step, 150th and 220th steps). This suggests that the individual's social scope is more and more widely and the wealth flow range become widely. More and more poor individuals get more wealth, social wealth imbalance eased.

The Wealth Distribution of the Value SP = 50% in the Network



(a) (b) (c)

Figure 18. Wealth Evolution of Network when SP = 50%

The wealth of the initial time is still shown a great imbalance, the poor quantity occupied the most and the gap between rich and poor is more serious. As time goes on, every individual has constantly accumulated wealth. But when the network achieved dynamic stability, as shown in figure 18 (c), although the gap between rich and poor got a certain amount of relief, the extent compared with SP = 20% become lower. SP = 50% said: according to the rule $\{F_p\}$, the individuals who have fewer resources must be taken at least more than 50% of the individuals who have more resources can become friends and establish connections, the larger the value of SP, the lower of the extent of communicate between the bottom and the upper of society.

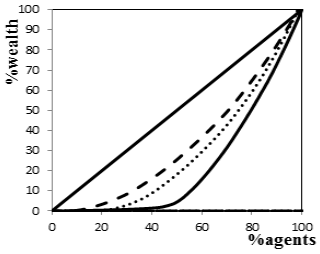
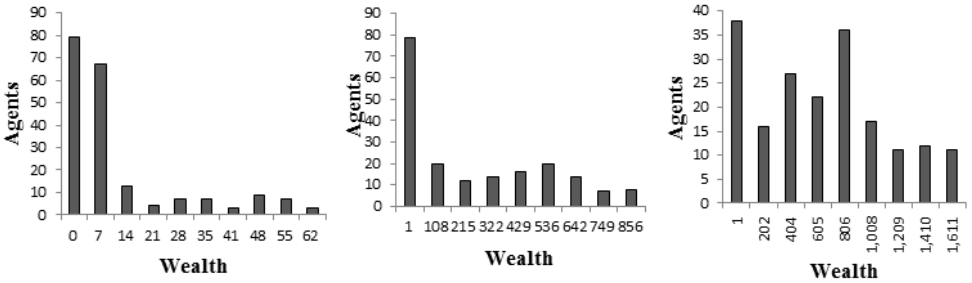


Figure 19. The change of Lorenz curve when SP = 20%

Lorenz curve can be seen from Figure 19, the imbalance of wealth in society also eased (The solid, dotted and dashed line in the figure representing the simulation process of the 80th step, 150th and 220th steps). When the network reaches a dynamic steady state, the area between the curve and the oblique straight line is greater than the parameter SP = 20% of the area.

The Wealth Distribution of the Value SP = 90% in the Network



(a) (b) (c)

Figure 20. Wealth Evolution of Network when SP = 50%

Wealth distribution are shown in Figure 20, the still exist polarization in the initial moment. With the passage of time, wealth differentiation is weakening. But compared with SP = 20%, 50%, the wealth of individuals is accumulated, as shown in Figure 16 (b), wealth value of all sectors were increased. When the network reaches dynamic stability, the alleviate degree of polarization is much smaller than SP = 20%, 50% of the network. The trend of alliance between giants is strengthened. The rich people are very easy to agglomerate and the channel linked between bottom and the upper of society is relatively blocked.

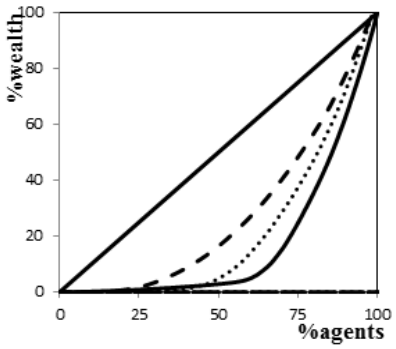


Figure 21. Lorenz Curve

As can be seen from the Lorenz curve (The solid, dotted and dashed line in the Figure 21 representing the simulation process of the 80th step, 150th and 220th steps), as long as the rule $\{F,G\}$, the gap between rich and poor will present a trend of decrease. Although individual wealth tend to be balanced, but the network to achieve dynamic stability moment when individual wealth difference is not the same with the change of the parameters of the SP. As shown in Figure 21, the area which is surrounded by the green curve with the oblique line is larger than the parameter SP = 20%, 50% of Lorenz curve. Wealth equalization under different parameters can use Gini coefficient to well portray.

The GIni Coefficient of the Network

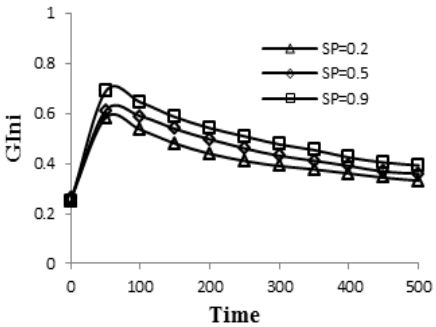


Figure 22. Comparison of Gini Coefficient under Different SP Value

The coefficients of Gini are between 0 and 1 and it can intuitively reflect the extent of people's income inequality. We should know that the larger the value, the higher the degree of inequality. Figure 22 are the cases of different values of SP, the change trend of network Gini coefficient contrast. From the Figure, we can see that no matter how the SP value is, Gini coefficient tended to decrease. This conclusion is according with the previous that the conclusions for reflecting the Lorentz curve of different SP values.

Regardless of the SP take any value, the society of the gap between rich and poor have been reduced. However, different SP has led to differences in the rate of decline of Gini coefficient. Rule $\{F,G\}$ tells us that the greater the value of SP, the larger the condition of the two individuals become friends. That is, smaller difference between two individuals' wealth value and the smaller the Friendship-circle network, and the opportunity to reduce the accumulation of wealth. So if we want to let the Gini coefficient drops rapidly in a short time, must try to reduce the SP value, strengthen the communication between individuals, let more people can enter the wealth sharing social network.

6. Conclusions

This article presents a complex agent network of artificial social model CASugarscape to achieve co-evolution simulation of social networks and wealth. Introduction of agent-based social networks to generate a dynamic circle of acquaintance networks which is closer to the actual structure of social networks. Then choose friends of acquaintance networks to generate friendship-circle network according to the rule of sharing wealth. The agents get information of wealth distribution from friendship-circle and they use this information to find wealth. The changes of this wealth distribution would affect the acquaintances networks and friendship-circle networks, and ultimately produces the co-evolution mechanism of social wealth and social network. The researches have shown that the rules of wealth sharing or wealth matching have a significant impact on the social network and the distribution of wealth. (1) The stronger of the wealth matching, the more similar of the agents become friends. In addition, the clustering coefficient of network decreases gradually, the degree of distribution shows multimodality, and the maximum degree of network decreases gradually. But the networks are correlated for all degrees; hence the compactness of network declines gradually. The number of communities increases progressively and it turns to be fragmentation. (2) The stronger the wealth matching rules of constitutes friends，the stronger possibility that the individuals with similar number of wealth would easily to form community networks. It means that it is required more similar amount of wealth to be friends, and then the richer are easy to be friends with the control of most resources in the networks. In addition, those people without the control of social resources only can make friends with their own classes. The trends of alliance among giants and the alliance among the weak tend to be remarkable. Hence, the polarization of wealth distribution has increased and the coefficient of Gini also increased.

Acknowledgements

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