Robot Societies -
From Simulator Studies towards a Real World Application

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Abstract

In our research we use a biologically inspired term robot society as a generic technical concept to describe a group of autonomous mobile robots working together towards a common goal. These robots operate under diverse interactions with each other and with the environment. Equipped basically only with simple behaviors they are in a way gaining "intelligence through interactions" and are capable of performing rather complex behaviors at the society level. Due to the nature of this research (i.e., large number of robots) simulators have been the main tools so far. Recently, however, we have been able to produce a physical underwater robot society. This society operates currently in laboratory conditions, but a real world application in clean water systems is under development.

Introduction

Nowadays, a clear trend seems to go towards adaptive, learning and cooperative robots, see (Cao, Fukunaga, and Kahng 1997) for an extensive overview. These robots are constantly interacting not only with the dynamic environment, but also with each other and with the persons who are using them. This large variety of interactions will produce behaviors that are going to be superior compared to ones performed by current robots. The robots will be equipped to survive as a part of a complex system, where the cooperation is essential for their survival. Collective intelligence emerging from these interactions gives a reason to call these systems at their highest level as "robot societies." But when the goal is to create a robot society, one is instantly facing a huge amount of both conceptual and technical problems. First of all, what is a robot society anyhow? How can it be defined? Is it even possible to accomplish something artificial that could be called as a society? The societal structures, so common in the nature around us, are not easily replicated with machines. Nevertheless, for five years already, our goal has been to create some sort of a general framework to build strongly application oriented robot societies. This framework is partly based on the information, which has been gathered from natural societies. Furthermore, the experience gained by building robot societies both for simulated and real world environments is an essential part of it. However, it has to be stated here, that at this point no solid theory can be formulated (it is argued also that neither can anybody else for that matter). Initially our research was mainly conducted in different multi-agent simulators, but recently we have started parallel studies with a real robot society. Our goal in the near future is to use this underwater robot society in a real world application monitoring conditions inside clean water systems.

Background in the Nature

In this research we are trying to benefit "the structures and functions" developed during millions of years of evolution. In the nature the survival of the fittest has always been the guiding line in the evolution process; organisms either adjust to changing environment conditions or they will become extinct. There are many societies in the nature, but we have concentrated on two of the simplest ones, namely on bacteria and ants. Until recently bacteria were more or less considered to be really simple unicellular microbes, even though there have been studies proofing opposite already at the beginning of this century. It took decades before the prejudices were won, and the idea of bacteria as multicellular organisms with abilities to form communities, hunt in groups and even communicate with each other were accepted (Shapiro 1988). All these features were before considered to exist only in higher level organisms. (Shapiro 1995) states that bacteria derive clear advantages from multicellularity. These include strength in numbers and the potential for specialization and cellular division of labor. Our main inspiration has nevertheless been obtained from social insects. The incredible work done by these little creatures has been known for thousands of years. Thus it is appropriate that it also provides us some ideas for the concept of robot society. Ant societies have several fascinating features like chemical and tactical communication, asyncrohonicity, self-organization, coordinated behaviors, self activation, stability, and so on. These small animals, equipped with "simple rules", can create rather complex global behaviors through local interactions. If these rules could be properly isolated and formulated then maybe we could actually build a real life-like society of robots with the same kind of astonishing robustness and adaptivity. The reason why individuals have formed societies is the fact that they will provide mutual advantages to the members of the society. In the nature these advantages include things like more efficient search for food, collective defense, coherent transferring, etc. (Deneubourg 1996) talks about "factories within fortresses." He compares an ant society to a well defended factory that gathers raw material from outside world, and then uses them to maintain and extent its infrastructure and outputs some products (i.e., new individuals).

The Concept of Robot Society

Similar ideas can easily be connected to robot societies as well. A robot society is, however, an artificial man-made system, which is constructed for certain tasks. This has to be kept in mind, when "transferring" properties of biological societies to machine societies. It is obvious that living systems have two main behaviors that have priority over everything else. The first one is so called self-preserving behavior, which just means that the individual tries to maintain the homeostasis. The second one is the species-preserving behavior. In some species in some special conditions the second behavior will rule out the first one (i.e., strong altruism). (Klopf 1982) suggests that another primary behavior would be what he calls as stimulation -preserving behavior, which means that knowledge acquisition and play are also vital for living systems. We have tried to include all these three points to our definition of a robot society. In short: the members should be able to monitor their energy level and get some more before they are "dying" (self-preserving), the members should be able to work as a society fulfilling the task that was given to the society (species -preserving) and finally we are also trying to accomplish knowledge acquisition in order to provide the members a way to improve their performance.

