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Investigate on the Forming and Its Evolving of Complex Diffusion Network Based on Netlogo

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Abstract: With the diffusing process of technological innovation, there is a close linkage between the initial innovator and the forthcoming adopter. So we should shift the research perspective and corresponding method from the analyzing each single unit, i.e., isolated enterprise, to the network depicting the relationship between them. The complex diffusion network of innovation, as the highest integrated forming pattern of innovation network units, has become an all-dimensional, crisscrossed and intermingled, collaborated organically pattern that conforming of all types of innovational enterprises and various middle types of organization, and it also has become the inevitable developing trend of innovation diffusion. Based on the current researching on complex network, this paper has established an infra-marginal analysis frame to analyze the forming motivation started with the gaming among the complex diffusion network's nodes. Ulteriorly, the evolving causation and tendency of that network also have been researched from the dynamic viewpoint. Lastly, the forming and evolving process of the complex diffusion network have been simulated based on the Netlogo. The conclusion of the paper can be used by the decision maker to improve the function of diffusion network infrastructure, its information system, serving and relevant resources collocating, etc.

Keywords: complex diffusion network (CDN), evolving, forming motivation, simulated by Netlogo

1 Introduction

Innovation Diffusion is the process by which an innovation communicated through certain channels over time among the members of a social system (E. Rogers, 1995). Rogers' definition contains four elements that are present in the diffusion of innovation process. The four main elements are: (i) innovation - an idea, practices, or objects that is perceived as knew by an individual or other unit of adoption; (ii) communication channels - the means by which messages get from one individual to another. (iii) time - the three time factors are: a) innovation-decision process; b) relative time with which an innovation is adopted by an individual or group; c) innovation's rate of adoption. (iv) social system - a set of interrelated units that are engaged in joint problem solving to accomplish a common goal.

Nowadays, from the viewpoint of network, there is an irresistible trend in the research field of diffusions that analyzing the forming and its evolving process of diffusion network combined with complex theory. Based on this standpoint, the paper has analyzed the forming and its evolutional process of complex diffusion network (CDN) from the theoretical analysis and positive simulation. The structure of paper is divided as follows: in Section 2 we look back the current research on the commonly networks, especially, the pace of progress in the field of social network. On that basis, extending the defining of the complex network (CN) to complex diffusion network (CDN), we have analyzed the relative partner of that network. We also review that network from complex theory. In Section 3 we provide a simple study frame through setting up an infra-marginal analysis based on the achievements of Yang, X. and Borland, J. (1991) as the preparation to explore the forming motivation of CDN. In Section 3 we analyze the evolving underlying forces and its future tendency of CDN. A simulation also used through presenting an illustrative example of the CDN in the environment of Netlogo. Section 4 presents the main conclusions. The conclusion and the further study of the paper are summarized by the section 4. The theoretical analysis and simulation inference of the paper could be used in the decision making and supporting of the function of CDN by its member of that league.

2 About the network, complex network (CN) and complex diffusion network (CDN)

Simply speaking, due to the integration of the disassembly activity, a network is represented by the relationship between the element and its conjunctive relationship in the system. In the field of natural science, especially, in the mathematics and its branch of graph theory, a network is abstracted to a graph conforming of a number of nodes (each node corresponding to a member of the group) and a number of edges (or ties). Nowadays, it has become an irreversible tendency in the research of systematic science from the viewpoint of

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network analysis, i.e., the unit of analysis in network analysis is not the individual, but an entity consisting of a collection of individuals and the linkages among them. The trend has also been turned gradually from the natural science to the field of social science to analysis the social relation network. Social network analysis is based on an assumption of the importance of relationships among interacting units. The social network perspective encompasses theories, models, and applications that are expressed in terms of relational concepts or processes (S. Wasserman etc., 1994). The forming of the network is the process that active nodes links forwardly or passively with other partner in the network showing the formal or informal relationships or flows between the nodes (Hakansson, 1987).

