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Towards a Meta-model for Context in the Web of Things

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Abstract

The Web of Things (WoT) uses Web technologies to engage connected objects in applications. Building context-aware WoT applications requires modeling and reasoning about context. In this paper, we overview different context modeling approaches related to the WoT, before studying the architecture of WoT applications. We then propose a multi-level, multi-dimensional and domain-independent context meta-model to help WoT applications identify, organize and reason about context information.

Keywords: Web of Things, Context modeling

1. Introduction

The Web of Things (WoT) applies to various domains such as homes, enterprises, industry, healthcare, city or agriculture. It builds a Web-based uniform layer on top of the Internet of Things (IoT) to overcome the heterogeneity of protocols present in the IoT networks. Today's WoT applications (WoT apps) need relevant context models to exhibit context-adaptive behavior. Basically, a WoT app provides added value by combining access to connected objects and external data sources (i.e. Web services). It requires an accurate description and exploitation of WoT apps context, hence

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justifying the need for context models. As a consequence of the diversity of use-cases and applications, numerous domain-specific models relying on different formalisms and reasoning mechanisms have been designed (Perera et al. (2014)). However, a single context modeling framework for WoT apps is still missing. In this paper, we propose a context meta-model as a first building block for a framework that allows reusing the same reasoning tools in the diversity of WoT use-cases. In Section 2, we study general definitions for context and the major existing context models. In Section 3, we draw conclusions on existing work and study the different parts of WoT apps to identify the elements that will contribute to build our meta-model. In Section 4, we discuss our solution according to a set of evaluation criteria. In Section 5, we summarize our results and give perspectives for future work.

2. Describing Context: Related Work

While Schilit and Theimer (1994) define context-aware computing as *"the ability of applications to discover and react to changes in the environment"*, context can be seen as the information thats answers to the *Where*, *Who*, *When* and *What* questions as discussed in Abowd et al. (1999). Dey (2001) defines context as *"any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"*. Chaari et al. (2005) define a situation as an instance of a set of contextual attributes. Context information described in Schilit et al. (1993) include environmental and geospatial information, such as location, co-location (i.e. what is nearby), time, etc.. Most work Schmidt (2003); Zimmermann et al. (2007); Abowd et al. (1999) structure context as multi-dimensional views. Some work describe context with a specific focus, such as privacy in Dey et al. (1999), or computing resources (availability, remaining battery power) and network information (types of connection, services in reach, distances, disconnection rates) in Gold and Mascolo (2001); Mascolo et al. (2002); Musolesi and Mascolo (2009).

Network context is often combined with other context elements such as user profile or preferences in Wei et al. (2006); Raverdy et al. (2006); Yu et al. (2006). Users are of major importance in context-aware applications as shown in Cao et al. (2008, 2009); Xiang et al. (2010). In Brézillon and Pomerol

(1996); Brézillon (1999); Bucur et al. (2005) the user and its environment have a central place in the context model together with its interaction and domain-specific information. Brézillon and Pomerol (1999) use context for helping users with decision making, later with different knowledge sources as in Brézillon (2003) and with the notion of situation as in Bazire and Brézillon (2005). Context information may be domain-specific as mentioned in Munnelly et al. (2007), or related to the application architecture as discussed in Truong et al. (2007, 2008); Kirsch-Pinheiro et al. (2004). More recently Coppola et al. (2010) include meta-information about context (Probability, Importance, Description and Name).

3. Modeling Context for Web of Things applications

The related work presented above highlights the diversity and complexity of context. Each work propose a unique combination of device, user, network, and application context elements. The traditional semantic heterogeneities can be found between context models, i.e. polysemy, heteronymy, and so on. In the following, we discuss these approaches and then present our arguments for a context meta-model.

3.1. A Context Meta-model for the Web of Things

In our work as part of the ANR ASAWoO project[1], physical object functionalities and applications are exposed as RESTful services. Based on the context model and instances, the framework should be able to activate or deactivate functionalities or applications. The latter might not be available due to physical constraints, security, privacy, or other policies, which can vary according to the use-case.

Hence, we design a context meta-model for WoT apps to control the instantiation of domain-specific models and to reuse the same reasoning mechanisms. We rely on the different context information studied in the literature to justify our choices, and organize our meta-model into levels that characterize the different parts of a WoT app. As depicted in Fig. 1, mobile and distributed clients communicate with the WoT app, which itself communicate

[1] `http://liris.cnrs.fr/asawoo/`

with physical objects and data sources. A client could be a user (via a smartphone or computer), or another software application to allow for composite applications.

According to Fig. 1, we organize context information in four levels. The *Physical* level (1) describes context information about physical objects, including their internal states and information coming from their sensors that describe the objects' environment. The *Application* (2) level describes the application architecture, its state, its configuration, as an application can rely on different architectural paradigms, such as components or services, and can be either locally stored or distributed. The *Communication* (3) level describes the context of links between the application and clients, physical objects and data sources. It includes information such as the state of the network, bandwidth, latency, or the type of connection, such as wired or wireless. The *Social* (4) level characterizes the client's environment. It includes cognitive aspects such as user roles withing an organization, user behavior, and types of users (human, software).

