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 replanning.

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 Ψ, Φ and Ω representing factual information on the object-level, the knowledge-level and the intention-level respectively, and a constraint-description Υ representing invariable informations including constraints and general rules in agents' world, given by sets of first-order logical formulas. We define

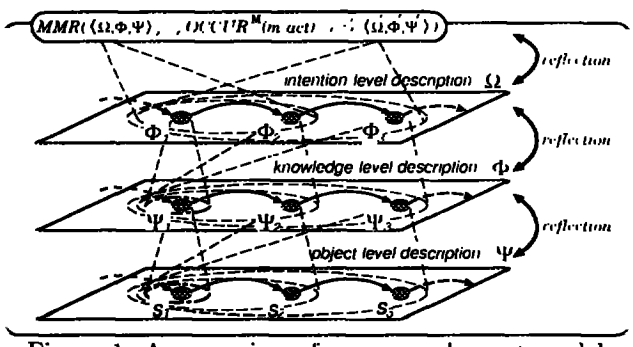

Figure 1: An overview of a proposed agent model

a truth-value of a modal logical formula based on the provability in a constraint-description and situation-descriptions on three levels as follows:

$$\Upsilon \cup \Omega \cup \Phi \cup \Psi \vdash \mathrm{T}(\ulcorner A \urcorner, s) \qquad (1)$$

The above relation means that a modal logical formula A is true at a state s in a constraint-description Υ, and situation-descriptions Ω, Φ and Ψ 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 $\mathcal{T}$ corresponding to the proof procedure on the object-level based on reflection, as follows:

$$\Upsilon \cup \Omega \cup \Phi \vdash \mathcal{T}(\ulcorner A \urcorner, s, \Psi) \Leftrightarrow \Upsilon \cup \Omega \cup \Phi \cup \Psi \vdash \mathrm{T}(\ulcorner A \urcorner, s) \qquad (2)$$

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

$$\Upsilon \cup \Omega \vdash \mathcal{M}\text{-}\mathcal{T}(\ulcorner \psi \urcorner, \Phi) \Leftrightarrow \Upsilon \cup \Omega \cup \Phi \vdash \psi \qquad (3)$$

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

$$\Upsilon \vdash \mathcal{MM}\text{-}\mathcal{T}(\ulcorner \phi \urcorner, \Omega) \Leftrightarrow \Upsilon \cup \Omega \vdash \phi \qquad (4)$$

where ϕ 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

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