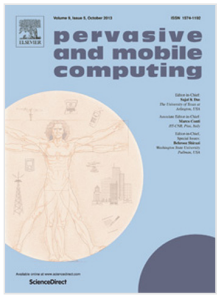
Accepted Manuscript



Uncertainty handling in rule-based mobile context-aware systems

Szymon Bobek, Grzegorz J. Nalepa

PII: S1574-1192(16)30211-5
DOI: http://dx.doi.org/10.1016/j.pmcj.2016.09.004
Reference: PMCJ 757

To appear in: *Pervasive and Mobile Computing*

Received date: 3 May 2016
Revised date: 12 August 2016
Accepted date: 11 September 2016

Please cite this article as: S. Bobek, G.J. Nalepa, Uncertainty handling in rule-based mobile context-aware systems, *Pervasive and Mobile Computing* (2016), http://dx.doi.org/10.1016/j.pmcj.2016.09.004

Uncertainty handling in rule-based mobile context-aware systems

Szymon Bobek, Grzegorz J. Nalepa

AGH University of Science and Technology,
al. A. Mickiewicza 30, 30-059 Krakow, Poland

Abstract

Uncertainty handling is one of the most important aspects of modelling of context-aware systems. It has direct impact on the adaptability, understood as an ability of the system to adjust to changing environmental conditions or hardware configuration (missing data), changing user habits (ambiguous concepts), or imperfect information (low quality sensors). In mobile context-aware systems, data is most often acquired from device's hardware sensors (like GPS, accelerometer), virtual sensors (like activity recognition sensor provided by the Google API) or directly from the user. Uncertainty of such data is inevitable, and therefore it is obligatory to provide mechanisms for modelling and processing it. In this paper, we propose three complementary methods for dealing with most common uncertainty types present in mobile context-aware systems. We combine modified certainty factors algebra, probabilistic interpretation of rule-based model, and time-parametrised operators into a comprehensive toolkit for modelling and building robust mobile context-aware systems. Presented approach was implemented and evaluated on the practical use-case.

Keywords: uncertainty, context-aware systems, mobile computing, rule-based systems

1. Introduction

Contextual data can be delivered to the mobile context-aware system in several different ways: directly from the device sensors [1], from other devices sensors, over peer-to-peer communication channels [2, 3], from external data sources like contextual servers [4]. Moreover, it can be provided by reasoning engines that based on the low-level context and a contextual-model provide higher-lever context [5]. In each of this cases, the system may experience problems caused by the uncertainty of contextual information.

Among many proposals of uncertainty handling mechanisms [6] like Hartley Theory, Shannon Theory, Dempster-Shafer Theory, the following have been found the most successful in the area of context-awareness:

- Probabilistic approaches, mostly based on Bayes theorem, that allows for describing uncertainty caused by the lack of machine precision and lack of knowledge [7, 8].
- Fuzzy logic, that provides mechanism for handling uncertainty caused by the lack of human precision [9, 10]. It allows describing imprecise, ambiguous and vague knowledge.
- Certainty factors (CF), that describe both uncertainties due to lack of knowledge and lack of precision [11, 12]. They are mostly used in expert systems that rely on the rule-based knowledge representation.
- Machine learning approaches, that use data driven rather than model driven approach for reasoning [13]. They allow for handling both uncertainties due to lack of knowledge and lack of precision.

The mobile environment is highly dynamic which requires from the uncertainty handling mechanism to adjust to rapidly changing condition. Probabilistic and machine learning approaches cope very well with most common uncertainties types, but they need time to learn an re-learn. What is more, despite the existence of various probabilistic approaches, there is arguably no method that is able to deal with between two very different sources of uncertainty: aleatoric uncertainty, and epistemic uncertainty [14]. The aleatoric uncertainty is caused by the statistical variability and effects that are inherently random. In the area of mobile context-aware systems this can be reflected as an uncertain sensor readings which cannot be reduced due to the low quality of sensors, or external environmental conditions. Epistemic uncertainty is caused by the lack of knowledge, and can be reduced if additional information is available. Although it is not possible to cope efficiently with aleatoric uncertainty, as it is not possible to derive certain conclusion from uncertain data, there is a way to compensate this problems by reducing epistemic uncertainty.

Moreover, the vital source of information in mobile context-aware systems is the user, who is not only a passive observer of the system but rather its active operator [15]. Therefore, if there is no other automatic source available, the user himself can provide additional information in order to reduce the epistemic uncertainty. However, machine learning methods use a model that is not understandable for the user, and therefore it cannot be modified by him or her. Fuzzy logic approaches can

Email addresses: sbobek@agh.edu.pl (Szymon Bobek), gjn@agh.edu.pl (Grzegorz J. Nalepa)