A First-Order Theory of Agent Models with a Layered Architecture

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For the efficient design and development of multi-agent systems, it is important to clarify a relationship of agent theories, architectures and languages. From this viewpoint, we propose a first-order theory of agent models by syntactic formulation. This formalization gives a unified model of intelligent agents for planning, executing, sensing, and re-planning.

Various concepts of agents' environment and mental attitudes, expressed by modal logics, are rebuilt into three-layered first-order theories (Figure 1): the object-level theory of agents' environment such as time, action, conditional and causality, the knowledge-level theory of information about his environment such as assumption, verification, planning and action execution, and an intention-level theory guiding his actions including goal achievement. A description of an agent on each level is formalized as a set of first-order logical formulas which express the states and the state transitions corresponding to the concepts on each level listed above. The relationships between three levels are defined based on reflection (Attardi & Simi 1991).

To formalize a reasoning system of an agent who perceives and acts depending on partial information about his dynamic environment, we introduce three situation-descriptions $\Psi$, $\Phi$ and $\Omega$ representing factual information on the object-level, the knowledge-level and the intention-level respectively, and a constraint-description $\Upsilon$ representing invariant informations including constraints and general rules in agents' world, given by sets of first-order logical formulas. We define a truth-value of a modal logical formula based on the provability in a constraint-description and situation-descriptions on three levels as follows:

$$Y \cup \Omega \cup \Phi \cup \Psi \vdash T('A',s) \quad (1)$$

The above relation means that a modal logical formula $A$ is true at a state $s$ in a constraint-description $Y$, and situation-descriptions $\Omega$, $\Phi$ and $\Psi$ by the first-order logical inference including default inference (Takamatsu et al. 1995). We consider a proof procedure in success on the object-level as a state on the knowledge-level, and define the knowledge-level predicate $T$ corresponding to the proof procedure on the object-level based on reflection as follows:

$$Y \cup \Omega \cup \Phi \cup \Psi \vdash T('A',s,\psi) \quad (2)$$

The above definition gives a relationship between the object-level and the knowledge-level. The intention-level predicate $M-T$ is likewise defined:

$$Y \cup \Omega \vdash M-T('\psi',\xi) \quad (3)$$

where $c$ is a knowledge-level formula. Finally, to define the predicate $MM-R$ for the representation of revision procedures on the intention-level corresponding to autonomous activities, we introduce the first-order predicate $MM-T$ based on reflection as follows:

$$Y \vdash MM-T('\xi',\xi) \quad (4)$$

where $c$ is an intention-level formula.

This formalization enables us to execute various descriptions of an agent by a proof system of first-order logic. It also gives an agent language as a first-order theory related with agent theories as specification descriptions of agents and agent architectures as a proof system in the framework of first-order logic.

References
