Chapter 5
Artificial Self-assembly and Self-repair

Abstract. In Chapter 2, we learned that biological systems have elaborate designs that cannot be matched by conventional engineering, thanks to the various self-organizing mechanisms deployed in each layer of their hierarchy. In Chapter 3, we summarized several attempts to reconstruct such biological mechanisms artificially. If we can uncover the principles of these mechanisms through reconstruction efforts, then we can in turn apply these principles in making devices for our own purposes. In other words, we proceed from science to engineering. Even if we obtain ideas for basic notions and principles from biological systems, though, when we actually build devices, many practical issues remain to be resolved. In such specific problem solving stages, there is no need to look to nature for ideas anymore; although humans were inspired by birds to create flying machines, the actual airplanes constructed by humans have quite different structures from those of birds. The technology or materials currently at hand must be used, and the problems may be solved with new ideas. The aim of this chapter is to construct artificial systems like the ones we discussed in Chapter 3, but this time from an engineering perspective. Specifically, we consider how to make systems which have self-assembly and self-repair functions.

5.1 Methods for Self-assembly and Self-repair: Homogeneous System Approach

The unit machine called a "Fractum", which we discuss in this chapter, is one typical realization of a distributed autonomous system [1-3]. All aspects of its hardware and algorithms are strictly based on the principles of distributed autonomous systems, such as homogeneity and local communication. Using such units, we built a mechanical system that is capable of self-assembly and self-repair. As we have seen in Chapter 2, biological self-repair depends on the self-reproduction of cells, and the technology of current ordinary mechanical engineering is not likely to be able to realize a system whose components can self-reproduce. However, we don’t think that an artificial self-repairing system cannot be achieved until technology for self-reproduction of elements is completed. This obstacle can be hurdled if the conceptual framework of the system is changed appropriately.
Firstly, *even if components cannot self-reproduce themselves, it is sufficient that only one kind of component is used*. Having only one kind of component is an advantage for self-repair because any broken component can be replaced by any other.

Secondly, *the components should have the ability to assemble into a system by themselves*. Here, the task of assembly can be further decomposed into two functions. One is the *mobility* of the component, its ability to move to a suitable position. In ordinary machine assembly, a human or a robot would move components to appropriate positions to assemble them into a machine. In the case of self-assembly by components, however, they themselves must move to appropriate positions by some method.

Another function required is *connectivity*. If components are to arrange themselves into a certain configuration to form a mechanical system, they must remain at certain geometric positions relative to each other. For that purpose, at least three connections are required for each component. If each component can connect to only two other components, the systems can only have a one-dimensional linear structure. If on the other hand each component can have at least three connections, desired three-dimensional structures can be built just like chemists build models of molecules.

Now, if we assume that the components already have connections when the assembly begins, the relative positions of components can be changed by *reconfiguring* the connections (“reconfiguration” hereafter means “replacing connections”). This means that the mobility of components is equivalent to their reconfiguration function.

To make components with such functions, each component needs control logic, and it must also have a certain level of information processing capability. Since the information processing in this case is autonomous and distributed, communication between units is also necessary.

So far, we have been using the term *component*, but realizing the above functions with simple components such as screws and magnets is out of the question. What we mean here by components is the unit of self-organization we discussed in Section 1.2. Therefore, in this chapter, we call such components *units*. (In later chapters, we call more advanced constituent elements *modules*. There is no strict

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1 This is not a particularly new idea. The cellular model of von Neumann is also based on the assumption of "a space filled with homogeneous cells that can become any type". It should be kept in mind that, in this model, a cell of a particular type can differentiate into 29 possible types. This is in effect the same as assuming that the desired component is available at the desired position any time.

2 The best way to move a component depends on the size of that component (See Section 1.3.2). In von Neumann's kinetic model and Penrose's building block model, components are assumed to be floating in space, and when they randomly collide it is decided whether to use this connection in the assembly. However, this kind of assembly by random collision can be adopted only when the components are very small and the effect of the gravity can be ignored, not for ordinary sized mechanical systems. On the other hand, if we equip units with legs or wheels, the system will be reduced to a collection of mobile robots.