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On the practicalities of place-based virtual communities: Ontology-based querying, application architecture, and performance

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ABSTRACT

While the Internet has allowed geographical boundaries to be transcended, with the increasing use of the mobile Internet, there is a shift towards a focus on locality and place-specific applications. This paper proposes a novel approach for constructing context-aware mobile services for a place using a commonly shared knowledge base, that captures not only static but dynamic aspects of a place. The approach is based on a conceptual model of a Place-Based Virtual Community (PBVC), represented using an ontology; a PBVC for a place augments the place with context-aware services based on querying an ontology. We present an implementation of a framework based on the ontology and an evaluation of the performance of queries over the ontology. We also illustrate architectures of specific applications as specialisation of a generic PlaceComm architecture.

1. Introduction

Mobile devices such as PDAs, mobile phones and pagers have woven themselves into people's lives. There is a trend towards a virtual community co-existing with a physical place. In other words, places contain not only physical objects, real people, but also digital services and digital devices, forming, increasingly, over a place, a kind of Place-Based Virtual Community (PBVC). This paper identifies and addresses the need for capturing, storing, and understanding the context dependencies between a physical place and the social context of users within a community in order to build context-aware place-based services. In previous work (Nguyen, Loke, Torabi, & Lu, 2011), we proposed a systematic approach for developing place-based context-aware applications via the introduction of the PlaceComm framework, namely, we build an ontology, and then encapsulate the queries over the ontology as agents to provide services. A key distinguishing idea of this work is that the ontology also serves as a "standardized" schema for knowledge about a place. The purpose of such a "standardized" schema is that different context-aware applications for a place can be programmed against this schema, and different places can be expected to have the kind of knowledge mentioned in the schema.

This paper extends previous work as follows. We provide an updated description on the PBVC ontology and an updated description on the PlaceComm architecture, compared to what was presented in Nguyen et al. (2011). This paper presents more details on the format of items in the knowledge base, and presents in detail a comprehensive series of queries to illustrate the ideas of the work, not previously described elsewhere. We address questions and research gaps relating to the practical aspects of the PlaceComm approach to mobile services, namely, (i) what queries can be used for PBVCs and whether such queries can be efficiently evaluated against the ontology we developed, and (ii) what architectures for applications that use PlaceComm and how they relate to the generic PlaceComm architecture (e.g., whether the architectures of specific applications be viewed as a specialisation of the generic PlaceComm architecture). Also, here, we discuss trust aiding mechanisms and place discovery, not in previous work. This paper provides a comprehensive performance evaluation not previously published elsewhere. This paper relates the applications (in Section 5) to the generic PlaceComm framework in a new way, showing the specific architectures and how they are derived from the generic PlaceComm architecture. We demonstrate the system's versatility by developing prototype applications based on our implemented framework.

As advocated by Gordon and Silva (2011, 2012), this paper highlights the "return of focus" to locality and place that the mobile Internet is enabling.

The paper is organized as follows. Section 2 reviews the background for the paper. Section 3 details the notion of Place-based Virtual Community, from definition to theory and representation in the form of a PBVC ontology built using the Web Ontology Language (OWL).[1] Section 4 details the PlaceComm framework from its

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[1] The Web Ontology Language, http://www.w3.org/2004/OWL/.

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conceptual model to its agent architecture. Section 5 introduces a number of application prototypes built on the PBVC framework. Section 6 presents further evaluation of the PlaceComm framework, including performance measurement and scalability of querying. We conclude the paper in Section 7 with future directions.

2. Background and related work

2.1. Context-aware frameworks and services

There are detailed surveys on context-aware frameworks and services, e.g., in Baldauf, Dustdar, and Rosenberg (2007), Endres et al. (2005), Sheng, Yu, and Dustdar (2010) and Raz, Juhola, Serrat-Fernandez, and Galis (2006). Our work differs from earlier context-aware middleware and toolkits (Dey, 2001) in that these toolkits and middleware generally do not support reuse of a common knowledge base across different applications or allow applications to contribute knowledge. Site-specific services accessed via smartphones were considered in Toye, Sharp, Madhavapeddy, and Scott (2005), but they do not consider the notion of a community and a place KB.

2.2. Context modelling and reasoning using ontologies

There are many research projects that apply ontologies for context modeling and reasoning in context-aware computing (Ye, Coyle, Dobson, & Nixon, 2007; Bettini et al., 2010). Below, we review some significant projects that inspire and motivate our research.

