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Synchrony in a Self-Repair Network with a Simple Lattice

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Abstract: We investigate a synchrony in a self-repairing network of autonomous agents capable of repairing mutually. In this paper, we define two models: a synchronous model and asynchronous one. They differ in the timing when the agents change their state. Computer simulations revealed that the synchronous model has a critical point, while the asynchronous one does not. We also studied a repair scheme in asynchronous model where the repaired agents in turn repair neighbor agents successively in a chain-reactive fashion. Performance of the scheme has been examined by computer simulations.

Keywords: self-repairing network, multi-agent, cellular automaton, reliability, network cleaning problem

I. INTRODUCTION

As a scale and complexity of computer networks increase, it would be more difficult to repair and even locate the failed nodes. Fault tolerant systems have been long studied to solve such problems, and they can indeed realize high reliability and availability, it would cost to high [1] to be used widely.

What makes the situation worse is that malicious programs and tempering are always possible for information systems. In spite of the development of anti-virus programs, it is still difficult to eradicate malicious programs such as computer viruses and worms from the Internet [2].

Rather than focusing on preventing all the possible incidences, focusing on recovering from unfavorable state rapidly would be an alternative way. Recovery-oriented computing has been proposed [3] in this line.

We have proposed yet another line of research that seeks for the network consisting of autonomous agents [4, 5] where repairing can be done in a decentralized fashion as opposed to a centralized fashion. We also studied a problem if cleaning the entire network is possible only by mutually copying among the agents. In the study of the self-repairing network modeled by a probabilistic cellular automaton, the model revealed that the cleaning is possible under certain situation; since the model is equivalent to a class of the probabilistic cellular automaton. Several repairing schemes including the strategic one using Spatial Prisoner's Dilemma have been also studied [4].

This paper concentrate on the synchrony of the model: whether the synchrony affect the critical phenomenon or not. A *chain repair* scheme for the asynchronous model is also studied.

II. A SELF-REPAIRING NETWORK

1. Self-repairing network by a cellular automaton

A self-repairing network consists of agents capable of repairing other agents connected. In this study, each agent is placed at each node of one-dimensional lattice (Fig. 1) with a periodic boundary condition (leftmost agent and rightmost agent are connected). Each agent has two states: normal (0) and abnormal (1).

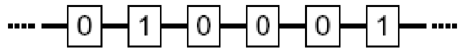


Fig.1 Cellular automaton with one-dimensional lattice and two states: normal (0) and abnormal (1)

Each agent tries to repair its neighbor agents. However, since the repairing is done possibly by abnormal agents, the repair could damage the neighbor agents rather than repair. Frequency of the repair trial is controlled by a parameter: repair rate ***Pr***. As shown in Fig.2 (a) and (b), the repair will be successful with a rate ***Prn*** (the repair success rate by normal agents) when the repair is done by a normal agent, and with a rate ***Pra*** (the repair success rate by abnormal agents) when it is done by an abnormal agent.

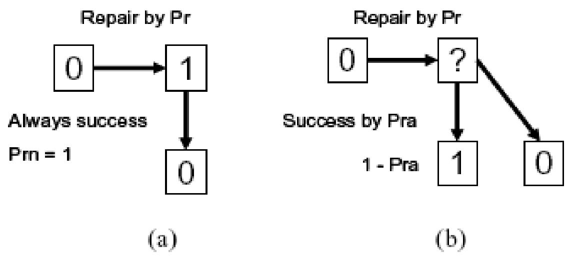


Fig.2 Repair (a) by normal agent and (b) by abnormal agent.

2. Synchrony of the self-repairing network

Whether abnormal agents can be eradicated or not may depend on the synchrony of the model. We compare two models: synchronous and asynchronous (Fig. 3). The synchronous model can be modeled with a probabilistic cellular automaton (pCA), while the asynchronous one can be modeled by the multi-agents system consisting of agents that determine the timing of their actions and the state is changed when the actions are made (not waiting for other agents). Thus, the order of repairing matters in the asynchronous model.

The repair will be successful when all the repairing from the neighbor agents is successful in the

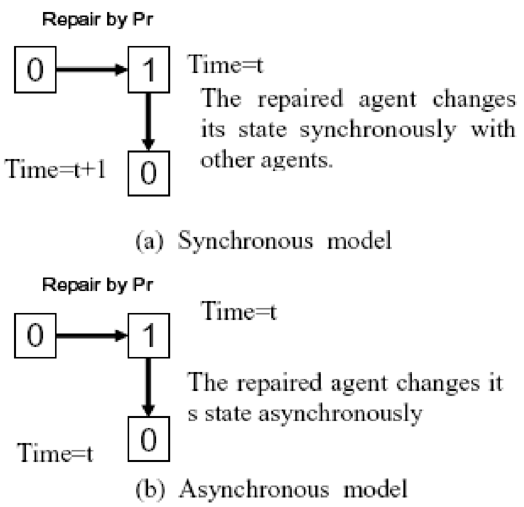


Fig.3 Two models: (a) Synchronous and (b) Asynchronous

synchronous model, while the repair can be successful at each time done by an agent is successful in the asynchronous model (notice that the repair is done by a single agent at one time in the asynchronous model).

