Available online at www.sciencedirect.com
ScienceDirect
Computers in Industry 58 (2007) 621–629
COMPUTERS IN INDUSTRY
www.elsevier.com/locate/compind

MAS coordination and control based on stigmergy

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Available online 29 May 2007

Abstract

This paper discusses a multi-agent coordination and control system. The system implements the PROSA architecture [12] and uses a specialized approach to stigmergy. This approach is discussed in relation to more commonplace designs based, for instance, on negotiation protocols. Next, the discussion focuses on the commonalities and differences between the source of inspiration for the system design – food foraging in ant colonies – and the resulting coordination control system itself. In particular, the discussion reveals that the multi-agent coordination and control system is based on deeper insights rather than a superficial translation of the biological example.

Keywords: Stigmergy; PROSA architecture; Multi-agent systems

1. Introduction

This paper describes the design of a class of multi-agent coordination and control systems. The description uses the term agent in a loose sense. These coordination and control systems are research prototypes [3,4] that focus on manufacturing control and supply network coordination. The manufacturing control systems handle the internal logistics and resource allocation in manufacturing plants. The supply network coordination systems extend the control system design toward resource coordination across multiple production sites, possibly owned by different organizations but cooperating on a regular basis.

The discussion first situates the class of control systems relative to work by others. Second, the paper presents the society of agents that constitute the control system. Finally, the coordination mechanisms are presented.

2. Related work

The aim of this section is to situate the coordination and control system technology, discussed below, relative to other research results and, in particular, to highlight the differences regarding the functionality offered by the respective technologies.

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doi:10.1016/j.compind.2007.05.003

2.1. Negotiation-based MAS control systems

An important class of research results in this domain, which historically often precedes the work in this paper, relies on negotiation to manage resource allocation and task assignment in MAS manufacturing control. Representative work is [5–7,17]. These control systems typically use the contract net protocol [1,2] and variants thereof to establish interactions among the agents. Such interactions require that:

- The agents involved perform a rendezvous requiring a synchronization, which usually is time-consuming and a non-negligible source of complexity when assessing systems dynamics. Often, broker agents are introduced to diminish this drawback.
- The requests and offers in the negotiations remain valid or open for a given amount of time, again limiting the reaction speed of the system. Indeed, service providers are likely to wait until the deadline gathering as many service requests as possible to optimize their offers. Likewise, service users are likely to wait while allowing more service offers, from which they can chose, to enter.
- The agents perform audience control, thus ensuring that requests and offers arrive at suitable places (i.e. agents) while avoiding communication overload.
- The developers establish a suitable common format for service descriptions both for service requests and offers, and

implement mechanisms to construct such requests and offers (including the associated time-outs).
- The developers establish suitable performance criteria for selection among offers (price, queue length, estimated processing time, ...) as well as mechanisms to decide when to decide (i.e. when to stop waiting for extra alternatives).

Overall, these systems have shown to be flexible but rather heavy (rendezvous, time-outs). These systems have few difficulties when the configuration of the underlying system changes or when a disturbance occurs. However, the above bullet list reveals that large parts of an implementation are likely to remain case-specific, where these parts determine system dynamics to a large extent. Moreover, the performance criteria (e.g. price) generally are losing much information in which case non-trivial coordination tasks may require never-ending tuning and human supervision.

Furthermore, these designs seldom have the capability to look ahead and simply schedule the next production step when the previous one is about to finish without assessing what comes beyond this step. Indeed, negotiating multiple steps ahead in time in combination with adaptation to changes and disturbances complicates the interactions considerably; among others, cancellations will become commonplace under such conditions. The widespread deployment of the control systems discussed in [5,6] was prevented by their steep requirements for investing in multi-function CNC equipment, which essentially was a consequence of the limitations listed above (cf. oral discussion at HoloMAS 2003, after a keynote presentation by Bussmann and Schild in [6]).

In contrast, the MAS coordination and control systems discussed in this paper rely on stigmergy as the main interaction mechanism among the agents. Stigmergy implies that signs in the environment are used to coordinate the activities. A well-known example is the pheromone trail created by foraging ants between the colony's nest and a food source that was discovered [8,14]. Details about the use of stigmergy in the coordination and control systems follow later. In particular, a stigmergic design has the following properties (in contrast to the above):

- No rendezvous is required. The entities that represent the environment in the computer system have information spaces attached to them that are accessible without any kind of synchronization. As an analogy, consider an old-fashioned hospital. In the stigmergic design, a nurse measures a patient's parameters and notes them on the board attached to the patient's bed. When the doctor arrives, s/he observes this board and acts in response. In the interaction protocol designs, nurse and doctor need to rendezvous to exchange information.
- Audience control is through the environment. Agents navigate through a (virtual) world and access data on information spaces attached to the entities that constitute their environment. The agents are situated agents [15].
- There are no time-outs indicating how long offers or requests remain valid. Agents simply observe and act. Instead, information evaporates unless it gets refreshed. This represents much less of a tuning challenge since evaporation and refresh rates simply determine the delay at which invalid information is forgotten and new information becomes known; the rate settings mainly balance computer/communication resource utilization against control performance.
- The information – which gets attached to the environment, gets modified, is observed, and possibly gets aggregated by the environment entity itself – is not restricted to a few specific types (see Section 4). Also, it suffices that the agents involved in a particular activity agree on the format of the information while other agents simply ignore it.
- The coordination systems need not agree on particular performance criteria, and the designer is at liberty to disseminate whatever performance-related information s/he chooses. In a stigmergic design of the kind discussed in this paper, the commitment to a specific performance criterion is delayed until the final stage of the software development activity.

Overall, a stigmergic design is much more lightweight. Because of this advantage, it becomes possible to anticipate multiple production steps ahead in time, which is done in the control system class discussed in this paper. Note that stigmergy is well suited for frequent and small actions but may require augmentation by a rendezvous-based interaction mechanism when agents need to make important long-term commitments.

Furthermore and for completeness, the MAS coordination and control systems discussed in this paper also use direct communication between agents that constitute a small team and that normally are developed together. Typically, an agent may report to the agent that created it and/or to agents that are made known to this agent at its creation. None of the above issues, burdening negotiation-based designs, arises.

2.2. Ant colony optimization (ACO)

A second collection of related work is the domain known as ant colony optimization [9]. The research results in this domain can be categorized in two classes. First, there are optimization results in the strict sense. These results basically are algorithms optimizing problems modeled by a graph. Virtual ants travel across such graph while generating solutions, and update routing tables on their way back depending on their degree of success. A typical problem is the traveling salesman problem. Characteristic is that these research results address static optimization problems—attempts to solve a traveling salesman problem in which the graph changes after some time revealed lock-in phenomena. In these systems, the evaporation rate impacts the amount of exploration versus the amount of exploitation. If the evaporation rate is high, information about previously discovered solutions is forgotten more rapidly and the algorithm will explore more, and vice versa. Proper selection and tuning of the evaporation rate impact the performance and convergence of these ACO algorithms. This class is not directly relevant for the discussion in this paper.