D. Demmler, D. Krupka, H. Federrath. (Hrsg.): INFORMATIK 2022,
Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn 2022 1565

Towards Integrating Multi-Agent Organizations in OPC UA for Developing Adaptive Cyber-Physical Systems

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Abstract: Developing adaptive Cyber-physical Systems (CPS) requires integrating physical components with run-time controls which monitor and adjust the operation of components appropriately. The use of multiagent systems (MAS) is an established approach for embedding adaptive features and the integration of multiagent systems in industrial systems is an active field of research. Industry standards, like OPC UA, allow for vendor independent information exchange and unit control in industrial settings. Here, we propose to represent MAS organizations within OPC UA information models. The organization of a MAS can be seen as a crosscutting concern in structing and integration distributed adaptive applications. Explicit modelling allows to express organizational structures in industrial settings and enables monitoring of these structures at run-time with established tools and frameworks for industrial control.

Keywords: Multiagent System, OPC UA, Organizational Model, Cyber-physical System.

1 Introduction

Multiagent systems (MAS) realize application functionality by the interplay of autonomous, interactive, rational agents. Utilizing agent technology and multiagent systems in industrial systems is an active field of research [Ka20]. These efforts particularly support designing Cyber-physical Systems (CPS), which integrate physical and digital components into coherent applications. Example application areas are i. a. Smart Grids and Industry 4.0 systems [Cr19]. Designing these systems requires integrating heterogeneous system entities and enabling adaptive features, e.g. robust and flexible operation of devices, which respond to local execution constraints and environmental contexts.

Open Platform Communications Unified Architecture (OPC UA)[2] is a standardized, cross-platform, international, and widely spread communication protocol for accessing sensor information and controlling devices in industrial settings (IEC 625413). A major design rationale is the adoption of a service-oriented approach for controlling industrial units. In order to facilitate interoperability, a standardized, graph-based modelling framework and extensible type-system enables the explicit provisioning of information models. These models describe the available information, e.g., sensor readings, set points, etc. [Go20, Iv21]. Open-source implementation frameworks are available [Mu21].

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[2] https://opcfoundation.org/about/what-is-opc/

doi:10.18420/inf2022_135

In a prior work [SK22], we outlined the benefits of organizational models in (adaptive) CPS development. Interdisciplinary multilevel modeling efforts benefit form a crosscutting view that integrates systems in a coherent system of systems. We particularly aim at extending engineering approaches for CPS, e.g. following the *Use Case Methodology* [Go17]. While organizational concepts support coherent system designs, a fully-fledged development process also addresses integrating organizational concepts in the actual application [SK22]. Here, we outline work in progress on integrating organizational models in OPC UA information models. This enables to describe and modify logical organizations at run-time. In addition, these models can be accessed and inspected using established protocols and tools in industrial contexts.

This paper is structured as follows. In the next section we outline the role of organizational modelling in the context of building CPS. In Section 3, we outline work in progress on expressing these models within the OPC UA information models, before we conclude and give prospects for future work.

2 Organizational Modelling in CPS Development

In agent-based applications, the application functionalities arise from the (microscopic) interplay of agents. In *organization-centered multiagent systems* (OCMAS) explicit organizational models prescribe and constrain the interactions among agents, as well as their interactions with their environment / context. These models provide means for defining the macroscopic applications behaviour [DP13].

CPS-development benefits form integrating an organizational modelling perspective [SK22]. Coherence of the interplay of physical and digital system elements can be supported by establishing appropriate design abstractions. Group / Team abstractions are used to denote how agents can interact. A common concept is the *Role* agents play in a specific group. *Structural*, *functional*, and *deontic* dimension are used to describe how an organization operates [Hü10]. Thus, it can be regarded as a blueprint which allows to infer run-time aspects of the system. Using this abstraction, it is a design-challenge to balance coherence (global) and agent autonomy (local). Adaptability at run-time can be achieved by explicitly altering the organizational structure itself [KW13].