3. Comparison between the two models

Computer simulations are conducted in one-dimensional lattice with the size 500. Initially, half of agents are set to be abnormal.

Figure 4 shows the number of normal agents after 10000 steps. It can be observed that the number of normal agents increases drastically as ***Pra*** increases in the synchronous model. On the other hand, all the agents can be normal almost independently from ***Pra*** in the asynchronous model.

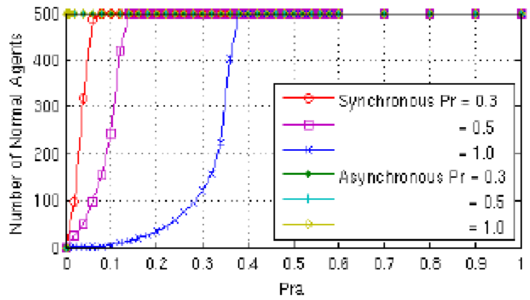


Fig.4 Number of the normal agents after 10000 steps (10 times averaged) plotted when the successful repair rate ***Pra*** varies.

Figure 5 is a phase diagram with two parameters: ***Pr*** and ***Pra***. Since the synchronous model is equivalent to a probabilistic cellular automaton with directed percolation [6], two phases are clearly separated. All the abnormal agents cannot be eradicated in the upper left region, while all the agents can be made normal in the rest region.

In the asynchronous model, however, all the agents can always be made normal in any value of ***Pra*** except ***Pra*** =0.

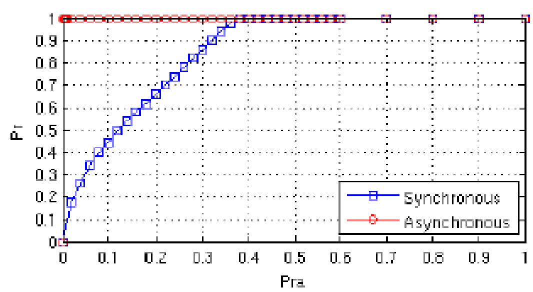
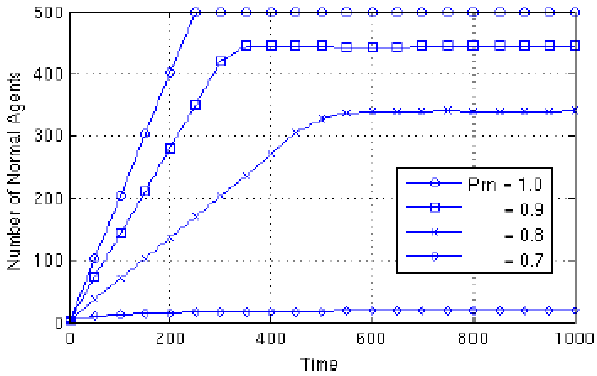
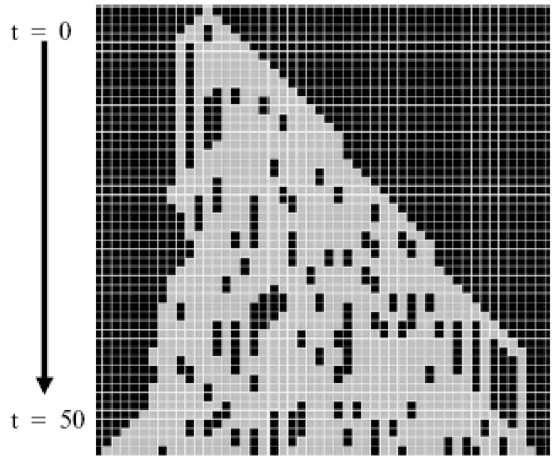


Fig.5 The phase diagram. The synchronous model has two phases: a disease phase (upper left region) and an extinct phase (right region), while asynchronous one does not.



(a) Time evolution of the first 1000 steps.



(b) A spatio-temporal pattern of a chaining repair when ***Prn*** = 0.8. Normal (abnormal) agents are indicated by light gray (black) co lor. The repair starts from a normal agent.

Fig.6 Time evolution of the chain repair

4. Repair Chain in the Asynchronous Model

Here we propose and test a chain repair in the asynchronous model. The chain repair takes advantage of the asynchronous model in which the order of the repair can be considered and the order affects the performance. Importantly, the chain repair suits to the autonomous distributed framework, since it uses only local information from or to the neighbors.

