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Sustainability of Open Systems Based on an Agent Model with Fluctuation

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Abstract

In IT technology, especially in software development, open development system has been proven to be useful. Linux, apache software and GNU software are typical examples. Still, it is also known that there are many open software development projects that failed or stopped developments. So far, it has not been clearly known what the key factor is to give the difference between the successful open projects and the ones that fails. In this report, we analyze the sustainability of open systems based on an agent model that explicitly takes the effect of fluctuation into account. Although the model is simple, it is shown that the system with many less-powered leaders is more stable than a system with small number of powerful leaders.

Keywords: open development system, sustainability, agent model, fluctuation, leader agent

Introduction

Open development system has shown effectiveness in the field of software. Linux, apache software and GNU software are typical examples. There are some hardware open systems that have achieved success. For example, Arduino microcontroller board (Hughes, 2016), whose electrical circuit designs and software development system are open, has been spreading all over the world. At the same time, it has been known that there are many open development projects that have halted or failed.

Our research question is:

1. What is the difference between the successful open development systems and the ones that failed or halted?
2. What is the most essential factor that gives the difference?

As is the case in many IT related services, the open development system is affected by the network externality. As for the effect of network externality, there have been rapid progresses based on the agent simulation approaches. Using these approaches, it has been known that the interaction between the members is one of the keys to determine the sustainability of a system. For example, Oh and Jeon (2007) has analyzed the stability of open systems based on Ising type agent model. Still there is an ambiguity in understanding the meaning of parameters in their model.

In this work, we extend the model so that it can take the role of the leaders and its fluctuation into account in a more explicit manner than previous works.

This paper is organized as follows. The next section provides a literature review of the network externality, agent models to analyze many aspects of economy and social features, and the role of leaders in open development system. In the following section, we briefly explain the agent model we use and show the difference of our model and the models in the previous works. In the fourth section, the results obtained by the numerical simulation are shown. The last section is devoted to conclusion, discussion and future prospects.

Literature Review

Network externality and its importance have been investigated in many research areas. The oldest work is made by Leibenstein (1950) who discussed the bandwagon effect. Bass (1969) also discussed the importance of the network externality in the framework of commodity spreading. Rohlfs (1974) pointed out the difference between the startup stage and growing stage, and then showed the meaning of the introduction policy to promote the spread of a service at the early stages. Katz and Shapiro (1985) used the two-period model to study the structure of the network externality. These works are made by the models that can be handled analytically.

Since around 2000, agent model has been used to analyze the effect of network externality and many other social phenomena. This approach is based on numerical calculation that has made progress due to the availability of fast computing resources (Oomes 2003, Fang and Wang 2012). In agent model approaches, agents interact with each other and make decisions. Each agent represents an individual or a firm to make a decision and macroscopic variables are given by the sum of microscopic interactions.

The simple model, in which only the nearest neighboring agents interact, is called as Ising model. Since Ising model is easy to handle numerically, there have been many works based on this model.

For example, Zhou and Sornette (2007) applied Ising model to analyzing the financial market. Zaklan et.al (2009) and also Hokamp and Pickhardt (2010) focused on some features of the model to study the tax evasion dynamics. Laciana and Rovere (2011) used the model to study the diffusion of a technology.

As for the open systems, Oh and Joen (2007) discussed it based on the Ising model and found the importance of the existence of a leader that gives the vision and incentive of development. In the case of Linux, Linus Torvalds takes this role. In many open development projects, however, even leaders are not engaged in the project full-time. They are sometimes engaged in the project, but sometimes have to do some other jobs etc. In the model of Oh and Joen, this is taken into account as thermal fluctuation. In Ising model, the probability that a state with utility U is realized is proportional to

$$\exp(U/T) \qquad (1),$$

where T is a parameter called as temperature. They considered that high T means larger fluctuation. They also considered that the fluctuation reflects the fact that a member or a leader is not a full-time worker for the project and sometimes cannot get engaged in the project for a period.

