Evolving Real-Time Local Agent Control for Large-Scale MAS

Thomas Wagner
Computer Science Department
University of Maine
wagner@umcs.maine.edu

Victor Lesser
Computer Science Department
University of Massachusetts
lesser@cs.umass.edu

ABSTRACT

Control for agents situated in multi-agent systems is a complex problem. This is particularly true in hard, open, dynamic environments where resource, privacy, bandwidth, and computational limitations impose restrictions on the type of information that agents may share and the control problem solving options available to agents. The MQ or *motivational quantities* framework addresses these issues by evaluating candidate tasks based on the agent's organizational context and by framing control as a local agent optimization problem that approximates the global problem through the use of state and preference.

1. MQ OVERVIEW

Our objective is to create *open*, *large-scale*, information and computational systems that are flexible, adaptable, robust, persistent, and autonomous. Now, consider the implications of this. Openness means that agents may interact freely, come and go from the network, and that the entire problem solving environment is dynamic. Openness thus often acts to thwart agent technologies that rely on detailed predictability or static properties of the problem space. In our work, we take the view that openness leads to a requirement for real-time agent control problem solving so that agents can respond to change and unexpected outcomes online.

Moving the scale of multi-agent systems from small groups to large groups, e.g., tens of thousands, throws two other problems into the mix: *increased interaction overhead* and *social complexity*. The term interaction overhead denotes the increase in communication between agents required to detect interactions in their problem solving and to coordinate their activities, i.e., it denotes the sheer volume of message traffic and problem solving required to evaluate the messages. This is being dealt with by imposing organizational structure on the agents so that they do not all communicate and by creating coordination and communication technologies that are adjustable [1, 4, 15, 5]. The other issue is social complexity and we do not mean social complexity in the human sense. Or rather, the goal of this research is not to study social complexity in human organizations [13] per se as our work in agent control has very specific task-centered properties. When agents are situated in a large open environment, and organizational structure is imposed upon them, they have different organizational objectives and they must reason about how their problem solving relates to satisfying their multiple, and possibly conflicting, organizational objectives.

This research focuses on exactly this problem – how agents in large-scale open environments reason about their organizational context and make appropriate choices about which actions to perform and how to go about performing them. It is important to emphasize that this research pertains to complex problem solving agents, e.g, the BIG Information Gathering Agent [11], where the agents are situated in an environment, able to sense and effect, and have explicit representations of candidate tasks and explicit representations of different ways to go about performing the tasks. Additionally, tasks are quantified or have different performance characteristics and, following in the thread of complex problem solving there are relationships between the tasks. The implications are that tasks cannot be reasoned about independently and that the value or utility of particular tasks differs depending on the context. We call the process of reasoning about which tasks to perform, when, with what resources, how or in what fashion, and with whom to coordinate, the *local agent control* problem. The term "local" is used in this expression because agency, as we use it, denotes an autonomous distributed problem solving entity. In our work, there is no global picture of all activities being carried out by all agents nor are the agents situated in specialized, tightly coupled environments like Tambe's teams [15] or robotic soccer [17].

We view local agent control in this context as a real-time action-selection-sequencing problem where an agent has n candidate tasks and alternative different ways to perform the tasks. Tasks have deadlines and other constraints as well as different performance properties, e.g., consuming different resources or producing results of varying quality. Control in this context is an optimization problem where different solutions are possible and they have different degrees of utility.

Historically in our work this class of control problem has been dealt with using the TÆMS task modeling framework [2, 10], GPGP coordination [2], and Design-to-Criteria (DTC) real-time agent scheduling [14, 19, 18, 21, 7]. Using these tools, an individual agent for use in a multi-agent environment is constructed by coupling a domain expert or planner with GPGP and DTC. In this model, the domain expert's function is to perform domain problem solving and to translate its internal representations into TÆMS for control problem solving by the coordination (GPGP) and trade-off/scheduling (DTC) experts. GPGP and DTC then work together to guide the actions of the individual agent and to coordinate the activities of the agent with the other agents in the network. This is the approach used in the BIG information gathering agent [12, 11], the Intelligent Home project (IHome) [9], the DARPA ANTS real-time agent sensor network for vehicle tracking [7], and others [22]. Though

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in some of these applications GPGP is replaced by other communication machinery that forms commitments between agents about which tasks will be performed and when. In all of these applications, DTC or its predecessor, Design-to-Time [8], is the oracle that guides and constrains the communication and commitment formation processes.

TÆMS and DTC are mature research artifacts and have been successfully reused in many applications (DTC since 1995). However, TÆMS is not suited to addressing the situational complexity that arises when agents are deployed in larger groups or in open environments. One of the fundamental limitations of TÆMS is that it is a static representation of an agent's problem solving process at a given instant in time. It is, in essence, a snapshot of the options available to the agent and a snapshot of their characteristics. In our applications, generally, when the situation changes and the characteristics of tasks (used to determine utility) change, the problem solver must adjust the performance profiles and emit a new TÆMS task structure. Another limitation is that in TÆMS, action performance produces *quality* which then propagates throughout the entire graph-like structure in ways that is intended to model distributed problem solving as in a distributed interpretation problem [6]. The formal details of TÆMS are in [3]. While this view is appropriate for reasoning about interrelated domain problem solving activities at a detailed level, it is not readily used to model concepts like tasks that contribute to one organizational objective while being detrimental to another. TÆMS also does not adequately support concepts like the value of forming a commitment with another agent or the penalty for decommitting from an activity once a commitment is formed.

To address these limitations, we have developed a new framework for representing tasks and actions at a different level of abstraction. The framework, called the *motivational quantities* (MQ) [16, 20] framework, uses state to achieve "automatic" changes in task valuation or utility (unlike the static view taken in TÆMS). The MQ framework also describes tasks in many different attribute dimensions so that we can model tasks contributing to, or detracting from, different objectives to different degrees. While control at the TÆMS level pertains to detailed evaluation of domain problem solving activities of an agent, control at the MQ level pertains to high-level valuation of candidate tasks based on an understanding of the relationship between tasks and organizational objectives. In other words, in the MQ framework, task value is determined not only by the intrinsic properties of tasks, but by the benefits and costs of the intrinsic properties as determined by the agent's current organizational situation. From another view, there is an intermediate evaluation step in the control process whereas such processes typically focus on intrinsic value rather than contextually interpreted value. While we have ideas about how to combine and interface [16] the two levels, integration is clearly unnecessary for many applications.

A preliminary version of the MQ framework was presented in [20]. A specification of the current model is located at [23].

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