Making Places Legible: Ontology Support for Context-Aware Applications in Place-Based Virtual Communities

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Abstract:
The context-aware capability of a mobile ubiquitous program is a distinguishing factor that realizes the vision of ubiquitous/pervasive computing. However, context gathering is costly and done repeatedly by different individual applications. There is a need for building a common knowledge base that facilitates context sharing and reusing as well as context contribution, for different applications. In addition, applications not only consume knowledge but also contribute knowledge. In this paper, we propose the PlaceComm framework for building such context-aware applications where knowledge can be shared, centered on an ontology which we call the Place-Based Virtual Community ontology. Our framework utilizes a multi-agent architecture for modularity, separation of concerns and extensibility. To illustrate the usage of PlaceComm framework, we introduce the Semantic PlaceBrowser, which is an application built using our approach.

1 Introduction

There is a consensus of opinion that context awareness is one of the key factors that enables pervasive computing. Many research projects have shown efforts to provide toolkit, middleware or framework for building context-aware applications (see [1] for survey). However, developing context-aware applications is still facing many difficulties. We make three observations: (i) many context-aware applications use knowledge about the individuals (and groups of people), places and objects within a particular place, that is, they are place-based, (ii) such knowledge about a place can be shared by different applications and reused, without each application having the same knowledge reengineered (there is at least overlap among such knowledge across different applications), and (iii) applications can not only be consumers of knowledge but also be contributors of knowledge about the place. There is a need of building a common knowledge base that enables context sharing, context reusing and context contribution among different applications. In this paper, we introduce a Place-Based Virtual

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Community Ontology, which is the core concept of our PlaceComm framework that facilitates context aware application development. The vision of the PlaceComm framework is context which not only can be sensed by the system, but also can be contributed by users and by different applications. In other words, applications not only consume the knowledge but also contribute knowledge during its runtime. In addition, a common shared context knowledge base is useful for different applications.

2 Background and Related Work

2.1 Community and Place

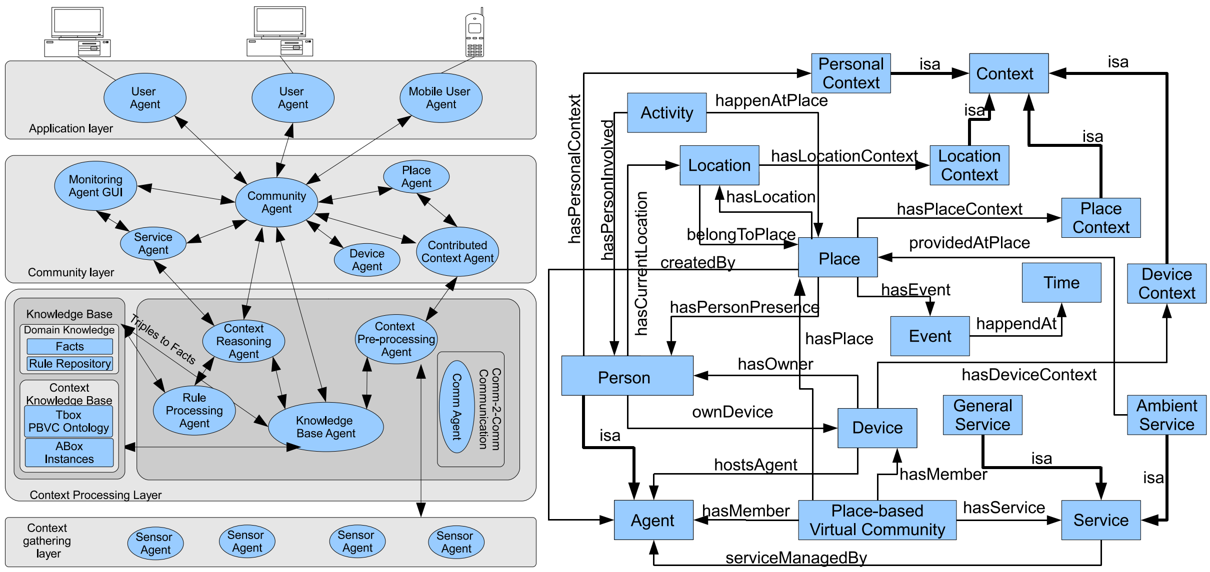
A virtual community typically transcends geographical boundaries. However, recent technologies with limited range connectivity such as Wi-Fi and Bluetooth have led to geographically based connectivity, on which virtual communities can be built upon, which are superposed on the local vicinity. Wi-Fi hotspots are increasing today. A place-based virtual community (or PBVC, for short) comprises the collection of people, objects, buildings, devices, services, history of movements, activities and interactions at a place, basically a virtual community rooted at a physical place, or a digital augmentation of an area. A place is not just a location but contains interactions among people and experiences that make the place meaningful, essentially, making a location a place. In crowded areas, such as urban areas, typically, one could be in multiple place-based virtual communities at the same time [12], that is, one is effectively located within a "stack" of communities, and moving in and out of such communities happens as a person moves around.