2.2.1. SOUPA – standard ontology for ubiquitous and pervasive applications

In Chen, Perich, Finin, and Joshi (2004) is an ontology called Standard Ontology for Ubiquitous and Pervasive Applications (SOUPA). SOUPA provides a formal way to model context (Ye et al., 2007). SOUPA includes common vocabularies for BDI agents, time, space, events, user profiles, actions and policies for security and privacy.

2.2.2. CONON – the CONtext ONtology

CONON is an ontology-based context model in which a two-layer ontology approach is adopted for designing context ontologies (Wang, Zhang, Gu, & Pung, 2004). In Wang et al. (2004) is noted that even though pervasive computing environments such as the home, office or vehicle are different from each other, they still share common generic context models.

2.2.3. Smart-Context ontology

The project "Smart-Context" (Moore, Hu, & Wan, 2008) proposes a context ontology for pervasive computing which supports autonomous decision-making. The Smart-Context ontology is built using RDF/S with OWL and Jena, which support context reasoning.

2.2.4. PECO ontology

Recent work in Niu and Kay (2010) built a three layer ontology called PECO, which is a key component in the PERSONAF framework. The three layers of the PECO ontology are: (i) Middle Ontology, which represents key concepts about buildings, (ii) Application Ontology, which represents a particular building, and (iii) Accretion Ontology, which is a novel ontology that supports personalization. The contribution of the PECO ontology is its support for personalization in the sense of different people or groups of people being allowed to name a physical place with different names. For example, for postgraduate students "Room 125 is a Social Hub", while for Bob "Room 125 is a Recharging Corner".

2.2.5. Discussion

The literature shows that using ontologies is considered a key approach for modeling and reasoning about context. We propose our PBVC ontology later, which is built upon concepts in the above reviewed ontologies; however, we also introduce new concepts that relate to the notion of PBVC and show how the new concepts relate to concepts in other ontologies.

2.3. The importance of the notion of place

Recently, the notion of place has gained greater attention from the pervasive computing community. In Ciolfi (2004), Ciolfi and Bannon (2005) and Ciolfi, Fitzpatrick, and Bannon (2007), the authors have considered place as the environment for pervasive computing. In recent years, short-range wireless networks have pervaded urban places. The millions of wireless access points deployed in public places.[2] can lead to "Location-based Electronic Communities" as defined in Loke (2002). Indeed, many projects have investigated the appearance of devices, people and wireless activities in places, such as Cityware,[3] and Realtime City at MIT Senseable Lab.[4]

As noted above, there have been numerous work on context-aware frameworks (Endres, Butz, & MacWilliams, 2005), context ontologies (Chen et al., 2004; Blackstock, Lea, & Krasic, 2007) and context modeling and reasoning (Bettini et al., 2010). However, in our work, the notion of "place" is central, and knowledge about a place can be built, even without committing to any application initially. Other context ontologies can indeed complement our work.

3. The PBVC ontology

The PBVC ontology was first mentioned in Nguyen, Loke, Torabi, and Lu (2009). We published initial ideas on the concepts, architecture, and ontology of the PBVC in Nguyen, Loke, and Torabi (2007), Nguyen, Loke, Torabi, and Lu (2008), Nguyen, Loke, Torabi, and Lu (2010) and Nguyen, Loke, Torabi, and Lu (2010), but this paper provides a more comprehensive and update-to-date view of the ontology. Although, in building the PBVC ontology we incorporated concepts from other ontologies, the core part of the ontology is novel. Also, we identified particular ontologies that could be aggregated for our purposes and show how to employ the PBVC ontology in place-based services.

A place can be a stadium, a shopping mall, a street (e.g., Orchard Road in Singapore or the Bourke Street Mall in Melbourne, Australia), a neighborhood, the city center (e.g., Central Business District of a city), a museum, a park, a university, a collection of buildings, and so on. Each place can be associated with at least one PBVC which has information about the physical place and the community of people living in or being at that place. In general, the boundaries around a place may be specified by an n-sided polygon, where each point is represented by a set of n GPS coordinates, or a circle with given GPS coordinates for a point and a radius. Note that our notion of PBVC does not aim to replace but can complement existing virtual communities that transcend boundaries. More generally, a place can be a union of polygons (i.e., a set of disconnected areas). For example, a place labeled as "myCommonPlaces" is a union of the university campus, my home, my parent's home and two shopping areas frequented.

Our vision is that each PBVC contains knowledge about a place, and the community at that place, a shared repository which we call

[2] http://www.skyhookwireless.com/howitworks/coverage.php.
[3] http://www.cityware.org.uk.
[4] http://senseable.mit.edu/.