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Context Ontologies - Enabling the Interaction of Embedded Devices in Heterogeneous Smart Spaces[A]

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Abstract: To enable the interaction of embedded devices in heterogeneous smart spaces, this paper proposes the utilization of context information to support novel applications that can dynamically discover and combine services offered by those smart spaces. By using context ontologies as an instrument for modelling contextual information, semantic interoperability is enabled by sharing common understanding of the structure and meaning of context information among users, devices, services and application domains. This allows devices in heterogeneous smart spaces to dynamically discover and composed available services as well as to automatically negotiate each other.

1. Introduction

The seminal pervasive computing paradigm of embedding sensors and devices into smart spaces has long been envisioned. With each new augmented environment, whether it is the office, the home, the hospital or the cafe, it seems that there is almost no physical area of our daily lives that cannot now be augmented by sensors and transformed into a smart space. As these smart spaces encroach upon each other, both physically and logically, the possibilities in enabling users to dynamically transition from one smart space to another and to interact with overlapping smart spaces, are endless.

Yet, these smart spaces are typically isolated islands, each gathering and exploiting their own contextual information independently, whilst typically requiring a-priori registration of users and devices within that smart space. The next generation of smart spaces need to be able to support dynamic ad hoc relationships that can form when smart devices move between these smart spaces. Enabling the creation of these dynamic relationships at run-time provides many research challenges such as mobility, discovery, security and addressing, and also a common understanding of the contextual information that can be shared between these different smart spaces.

Context ontologies have been proposed as one possible solution for capturing the information required to facilitate the formation of these spontaneous relationships. Ontologies provide a common extensible language that meets the typical modelling requirements for integrating smart spaces, and ontologies natural support for extensibility means that they can be specialised to domain specific smart spaces where required.

2. Enabling Heterogeneous Smart Spaces

Facilitating the interaction of heterogeneous devices originating from different smart spaces, as targeted by the PECES project, allows the development of novel applications which combine services from different smart spaces. Context information, and the ontologies used to model the context, is a key enabler in the service discovery and consumption process. Context aware service descriptions enable service consumers to access the described services without any prior knowledge about the smart space it has entered. On the other hand, information about the capabilities of the consumers devices will let the service provider know what the most appropriate method for the device to consume the service is.

The PECES project has identified three use cases, combining aspects from the navigation, access control, eHealth and localization domains, which illustrate the use of context ontologies within the pervasive computing and embedded systems domains. It is beyond the scope of this paper to go into the details of each use case, however the access control and navigation use case has been chosen to illustrate how context information is exchanged between service providers and consumers.

> "*Imagine the user, John Smith, is travelling in his car. He has a PDA which he used to plan his trip – a visit to one of his main customers to hold an important meeting. The moment he got in the vehicle, all smart devices on board – from the PDA to the in-car satellite navigator - became aware of each other's presence. The PECES middleware enables their mutual discovery and dynamic interaction. Based on the interests of the user, the devices present the possible functionalities available and offer the user a number of services. These services may include the computation of the optimal route to the customer's office, taking into account the real-time restrictions imposed by weather conditions and the traffic jams in the city. Furthermore, they may include the tuning of John's favourite radio station, and a number of other convenience-related functionalities*".

To enable the mutual discovery and dynamic interaction in the situation outlined above, the devices must exchange information about themselves, such as device configuration, communication protocols and control flow, etc. Based on the user's profile, which is stored on the PDA, the service provide knows John's favourite radio station. Other contextual information used within the scenario includes local weather conditions, local traffic data and the users PDA screen dimensions. The scenario then continues as follows:

> *"when he approaches his destination, his personal device makes contact with the system managing access to the building where his customer's offices are located. They negotiate the access of John's car to the parking facilities of the building. Once there, John's car number plate is recognized by a CCTV camera and his car is granted access to the car park. Within the car park, the in-car navigation system leads John to the parking space which has been allocated to him by the system. While he parks, the reception management system of the building negotiates with John's personal device his personal access to the building. He leaves the car, follows the directions displayed on his PDA's screen and reaches reception, where his fingerprint is recognized and the gates are opened for him. Once he is in the building, he will get access to all the locations and services that the system assigns to users with a 'guest' profile".*

In this use case, the main challenges include supporting mobility, discovery, security and addressing, in order to enable smart space interaction. Contextual information plays a key role in addressing some of these challenges. This data must be modelled in a consistent way so that all participants can interact without prior knowledge of each other, thus enabling this seamless smart space interaction.

