Ontological Basis for Agent ADL

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Abstract. Multi-Agent Systems (MAS) architectures are gaining popularity over traditional ones for building open, distributed or evolving software. To formally define system architecture and reasoning about it, numerous architecture description languages (ADLs) have been proposed during the last decade. However, few research efforts aim at truly defining a description language for MAS architectures. The paper introduces an ontological basis aimed at capturing a "core" set of structural and behavioral concepts, and their relationships, we consider fundamental to define an ADL for MAS architectures.

1 Motivation

The explosive growth of application areas such as electronic commerce, knowledge management, peer-to-peer and mobile computing has profoundly changed our views on information systems engineering. Systems must now be based on open architectures that continuously evolve to accommodate new components and meet new requirements. These new requirements call, in turn, for new concepts and techniques for engineering and managing information systems. For these reasons – and more – Multi-Agent Systems (MAS) architectures are gaining popularity over traditional systems, including object-oriented ones [5].

To cope with the ever-increasing complexity of such architectures, there have been, through the last decade, different proposals for providing a sound basis for formally describing system architecture and reasoning about it. In particular, a number of Architecture Description Languages (ADLs) have been proposed (see e.g., [2]). ADLs provide constructs for specifying architectural abstractions in a descriptive notation. They offer formal mechanisms for decomposing a system into architectural elements, specifying how these elements are combined to form a configuration.

Unfortunately, few research efforts have aimed at truly defining an ADL for MAS architectures. Therefore, we introduce here an ontological basis that take the *Belief-Desire-Intention* (BDI) agent model into account to identify ADL concepts for specifying MAS architectures.

2 BDI Agent and MAS

An *agent* defines a software entity, situated in some environment that is capable of flexible autonomous action in order to meet its design objective [5].

A *multi-agent system* can be defined as an organization composed of autonomous and proactive agents that interact with each other to achieve common or private goals [2].

In order to reason about themselves and act in an autonomous way, agents are usually built on rationale models and reasoning strategies. A simple yet powerful and mature model is the *Belief-Desire-Intention* (BDI) model [1]. The main concepts of the BDI agent model are:

- **Beliefs** *that represent the informational state of a BDI agent, that is, what it knows about itself and the world*;
- **Desires** *(or goals) that are its motivational state, that is, what the agent is trying to achieve*;
- **Intentions** *that represent the deliberative state of the agent, that is, which plans the agent has chosen for possible execution*

3 ADL Ontology

From the generic features of the BDI agent model and ADL concepts identified in the software architecture literature, we have extracted a set of concepts necessary to define and specify BDI-MAS architectures. We categorize the main elements of this ontology in two sub-models that operate at two different levels of abstraction: internal or global. The internal model captures the mental states of the agent and its potential behavior. The global model describes the interaction among agents that compose the MAS architecture.

3.1 Internal Model

Figure 1(a) illustrates the main concepts of the internal model and their relationships. The agent needs to know about the environment in order to take decisions. The knowledge is captured in *knowledge bases.* A knowledge base consists of a set of *beliefs* the agent has about the environment and a sets of *goals* it pursues. A belief is a finite set of objects, things with individual *identities* and *properties,* that represents a view of the current environment of an agent. However, beliefs about the current state of the environment are not always enough to decide what to do. Hence, the agent needs some sort of goal information to describe environment states that are (not) desirable.

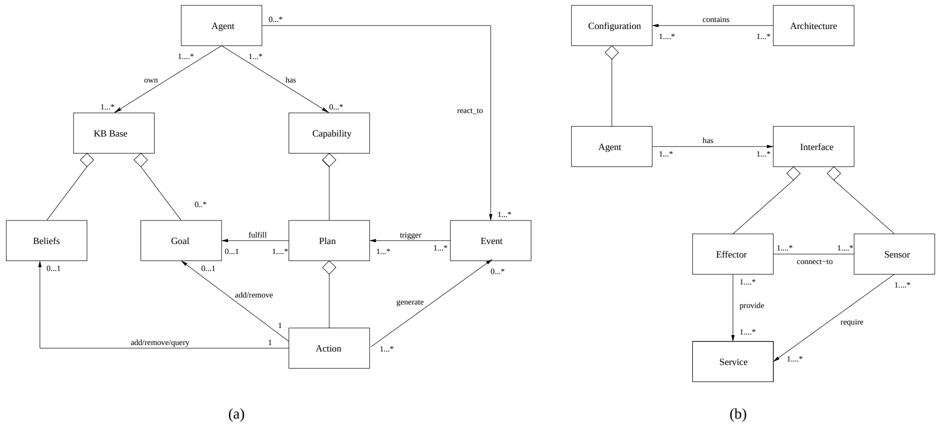

Fig. 1. Conceptualization of the Internal Model (a) and Global Model (b)

The intentional behaviour of an agent is represented by its *ability* to react to *events*. An event is generated either by an *action* that modifies beliefs or adds new goals, or by service*s* provided by another agent. These services, represented in the global model involve interactions among agents that compose the MAS.

An event may invoke (trigger) one or more *plans*; the agent commits to execute one of them, that is, it "*becomes"* intention. A plan defines the sequence of actions chosen by the agent to accomplish a task or achieve a goal. An action can query or change beliefs, generate new events or submit new goals.

Due to lack of space, we only overview the specification of two of the ADL concepts introduced above: *belief* anf *goal*. To this end, we use the Z specification language [4].

Beliefs can be defined as first-order predicates. The set of all predicate symbols is denoted by [*PredSym*], and a *BeliefAtom* is a predicate symbol with a sequence of terms as its argument. A term is a logical expression that refers to an object.

```
BeliefAtom
head : PredSym
terms: seq Term
```

```
[Term]   :=  Function(Term,…)
           | Constant
           | Variable
```

A Belief is then either an AtomBelief, the negation of an AtomBelief or a more complex belief.

```
[Belief] :=  AtomicBelief
           | Belief  Connective  Belief
           | ¬Belief

Connective :=  ∧  |  ∨  |  ⇒
```

With respect to beliefs, goals can be specified as follows:

```
┌───────  Goal  ──────────────────────────────
│
│   head : GoalPattern
│   state: set of Belief
└─────────────────────────────────────────────
```

[*GoalPattern*] is the set of all goal patterns. We consider goals according to four patterns:

- *Achieve*: $P \Rightarrow \bullet Q$ (P means "state P holds in the current state" and $\bullet Q$ means "state Q holds in the current or in some future state")
- *Cease*: $P \Rightarrow \bullet \neg Q$
- *Maintain*: $P \Rightarrow £Q$ ($£Q$ means "state Q holds in the current and in all future states")
- *Avoid*: $P \Rightarrow £\neg Q$

3.2 Global Model

Figure 1(b) illustrates the main concepts of the global model and their relationships. It describes the interaction among agents that compose the MAS.

Configurations are the central concept of the architectural design. A configuration consists of an interconnected set of *agents*. The topology of a configuration is defined by a set of bindings between *provided* and *required* services.

An agent interacts with its environment through an *interface* composed of *sensors* and *effectors*. An effector provides the environment with a set of services. A sensor thus requires a set of services from the environment. A service is an action involving an interaction among agents.

The whole MAS is specified with an *architecture* that contains a set of configurations. The architecture concept allows to represent agents with one or more detailed, lower-level configuration descriptions.

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