In the nature most of the solutions are not optimal but rather suboptimal. The way to survive in evolution is to create robust systems, that can deal with various changes in their environment without loosing their operation capabilities. The difference between the natural and the artificial societies is that *in the natural societies all tasks are done for the sake of surviving, though in doing so one might found surprising accomplishments, like ants forming a living bridge over a small gap in the ground. While in the natural societies one may regard those accomplishments as side effects, in machine societies these are the objectives.* All functions of the society are obviously realized through its members. The members' behaviors are results from their own needs and from the constraints (dynamic by their nature) set by the society. One of the main tasks when we started this study, was to develop a model for controlling the operation of the society. Our model is based on the use of so called society states. Each member has a way to represent the status of the society by certain variables. These variables will summarize all the information that an individual agent has about its own performance and the performance of the other society members. These variables are usually expressed explicitly, but they can as well be presented implicitly with a some sort of self-organizing process, for example, in a neural network. The society is defined with a three level hierarchy: the society, the task, and the member. Each of these levels is implemented to the members and the use of society state variables will define the decision making on these levels. The society level will ensure that the society is operating as planned toward mission goals. For instance if four society members are performing well in the foraging task by collecting objects from nearly same location, then at the society level (which is still happening in each individual member involved) a decision of an object quarry will be made. After that it is reasonable to recruit some additional members to work with the same quarry and thus improve the performance of the society. The task level control is highly domain specific and includes problems like how to initiate a swarming behavior in a group. In many cases the in-build reactivity will be able to deal with many problems earlier related to this level, e.g., the swarming behavior will emerge based on the interactions between members and with the environment. The agent level control must be based on the same issues, i.e., on the interactions and the lowest level behaviors.

There are clearly some general principles that are connected to our definition of a robot society. It is, of course, possible to create a society of robots that doesn't have all these features, but generally the society should have the following properties at least to some extent: *constrained local interactions, autonomy, asynchronicity, coordinated behaviors, goal oriented, value system, way to represent knowledge, decision making capabilities and, possibility to learn.*

A Short Research History

At the beginning of our research we designed a scenario where the society of robots would collect objects from an initially unknown 2D environment and simultaneously create collectively a map of the area, see e.g., (Halme et al. 1993), (Vainio, Schönberg and Halme 1995a) and (Vainio et al. 1995b). While studying the concept of robot society with the foraging society, we became aware that there actually was a practical demand for another type of robot society. The goal of this study, along with theoretical considerations, was to design and manufacture an underwater robot society, called as Bacterium robot society, to work inside 3D processes. The research includes the development of a robust adaptive mapping algorithm to be used inside processes, the idea of using chemical communication to initiate a collective cooperation, and the scenario of using the concept of altruism, see e.g. (Vainio et al. 1996). Besides the ongoing work with the physical robot society members we have developed two separate multi-agent simulators. These tools provide a fast way to test algorithms before down loading them to the real society members and enable testing with large populations, for example, when implementing Evolutionary Algorithms.

A Real World Application

In industrial and other processes the sensors used in monitoring and controlling are normally fixed. Thus they provide information only from certain selected parts of the process. In many cases additional information and improvements in control could be obtained if some of the sensors were made mobile. Although actuators are more difficult to think mobile, such concept may also be beneficial; e.g., when distributing chemicals spatially in the process for local reaction or cleaning purposes. This is the leading principle and motivation for the use of robot society concept in process industry. In (Halme et al. 1997) the inspection and leak monitoring of clean water systems were especially described.

Conclusions

It seems obvious that the number of distributed autonomous robotic system applications will increase rapidly as the technology and knowledge improve. Within few years, various robot societies will move out from research laboratories into everyday life. Normal applications will include tasks like cleaning, monitoring, delivering, etc. Besides that a number of more revolutionary applications will probably also emerge. These will take robot societies to distant planets, deep sea nodule collection missions, mining operations, and when the time comes maybe even inside human veins for search of tumors, which they will attack at close range. In these scenarios the multiplicity of robots is more important than the intelligence they possess. Just as in natural systems the intelligence of the system will emerge from the multiple interactions among the members and with the environment. (Deneubourg, Theraulaz, and Beckers 1992) state: "It is moving from the point of view of nature lovers and admires of technology, to imagine that the next robots could be the nephews of modest animals that have been on the earth for millions of years." It summaries all rather nicely.

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