3. Challenges in Modelling Contextual Information

Modelled contextual information provides a common shared understanding of the information that is exchanged between different smart spaces. To ensure that this understanding exists and to ensure that it can be flexibly extended to new application scenarios, PECES will rely on context ontologies to represent the shared information. The ontologies will be an integral part of the dynamic addressing and grouping scheme and they will ensure that the addressed or grouped devices are sound. Furthermore, the use of ontologies will also ensure that there is a standard way of extending the context modelled for new application domains.

Recent efforts to modelling context information using ontologies [1,2,3] are not suitable for use in most of the PECES use cases. Some of them are quite generic and oversimplified whilst others are too domain-specific. However these modelling methodologies as well as modelling artefacts such as concepts, taxonomies, modelling languages, reasoning tools, etc are useful. Hence, the PECES ontology will strive to reuse as many artefacts as possible from available ontologies by re-engineering them to fit into pervasive environments as well as embedded devices. At the core of this will be a generic, flexible and extensible upper-level context ontology. Based on this ontology, ontologies for capturing contextual knowledge of specific application domain will be easily extended.

3.1 Discovery

The primary objective of the PECES context ontology is to enable the sharing and common understanding of contextual information across difference smart spaces to create novel applications composing of services offered by these smart spaces. Having a common understanding of contextual information of the smart spaces will enable embedded devices to automatically/semi-automatically discover the services to consume without any prior knowledge about their counter parts. To achieve this goal, the context ontology not only has to model all necessary contextual information, it also must consider the constraints of heterogeneous, embedded and pervasive environments such as resource constraints, diversity of devices configuration, mobility, and adaptability. These constraints will be addressed and realized through the PECES use cases.

3.2 Expressiveness

A final challenge for ontology engineering in pervasive embedded environments is to strike the right balance between the expressiveness and the complexity of the ontology. As resources are highly constraint, hosting the ontology and all ontological instances in an embedded device is not always applicable. Hence, in most cases, heavy processing of context ontology information including reasoning and complex querying must occur in a PC or a server. To deal with the challenge of processing ontological context information in limited resource devices, a partial set of ontological instances can be hosted in a PDA or smartphone. A lightweight parser can be implemented for interpreting and matching simple contextual data. In a strictly resource constrained devices, contextual information under ontological instances can be reified as symbolic data for simple processing like equality matching.

3.3 Resource Constraints

Another key challenge that must be considered is the resource constraints that exist on the devices and to a lesser extent within the smart spaces. Devices with less processing power must have the capability to still interact with PECES enabled smart spaces, albeit with lesser functionality. The contextual information must be encoded as simply as possible so that the middleware running on the embedded devices has enough resources to handle it. For example, querying and parsing of ontologies can be resource intensive tasks. At runtime however, ontological contextual information may be used in the discovery process. Therefore a key challenge is to provide a sufficiently flexible encoding mechanism supporting the diversity of hardware capabilities, whilst also considering the resource constraints of those devices.

4. Possible Approaches

In order to realise the vision of the PECES project, the authors outline how PECES context ontologies could be potentially deployed in two roles: smart space discovery and smart space negotiation.

4.1 Smart Space Discovery

One approach to enabling the discovery of PECES smart spaces is to use a centralised registry that stores references to all smart spaces. Smart spaces provide descriptions of themselves, based on the smart space and service ontologies to the registry. The smart space and service description ontologies would then allow mobile devices, PECES consumers, to query the registry for the smart space services in which they are interested. For example, the mobile device might submit a query to the registry search for all "fixed smart spaces" that offer a "parking service", two concepts that would be captured within the PECES ontology. The additional context information that is associated with each service within the registry would allow mobile devices to search for *relevant* services, for example, parking services within a certain proximity of a location, for example, its destination. Figure 1 below specifies a typical Sparql query that could be executed at the central registry in order to find the appropriate parking service.

```
SELECT ?smartSpace ?service
WHERE { ?smartSpace rdf:type hierarchy:Fixed_SmartSpace .
      ?smartSpace owls_service:presents ?service .
      ?service rdf:type hierarchy:Parking_Service>  }
```

Figure 1: A Sparql contextual query executed against a PECES service description ontology.

