Computers and Electrical Engineering 44 (2015) 280–306

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

CONSERT: Applying semantic web technologies to context modeling in ambient intelligence ☆

Alexandru Sorici [a,b,*], Gauthier Picard [b], Olivier Boissier [b], Antoine Zimmermann [b], Adina Florea [a]

[a] University Politehnica of Bucharest, Department of Computer Science, 313 Splaiul Independentei, 060042 Bucharest, Romania
[b] Ecole Nationale Supérieure des Mines, FAYOL-EMSE, LSTI, F-42023 Saint-Etienne, France

ARTICLE INFO

Article history:
Received 7 February 2014
Received in revised form 11 February 2015
Accepted 10 March 2015
Available online 4 April 2015

Keywords:
Ambient intelligence
Context modeling
Ontology
Semantic web
SPARQL
Rule-based reasoning

ABSTRACT

Representation and reasoning about context information is a main research area in Ambient Intelligence (AmI). Context modeling in such applications is facing openness and heterogeneity. To tackle such problems, we argue that usage of semantic web technologies is a promising direction. We introduce CONSERT, an approach for context meta-modeling offering a consistent and uniform means for working with domain knowledge, as well as constraints and meta-properties thereof. We provide a formalization of the model and detail its innovative implementation using techniques from the semantic web community such as ontology modeling and SPARQL. A stepwise example of modeling a commonly encountered AmI scenario showcases the expressiveness of our approach. Finally, the architecture of the representation and reasoning engine for CONSERT is presented and evaluated in terms of performance.

1. Introduction

Ambient Intelligence (AmI) is nowadays a well recognized area of research with work done in domains ranging from hardware (e.g. sensors, actuators) through middleware (e.g. information management, basic services) to innovative end applications and human computer interfaces. The industry is also starting to embrace scenarios and ideas from the ambient intelligence domain, most notably in activity areas such as home monitoring and automation, smart city sensing and monitoring infrastructures. There is a growing number of start-up enterprises that are active in the mentioned areas (e.g. Ninja Sphere,[1] Nest,[2] SmartThings[3]) and increasingly more cities are offering their support for installing prototype smart environment infrastructures.

The possibilities for AmI application development increase even further, given the emerging industry enterprises that offer entire development platforms for creating application and business logic in the IoT and M2M (machine-to-machine) domains

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. Tor-Morten Grønli.

* Corresponding author at: Aleea Politehnicii, nr. 2, bl. 5A, ap 14, 060813 Bucharest, Romania. Tel.: +40 726 379 386.
E-mail addresses: alex.sorici@gmail.com, sorici@emse.fr (A. Sorici), picard@emse.fr (G. Picard), boissier@emse.fr (O. Boissier), antoine.zimmermann@emse.fr (A. Zimmermann), adina.florea@cs.pub.ro (A. Florea).

[1] http://ninjablocks.com/.
[2] https://nest.com/.
[3] http://www.smartthings.com/.

http://dx.doi.org/10.1016/j.compeleceng.2015.03.012
0045-7906/

(e.g. Xively,[4] ThingWorx[5]). Such initiatives open up a trend that leads towards systems which promote anonymous social experiences and focus on models of group activity rather than just individual ones. It raises an AmI that is centered on enhancing human interaction apart from supporting individual needs and preferences.

In terms of information and situation supervision (the Context Management research branch of AmI), the perspectives listed above translate to requirements of being able to support interoperability and openness. They also demand an increased expressiveness of contextual information models and the accompanying reasoning and query solutions. The growing complexity of situation definitions in AmI scenarios as promoted by the consideration of models for social activities and experiences drives the need for model expressiveness, whereas the decentralized and heterogeneous nature of devices and applications found in the IoT and M2M domains imposes the necessity for interoperability through standards.

With this in mind, the information management middleware and the way in which it handles the notions of context representation and reasoning, as introduced by Dey [1], are of first importance. The past decade has seen many contributions in these particular fields of research [2–4]. Recognizing the need for interoperability and standards in terms of languages and approaches, works have started focusing on ontology models in support of context modeling. The representation potential of description logics, the ability to ensure knowledge consistency and the support for reasoning make for compelling benefits. However, the majority of approaches for ontology-based context modeling focus on building either a very generic (e.g. [5]) or a highly specific (e.g. [6]) vocabulary for the domain knowledge of a given AmI application. Consequently, many such models cannot support important design expressiveness aspects of domain statements such as arbitrary arity of predicates or well-structured representation and reasoning on statement meta-properties (e.g. quality metrics, temporal validity).

Furthermore, an inference process based solely on the capabilities offered by description logics is not sufficient to address the challenges of having a well-structured means for concomitantly reasoning over context domain knowledge, time dependent meta-properties and integrity constraints.

In this article we propose to address the earlier mentioned shortcomings by developing CONSERT, a context representation meta-model implemented as an ontology, which extends and combines previous works [7,8], providing extensive design support for expressing statement meta-properties (annotations) and constraints. We furthermore define a context representation and reasoning engine (CONSERT Engine) which tackles the problems of (i) combining rule-based and ontological reasoning for domain knowledge, (ii) structured manipulation of context annotations and (iii) detection of context integrity violations. Thereby we make use of the latest proposals of the semantic web community for standards such as RDF and SPARQL in order to address the storing, querying and reasoning aspects. As we will see later on, the latter reliance on semantic web standards is our solution to the requirements of interoperability with third party applications and general openness in AmI systems.

The remainder of this paper is structured as follows. In Section 2 we analyze related work in the domains of context ontology models and semantic web approaches to reasoning over context information and point out the works and concepts that influenced our own approach the most. Section 3 presents an application scenario which we further use to illustrate examples of the notions we define along the way. We then start a formal definition of our proposed context model in Section 4, present its implementation in Section 5 and provide, in Section 6, a designer's guidelines for using our approach to model the scenario exposed earlier. Sections 7 and 8 describe the architecture of our proposed representation and reasoning engine as well as the validation and performance tests we carried out. The paper concludes with Sections 9 and 10, where we discuss the contributions, existing limitations and future directions of work.

2. Related works and foundations

The field of context modeling has received a noticeable amount of contributions over the last decade [2,3] ranging from simple key-value models, through mark-up and graphical models and down to different ontology models [5,7,9]. As mentioned in the introduction, the need for expressive modeling and reasoning support has led to ontologies for context modeling becoming a focus in many research approaches. In the following we provide an overview of ontology based context models going through domain centric proposals, works on context meta-models and approaches of reasoning about context. Throughout the analysis we try to point out how the presented works address the concerns of expressiveness and interoperability that we mentioned as focus elements in the introduction. At the end of the section we briefly explain how our own proposal tries to collect and combine relevant influences from the listed research works.

2.1. Domain-centric context models

As mentioned in the introduction, many lines of work tackled the problem of expressiveness by focusing on developing extensible and generic context modeling ontologies that would cover as many context domains as possible. Some of the works tried to also address the dimension of quality of context information.

CONON [9] defines a set of 14 classes that constitute its core vocabulary, which focuses on modeling persons, locations, activities and computational entities. It further defines a QualityConstraint class that can represent different quality aspects

[4] https://xively.com/.
[5] http://www.thingworx.com/platform/#how-it-works.