Along with growing interest and increased use of network analysis has become a consensus about the central principles underlying the network perspective. Network theory is sympathetic with systems theory and complexity theory. According of the standpoint of complex science, complex systems typically comprise a large number of units that interacting strongly which can be treated properly as a network. Complex network (CN) is a large scale network describing the complex topological structure and their motivational behavior in the process of linkage. It is also a graph that constitutes large amount of nodes and their edges interconnected (Albert R., Barabási A. L. ,2002). Traditionally, CN is a branch of graph which researching on the series of practical questions such as: what is the maximum flow per unit time from source to sink in a network of pipes, et al. (Bollobas, B.,1998). It is usually used mainly in the studying of regular and random graph. Systematically, combining with the networks whose structure is irregular, complex and dynamically evolving in time, CN is depicted with the main focus moving from the analysis of small networks to that of systems with thousands or millions of nodes, and with a renewed attention to the properties of networks of dynamical units. The nodes of that network are the basic active elements which with special motivation and information intension. The edges of that network show the complicated linkage and interaction of these nodes.

The main content in the current research result on CN , beginning with the effort of defining new concepts and measures to characterize the topology of real networks, can be summarized in the identification of a series of unifying principles and statistical properties common to most of the real networks considered. The micro quality of relevant properties of nodes and the macro quality of network have been also analyzed, for example, the former including the degrees of nodes which are the number of their direct connection to other nodes, so the degree distribution defined as the probability that nodes chosen uniformly at random have the numerical value of, some degree of a network has a high degree of clustering as in some regular network and a small average distance between nodes as in a random network and other significant recent discovery is the observation that many large-scale complex networks are scale free with characteristic scale of power laws, such networks are called ‘scale-free networks’ (Barabási A L and Albert R, 1999), and the each edge’s weighed value is shown the existence of strong or weak ties between nodes, etc.; while the later consisting of the geometrical character, efficiency, and the stability of the CN. The languages of graph theory and its research methodology have also been introduced into this field as the analysis instrument to describe the characteristic of CN.

Simon (Simon, 1969) defined the complex theory as to research on the complex system that linking and interaction mutually. Complexity takes the form of hierarchy and that hierarchical systems evolve faster than nonhierarchical ones. Very generally, a hierarchy is a recursive partition of a system into subsystems. Meanwhile, the system could also be treated as a network including nodes and connecting edges. The nodes in the network are the elements and their grouping while the links show relationships or flows between the nodes. The complexity of the network is measured by analyzing the internal ties or the relations, or in other words, concentrated on the nodes and its relative edges (Koen Frenken, 2005).

The evolving network, having recently arisen in the field, is another type of CN with more complexity (Albert R., Barabási A. L., 2002). To this network, the propensity of select probability of linkage among the nodes is the nonlinear relationship. There are competitive states in the existing nodes for the resources allocating. The competitive layout has been getting tough with the new nodes adding, the former nodes reducing and the rewiring of links from one node to another. Especially, the removal of nodes, either by random breakdown or intentional attacks, has changed the balance of flows and lead to a global redistribution of loads over the entire network. The increasing trend of the network is also restricted by the aging of nodes. All these influent factors have constituted the analysis on the forming and evolution of evolving network.

A network models a communication group in the social network. As an example, diffusion network is made up some sorts of agents and their group that containing government, manufacturing, circulation and diffusion enterprises and various middle types of organization. The character of interaction is that each one being associated to a communication connection between two nodes in the network. Viewing on the entity, it is a reticulated allocating system with some nodes and their mutual linking. As a subsystem of social system, each member with the characteristic of complexity is complementary in the diffusion network. Every member of diffusion relative ally, as the internal node of network, has dual identity that depicting both an independent unit and also making connection with other units in the integrated network. So, the individual attribute property and its shelter surrounding should be concerned in the process of analysis. However, the complete denotative meanings of diffusion network is not the concrete or

physical diffusion organization and their infrastructural facilities merely, but the intangible synthesized serve system that build on the basic platform of material facilities to support the operation of diffusion organization which manipulating on the net, i.e., the synergy in the coordinating process of the diffusion network's member that also be seen as a pledge of network function. It is also have the character of complexity that the exerting of the synergy effect in the process of cooperation. So the diffusion network could be regarded as a sort of CN. Thus, according to Wasserman, S. etc. (Wasserman, S. and K. Faust, 1994), as a new branch or a sub network of CN, the complex diffusion network (CDN) can be described as that network with diffusion agents (nodes) and their relational ties (edges) in the process of market transaction and division. The following characters as being important to depict the CDN:

(1) Agents and their actions in the CDN are viewed as interdependent rather than independent, autonomous units;

(2) Relational ties (edge) between agents are channels for transfer or "flow" of innovational resources (either material or nonmaterial) and information, all interactions are bi-directional - i.e. an edge between A and B means that A regulates B, and B regulates A;

(3) Network models focusing on individuals view the network structural environment as providing economic opportunities for or constraints on individual action;

(4) Network models conceptualize structure (economic, political, and so forth) as lasting patterns of relations among agents.

Though the analysis been detailed on the other social network, the forming and evolving of CDN have not been call attention enough to the matter yet, which just the main part of this paper is.

3 The infra-marginal analysis on the forming of CDN with two agents in the process of innovation diffusion

Each agent in the CDN has its different selecting strategy. To define it, let us consider a CDN including n agents as an example, supposing for simplicity, the every node in the network may be in one of two states: participating or nonparticipating, which meaning there are only two elements enclosed in the selecting strategy set for a agent. Even the amount of n is small, all the elements containing in the alternative strategy space could reach to 2^n which is a very large number. So, it is a hyperspace composed of the choosing strategy space of agents with different interests in the CDN. The amount of participating agents or the nodes in network is the dimension of that space and the feasible strategy profile are the Cartesian set. In the course of diffusion division of economic transaction, each node of CDN could change the relationship with other agents, i.e., the linking edges in the network interaction (adding or reducing), which is the motivation the forming and evolving in that complex network（Cowan, R., and Jonard N., 2004）.

To define a CDN, we modify a network $CDN_i, i = 1, \cdots, n$ with number of interconnected agents is n. The quality and character of the agent i is marked by $CDN_i = (x_i, y_i, \omega_i, R_i)$, where the element x_i is set of the innovation resources spending and obtaining or transforming of agent i in the participation process of CDN; y_i the available product set except the x_i ; ω_i the initial endowment of i; R_i the reference of i represented usually by its utility function u_i. Then, the characteristic profile of all agents taking part in division of social network could be represented properly as the domain formed by the internal nodes' mutual connection.

To the agent i, it is a decision which should be made that whether participating in the network to sharing with other agent or not engaging in which means the whole process of innovation on himself and not connect with others. However, the former two selecting plans should allocate and use innovation resources that producing technical and economic revenue to the whole social network because of innovation is resource expended industry. At present, every agent of CDN has enjoyed the sharing value-added with other agents more or less. But that is definitely correct or incorrect should solve on the theoretical analysis. Even on this condition, to a rational agent i, diffusion procedures which need to be done by himself or to participate the network? If he decide to take part in the network, how much the amount of spending resource or the ratio of his decision made on the resource allocated ? So the agent is besieged by these problems. What they come down to are six relative decision variables: $x_i, x_i^s, x_i^d, y_i, y_i^s, y_i^d$ that each variable is nonnegative number. The variables x_i^s, x_i^d are the diffusion serves an agent supplying to other agent and demanding for others. That is devoting and charging to other member for each agent as a medial unit connecting with other internal nodes in the CDN. For the studying simply, we often use the amount of money paid and acquired to symbolize that two variable. While the variables y_i^s, y_i^d are the amount of other serve except diffusion an agent supplying and demanding. Then, the optimal decision programming can be described by (1):

$$\underset{x_i, x_i^d, x_i^s, y_i, y_i^d, y_i^s, l_{ix}, l_{iy}}{Max} \quad U_i = (x_i + kx_i^d)^{\beta} (y_i + ky_i^d)^{1-\beta} \qquad (1)$$

$$\text{s.t.} \begin{cases} x_i + x_i^s = a_{ix} l_{ix} & \text{(i)} \\ y_i + y_i^s = a_{iy} l_{iy} & \text{(ii)} \\ l_{ix} + l_{iy} = 1 & \text{(iii)} \\ p_x x_i^s + p_y y_i^s = p_x x_i^d + p_y y_i^d & \text{(iv)} \\ x_i, x_i^s, x_i^d, y_i, y_i^s, y_i^d \geq 0 & \text{(v)} \end{cases}$$

