FORMAL MODELING AND ANALYSIS OF ORGANIZATIONS

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The full version of this paper appeared in: O. Boissier, V. Dignum, E. Matson, and J. S. Sichman (Eds.), *Proceedings of the AAMAS-05 Workshop From Organizations to Organization Oriented Programming (OOOP2005),* p. 17–32. July 26, Utrecht – The Netherlands.

Organizations have proven to be a useful paradigm for analyzing and designing Multi-Agent Systems (MAS) [2]. Representation of MAS as an organization consisting of roles and groups can tackle major drawbacks present in traditional multi-agent models; e.g., high complexity and poor predictability of dynamics in a system. Moreover, organizational research has recognized the advantages of agent-based models; e.g., for analysis of structure and dynamics of real organizations [1]. However, formal theories, approaches, and tools for designing such models are rare.

In this paper, we propose an approach for formal specification of organizations. In contrast to most social science theories it can capture both structural and dynamic aspects of the organization formally and, subsequently, has four advantages: (1) Formal representation of organization structure (including specifications of actors (or roles), relations between them, and information flows). (2) The means for simulations of different scenarios on the basis of a model and observing their results. (3) Organization analysis by means of verifying static and dynamic properties against either simulated scenarios or (formalized) empirical data, taken from real organizations. (4) Diagnosis of inconsistencies, redundancies, and errors in structure and functioning of real organizations and providing recommendations for their improvement (e.g., with regard to organizational performance indicators).

Both the general (or abstracted) structure and the behavior of organizations is specified by a generic (or template) model, which is used for a high level organization analysis. For a more detailed analysis, a deployed model is introduced. Such a model is based on both unfolded generic relations between roles, as defined in the generic model, and on creating new role instances. For each role instance, a set of requirements is identified. These requirements are imposed onto the agents, who will eventually enact these roles. For formalizing structural and dynamic aspects of both a template model and a deployed model, ontologies specified in an order-sorted logic are used.

The specification of an organization structure in a template and a deployed model uses the following elements: (1) A role that represents a subset of functionalities, performed by an organization, abstracted from specific agents that fulfill them. In contrast to many other organization models from computational organization theory and artificial intelligence, each role in the proposed model can be composed by several other roles, until the necessary level of detail of aggregation is achieved. A role that is composed of (interacting) subroles, is called a composite role. Each role has an input and an output interface, which facilitate in the interaction (communication) with other roles. (2) An interaction link, which represents an information channel between two roles at the same aggregation level. (3) Frequently ignored in other organization models environment is represented as a special component of the proposed model. Similarly to roles, the environment has input and output interfaces, which facilitate in the interaction with roles of an organization. The environment is defined by a set of objects with certain properties and states and causal relations between objects. (4) An environment interaction link, which represents an information channel between a role and the conceptualized environment.

The dynamics of each structural element at every aggregation level are defined by the specification of a set of dynamic properties using the Temporal Trace Language (TTL) [3]. We define five types of dynamic properties: (1) A role property: the relationship between input and output states of a role, over time. The input and output states are represented as an assignment of truth-values to the set of ground atoms, expressed in terms of a role interaction (input or output) ontology. (2) A transfer property: describes the relationship of the output state of the source role of an interaction link to the input state of the destination role. (3) An interlevel link property: the relationship between the input or output state of a composite role and the input or output state of its subrole. Note that an interlevel link is considered to be instantaneous: it does not represent a temporal process, but gives a different view (using a different ontology) on the same information state. An interlevel transition is specified by an ontology mapping, which can include information abstraction. (4) An environment property: a temporal relationship between states or properties of objects of interest in the environment. (5) An environment interaction property: a relation either between the output state of the environment and the input state of a role (or an agent) or between the output state of a role (or an agent) and the input state of the environment. On the one hand, roles (or agents) are capable of observing states and properties of objects in the environment; on the other hand, they can act or react and, thus, affect the environment. We distinguish passive and active observation processes. For example, when some object is observable by a role (or an agent) and the role (or the agent) continuously keeps track of its state, changing its internal representation of the object if necessary, passive observation occurs. For passive observation, no initiative of the role or agent is needed. Active observation is always concerned with the role or agent's initiative.

Based on a model specification, simulations of different scenarios can be performed in the dedicated software [3]. The software automatically generates and visualizes traces, which describe organizational behavior for corresponding scenarios. Furthermore, traces can be used for the purposes of automated verification and validation of organizations. The method proposed allows both role-centered and agent-centered verification and validation. Role-centered verification techniques can be used for analysis of both template and deployed models of organizations. Subsequently, inconsistencies and bottlenecks in an organization can be detected. Agent-centered verification techniques are used for analyzing scenarios with roles of an organization model, allocated to (human) agents.

This research also presents a newly developed graphical representation of organization models, which allows a modular representation of organizations. Components at every aggregation level can be visualized and analyzed both separately and in relation to each other. Hence, the graphical representation of organizational models is scalable.

The new, formal, role-based, framework for modeling and analyzing both real world and artificial organizations (e.g., MAS) that is introduced exploits static and dynamic properties of the organizational model and includes the (frequently ignored) environment. Its use is illustrated by a case study, within the DEAL project line (Distributed Engine for Advanced Logistics).

Acknowledgments: This research was supported by the Netherlands Organization for Scientific Research (NWO) under project number 612.062.006. SenterNovem is gratefully acknowledged for funding the projects Cybernetic Incident Management (CIM) and Distributed Engine for Advanced Logistics (DEAL) that also funded this research partially. Further, we thank the reviewers for their detailed comments on the original manuscript.

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