We view the pervasive computing environment as a place with all of these aspects: location, people present, activities at that place and relationships among them. There are three words we might find when speaking about place: location, space and place. Location is a point or extent in space, the landmark is a kind of special place, however, we observe the landmark from a distance, while we live in a place [5] (page 10).

2.2 Ontologies for pervasive computing

Many ontologies have been developed for context-aware pervasive computing [16]. However, different ontology serves different purpose. Among related ontologies projects in pervasive computing, SOUPA is considered the first standard ontology for modeling context in pervasive computing environments [4]. SOUPA contains almost all vocabularies that are needed for representing context-aware applications.

Gu et al. [7] propose a service oriented context-aware middleware (SOCAM) based on a context model with person, activity, location and computational entity as basic context concepts. The



(a) PBVC Architecture (b) PBVC Ontology

Figure 1: PBVC Ontology and System Architect

key distinguish feature of SOCAM is two-layer ontologies. The top-layer provides a common concepts for general environment. While the bottom layer is an extended ontology with specific definitions for particular environment such as a smart-home, a supermarket or an office.

Ontologies are hard coded in the software or agents code. The ontology usage is limited by sharing common vocabulary and knowledge for individual applications or users in an application. The context history that might be useful for different applications is not adequately mentioned. The PBVC framework approach enables a common knowledge base for a place that can be shared and contributed in order to maximize the context re-using and reasoning to avoid the re-engineering context module in different applications. To build this knowledge base, we can leverage on other ontologies mentioned above.

3 The PlaceComm Framework

Our vision is that each PBVC contains knowledge about a place, and the community at that place, a shared repository which we call a place knowledge base (or place KB, for short). Each person, via his or her device(s) might use such knowledge (or such knowledge used by a context-aware application on the device) or might contribute such knowledge back to the place KB. Different applications running on users' mobile devices can consume and/or contribute knowledge to the place KB.

With the vision of PBVC, we propose a framework called PlaceComm. PlaceComm framework enables context-aware applications development with place as a key abstraction. PlaceComm is built using the JADE/LEAP framework [2].

The PlaceComm framework contains four main components: (i)sensing components: takes care of context information sensing and gathering, (ii) knowledge base: used for storing context knowledge as well as answering semantic queries about context, (iii) PlaceComm APIs which is a collection of libraries for building agents for modeling the Place-based Virtual Community, and (iv) service enabler component, which is a collection of agents that enable user to build their own service with predefined formats.

Figure 1(a) shows the system architecture of the Place-Comm framework. The architecture is divided into four layers: context gathering layer, context-processing layer, community layer and application layer.

4 The PBVC Ontology

Our key contribution is the ontology that serves as the core component for the knowledge base. In this section, we introduce details of the PBVC ontology. There are many methods for building ontologies. Even though Uschold and King [14] are not the first authors to propose a procedure for building ontologies, they were the first to note the necessity of using methodologies for ontology development. Uschold and King proposed a skeletal methodology for building ontologies including four main steps: (i) identify purpose, (ii) building the ontology which contains three sub-steps: ontology capture, ontology coding and integrating existing ontologies, (iii) evaluation, and (iv) documentation.

In the building ontology step, we started by listing and carefully choosing all necessary concepts. The PBVC ontology includes 11 main concepts: Agent, People, Device, Context, Place, Location, Service, Activity, Event, Time and Place-Based Virtual Community. The PBVC ontology is summarized in Figure 1(b). The key terminological concepts are boxes and arrows indicate relationships among the concepts. We have used OWL to represent our ontology. The ontology forms the core schema for the CKB in PlaceComm. Inherited OntologiesThe PBVC ontology includes and extends previous ontologies as follows.

4.1 Inherited Ontology

PBVC is not built from scratch. It inherits with carefully selection from published ontologies: FOAF, Service, Device, Time and Location ontologies.

Person & FOAF ontology: The Person and Agent concepts in the PBVC ontology inherits from the FOAF ontology.[1] The FOAF project defines ontology terms for capturing personal information and their relationships in social networking. In this work, we would like to clarify

[1] http://xmlns.com/foaf/spec/

that the difference between ‘knows’ and ‘friendOf’ relationship: ‘friendOf’ is a subproperty of the ‘knows’ relationships, and ‘knows’ is not a reflexive relationship. But ‘friendOf’ is a reflexive relationship: if A is a friend of B then B is also a friend of A, whereas A knows B but B may not know A.

Service: The service ontology is adapted from DAML OWL-S ontology [11]. We have created two subclasses of Service which are GeneralService and AmbientService. The GeneralService is a kind of service provided in the PBVC regardless of the place. The AmbientService is a kind of service that is provided at a specific place and may be different in each place. The services belonging to GeneralService exist in any PBVC community, while an AmbientService may be different at different places and communities. Each service has category properties that allow service matching.