Our model definition is based on the fundamental Agent/Group/Role (AGR) model [Fe04]. Due to its generic structure, this model it can serve as a foundation for application dependent, elaborate models. In addition, usages to model cyber-physical systems have been reported, e.g. [Se17]. Figure 1 shows an AGR-based organization, where agents also integrate physical devices. The so-called *cheeseboard* notation from [Fe04] is used to denote the interplay of Agents, Groups and Roles. Agents may participate in several groups and can interact with each other. The notation is extended to denote the interactions of agents with physical devices. Agents can access physical devices and exert control (filled arrows in Figure 1) following integration modes as described in IEEE 2660.1 [Le21]. Here, single agents are responsible for controlling physical units. E.g. the groups G1 and G2 may follow *Resource Agent* Pattern [Cr19]. Groups may also include the collaboration of agents for controlling units as described by the additional patterns in [Cr19]. In addition, members of the group G_3, playing the role *P* represent sets of physical assets. This may resemble the establishment of a peer-to-peer trading system for energy [Hu21], where agents playing the Role *P* trade energy and trading is supervised by a managing agent (Role *M*), e.g. as motivated in [SK22].

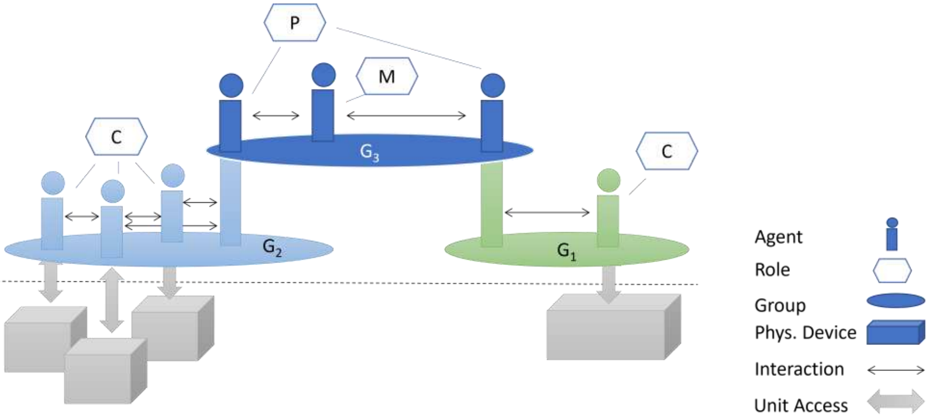

Fig. 1: AGR-based organization model structures the agent-based control of physical devices.

3 OPC UA Integration

OPC UA provides a comprehensive framework for exchanging information in industrial settings and controlling industrial devices. Servers provide data, in addition, methods can be invoked on these servers. A graph-based information model describes i. a. the available data, meta-data and executable functions (e.g. see [Go20, Iv21] for details).

We reviewed works integrating multiagent Systems with OPC UA. Despite the prominence of OPC UA in industrial control systems the integration of MAS has been addressed in selected works only. The seminal work [Ho17] showed that MAS can be integrated in OPC UA, including agent types and inter-agent communication. It has been shown that OPC UA can be used to decouple physical devices and MAS, particularly enabling MAS that are independent from underlying automation systems [Se21] and allows integrating differing frameworks [BV20]. Our approach builds on these efforts, since OPC-based information models are used to supplement high-level information about the organizational structure of the applications. To the authors knowledge, *explicit* modelling of mutable MAS organizations in OPC UA has not been addressed yet.

A generic structure for an organizational model, defined in terms of an OPC UA information model is given in Figure 2. Typically, organizational models are defined in terms of object-oriented meta-models [Fe04]. Thus, our integration of these models in OPC UA builds on works which study how to translate object-oriented structures in the specifics of OPC information models [Le17,Pa18]. E.g. in [Pa18], it has been shown that compositions can be described by OPC UA folder structures. Thus, *Groups* aggregate *Roles* and *Interactions*. Additional functions and information, e.g. a *MemberCount*, can be added as sub-nodes as needed. Sub-elements of organizational Roles denote which agents play a specific Role. *RoleConstraints* indicate structural constraints on roles, e.g. the *dependence* of additional memberships or the *correspondence* of Roles [Fe04]. *Interactions* denote communication patterns among Roles.