Where, k is the transaction efficiency between two different types of serve in the market; β is the utility

index; l_{ix}, l_{iy} are the two spending shares in the serve producing on his endowment to an agent; a_{ix}, a_{iy} are the producing or transforming efficiency for an agent; p_x, p_y are the two products' prices in the market.

Considering the nonlinear programming (1), the objective function is the utility function of an agent. To maximize his utility is the participating motivation to a rational agent. The formulas (i) and (ii) are the production functions of two products; (iii) is the resource restraining of his endowment; (iv) is the budget restraint of the agent *i*.

For every variable could be represented by the number of positive or zero, the whole amount of profile concluding six variables is2^6=64. However, to the agent *i*, it is unnecessary to supply and pay for the same product because that needing too much transaction cost. Therefore, the numerical values of x_i^s and x_i^d are not possible the positive numbers at same time, so are the variables y_i^s and y_i^d . Moreover, there are also the conditions coming into being that the number of x_i^d and y_i^d greater than zero while x_i^s and y_i^s equal to zero or the conditions x_i^s and y_i^s greater than zero while x_i^d and y_i^d equal to zero. So we get ride of the 61 sorts of variable profile among the 64 possible situations that not satisfying the restrain of positive utility, i.e., $U_i > 0$, and the budget binding, all the feasible situation remain three sorts:

(i) $x_i > 0, y_i > 0, x_i^s = x_i^d = y_i^s = y_i^d = 0$;

(ii) $x_i > 0, y_i > 0, x_i^s > 0, y_i^d > 0, x_i^d = y_i^s = 0$;

(iii) $x_i > 0, y_i > 0, x_i^d > 0, y_i^s > 0, x_i^s = y_i^d = 0$;

Now, the budget bonding in the programming (1) will be the identical equation $p_x x_i^s = p_y y_i^d$ or $p_y y_i^s = p_x x_i^d$.

The corresponding space states of the CDN on the conditions of (i) ~ (iii) will be depicted by the fig. 1-3:

(1)Network state Ⅰ:

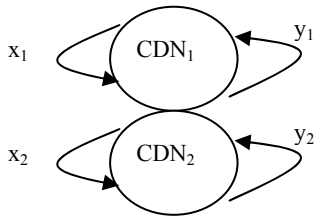


Fig.1 The first spatial distribution state between two unattached CDN$_1$ and CDN$_2$

(2) Network state Ⅱ:

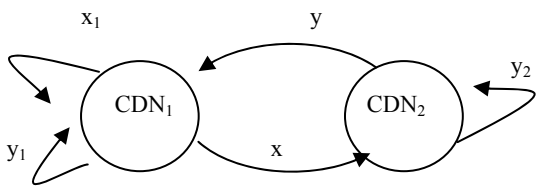


Fig.2 The second correlated state between two agents of CDN$_1$ and CDN$_2$ in space

(3) Network state Ⅲ:

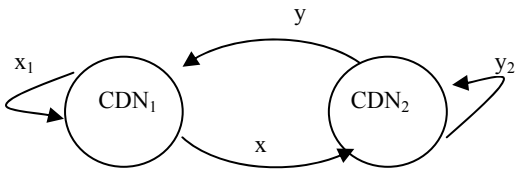


Fig.3 The third correlated state between two agents of CDN$_1$ and CDN$_2$ in space

4 The simulation on the process of forming and its evolving of CDN with multi-agents based on Netlogo

In virtue of the NetLogo as a proper instrument developed by Northwestern University's Center for Connected Learning in Unite States, we simulate the forming and evolving of CDN based on the environment of Netlogo in the follow.