4.2 Smart Space Negotiation

Once the device has found a service that it wishes to consume, a period of negotiation should occur between the device and the smart space itself. As devices have different configurations and specifications, a small description of the devices capabilities would allow the smart space to tailor its service to the devices capabilities. For example, a navigation service might offer two alternative services: a streamed voice navigation service to devices that have speakers only, and a visual navigation display to devices that have a screen with a minimum resolution. These device capabilities, allowing this device specific service tailoring is achieved by the smart space querying the PECES device ontology that is hosted on the device itself. Figure 2 below specifies the query a smart space could execute in order to determine the resolution of a device.

```
SELECT ?device ?height ?width
WHERE { ?device amigo_mobile:Accessories ?display.
      ?display rdf:type amigo_mobile:Display .
      ?display amigo_domains:hasQuality ?quality.
      OPTIONAL{ ?quality  amigo_domains:height ?height.
      ?quality  amigo_domains:width ?width}  }
```

Figure 2: A Sparql contextual query executed against a PECES device ontology

Of course, additional factors such as security and addressing would have to be taken into consideration but these are outside of the scope of the context ontology, but are accomplished within other parts of the PECES project.

5. Related work

There have been several related works on context ontology engineering in recent years and this section highlights the most relevant works to the PECES context ontology. Best practise in ontology engineering and specification is to reuse as many as possible existing artefacts from off-the-shelf ontologies.

There have been several approaches to building context ontologies specifically for pervasive computing environments. CAMidDo [3] uses ontologies to represent its meta-model in 3 tiers: middleware, context and applications. CONON [2] is an upper context ontology which defines 14 extensible core classes which model Person, Location, Activity and Computational Entities. Similarly, by focusing on Ambient Intelligence environments, the CoDAMoS [4] ontology captures the user, environment, platforms and services aspects. The Amigo [5] context ontologies are a set of ontologies used within the "Amigo: Ambient Intelligence for the Networked Home Environment" project. Of particular interest are the mobile and device ontologies which provide the concepts for modelling a vast array of both static and mobile devices.

Together with the aforementioned context ontologies, there are some additional ontologies relevant to contextual aspects within pervasive computing environments. Upper ontologies like DOLCE [6], SUMO [7] or Cyc [8] could be used to generalize or ground any context ontology. Two common aspects of pervasive context information are temporal and spatial. The Time Ontology in OWL [9] can capture the temporal aspect of contextual information, whilst the Geonames ontology [10] can be used for model spatial information. One more important piece of contextual information for pervasive embedded system is the delivery context defining characteristics of the environment in which embedded devices interact. SOUPA [1] is an ontology that supports the largest amount of concepts because it builds upon the following existing relevant ontologies: FOAF[11], DAML-Time & the Entry Sub-ontology of Time [12, 13], OpenCyc Spatial Ontologies [8] & RCC [14], COBRA-ONT [15] & MoGATU BDI [16] Ontology, Rei Policy Ontology [17].

6. Conclusions and Future Work

In conclusion, the PECES context ontology will address two challenges: 1) It will capture the expressiveness and the complexity of contextual information in a broad area such as pervasive computing. 2) Additionally, it will overcome the limitations of any devices that may use that ontology thus providing a significant advancement to the state of the art, enabling the first generation of semantically enabled smart spaces.

The diverse properties of the use cases, including their inherent complexity, heterogeneity, and the mobility of both sensors and users will validate the use of the context ontology as a means to enabling the dynamic cooperation between devices and heterogeneous smart spaces. With respect to the overall PECES project, the context ontology developed to satisfy these use cases will be developed within the next year. An iterated version of the context ontology, also provided within the next year, will also underpin additional group communication and addressing roles provided by the PECES middleware. This will allow devices and users to be addressed not by conventional addressing schemes such as IP but more symbolically using contextual information.

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