The Role of Assumption Identification in Autonomous Agent Reasoning
(Extended Abstract)

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ABSTRACT
The concept of autonomy is central to the notion of agenthood and has been addressed by many researchers in the multi-agent systems community. We argue that the degree to which an agent's reasoning is autonomous is affected by the degree to which it is able to choose its assumptions autonomously. We discuss a technique that enables agents to identify appropriate assumptions dynamically, by employing representations of norms in Default Logic.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence - *Multiagent systems*, I.2.4 [**Artificial Intelligence**]: Knowledge Representation Formalisms and Methods - *Representations (procedural and rule-based)*

General Terms
Theory

Keywords
Autonomy, Assumptions, Agents, Default Logic

1. INTRODUCTION
This paper addresses the issue of agent autonomy and reports on work that is conducted in the context of a broader project, which is concerned with the development of appropriate computational environments for open multi-agent systems. Etymologically the term 'autonomy' (auto=self + nomos=law) refers to the ability of an entity to choose its own norms and regulate its own behaviour accordingly. In common usage the term 'autonomy' is defined as the quality or state of being self-governing (especially the right of self-government), self-directing freedom (especially moral independence), and a self-directing state**.** Since autonomy is a key characteristic of an agent, all researchers in the multi-agent systems community address this issue.

In our work we take the most recent perspective on autonomy and address it relevant to an agent's reasoning process, within the context of an *open* norm-governed system. In this context, our agent is expected to make inferences about which beliefs to adopt about its environment, other agents and norms in force, which goals to commit to, and which actions to perform, in the presence of incomplete or inconsistent information, and it is expected to be independent from external intervention in this reasoning process. In other words, to reason in an open norm-governed environment, our agent needs to employ *assumption*s, and to be truly autonomous it needs to be able to infer which assumptions are appropriate without external intervention. In this sense, the degree to which an agent's reasoning is autonomous is affected by the degree to which the agent is autonomous in its choice of assumptions. In what follows we consider that the agents that populate an open norm-governed environment seek to establish which norms they are subject to, and we discuss a technique that enables them to *reformulate* an initial set of norms by identifying and employing appropriate candidate assumptions dynamically.

Cite as: The Role of Assumption Identification in Autonomous Agent Reasoning, (Extended Abstract), Georgios K. Giannikis, Aspassia Daskalopulu, *Proc. of 8th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2009),* Decker, Sichman, Sierra and Castelfranchi (eds.), May, 10–15, 2009, Budapest, Hungary, pp. 1135–1136

2. THE REASONING PROBLEM
We claim that hypothetical reasoning may be useful in two cases: (i) An agent cannot know the future, yet it may need to plan its activities on the basis of hypotheses that concern the future. (ii) An agent may not know everything about the past and present, i.e., the history of its environment, other agents and itself so far, yet it may need to plan its activities on the basis of hypotheses that concern the past and present.

The reasoning problem faced by an agent in this context, when it does not possess complete knowledge about the past, present or the future is:

1H. What assumptions are applicable to fill in information gaps, i.e., what can be assumed to be true or false at various time points?
2H. How do assumptions employed at some time point affect subsequent inferences? and
3H. What happens when information that becomes available at some time point confirms or disproves assumptions made at previous times, i.e., how does new information affect previously drawn conclusions?

Essentially, to answer question (1H) the agent seeks to establish which conditions of the norms it knows about and which it needs to assume. In an open environment, norm conditions may dynamically become known or unknown to the agent. In order to answer question (2H) the agent needs to employ some way that commits its reasoning to specific assumptions. Finally, in order to answer question (3H) the agent needs to reason nonmonotonically.

3. AUTONOMOUS HYPOTHETICAL REASONING

Consider an open norm-governed environment populated by agents, in which some temporal logic is employed, for instance Event Calculus [5]. The behaviour of agents in this environment is regulated by an initial set of norms that we may represent in the form:

$$Y \leftarrow X_1 \wedge X_2 \wedge \ldots \wedge X_k \quad (1)$$

where Y and X_i $(1 \leq i \leq k)$ are first-order logic positive or negative literals and all variables are universally quantified. This representation employs the predicates of the temporal logic augmented with some special predicates to denote normative relations (obligation, prohibition, permission, power). We view normative relations as properties that are initiated or terminated by the occurrence of agents' actions or events. In [2, 3] we give an example of such a representation where the underlying temporal logic is Event Calculus.

We propose a mapping [4] from the initial norm representation to Default Logic (DfL) [6] for three reasons: (i) The syntax of DfL offers a natural way to represent separately what is known, what is assumed and what is concluded on the basis of this knowledge and assumptions. (ii) The semantics of DfL and its variations offers a way to preserve the relation of an assumption and any inferences drawn on its basis, to maintain consistency and rationality and to reason nonmonotonically. (iii) We can implement the inference mechanism of DfL without resorting to theorem proving, by set manipulation. The problem that an agent faces is how to compute this mapping and how to use it for its inference.

Each initial norm of the form (1) that involves k conditions may be mapped to 2^k+1 default rules of the form $P : J / C$, where P is a set of prerequisites, J is a set of justifications, and C is the derived consequent [4]. The corresponding 2^k+1 defaults derive by populating appropriately the P and J sets and represent 2^k+1 alternative default rule formulations, for each initial norm, that the agent may employ in its inference. These 2^k+1 possible formulations may be organized in a hierarchical structure of height (k+1), where the binary relation that causes them to be partially ordered is the number of assumptions employed. It turns out that this structure is, in fact, a lattice. The question that arises for the agent that reasons with incomplete knowledge and seeks to establish autonomously which assumptions are appropriate in order to fill in information gaps is tantamount to the question "which *one* of the 2^k+1 defaults should be chosen and employed in the inference procedure", for each of the norms in the initial set of norms. Essentially the agent tries to establish which formulation is appropriate for each of the norms of the initial set, by traversing this lattice structure. Note that the agent seeks to identify which norm conditions it knows about *explicitly*. Any other conditions are treated as information gaps. In this way, the agent does not need to perform any theorem-proving on its knowledge base.

Of course, systems are typically subjects to multiple norms, each of which may be formulated as a default rule, i.e. candidate default rule formulations that are organized in hierarchical structures. During its reasoning, the agent will need to remember which default rule formulation it chose for each of the norms that it reasons with in order to be able to answer question (2H). Moreover, as its reasoning progresses and new information becomes available, either merely augmenting its knowledge base, or updating some part of it, the agent will need to update its choice of default formulations, moving upwards or downwards within each lattice. Upward moves correspond to the agent trying to answer question (1H), while downward moves correspond to the agent trying to answer question (3H).

4. CONCLUSIONS

In this paper we discuss the relation between an agent's ability to identify and employ assumptions independently, and its autonomy. We claim that an agent that answers the reasoning problem (1H)-(3H), addresses also the autonomy problem:

1A. What is the appropriate behaviour, i.e. physical and/or mental actions, in order to be autonomous?

2A. How does my independence at some time point explain my current state and how does it affects my inferences in the future? and

3A. What happens when I need to adapt my independence (reduce or increase it) because of changes in the environment?

We discuss an incremental technique that enables agents to 'develop for themselves the laws and strategies according to which they regulate their behaviour (in the spirit of [7]) and to 'make their own inferences and reasoning and to rely on their own conclusions' (in the spirit of [1]).

5. ACKNOWLEDGMENTS

This work was supported by PENED 2003 – 03EΔ466 Project.

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