4.1 The explaining of simulation object

According to CN, it is a self-organization phenomenon emerging in the domain of behavior selecting strategy at macro level that is result of interaction of the network with multi-agent at the micro level. On the forming and evolving of CDN, two level contents are divided for the agents of the network contacting each other: the first level is macro environment which is the carrier depending by the agents and their activities; the second is the agents that composing the main body of the network and also are the members of diffusion cooperation units.

4.2 Designing the simulating process

There are series of systematic operating parameters influencing the forming and functioning of model outside of the overall structure making of those two levels of agents and domain of their behaviors strategy selecting. They can be controlled to simulate the influence that outside macroscopic environment on the agents. The simulate model designing and the procedure sketch describing the behavior of CDN's agents forming and evolving are shown by the fig.4-5:

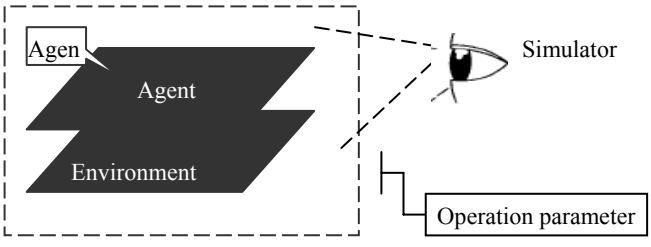


Fig.4 The modeling blueprint to simulate the forming process of CDN

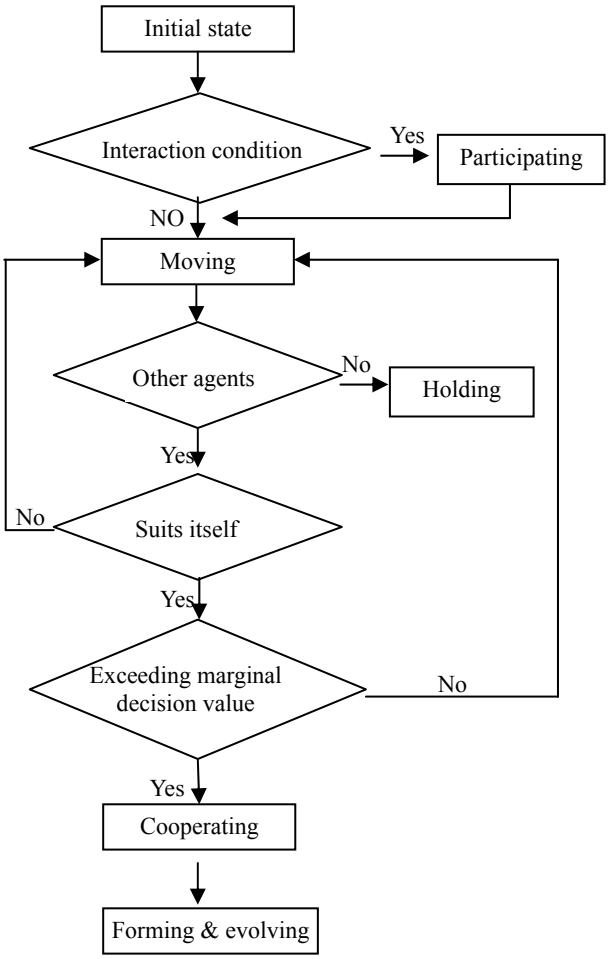


Fig.5 The procedure sketch describing the behavior of CDN's agents forming & evolving

In reality, the structure modeling the agents of CDN and their surrounding environment have tallied typically with the units of diffusion in the market transaction. So, it suits extremely to use Netlogo to simulate the state that coupling the diffusion system with multi-agents and their environment. Among them, the multi-agents modeling the behaviors of every diffusion unit or the node in network are the first level and the outside influencing factors acted on the process of grouping and clustering of diffusion units that are the forming and evolving of CDN through the changing the existence stated structure of network, i.e., node-added, edge-added and rewiring the linkage between the different nodes, etc. The simulation we using in the paper on the CDN is to only investigate the impact of agents' activities on the internal structure of network states. So, the guidance effect of outside surrounding environment on the agent's behavior is neglected. We suppose that the agent's behavior influenced by the space structure of strategy and its diversity, and not by the other outside factors. So, the former researching model is explained theoretically by two levels of agents and surrounding, there are no mutual interaction or the direct linkage between them. The core content analyzed on the CDN model is to explore the complex interaction and linkage among these nodes. The model's operation environment is only to provide the carrier for the behavior of agent but there has no influence on it. So, saying from the strict significance, the simulation model of CDN established in the paper is a pure multi-agent system model which is analyzed simply.