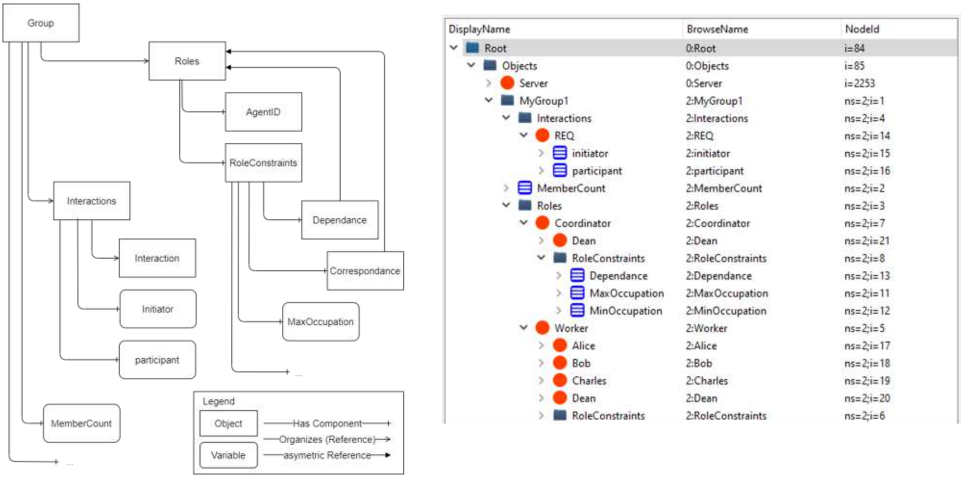

Fig. 2: Left: Information model excerpt, using OPC UA standard notation [IEC21]; Right: Demonstrative instantiation of a corresponding organizational model[3]

Providing organizational models in an OPC-based application setting requires deployment in an OPC UA server. Three major options for this provisioning are (1) hosting the server within a dedicated agent, (2) hosting a dedicated server in the environment or (3) hosting the model as a supplemental model within already existing servers. Deployment is an architectural choice, independent of the contents of the model. Due to the availability of lightweight server implementations in various programming languages [Mu21], the second option is used in our proof of concept. This corresponds to the Agent & Artifacts approach, which allows to provide organizational models [Hü10].

A major motivation for explicit modelling of organizational structures it to enable *transparency* and *adaptability*. Organizations can be understood as *static* structures, which describe agent collective, e.g. using established patterns [Sa19]. This corresponds to a permissioned model on servers, which is set up at design time, can be inspected using OPC UA clients, and would only be altered by privileged agents or users. A major

[3] Displayed using the freely available client from: https://github.com/FreeOpcUa/opcua-client-gui

requirement for *adaptive* systems would be to adjust organizations at-runtime, as agents enter and leave the system or internally adjust their execution. This can be achieved by adding / removing the corresponding nodes, e.g. indicating group membership. Based on that, Groups and Roles can be created interactively, e.g. by direct interaction with OPC UA servers and creating organizational structures on the fly. Following this approach, agents can maintain and manage information nodes themselves. Future work comprises enabling open systems, where these modifications would have to be constrained and validated, e.g., using OPC UA-based authentication and/or guarding modifications.

4 Conclusions

In this paper, we have argued that OPC UA provides suitable abstractions to describe organizational models in industrial systems. While prior works have studied how agents can be embedded in CPS using OPC UA, we propose here to supplement organizations as a logical view on inter-agent structures. Future work will address the pragmatics of integrating OCMAS in OPC UA. While freely available frameworks [Mu21] allow programming level integration in agent-based systems agent development would benefit from a suitable programming model for describing and altering organizations at run-time. In addition, the integration of organizational modelling in CPS development practices, e.g. based on the *Use Case Methodology* [Go17], is to be explored.

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