Ubiquitous Semantic Spaces

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ABSTRACT
In a highly mobile and active society ubiquitous access to information and services is a general desire of humankind. The advances around the Semantic Web and Semantic Web services allow machines to help people get fully automated anytime, anywhere assistance. However, most of the available IT applications and services depend on synchronous communication links between consumers and providers. Tuple Spaces overcome this limitation. We introduce a combination of space-based computing and Semantic Web to provide a powerful communication paradigm which is especially interesting for ubiquitous services.

Keywords
Tuple Spaces, Semantic Web, ubiquitous services

INTRODUCTION
Tuple Spaces [4] allow for distributed sharing of information. The Semantic Web [1] extends the Web with machine-processable data to process information in heterogeneous application fields. Combining the two as *Semantic Spaces* introduces a new communication platform that provides persistent and asynchronous dissemination of machine-understandable information [3], especially suitable for distributed services. Semantic Spaces provide emerging Semantic Web services (SWS) and Semantic Gadgets [5,6] with asynchronous and anonymous communication means, particularly attractive for Smart Spaces [2,8]. Distributing the space among various devices allows anytime, anywhere access to a virtual information space even in highly dynamic and weakly connected systems. Hence, *Ubiquitous Semantic Spaces* provide an ideal communication infrastructure for pervasive systems.

In the next section we introduce in more detail the concept of Semantic Spaces. Thereafter we show the effects on ubiquitous computing before finally concluding the paper.

SEMANTIC SPACES
Semantic Spaces are tightly related to the Linda system introduced in the mid 80's [4]. Linda Tuple Spaces provide a shared memory for data tuples. The Linda interface is as simple as it could be: out(tuple) to write and in(template) to read from the space, where templates match tuples that have the specified internal structure. This procedure allows neither knowledge inference nor advanced querying: a major disadvantage that is however a strength of the Semantic Web.

In the Semantic Web data is described by the Resource Description Framework (RDF) or by languages based upon it. RDF provides a semi-structured graph data model that is highly flexible: Graphs (sets of triples) can be merged, various vocabularies combined and triples added as desired. The semantic data allows machines to process the data and to reason about it.

Semantic Spaces provide a smart infrastructure that takes on information processing and filtering as well as communication coordination on behalf of the user and the various information and service providers to support automated interaction. Annotated data has been effectively used for context-aware applications [2,5,6,8], while SWS profit highly from stateless and 'persistently publish and read' data exchanges [3]. Semantic Spaces therefore ensure an infrastructure that specializes in communicating semantic data by integrating the best of space-based computing and the Semantic Web.

Context Information for Semantic Spaces
The integration of sensors, mobile devices and Web services results in the accumulation of vast numbers of information sources. To handle all the semantic data emerging in such versatile systems, data stores will have to deal with millions of triples. In consequence reasoning and processing the data becomes highly time and resource consuming. The solution is to distribute the storage and computation among the involved devices. Every interaction partner provides parts of the space infrastructure and data. It is necessary to add meta information to the data revealing the location in the space and the responsible applications [7]. Context information can also be used to improve matching and query algorithms. This is an important aspect especially in ubiquitous computing, where context-aware applications have to adapt to changing situations [8] based on detailed information about relevant aspects of the user and the surroundings.

UBIQUITOUS SEMANTIC SPACES
Ubiquitous computing applications build upon a highly dynamic and weakly connected infrastructure. The systems consist of very different devices and sensors providing large amounts of varying data. The devices dynamically enter and leave the system voluntarily or are forced to by breaking communication links or energy insufficiencies.

Nonetheless the consistency and availability of semantic data needs to be guaranteed, at least as much as possible. Hence, the computation environments demand a very flexible infrastructure: flexible in coordination and interaction, but also very flexible with respect to the syntax and semantics of the exchanged data.

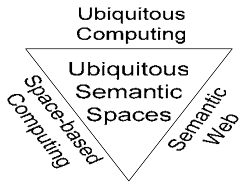

Fig.1. The basis of Ubiquitous Semantic Spaces

Ubiquitous Semantic Spaces present a solution because it brings together (Fig.1.):

1. *Space-based computing* allows information sources to share data also by use of heterogeneous access patterns and data structures. Tuple Spaces, in comparison to common database systems, are very flexible with respect to the data model. Moreover space-based computing refrains from synchronous communication links that are barely accomplishable - if at all - due to the weak connectivity of ubiquitous systems.
2. *Semantic Web* provides technologies to semantically enrich data. Semantic data is essential for service discovery, negotiation and information exchange and mediation between various communication entities. Reasoning engines permit information from various sources to be combined, and further facts inferred - going beyond subsumption reasoning of common domain classifications. Moreover the interactions happen on a machine-to-machine level.
3. *Ubiquitous Computing* permits access to the space even for weakly connected and highly dynamic systems. All devices involved in the system hold a share of the space and access to the "global" space. The information is not stored in a federated Tuple Space but in a shared information system where the data is persistently stored. Tools for prefetching and smart updating of data allow devices to provide and process semantic data even if disconnected from the overall system. These tools have to ensure data consistency and consider constraints implied by network dynamics and service contracts.

Ubiquitous Semantic Spaces do thus not only specialize in communicating semantic data, but provide a highly dynamic infrastructure to share heterogeneous data and to coordinate applications in unstable environments by distributing the space infrastructure among all involved entities. Ubiquitous Semantic Spaces allow self-organization and highly flexible integration of devices and sensors. They have the power to become the information market place for ubiquitous applications just as the World Wide Web is the primary information source for humans.

TAKING ON THE CHALLENGE

Establishing Ubiquitous Semantic Spaces carries along many challenges especially due to the constraints implied by ubiquitous computing: weak connectivity, low computation power and memory. The main task is to bring Semantic Spaces to ubiquitous computing. It is essential to define an architecture that matches performance and memory weak embedded devices that are autonomous and still collaborate to provide a full information system. Based on the efforts of the Triple Space Computing (TSC) project*) further concretisation of the architecture for Ubiquitous Semantic Spaces is a work in progress. TSC aims at Semantic Spaces on top of virtual shared memory middleware. In addition, Ubiquitous Semantic Spaces require comprehensive work on distribution and scalability. For the advancement of our ideas we will first have to tackle the underlying storage infrastructure to provide and coordinate the access to data that is located in different data stores from different communication entities. Moreover sophisticated data management and coordination algorithms have to be defined for networks that are at once highly dynamic and weakly connected.

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