4.3 The simulating process & result

According to the above designing simulation model, with the aiding of the modular of preferential attachment in the models library of Netlogo, we redesign and revise some program in the modular to simulate the interaction and the linkage of agent in CDN. The designing method of simulating procedure is as follows: supposing the diffusion unit or the node in the CDN distributed randomly in the space of environment, the initial agent is seeking for the attachment to other agents attracted by the value-added following that compared with its marginal decision value, , if that value is under the amount that all the diffusion process done by itself, the unlinking network will be the states of structure that agent in the CDN; otherwise, if the value is above it, the agent will select the agents which could bring it the best economic revenue and will make the juncture to it, so a new edge or rewiring side will be added in CDN, in this foundation striding forward step by step, the whole configuration of that network will be formed; with the more and more the agent (node) adding in, the evolving will be inevitable.

Evolved on the dimension of time, we simulate the forming and evolving process of CDN dividing it in four situations: t=0, t=20, t=50 and t=100. The CDN's shape and the degrees of its nodes represented by the histogram and logarithm scattered diagram depicted the result of running the simulation program are shown as the following figure 6- 7:

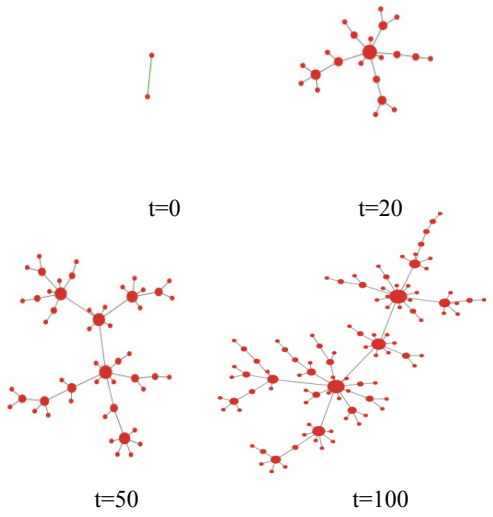
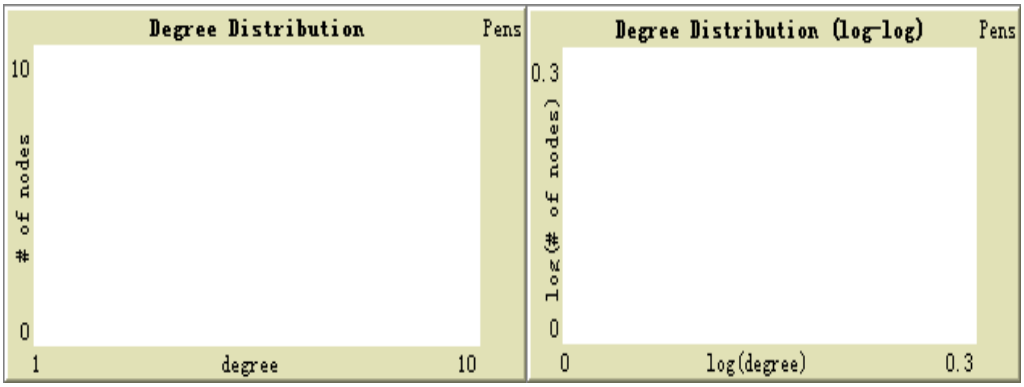
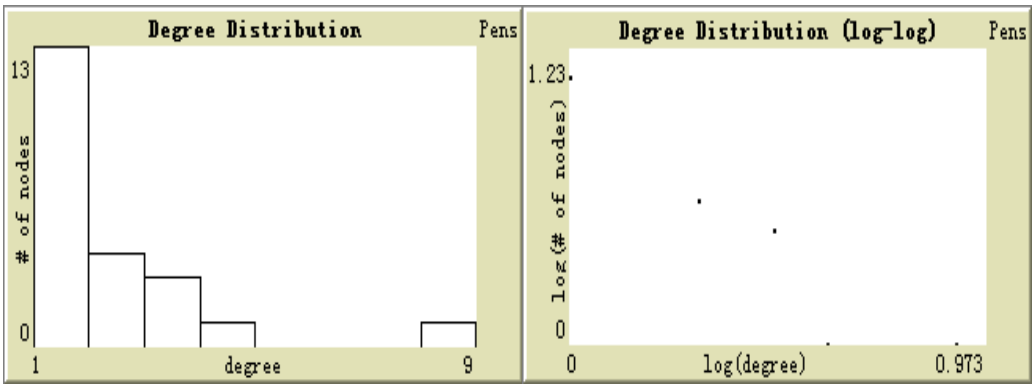


