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# Awareness and self-awareness for multi-robot organisms

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*When multicellular systems acquire awareness and self-awareness they become highly adaptable and can develop unexpected abilities.*

Awareness and self-awareness are two different notions related to an entity knowing the environment and knowing itself, respectively. In a general context, self-awareness belongs to a class of so-called self-* (or 'self-star') issues, which include self-adaptation, self-repair, self-replication, self-development and self-recovery. The self-* issues are connected in many ways to the emergence of behaviour, the ability to adapt and evolve and also the control of long-term developmental processes.[1]

Self-* issues can occur as natural properties of systems, such as self-assembling of molecular networks, or they may emerge as a result of homeostatic regulation (which inherently involves some degree of self-monitoring and self-adjustment). For instance, organisms may optimize their energy consumption and other characteristics via processes that perform homeostatic regulation. Moreover, conditions of ecological survival, imposed on collective systems, lead to a discrimination between 'self' and 'non-self' as well as to the emergence of various self-phenomena. Many profound challenges related to self-* issues, such as understanding these mechanisms or achieving long-term predictability of artificial evolution, are of considerable interest to researchers of artificial intelligence and intelligent systems.

The appearance of collective awareness in artificial social systems is another very relevant topic of modern research. Collective systems—such as swarms of insects, groups of animals or robots and traffic systems—possess several key properties: scalability, reliability and adaptability to a large variety of environmental conditions. More generally, collective systems play very important roles on Earth. We encounter them in all sizes and forms, in biological and technological systems, in the oceans, in the air and on the ground. Life as we know it is impossible without collective forms of existence, such as multicellular or multi-individual entities.

The mechanisms of awareness in collective systems include components such as common knowledge, a model of the environment, a model of the self and reasoning with models. These collective mechanisms perform a very interesting task:

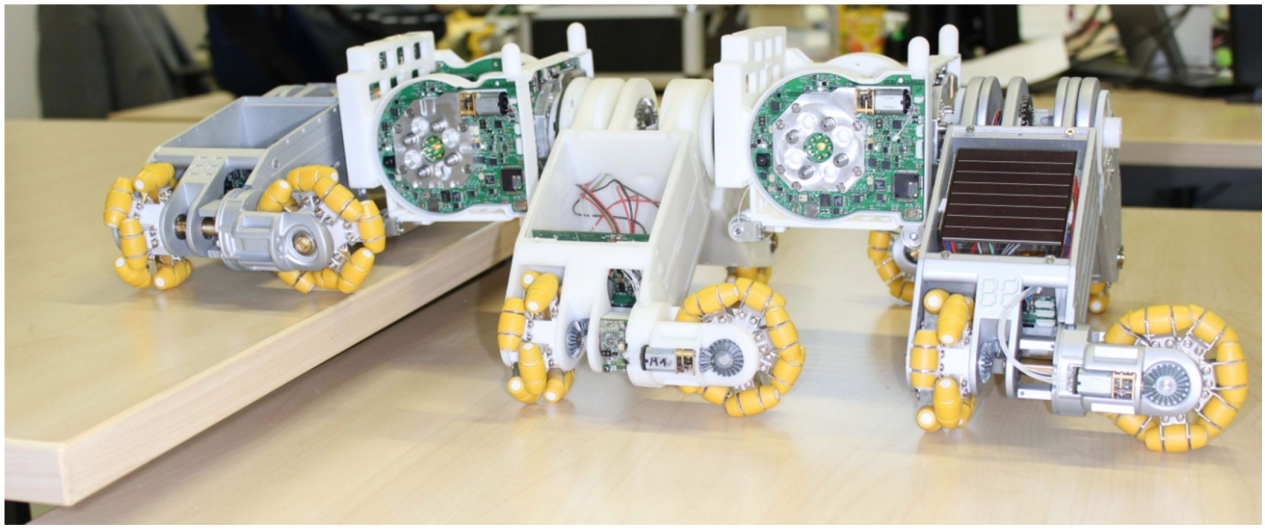

***Figure 1.*** *Simple artificial organism consisting of five robotic modules, which combine information from their different sensors to create a common awareness.*

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the system models its environment and itself, and based on collective reasoning it recognizes itself (as the whole collective system) in the environment. The recognition of the collective self is comparable to the simplest forms of collective artificial preconsciousness, which is very hard to achieve, especially taking into account the distributed nature of collective systems.

Mechanisms of awareness and self-* properties are of special interest in multicellular systems. Such systems consist of a large number of cells or modules, which can behave independently like a swarm or can be connected to one another (see Figure 1). Multicellular organisms are self-adaptive, self-regulative and self-developing. They are studied in fields of basic research such as artificial embryology and evolutionary computation, but are also of practical importance for technology because of their structural and functional reconfigurability and adaptability.

The European Union research projects SYMBRION[2] (symbiotic evolutionary robot organisms) and REPLICATOR[3] (robotic evolutionary self-programming and self-assembling organisms) deal with artificial multicellular systems and the processes that take place in them.[4] The main focus of these projects is to investigate and develop novel principles of adaptation and evolution for multi-robot organisms based on bio-inspired designs and modern computing paradigms. These robot organisms consist of a large-scale swarm of robots, which can dock with each other to share energy and computational resources. In addition, the individual robots can be equipped with special tools and can share information from sensors, both their own sensors and also remote ones. When it is advantageous to do so, the robots can dynamically aggregate into one or more symbiotic organisms and collectively interact with the physical world via a variety of sensors and actuators.

Mechanisms of awareness and self-awareness in robot organisms are based on bio-inspired and evolutionary paradigms, such as artificial embryogenesis or online, onboard embodied evolution. For instance, the organisms can autonomously manage their own hardware and software organization to reprogram themselves without human supervision. In this way, artificial robotic organisms become self-configuring, self-healing, self-optimizing and self-protecting, at both the hardware and software level. The mechanisms of awareness and self-awareness can be evolved, emerging through adaptive self-organization, or can appear as a result of homeostatic regulation. Such mechanisms not only lead to robotic systems that are extremely adaptive, evolvable and scalable, but also enable unforeseen functionality to emerge. For example, when a multi-robot system designed for flat surfaces encountered a gap on the surface, it evolved a kind of legs to get across the gap.

These capabilities of multi-robot systems—autonomous large-scale self-aggregation, reprogramming and evolution—have the potential to open up a wide range of current and future applications. One of the main application scenarios of such artificial organisms is human-free environments with a high degree of danger or uncertainty.

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