Device: FIPA and W3C have defined different device ontologies for different purposes. While FIPA's device ontology looks at device as the platform that can host an agent,[2]), e.g., W3C's goal is to describe whether a device is suitable for displaying a particular web page.[3]) However, in our vision, a device can be any object such as a computer, a smartphone, a kind of furniture or even an RFID tag. In other the words, the device ontology should facilitate describing a wider range of objects. Furthermore, a device can have an owner (hasOwner) or a person can own the device (ownDevice). By modelling this, we can discover a person's presence by the presence of an owned device in a place.

Time: Time is an important context information for all events happening in the environment. Most context-aware applications are based on sensed context or reasoned context which means that we can only know about the past. Therefore, the time factor must be carefully examined. We inherited the OWL-Time ontology defined by Hobbs and Pan [10] for our ontology. In addition, in every class of our ontology, we also have the timestamp attribute. By doing this, we can allow querying about past events.

Location Location has been considered important context information. Even though our point of view of the environment is place, location is still needed. Place can have location(s). We used the SOUPA location-ontology for our system. The location ontology is used for reasoning about objects or persons in spatial regions. But we view place as more than a location as detailed in the next section.

[2])http://www.fipa.org/specs/fipa00091/PC00091A.html
[3])http://www.w3.org/Mobile/CCPP/

4.2 Place

Currently, there are three common ways to determine a place: (i) using reverse geo-coding by providing GPS coordinates, with the help of many map APIs such as Google Map[4)] or PTV[5)] we can get the exact address of that place, (ii) using significant objects in the place, beacons, and the environment such as in PlaceLab project [9], and (iii) using place finger printing or eigen place by wireless fingerprinting in place or by analyzing GSM mobile usage in a particular place [3]. However, place is not not about the physical things. It also has social attachments. Hidalgo and Hernández [8] stated that social attachment is greater than physical attachment; In general, place attachment is defined as an affective bond or link between people and specific places. We introduce three more ways to determine a place: place is defined by people, by event/activities or memory/history and place where location is optional.

4.3 PBVC ontology

The PBVC ontology is illustrated in Figure 1(b), which details the relationships among main classes that describe the environment. A PBVC contains Place, People, Agent, Context, Activities and Services. The contribution of the PBVC ontology is to make explicit the semantic link among concepts that allow us to extract relevant context information. Repositories for storing instances are needed for recording purposes, whenever context has changed in the aspects of Place, Device, People, Agents and Community.

5 Sample Application: Semantic PlaceBrowser

We contend that capturing and understanding the context of place is crucial for context-aware applications. Therefore, we build an application called Semantic PlaceBrowser which not only can sense the environment but also can discover hidden context using a semantic browsing technique based on ontology reasoning and context reasoning. The details of Semantic PlaceBrowser is presented in [13]. The key distinguishing aspect of the Semantic PlaceBrowser is that it not only can sense physical devices in the place but also can issue the semantic query to the KB so that it can gain more knowledge about the place.

More interestingly, as in our definition about Place Based Virtual Community, where a community has it own place. In this example, the community of people maps to a different place at a specific time. By discovering particular people in the same community at a place, we can infer that a community of people has come to a place at certain periods automatically by querying the KB.

[4)] http://code.google.com/apis/maps

[5)] http://www.dev.ptv.com

6 Evaluation and Discussion

Evaluating an ontology has challenges since developers cannot just compile and run them like other software [15]. In our work, we are applying evaluation methods proposed by Gómez-Pérez et al. [6] which are requirements specifications, competency questions, and building applications using our ontology. For the context-aware computing domain, the vocabularies provided in the ontology is enough to describe most of the scenarios of applications. Furthermore, based on the concept of place, the environment can be indoor or outdoor.

In addition, we have built over thirty competency questions which can be answered by using the PBVC ontologies (some of competency questions are detailed in section 5 as queries). Furthermore, most of the competency questions can be answered directly by SPARQL queries, which means that required context (represented as a query) is not hard coded into the program, we can automatically extract context from the knowledge base. In our previous work [13], we can even issue a SPARQL from the mobile device to get context from the KB.

Our contributions can be distinguished from other related works in the sense of: context sharing and allowing applications contribute and query context. The ontology not only serves as a common vocabulary for the domain, but also enables a knowledge base that can be shared by different applications. In addition, while most of the ontologies can be hard coded inside a program, our approach is to enable users to query a shared KB via SPARQL, which is more flexible and robust. The KBA's roles are similiar to the Context Broker Agent in the CoBra architecture [4] at first look. However, the key distinguishing feature of KBA is the ability to collect context information from the user and sensor agents.

7 Conclusion

We have presented the concept of Place-Based Virtual Communities (which can complement general Internet-scale virtual communities) and the PlaceComm middleware for context-aware applications in PBVCs. A key idea is the sharing of a community KB (supported by an ontology) by applications. The ontology provides a "standard" view or schema of the minimal knowledge contained in, or which can be expected from, a PBVC. This can help applications know that, for whatever PBVCs one is developing for, the knowledge in the community KB is at least that prescribed in the PBVC ontology. The Semantic Web is envisioned to be a global database of knowledge that continually grows and expands. In the same spirit, we consider a community KB as knowledge about a place that will continue to grow and expand, and so, we leverage on Semantic Web technologies in our work.

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