Sharing Context Information in Semantic Spaces

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Abstract. In a highly mobile and active society, ubiquitous access to information and services is a general desire. The context of users is of high importance for an application to adapt automatically to changing situations and to provide the relevant data. We present a combination of space-based computing and the Semantic Web to provide a communication infrastructure that simplifies sharing data in dynamic and heterogenous systems. The infrastructure is called *Semantic Spaces*.

1 Introduction

In general, context-aware applications have to deal with big volumes of heterogenous data from various heterogenous data sources. Moreover, most of the available IT applications depend on synchronous communication between information sources and sinks.

Tuple Spaces [3] allow distributed sharing of information by various devices without requiring synchronous connections. The Semantic Web [1] extends the Web with machine-processable semantic data, allowing data exchange in heterogeneous application fields. Combining the two introduces a new communication platform that provides persistent and asynchronous dissemination of machine-understandable information [2], especially suitable for distributed services. We call this combined communication platform *Semantic Spaces*.

In Section 2 we first present a context-aware application and show how it would be implemented without Semantic Spaces. Section 3 depicts the technical background for our approach, while Section 4 talks about how the application from section 2 benefits from using Semantic Spaces. Finally in Section 5 we conclude the paper.

2 Scenario: Enriching the Conference Experience

To illustrate our interaction scheme and how it would improve a ubiquitous computing system, we present a hypothetical use case: a mobile application supporting conference participants. The application enriches the conference experience and improves communication between attendees.

At the Conference: As Alice arrives at the conference venue, the application completes the registration process. The application has to query the necessary information about Alice from her *user profile service* (UPS) and forward it to the *registration service*. After the first presentation, Alice has to change buildings. There is a problem with the central heating in the second building indicated by the *building management service* (BMS). In consequence the application informs Alice that it will be unusually cold. The provision of the relative temperature is a non-trivial task. The application and the BMS have to agree ex ante on the "value" for cold.

Coffee breaks and lunch time (time and location are obtainable from the *conference program service* (CPS)) are very important for successful social networking, and the device guides Alice to the people whom she wants to meet. To be able to provide this simple service the application first retrieves the set of people she would like to meet from her UPS. In order to discover all the desired fellow researchers the application exchanges various messages with the CPS and the *location service* (LoS).

Our application integrates many different services in order to automatically adapt to changing situations. Many messages are sent around and the information contained is often encoded in different ways by different sources. Hence, the application has to deal with heterogenous data communicated over heterogenous channels.

3 Technical Background

This section gives a short introduction to the two fundamental technologies underlying the Semantic Spaces idea: Tuple Spaces and the Semantic Web.

Tuple Spaces were first introduced in the mid 80's in form of the Linda programming language [3]. Linda programs exchange data by using Tuple Spaces as shared memory for data tuples. A tuple is an ordered set of typed parameters. Linda defines a simple interface to access the space: out(tuple) to write and in(template) to read from the space, where templates match tuples that have the specified internal structure. The template matching procedure supports neither inference nor advanced querying — these features are added by the integration of Semantic Web technology.

In the **Semantic Web**, data is represented in the Resource Description Framework (RDF) or in languages based on it. Semantic data representation together with reasoning engines permits information from various sources (possibly using differing vocabularies) to be easily combined, and further facts inferred; going beyond subsumption reasoning of common domain classifications.

In contrast to the current synchronous communication approaches, Semantic Spaces decouple the information sources and clients in the following ways:

- **Time autonomy:** every agent can access the space at its own discretion.
- **Reference autonomy:** agents do not need to know each other, they only need to know the shared space.
- **Vocabulary autonomy:** by using semantic mappings between vocabularies, at least partial understanding of heterogenous data is achieved.

4 Applying Semantic Spaces to the Scenario

It is the central functionality of our context-aware application to collect and process vast amounts of information about Alice and the conference. In particular the application makes use of time and location information, temperature sensors and user profiles. The key processes here are the discovery of information sources on the one hand and the collecting and dissemination of information on the other. Most current mechanisms rely heavily upon a priori identification of all the things one would want to communicate with [4]. Our goal is to automate these key processes and to run them without human intervention. Sharing basic vocabularies and allowing machines to understand and reason about the semantics of context information enables them to interoperate automatically, i.e., to use, interpret and combine context information, as well as to infer further facts [5]. Below we apply Semantic Spaces to the conference scenario to demonstrate how the coordination of information providers and consumers can be improved.

At the Conference: As Alice arrives at the conference and her device stores her profile in the space, the registration service has all the necessary information to automatically complete Alice's registration. The presentation venue, attendee locations and profiles are described by semantic data in the space and hence every application interested in any of that information can simply read it from the space and does not need to discover the appropriate services and interact with them. When Alice needs to change the building, the application informs her about the unusually low temperature — revealed by sensors — in the second building. To do so, the application combines and reasons about the sensor data, location information and Alice's temperature preferences.

During the breaks the application assists Alice in finding the fellow researchers she desires to meet. All the necessary information (her location, the information about the people to meet and their locations) can of course be found in the space. Every application involved in the organization of the conference can read this information from the space and many-to-many message exchanges are not required.

The following is a sample of triple data present in the space that is used to bring Bob and Alice together during the coffee break:

```
<Alice wants-to-meet Bob>       - from Alice
<Alice is-at room-xyz>          - from location service
<Bob is-at room-zyx>            - from location service
<coffeebreak at-time 10.30am>   - from conference organizer
<coffeebreak is-at room-xyz>    - from conference organizer
```

Context-aware applications demand an exhaustive volume of communication to ensure the coordination and data exchange between information providers and consumers. Semantic Spaces replace the manifold message exchanges by read and write operations on a commonly accessible space. Adding semantics to the space reduces data heterogeneity and ambiguity, as well as incomplete and sometimes low quality data. Reasoning, knowledge inference and data mediation are effective tools of the Semantic Web and can be performed directly in the space.

5 Conclusions and Future Work

The Semantic Web aims at making information understandable to computers by adding machine-processable semantics to data. Tuple Spaces additionally allow complex networks of message exchanges to be replaced by simple read and write operations in a commonly accessible space. Overlaying the combination of Semantic Web and Tuple Spaces on a ubiquitous computing environment allows for interlinking services and sensors with clients without an explosion of communication. Semantic Spaces provide not only a promising basis for an infrastructure that addresses data and communication heterogeneity, but certainly an infrastructure that largely decreases the communication overhead commonly necessary to gather context information.

The proposed Semantic Spaces are not intended to replace all communication and coordination methods in distributed applications. Synchronous point-to-point links are still going to be used for time-critical tasks where one node needs to interrupt another. In spaces, a node will not notice an urgent request if it does not check the content often enough. Notification mechanisms are proposed for such situations, however bypassing the space is most likely the better solution.

When concretizing the architecture for the space infrastructure, we need to take into consideration distribution and scalability issues, as we are mainly dealing with mobile networks that are at once highly dynamic and weakly connected. Other immediate concerns are security and trust. Sharing information, particularly about humans, is a delicate task.

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