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Exploiting semantic technologies in smart environments and grids: Emerging roles and case studies

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HIGHLIGHTS

- We provide an updated overview of roles played by semantic technologies in the smart environment and smart energy domain.
- We define general roles played by semantic technologies in these domains.
- We provide a case study on smart environments.
- We provide a case study on smart grids.
- We discuss the current and future landscape of semantic applications in the smart environment and smart grid domains.

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ABSTRACT

Semantic technologies are currently spreading across several application domains as a reliable and consistent mean to address challenges related to organization, manipulation, visualization and exchange of data and knowledge. Different roles are actually played by these techniques depending on the application domain, on the timing constraints, on the distributed nature of applications, and so on. This paper provides an overview of the roles played by semantic technologies in the domain of smart grids and smart environments, with a particular focus on changes brought by such technologies in the adopted architectures, programming techniques and tools. Motivations driving the adoption of semantics in these different, but strictly intertwined, fields are introduced using a strong application-driven perspective. Two real-world case studies in smart grids and smart environments are presented to exemplify the roles covered by such technologies and the changes they fostered in software engineering processes. Learned lessons are then distilled and future adoption scenarios discussed.

1. Introduction

In 2001 Tim–Berners Lee proposed the Semantic Web vision: a new generation of the World Wide Web in which content was given well-defined, machine understandable meaning, better enabling cooperation between humans and computers. Almost a decade later, Semantic technologies are recognized as a means to reliably address issues related to information processing, organization, manipulation, visualization and exchange. As a consequence, semantic-based applications are crossing the boundaries of research-level applications and more and more enterprise-grade solutions are now offered on the

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market. This transition contributes to shape the role of semantics in software engineering and fosters previously unforeseen programming patterns.

This paper focuses on changes brought by semantic technologies in software engineering approaches and solutions typical of the home automation (smart homes) and smart grid domains. Starting from a detailed and updated overview of the state of the art in these fields, we analyze how semantic technologies impact the design of smart environments. The analysis follows two parallel paths: firstly we analyze emergent, cross-domain adoption patterns, using a top-down approach (see Section 3); secondly we address the specific domain of smart environments by focusing on two real-world case studies covering the vertical domain of energy monitoring and exchange, from smart environments (Section 4) to smart grids (Section 5). The two selected case studies, stem respectively from a 7-years old research effort carried by the some of the authors, currently part of a larger effort towards standardization of *Energy Using and Producing Products Management* [1], and from an on-going research in the smart grid domain involving one of biggest actors in the smart environment domain, in Italy, i.e. the Loccioni group. As shown in the paper, some clear roles for semantic technologies can be identified, involving both off-line modeling and run-time operation. The latter, in particular, is particularly interesting, from a computer programming standpoint, as it is currently fostering new programming paradigms mainly based on automatic code generation. In general, a tangible effort in finding the right trade-off between "pure" semantic-based operation, supported by full logic inference, and hybrid approaches were semantic information is translated into more operational representations, can be noticed. The first approach exploits the full power of logic to provide advanced data processing/management, but suffers from computationally intensive processes, seldom suited for on-line/real-time operation. The last, instead, is less formal, possibly dealing with, or generating, inconsistencies in modeled information, however it can easily be exploited at runtime, with computation loads typically lower than the full semantics approach. The results of our analysis provide hints on the increasing importance of semantics in smart home and smart grid domains, and, in the next years, we expect an even higher impact on related software engineering processes, particularly for what concerns monitoring and big-data issues.

The reminder of the paper is organized as follows: Section 2 depicts the current state of the art, highlighting typical cases of semantic-based approaches to smart homes and smart grids. Section 3 provides a top-down analysis of emergent roles of semantics in the knowledge domain tackled by the paper and provides an overview of technologies and approaches which are better detailed in the following sections. Sections 4, and 5 exemplify the roles identified in the former section by focusing on two real-world case studies respectively related to smart environments and smart grids. Finally, Section 6 discusses the emerging approaches and provides a view on the future trends in semantics-powered systems for the energy monitoring and exchange domain, while Section 7 concludes the paper and proposes future works.

2. State of the art

Firstly introduced by Tim Berners Lee et al. [2] and lately evolved in one of the main pillars of the next generation web, the Semantic Web and related technologies have quickly crossed the Web boundaries and have been considered as one of the enabling technologies for smart environments, in particular for smart homes and buildings. The earliest applications of semantic technologies (i.e., of technologies such as ontology modeling, reasoning, etc., stemming from the Semantic Web initiative) dealt with *context modeling*, a key technology for smart homes. In this domain, several research efforts [3–6] can be cited dating back to the first Semantic Web years.

2.1. Context modeling

COBRA-ONT [3], for example, is an ontology-based modeling effort for supporting pervasive context-aware systems, and provides a collection of ontologies for describing places, agents and events and their associated properties in an intelligent meeting-room domain. The ontological core of COBRA is SOUPA [7] a Standard Ontology for Ubiquitous and Pervasive Applications. SOUPA is expressed using the Web Ontology Language (OWL) [8] and includes modular component vocabularies to represent intelligent agents with associated beliefs, desires, and intentions, time, space, events, user profiles, actions, and policies for security and privacy.

Another relevant effort to adopt semantic technologies in the context of a pervasive computing environment (GAIA [9]) is reported in [4], where the use of ontologies helped to face some challenges that are not unique to pervasive computing, but that are faced by any multi-agent software system. The work considered three major issues that confront the development and deployment of pervasive computing environments: discovery and matchmaking, interoperability between different entities and context-awareness. From this work, several challenges related to the adoption of semantic technologies in intelligent environments emerged, part of which still have to be solved:

(a) the need to simplify the construction and maintenance of ontologies,
(b) the need to integrate ontologies with software generation and management, for example using ontologies to semi-automatically generate interfaces,[1]

[1] This has been extended to automatic code generation in the last few years.