The meaning of temperature, however, is not explicitly known. The original Ising model was invented to explain the ferromagnetism of iron, in which the temperature makes sense as a physical parameter (Onsager 1945). In applying the model to open system, however, the meaning of the temperature is not clear. It has not been clarified in what sense the temperature can describe fluctuation.

In this paper, we incorporated the effect of fluctuation in a more explicit manner. We split the agents into two kinds. One kind of agent is the one that gives influence to other agents and decides its own commitment by oneself regardless of the states of other agents. This is a simplified model of the leaders and is called as a leading agent hereafter. The other kind is the agent that is influenced by the leading agents and also gives/receives influence to/from each other, which is called as a follower agent hereafter.

We handle the commitment of the leading agents stochastically, which gives the fluctuation. Through this process, we explicitly incorporate the fact that leaders are not get engaged in the project full-time.

We study the response of follower agents and its dependence on the number and the influence range of the leading agents. In other words, we investigate the difference between the two systems: one is the system in which there are many leaders but the power of each leader is small, and the other one is that there are only one or small number of powerful leaders.

Nearest Interacting Agent Model and Its Extension

In this section, we briefly explain Ising model which is also called as the nearest interacting agent model, and then show how to extend the model to study the sustainability of an open system.

In the first subsection, we show the original Ising model. In the original Ising model, all the agents are equal. There is no special leader agent that is more influential than others. As is shown in the first section, we have to consider the cases that there are two kinds of agents: leader and follower. In the second subsection, we extend Ising model to take the two kinds of agents into account. It is also shown how to take the effect of fluctuation into account.

Original Ising model

In this subsection, we describe the original Ising model that has no leader.

In Ising type agent model, each agent has an index i and state S_i. S_i can be either +1 or −1. +1 means that the agent is in a positive condition i.e. being a member of an open development system. −1 means a negative state i.e. not a member of the system. For historical reason that this model was first invented to explain ferromagnetism in physics, the state S_i=+1 (S_i=−1) is depicted as upwards (downwards) arrow as Figure 1 (Figure 2).

Figure 1. The state S_i=+1

Figure 2. The state S_i=−1

In this model, the utility of an agent is given

$$U_i = -H S_i + J S_i (S_{i-1} + S_{i+1}) \quad (2),$$

where U_i is the utility of the agent with its index i.

The first term $-H S_i$ gives the utility of just joining the open system, regardless of the states of other agents. H is the strength of this term, whose value is positive. Since S_i=−1 gives the utility H and S_i=+1 gives $-H$, S_i=−1 is preferred to S_i=+1. This shows that an agent does not join the open system, as far as there is no incentive given from other agents. (As is shown later, this is the case for the follower agent. The leader agents take S_i=+1 even if there is no incentive from others.)

The second term of equation (2) is the utility coming from the interaction between the agents. J is the positive value parameter to give the strength of this term. For example, if $S_i=S_{i-1}=S_{i+1}$=+1, this term gives 2J. If S_i=−1 and $S_{i-1}=S_{i+1}$=+1, this term gives −2J. This means that S_i=+1 is preferred to S_i=−1, if $S_{i-1}=S_{i+1}$=+1. This is the incentive to drive the agent with index i to join the open development community as far as $S_{i-1}=S_{i+1}$=+1.

As initial state, we take the state that all the agents are joining the open development system, as is shown in Figure 3.

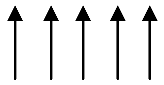

Figure 3. The initial state

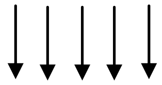

Figure 4. The state that no one joins the open system

If there is no other incentive to stay in the state S_i=+1, this initial state is not stable, because it has lower utility than the state shown in Figure 4. As for the first term in the equation (2), Figure 4 gives $+H$ for each agent while Figure 3 gives $-H$. As for the second term, both Figure 3 and Figure 4 give $2J$. As the sum of these terms, Figure 4 has higher utility and is preferred to Figure 3. Thus, there must be some other effects in order to have some agents stay in the state S_i=+1 and keep the open system active. The incentive to stay in S_i=+1 coming from the leader agent will be shown in the next subsection.