Fig.6 Different states of CDN (t=0, t=20, t=50 and t=100)

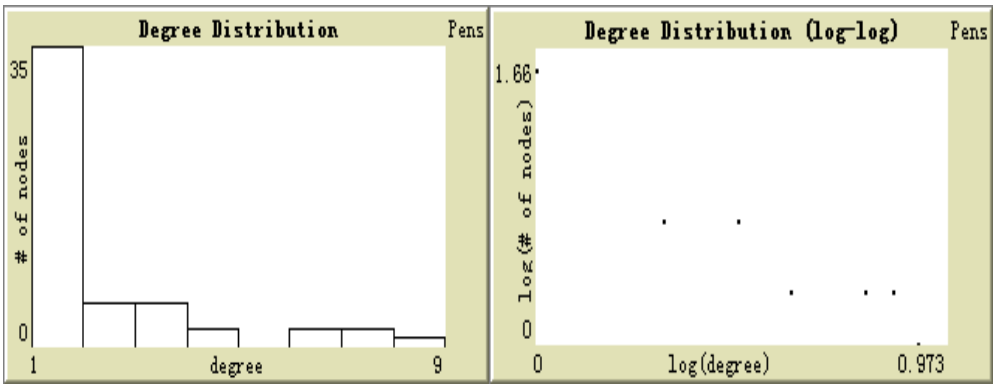
t=0



t=20



t=50



t=100

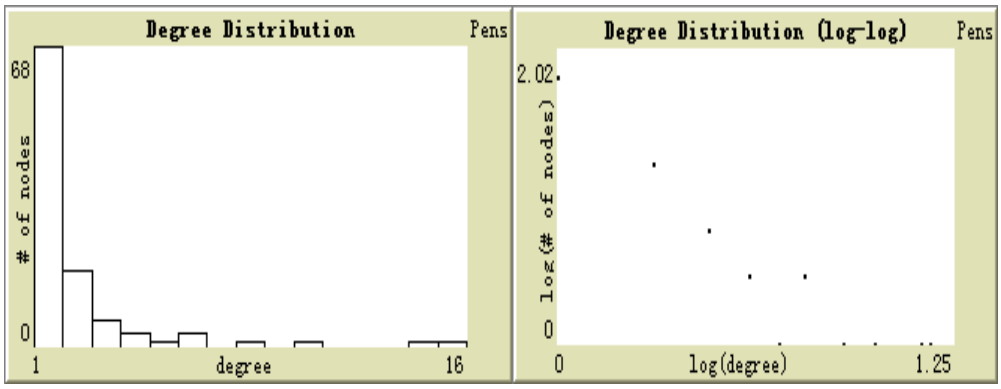


Fig.7 The degree distribution of different states of CDN's nodes (t=0, t=20, t=50 and t=100)

5 Conclusion

From the simulating result, we can conclude that more and more new nodes joining in CDN and their degrees also increasing that consistent with the characteristic of S-F network as the time passed. Moreover, the result also indicates that the probability of selecting propensity between these nodes' linking has obvious characteristic of nonlinear relationship in the process of evolving. New node's adding intensifies the fierce competition among the original nodes. Node- or edge-added and side-rewired in CDN coincide with the feature that shows in the evolving network and also synchronized with the CN.

