



## Chapter III

# Information Networks as Complex Systems: A Self-Repair and Regulation Model

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### Abstract

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*Complex networks such as scale-free networks and small-world networks, and their dynamics when information percolates through the networks, have been studied. This chapter reports the problem of spreading of the normal state (rather than spreading of the abnormal state) that is formalized as cleaning a contaminated network by mutual copying. Repairing by copying is a double-edged sword that could spread contamination when properly used. A framework for controlling copying involving a spatial prisoner's dilemma is introduced. A characteristic adaptation to the network environment has been observed.*

### Introduction

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A new way of viewing networks from topological or structural viewpoints has been proposed. Many artificial and natural networks have been studied using this approach, and special attention has been paid to their structural properties, such as “scale-free” (Barabasi, 2002) or

“small-world” (Watts, 2003). On the other hand, studies on the interaction in the network, or dynamics of the network (as opposed to structure), have also become an important topic. For example, information propagation in a scale-free network seems to be important.

In the context of fault-diagnosis, the scale-free network theory has shown that the Internet is robust against random faults, but vulnerable to selective attacks targeted at hubs (Dezso & Barabasi, 2002), and that viruses and worms may not be eradicated since the epidemic threshold is absent in the scale-free network (May & Lloyd, 2001; Pastor & Vespignani, 2001).

Malicious faults, such as viruses and worms, completely change the nature of faults. Machine faults are usually random faults, since their occurrence is not “selective,” and also they correspond to designed functions and hence are recovered when the parts covering the function are replaced. The point is that viruses and worms change the intended function rather than causing malfunction, hence they cannot be treated by usual redundancy and/or stand-by techniques. This drastic change of the aspect of faults calls for the design paradigm of the immune system, whose “self” is adaptive to the environment.

We have been studying the interaction of the network and proposed a dynamic relational network based on the immune network to increase robustness and adaptability to the dynamic environment (Ishida, 2004). In the framework, the network is double-sided and would raise the self-referential paradox in a flat logic without distribution, and hence subtle tuning is needed as in the immune system. Organizing responses to faults in large-scale systems has been proposed in a new approach of recovery-oriented computing (Brown & Patterson, 2001).

For physical systems such as mechanical systems, they are repaired by identifying the faulty components and replacing them with non-faulty ones. For information systems, however, they can be repaired by simply copying the clean system to the contaminated system. As the first step toward the adaptive defense of information systems, we consider self-repairing of the network by mutual copying (Ishida, 2005).

In self-repair systems with autonomous distributed units, abnormal units may adversely affect the system when they try to repair other normal units. Thus, the problem involves a double-edged sword similar to the immune system. We consider a critical phenomenon by modeling the problem by a probabilistic cellular automaton (pCA) which turns out to be a generalization of the well-known model (Domany & Kinzel, 1984). Self-repairing cellular automata have been attracting a widespread attention including in the field of statistical physics (Gacs, 2001).

Since the problem involves the double-edged sword leading to a critical phenomenon, repairs have to be decided giving consideration to the resources used and remaining in the system and the network environment. When the self-repair is done in an autonomous distributed manner, each unit does not voluntarily repair other units to save their own resources, thus leaving many abnormal units not repaired. This situation is similar to the dilemma that would occur in the prisoner’s dilemma (Axelrod, 1984, 1987). Thus, we use a spatial version of the prisoner’s dilemma (Nowak & May, 1992) for emergence of cooperative collectives and for controlling copying to save resources.

The next section explains the motivations and background of the models in this chapter. The approach of immunity-based systems involving the self-referential network is introduced. The approach inevitably leads to the double-edged sword. The problem of cleaning

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