Leader agent and follower agent

Now, we extend the Ising model and introduce another kind of agent that gives incentive to other agents. This kind of agent is called as leader agent.

The leader agents have incentives on their own, regardless of the states of the other agents. This is a model of a starter of an open project who feels that it is interesting whatever others say.

The leader agents, however, are not engaged in the project full-time, because most of the open project is not profitable. Even the leaders work part-time for the project. This is incorporated into the model by setting the state of the leader agents to sometimes –1 and sometimes +1.

In our model, a leader agent takes +1 state with probability p and –1 state with probability $(1-p)$. The state is determined stochastically. This gives the fluctuation of the leader agents.

Leader agents have the role to affect follower agents and drive them to the state +1. This effect is taken account into the model by modifying the equation (2) as

$$U_i = -H\, S_i + J S_i (S_{i-1} + S_{i+1}) + J \sum_l S_i S_l\, g(i,l) \qquad (3)\ ,$$

where S_l is the state of a leader agent with its index l. The third term is the sum of the effects coming from the leader agents, and gives the incentive for the follower agents to stay +1 state as far as S_l=+1. The function $g(i, l)$ gives whether or not the agent with index i is affected by the leader agent with index l. It takes 1 if the agent with index i is affected by the leader agent with index l, and takes 0 if not affected. This is determined by the distance between the agents. In the last subsection, we explained the model in one dimension for simplicity. In the real numerical calculation based on agent models, two dimensional model is used, in which agents are aligned in lattice shown in Figure 5. In the numerical simulation, leader agents have interaction ranges and are randomly distributed. For example in Figure 6, the follower agents within the two circles are affected by the leader agents that are in the center of the circles and shown by large dots.

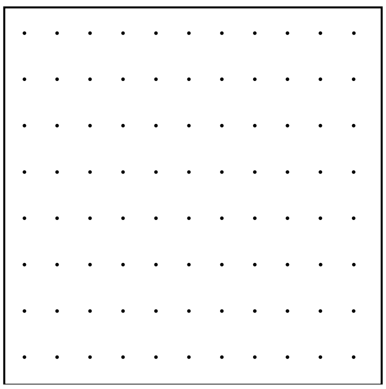

Figure 5. Two dimensional case used in the real calculation. Each dot shows a follower agent.

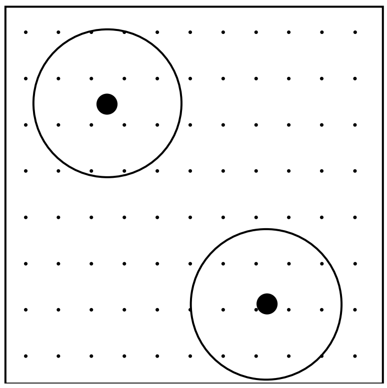

Figure 6. Two leader agents shown by large dots affect the agents within the circles.

As the range of the leader agents, we choose so that it covers most all of the follower agents in average. If we denoted the total number of leader agents as N and the size of one side of the rectangle of Figure 5 as L (i.e L^2 is the area), the diameter of the interaction circle is chosen to be

$$\frac{L}{\sqrt{N}}$$

For example, Figure 7 is the case for N=1 and Figure 8 is the case for N=4. Since the positions of the leader agents are given randomly, the circles are not necessarily aligned as Figure 9.