In conclusion, all the work we done before have analyzed on the model structure of CDN and simulated the evolution process of that network. However, as a preparatory groping production that research on the issue theoretically, some limitations of the study that should be point out that each agent (node) is treated as homogenous unit in CDN that we do not considering each node's otherness consisting of initial innovational endowment, their special preferences, etc. Practically, these problems could be solved if we consider the first state existence of CDN on some given conditions. As the further question calling for discussion, these limitations could be explored by positive researching.

References

[1]Rogers, E. M. Diffusion of innovations (4th edition)[M]. New York: Free Press, 1995.

[2]Yang, X. and Borland, J. A microeconomic mechanism for economic growth[J]. Journal of Political Economy, 1991, 99: 460-82.

[3] Hakansson, H. Industrial technological development: A network approach[M]. Croom Helm eds., London Press, 1987.

[4]Albert, R., Barabási, A. L. Statistical mechanics of complex networks[J]. Reviews of Modern Physics, 2002, 74: 47-97.

[5]Bollobas, B. Modern graph theory[M]. New York: Springer-Verlag, 1998.

[6]Barabási, A. L. Albert R. Emergence of scaling in random networks[J]. Science, 1999, 286: 509- 512.

[7]Simon, H. A. The sciences of the artificial[M]. London: Cambridge, MA.MIT Press, 1969.

[8]Koen Frenken. Technological innovation and complexity theory[J]. Econ. Innov. New Techn, 2006, 15(2):137-155

[9]Wasserman, S., Faust, K. Social network analysis[M]. Cambridge Univ. Press, Cambridge, U.K and Scott, J., 2000, Social Network Analysis: A Handbook .Sage Publications, London, 2nd Ed.

[10] Cowan, R., Jonard N. Network structure and the diffusion of knowledge[J]. Journal of Economic Dynamics and Control, 2004, 28(8): 1557-1575.

[11]Rogers E. M., Scott K. L. The diffusion of innovations model and outreach from the national network of libraries of medicine to native American communities[C]// Seattle, WA: National Network of Libraries of Medicine, Pacific Northwest Region Web site. http://www.nnlm.nlm.nih.gov/pnr/eval/rogers.html, 1997.

[12]Chatterjee, B., Eliashberg J. The innovation diffusion process in a heterogeneous population: a micro modeling approach[J]. Management Science, 1990, 36 (2): 1057-1079.

[13] Stoneman, P., Battisti, G. Intra-firm diffusion of new technologies: The neglected part of technology transfer[J]. International Journal of Industrial Engineering Ohio–US, 1998, 4(2): 280-282.

[14]Putsis, William P. Parameter variation and new product diffusion[J]. Journal of Forecasting, 1998, 17(3/4):231-257.

[15] Steffens, P. R. A model of multiple ownership as a diffusion process[J]. Technological Forecasting and Social Change, 2003, 70(S):901-917.

[16]Swami S, Khairnar P. J. Diffusion of products with limited supply and known expiration date[R]. Marketing Letters , 2003, 14:33-46.

[17]Bass, F. M. Empirical generalizations and marketing science: A personal view[J].Marketing Science, 1995, 14: G6-G19.

[18]Bass, P. I., F. M. Bass. Diffusion of technology generations: A Model of adoption and repeat sales[R]. working paper, University of Dallas, 2001.

[19] Zeng-Hu LI. Immigration processes associated with branching particle systems[J]. Advances in Applied Probability, 1998, 30:657-675.

[20]Feller, W. On a generalization of Marcel Riesz potentials and the semigroups generated by them, Meddelanden Lunds Universitets Matematiska Seminarium[R]. Lund, 1952:73-81.

[21] Mainardi, F., Luchko Y, Pagnini G. The fundamental solution of the space-time fractional diffusion equation[J]. Fractional Calculus and Applied Analysis，2001,4(2):153-192.