

# Self-Assembling Robots

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**Self-assembly is a process by which pre-existing components organize into patterns or structures without human intervention. Such processes are responsible for the generation of much of the order in nature. This thesis investigates the use of self-assembly in autonomous mobile robots, and relates the findings to the biological literature.**

## 1 Introduction

One of the grand challenges of robotics is the design of robots that are adaptive and self-sufficient. This can be crucial for robots exposed to environments that are unstructured (in space and time) or not easily accessible for a human operator, such as the inside of a blood vessel, a collapsed building, the deep sea, or the surface of another planet. *Modular reconfigurable* robots are among the most flexible robots that exist. They are made of one or a few types of component modules which can be connected into many distinct topologies. Therefore, exploring a limited set of modules, it is possible to set up a robot with context-dependent morphology.

An interesting category of modular robots are *self-reconfigurable* robots, which can autonomously transform between different morphologies [8]. For instance, a self-reconfigurable robot could adapt its locomotion strategy by transforming from a snake morphology (which could offer advantages when navigating through narrow passages) to a hexapod morphology (which could offer advantages when navigating uneven terrain) and vice versa. In many of the current implementations, self-reconfigurable robots are initially manually assembled and once assembled, they are incapable of assimilating additional component modules without external assistance. In our view, this lack of autonomy is a severe limitation to the adaptivity and self-sufficiency of these robotic systems. In contrast, this thesis focuses on reconfigurable robotic systems whose components are capable of *self-assembling* autonomously. Thereby, the components can in principle set up modular robots of arbitrary size, composition, and function.

## 2 Methods

Natural self-assembly processes are our primary source of inspiration [10]. Of particular relevance to our study in autonomous robots are processes involving macroscopic components, such as social insects like ants or bees [2, 4]. We follow the principles of *swarm intelligence* [3], aiming at systems that are fault tolerant, robust, and scalable. We consider robots of "identical" hardware and with decentralized control. The robots make little use of memory and take actions on the basis of local information. The control policies (e.g., artificial neural networks) are designed in simulation using evolutionary algorithms [6], and subsequently ported onto a physical system. Their performance is assessed in a range of different conditions, and compared with the performance of

reference strategies and with a lower/upper bound performance.

## 3 Contribution

We review half a century of research on the design of systems displaying self-assembly of macroscopic components. We report on the experience gained in the design of 22 such systems, exhibiting components ranging from (externally propelled) passive mechanical parts to (self-propelled) mobile robots. We present a taxonomy of these systems, and discuss design principles and functions.

We then focus on systems in which the components that assemble are (self-propelled) mobile robots. Previous work in mobile robotics has focused on self-assembly *per se*, that is, on the process by which structure forms through interactions of specifically designed robots. Instead, we look at self-assembly as a mechanism that helps robots to accomplish autonomously concrete tasks. In particular, we address a simple object manipulation task—the group transport of a heavy object.

In a first study, we simulate robots that have very limited acting and cognitive abilities. They can neither perceive teammates nor communicate with them directly. Using an evolutionary algorithm, we train groups of these robots to accomplish a transport task. The underlying objective function does neither explicitly reward the robots for self-assembling, nor does it impose any bias concerning the spatial organization of the robots during task performance. Nevertheless, self-assembly behaviors evolve and in many cases are the most effective. The "emergence" of self-assembly is a striking result, confirming that such capability (as in social insects) can provide adaptive value to the group. The analysis reveals a variety of proximate mechanisms that cause coordinated behavior in groups. Interestingly, some of these mechanisms are also exhibited in groups of robots that were trained for solitary task performance (biologists reported that, in some species, individuals show no difference in behavior when engaged in solitary and group transport, for example, see [9]). As a result of this, we hypothesize that in some species group transport has evolved from solitary transport, presumably from situations in which solitary transporters, without being aware of each other, cooperatively transported a common load. Further analysis of our system shows that the transport is relatively ineffective when the assembled structures are large. This might be a consequence of the low degree of mobility of our simulated robots; animals that are subject to similar limitation do not form large, self-propelled structures either.