Holonic Multiagent Systems

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With the growing usage of the world-wide information technology networks, agent technologies and multiagent systems are attracting more and more attention, as they perform well in environments that are not necessarily well-structured and benevolent. Looking at the problem solving capacity of multiagent systems, emergent system behaviour is one of the most interesting phenomena. But there is more to multiagent system design than the interaction between a number of agents: For effective system behaviour we need structure and organisation. Moreover, it is difficult to specify the organisation of a multiagent systems in a changing environment at design time.
The theory of holonic multiagent systems promises both, to provide a methodology for the recursive modelling of agent groups and to allow for dynamic reorganisation during runtime.

1 Introduction

A multiagent system (MAS) consists of a collection of individual agents, each of which displays a certain amount of *autonomy* with respect to its actions and perception of a domain. Overall computation is achieved by *autonomous computation* within each agent and by *communication* among the agents. The capability of the resulting MAS is an *emergent functionality* that may surpass the capabilities of each individual agent. It is a widely supported assumption in the multiagent community that the development of robust and scalable software systems requires autonomous agents that can complete their objectives while situated in a dynamic and uncertain environment. To this end, these agents need to be able to engage in rich, high-level social interactions, and operate within flexible organisational structures [3]. Organisational structures institutionalise anticipated coordination, which is especially useful for medium- and large-scale applications that require limitation of the agents' communication behaviour. Agents acting in such structures can encapsulate the complexity of subsystems (simplifying representation and design) and modularise its functionality (providing the basis for rapid development and incremental deployment).

Holonic multiagent systems provide terminology and theory for the realisation of such dynamically organising agents. They transfer modularity and recursion to the agent paradigm. In a holonic multiagent system, an agent that appears as a single entity to the outside world may in fact be composed of many sub-agents and conversely, many sub-agents may decide that it is advantageous to join into the coherent structure of a super-agent and thus act as single entity. We call agents consisting of sub-agents with the same inherent structure *holonic agents*.

2 History

The term "holon" was originally coined by Arthur Koestler [4], basing it on the Greek word "holos" for "whole" and the suffix "-on" that denotes "part". According Koestler a *holon* is a self-similar or *fractal* structure that is stable, coherent and that consists of several holons as sub-structures and is itself a part of a greater whole. As biological examples he names e.g. a human being, which consists of organs which in turn consist of cells that can be further decomposed and so on. Furthermore, the human being is part of a family and a society. None of these components can be understood completely without their sub-components or without the super-component they are part of. The concepts of *fractal* and *holonic* system design in manufacturing were proposed to combine top-down hierarchical organisational structure with decentralised control, which takes the bottom-up perspective [1, 7]. While earlier approaches in this area restricted self-similarity and did not employ the recursive power of the approach, newer developments make full use of it.

3 Definition of a Holonic Multiagent System

Although it is possible to organise holonic structures in a completely decentralised manner, for efficiency reasons it is sometimes more effective to use individual agents to represent a holon. This may either be achieved by selecting one or several of the already existing agents as representatives of the holon based on a fixed election procedure. Or, new agents are explicitly created to represent the holon during its lifetime. Representatives are called the *head* of the holon (or "mediator" in the conception of [6]), the other agents in the holon are part of the holon's *body*. In both cases, representative agents (and only they) stand for the shared intentions of the holon *and* negotiates these intentions with the agents in theholon's environment as well as with the agents internal to the holon. The binding force that keeps head and body in a holon together can be seen as commitments. This differentiates the approach from classical methods like object-oriented programming: the relationships are not (statically) expressed on code level, but in commitments formed during runtime.

For a MAS consisting of the set $\mathcal{A}_t$ of agents, the set $\mathcal{H}_t$ of all holons at time t is defined recursively:

- for each $a \in \mathcal{A}_t$, $h = (\{a\}, \{a\}, \emptyset) \in \mathcal{H}$, i.e. every instantiated agent constitutes an *atomic* holon, and
- $h = (Head, Subholons, C) \in \mathcal{H}$, where $Subholons \in 2^{\mathcal{H}} \backslash \emptyset$ is the set of holons that participate in h, $Head \subseteq Subholons$ is the non-empty set of holons that represent the holon to the environment and are responsible for coordinating the actions inside the holon. $C \subseteq Commitments$ defines the relationship inside the holon and is agreed on by all holons $h' \in Subholons$ at the time of joining the holon h.

A holon h is observed by its environment like any other agent in $\mathcal{A}_t$. Only at closer inspection it may turn out that h is constructed from (or represents) a set of agents. As any head of a holon has a unique identification, it is possible to communicate with each holon by just sending messages to their addresses. Given the holon $h = (Head, \{h_1, ..., h_n\}, C)$ we call $h_1, ..., h_n$ the *subholons* of h, and h the *superholon* of $h_1, ..., h_n$. The set $Body = \{h_1, ..., h_n\} \backslash Head$ (the complement of $Head$) is the set of subholons that are not allowed to represent holon h. Holons h' are allowed to engage in several different holons at the same time, as long as this does not contradict the sets of commitments of these superholons. C specifies the organizational structure, a more detailed coverage of this topic can be found in [5].

4 Applications

The theory of holonic multiagent systems has been iteratively tested, developed, and applied in a series of projects over several years with a big variation in requirements. In one domain (flexible manufacturing) agents form holons because they have different abilities and can only as a group achieve the task at hand [2]. A second example (train coupling and sharing) demonstrates that even in a setting where we have agents with identical abilities holonic structures can be beneficial [2]. Also, holonic agents proved to be an important modelling technique for medical information systems [6]. In several other projects special aspects of holonic modelling play an important role (e.g. Socionics [5]). The most striking application that used the presented approach to holonic multiagent systems is the TeleTruck system, which was designed to do order dispatching in haulage companies [2]. In all examples, the holonic multiagent systems were exposed to constantly changing environments that required equally constant adaptation.

Literatur

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