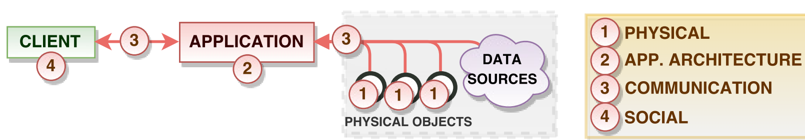

Figure 1: A typical WoT app architecture and its context dimensions

Fig. 2 shows an UML representation of our meta-model. The `Model` class aggregates the four levels presented above, which themselves compose the dimensions. For each level, the `Dimension` class contains a `name` URI that provides the ontological concept that describe the `value` object.

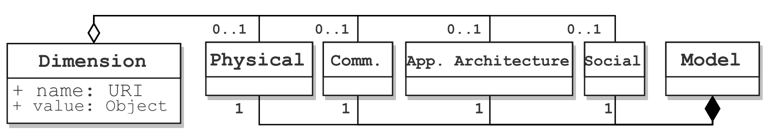

Figure 2: UML representation of our meta-model

Our meta-model presents the following advantages. First, it allows WoT app developers for high flexibility with an unrestricted numbers of dimensions to be created. Second, all the models will follow the same description language

(DL) thus allowing the reasoning process to always be effective. Third, the level/dimension view can be reused differently according to a WoT app settings, or even between several WoT apps. We illustrate the latter advantage in the section below with two use cases that rely on different models, and one use case that uses different combinations of levels/dimensions from the same model.

3.2. Illustration with different use-cases

We illustrate our meta-model with two use-cases that use specific context models. The first one is temperature regulation that needs to adapt to the user presence and settings. Its context model involves four dimensions that contains geolocation and network information, as well as time, actuator states, and user home preferences as shown in Fig. 3. Depending on the user settings, the application can rely different combinations of levels and dimensions to enable context-awareness. Typical users would rely on a model that includes both home and enterprise settings (plain squares in Fig. 3); children and elderly people would require different levels and dimensions (dashed squares in Fig. 3).

	Location	Status	Time	Profile
SOCIAL	Home	Awake	Evening	Cold sensitive
APPLICATION	n/a	Availaible	n/a	Low performance High security
COMMUNICATION	Local network	Not conjested	n/a	High bandwith usage
PHYSICAL	Lat. 45.7 Lng 56.3	Raining	h:7, min:25	Homebody

Figure 3: An example of Multi-level context model

The second use-case concerns agriculture. It involves drones that scatter bugs on plantations to protect them from threatening insects, an automatic watering system, and robots that pull off weeds from plantations. Each of them have their own context model, to provide the whole system with safe operation. According to the type of devices, level and dimension combinations to describe the context models can also differ. For example, drones robots only require a day/night granularity whereas the watering system requires hourly time slots. As well, the watering system do not use location information due to its immobility.

4. Evaluation

We build on the methodology proposed in Gómez-Pérez (1998) to evaluate our meta-model according to the following steps: (S1) Purpose and scope, (S2) Intended uses, (S3) Intended users, (S4) Requirements, (S5) Competency Questions (CQs), and (S6) Validation of CQs, as shown in Fig. 4. We refer to the metrics proposed in Hlomani and Stacey (2014) in (S6).

(S1)	The scope of our work includes smart home, smart farms… Our purpose is to provide context-awareness with reusable and relevant models.
(S2)	Any WoT scenario (see Section 3.2).
(S3)	WoT apps developers.
(S4)	Context information coverage (Location, Time, User Preferences...).
(S5)	(CQ1) Does the model cover required context information?
	(CQ2) Does the DL language allow for complete and sound results in a finite time?
	(CQ3) Does the DL language provide the logical constructs required by the reasoner?
	(CQ4) Are the number of levels sufficient to describe a WoT app context ?
	(CQ5) Are the levels redundant or overlapping?
(S6)	(CQ1) The meta-model allows any dimension to be created for complete coverage.
	(CQ2) The DL used (OWL) provides 3 profiles (EL, QL, RL) that are able to answer any reasoning problem (conjunctive query answering, class expression subsumption...) in a finite time.
	(CQ3) OWL provides expressive relationships (object, datatype properties) and concepts (classes, individuals, data values) allowing the reasoner to correctly answer queries.
	(CQ4) Levels are based both on related work and a typical WoT app architecture, thus covering the needed context information.
	(CQ5) Our levels do not overlap by design.

Figure 4: Evaluation of our meta-model.

5. Conclusion and perspectives

In this paper, we build a meta-model that combines levels and dimensions to help WoT apps identify, organize and reason about context information. Our meta-model aims at enhancing the reusability of reasoning mechanisms across application domains while leaving flexibility for developers to design their application-specific context models.

As future work, we aim at optimizing the reasoning process for WoT apps to handle fast-paced data streams as context sources, as well as to provide dynamic reconfiguration and adaptation for their components.

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