Chapter 46
Adaptive Self-Organizing Organisms Using a Bio-Inspired Gene Regulatory Network Controller:
For the Aggregation of Evolutionary Robots Under a Changing Environment

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ABSTRACT

This work has explored the adaptive potential of simulated swarm robots that contain a genomic encoding of a bio-inspired gene regulatory network (GRN). An artificial genome is combined with a flexible agent-based system, representing the activated part of the regulatory network that transduces environmental cues into phenotypic behavior. Using an Alife simulation framework that mimics a changing environment, we have shown that separating the static from the conditionally active part of the network contributes to a better adaptive behavior. This chapter describes the biologically inspired concept of GRNs to develop a distributed robot self-organizing approach. In particular, it shows that by using this approach, multiple swarm robots can aggregate to form a robotic organism that can adapt its configuration as a response to a dynamically changing environment. In addition, through the comparison of several different simulation experiments, the results illustrate the impact of evolutionary operators such as mutations and duplications on improving the adaptability of organisms.

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INTRODUCTION

Self-organization is a phenomenon that has been observed in disciplines as diverse as physics, molecular chemistry and biology. For example, in biological self-organized system, hundreds to even billons of homogeneous or heterogeneous cells can aggregate to form colonies or tissues. Social insects such as ants, termites, bees, or even schools of swimming fish also can be regarded as self-organizing systems where coordination arises out of the local interactions between entities of an initially disordered system, which allows the system as a whole to perform more complex tasks than those performed by the individual entities (Camazine et al., 2003). In robotics, one of the most widely adopted approaches that mimic this biological behavior are swarm robots and robotic organisms (Levi, et al., 2010; Kornienko et al., 2007). Swarm robotic systems are self-adaptive systems in which individual swarm robots can aggregate and form a robotic organism with an emerging global behavior (see examples in Dorigo, et al., 2004 and Yim et al., 2000). Ideally, such systems should have the potential to be adaptive by changing their configuration in different situations in an unbiased way (Ampatzis, 2009). In other words, swarm robots should decide themselves when and how to assemble, depending on environmental cues and the current configuration of the robotic organism. Configuration here refers to the topological position according to which individual swarm robots assemble into a more complex 'organism'. This could improve the adaptability and robustness of swarm robots and increase their performance in complex tasks (such as Mars exploration, disaster rescue, etc.). For example, one can imagine that, for different reasons, people cannot replace or fix defective robots during the performance of a certain task. If a robotic organism could re-organize or fix the damage itself instead of waiting for help, this would certainly extend the applicability of the robot. Ideally, such configuration of the robotic organism is the emerging result of the interaction between robots and the environment (see Nolfi and Floreano, 2000) and thus should not be predicated on predefined configurations that should be adopted under different predefined settings. However, this is difficult to achieve with robots driven by a global and explicit algorithm in which the configuration of the robots is distributed, the reasons being that an explicit global algorithm can hardly identify the 'right' topological position of each robot in response to possible environmental changes that can occur during the aggregation process. Indeed, each robot may 'sense' a different or differently changing local environment and context, and adequate, but different reactions can have consequences at later stages. Optimizing swarm robot systems with such enormous uncertainty probabilities however is generally too complex for global algorithms. Furthermore, since most of the different environments may not be identifiable during model design and development, it is very difficult to decide on an explicit and suitable paradigm for measuring the 'adaptability' of particular configurations. To achieve higher adaptation of multi-robot organisms, some recent studies have used the distributed interaction between swarm robots to determine the local relationship between individual robots (Ducatelle et al., 2011; Trianni et al., 2003; Correll and Alcherio, 2006). In these approaches, after all local relationships have been decided during a developmental process, the overall configuration also is self-organized. The most critical part of such approach is that the interactive behavioral pattern (i.e. the particular robot will only aggregate with a certain type of robot or under a certain condition) of each robot evolves continuously and only the robots that can build more adaptive organisms will be selected for docking. This way, the adaptability of the multi-robot organism can be improved by individual evolution of each robot and suitable organism configuration can be reached during the self-organizing process. Some concrete examples of such approach have been described by the works of Trianni (2008) and Holland et al(1999).