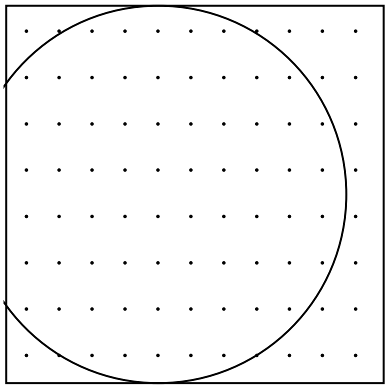

Figure 7. The case N=1

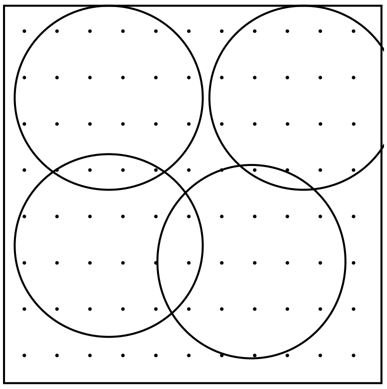

Figure 8. The case N=4

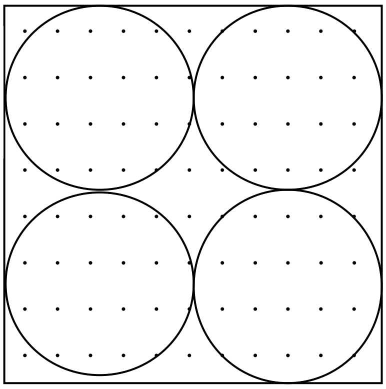

Figure 9. The leader agents are distributed randomly, and not aligned like this.

As is shown previously, the states of the leader agents are given under the probability p. Even if a leader agent takes the –1 state, the surrounding agents do not move to the –1 state immediately because the second term in equation (3) tries to keep the neighboring agents in the same state. If the leader agent comes back to the +1 state within a reasonable time, some of the follower agents are expected to be kept in +1 state.

In this paper, we investigate the sustainability through the dependence of the average state of the followers upon N and p.

In our simulation, we choose N=1, 2, 4, 8 and 16. We count the number of the follower agents with its state +1 after enough long time has elapsed from the initial state. The essential procedures to carry out the numerical simulation in stochastic manner are the same as previous works.

Results of Numerical Simulations

In numerical simulation, the total number of the follower agents is chosen to be 10,000. The size L is now 100. The number of the leader agent is chosen to be 1, 2, 4, 8 and 16. We carried out the calculation until the iteration count of the interaction, which is interpreted as the time elapsed and is called as steps hereafter, reaches 500. We then counted the number of the agents in the +1 state at the 500th step. We confirmed that the ratio (counted number of the agents in S_i=+1 state)/10000 converged.

Table 1 is the result for H=1.0, J=2.2 and p=0.95. It can be seen that about 20%-25% of all the agents are staying in the +1 state, namely joining the open system. One can see that the ratio of the +1 agents increases as N increases. This means that a system with more leaders with its interaction range smaller is preferred from the viewpoint of sustainability.

Table 2 in another example for H=0.8 J=2.1 and p=0.90. One can see the same dependence on N.

We calculated for several other sets of parameters and obtained the same results.

It may seem strange that about 80% of the follower agents quit joining the open development project, considering p=0.95. This, however, is reasonable considering that the leader agents do not cover all the follower agents. The agents not covered by leader agents soon quit joining the open system. Those agents affect the neighboring agents and drive them to the –1 state. Finally the whole system converges to the state that about 80% of the follower agents are in the –1 state.

Table 1. Results for H=1.0, J=2.2 and p=0.95.

N	Ratio of +1 states
1	18.4%
2	22.6%
4	23.1%
8	24.0%
16	26.4%

Table 2. Results for H=0.80, J=2.1 and p=0.90.

N	Ratio of +1 states
1	20.2%
2	25.7%
4	27.5%
8	27.7%
16	28.0%

Conclusion and Future Works

We investigated the sustainability of open development systems from the viewpoint of leader agents under fluctuation. We used Ising type agent model and extended it so that it can take the role of leader agents into account. It was found that the system with distributed less-powered leader is more stable than a system with one powerful leader.

We obtained this result based on a simple agent model as Ising model. In the Ising model, all the follower agents are equal and interact with four neighboring agents. It has been known, however, that the way of interaction obeys the free-scale network, in which the number of the interacting agents is described by power law. To investigate whether the same results can be obtained under free-scale network is open to the future works.

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