The chain repair is defined to form a consecutive repair where the agent repaired will in turn repair the neighbor agents successively. When the agents are repaired successfully, they (hence normal agents) repair only in the next time step once. When the repair failed, however, the repaired agents become abnormal (with a rate 1- ***Prn***), and the abnormal agents do not repair anymore.

The chain repair would obviously eradicate all the abnormal agents if ***Prn*** = 1.0 and the repair started from the normal agents.

Figure 6 (a) plots the time evolution of the performance (the number of normal agents) when the chain repair started from a normal agent. It is observed that the number of the normal agent increases constantly until the steady level is attained. The attainable ratio of the normal agents and the gradient of the each plot differ depending on the repair success rate ***Prn***. The number of normal agents does not increase unless ***Prn*** exceeds the value 0.7.

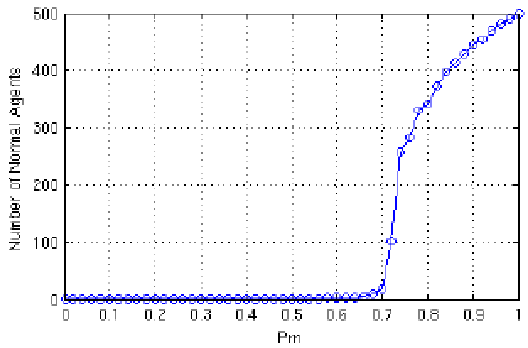


Fig.7 Number of the normal agents after 1000 steps (100 times averaged) varying the repair success rate by normal agents ***Prn*** in the chain repair starting from a normal agent.

Figure 6 (b) shows a spatio-temporal pattern of the first 50 steps starting from a normal agents when ***Prn*** = 0.8. The normal agents (colored light gray) spread to the network as the time step proceeds (downwards in the figure).

Figure 7 plots the performance (the number of normal agents) after 1000 steps varying the repair success rate by normal agents ***Prn*** in the chain repair starting from a normal. The abnormal agents persist in the network when the ***Prn*** is less than 0.7. However, the number of normal agents increases drastically.

Figure 8 also plots the performance in a situation similar to the case shown in Figure 7 except the chain repair started from an abnormal agent. Since the chain start from the abnormal agent, the repair success rate by abnormal agent ***Pra*** matters. It is observed that the number of normal agents can increase as ***Pra*** increases when ***Prn*** is 1 or 0.8, while it does not when ***Prn*** is 0.7.

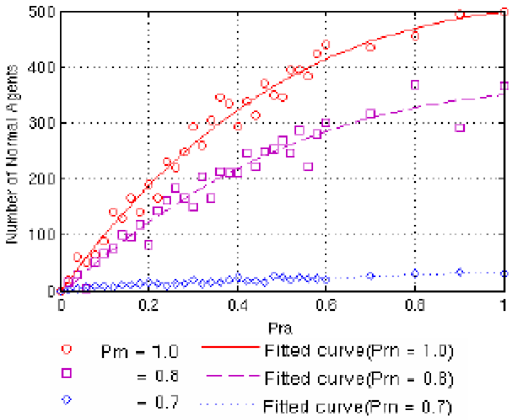


Fig.8 Number of the normal agents after 1000 steps (100 times averaged) varying the repair success rate by abnormal agents ***Pra*** in the chain repair starting from an abnormal agent.

III. DISCUSSION

Synchrony in the self-repairing network can affect the performance (the attainable ratio of normal agents) in many ways. Since the evaluation of whether or not the repair is successful is done synchronously after all the repairing by the neighbor agents, there are two extreme evaluations: the repair is successful; (1) when all the repairs are successful (named AND-repair); or (2) when any of the repairs is successful (named OR-repair). Although the OR-repair in the synchronous model is similar to the evaluation of repair in the asynchronous model where the evaluation is done at each time when the repair is done, a simple calculation shows the performance of OR-repair is better than that of asynchronous model.

When the chain repair is used in the asynchronous model, it would obviously eradicate all the abnormal nodes when the repair success rate by normal agents ***Prn*** = 1 and the repair chain started from a normal agent. The chain repair would eradicate all the abnormal agents even when all the agents are initially abnormal if the repair success rate by abnormal agents ***Pra*** is close enough to 1.0.

IV. CONCLUSION

We conclude that the asynchronous model of the self-repairing net does not have the disease phase where normal and abnormal agents both persist, while the synchronous model has the phase because it is equivalent to the Domany-Kinzel model, which in turn known to be equivalent to Ising model.

We also proposed a *chain repair* scheme for the asynchronous model. Computer simulations revealed that the chain repair would eradicate almost entire abnormal agents even when all the agents are initially abnormal, if the repair success rate is close enough to 1.

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