

TOWARDS A CONTEXT-AWARE EMBEDDED INTERNET

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ABSTRACT:

A vast **quantitative growth** of the Internet over the past years has fertilized “desktop” information society technologies, the most prominent instance of which is the personal computer. The growing availability of wireless communication technologies in the wide, local and personal area, together with the pervasive use of mobile and embedded computing devices gives strong raise, however, for Internet services adapted to context, particularly to the person, time and location of their use. The seamless provision of services to anyone (personalized services) at any place (location based services) and at any time will presumably fertilize a much bigger **qualitative growth** of the Internet.

It is expected that an “embedded Internet” will evolve, enabled by wirelessly networked autonomous special purpose computing devices (i.e. Internet appliances), providing largely invisible support for tasks performed by users. Traditional I/O oriented computing will be replaced by a computing landscape sensing the physical world via a huge variety of electrical, magnetic, optical, acoustic, chemical etc. sensors, and controlling it via a manifold of actuators in such a way that it becomes merged with the virtual world. Applications and Internet services will have to be greatly based on the notion of **context** and **knowledge**, will have to cope with highly dynamic environments and changing resources, and will need to evolve towards a more implicit and proactive interaction with users. In this paper we explore some issues, challenges and enabling technologies associated with this vision of such a “pervasive” Internet.

Keywords: WWW, Context Computing, Embedded Systems, Pervasive Computing.

1. Interaction and Context

The Internet as a global network – but prevalently its most popular service, the WWW – so far has been operated in a client server style based on the HTTP protocol. Today the Internet is facing the maturing of wireless networking, exciting new information processing possibilities induced by submicron IC designs, low power storage systems, smart material, and motor, controller, sensor and actuator technologies, envisioning a WWW in which almost every object in our everyday environment will be equipped with embedded processors [Arno 99], wireless communication facilities and embedded software to percept, perform and control a multitude of tasks and functions. Since many of these objects will be able to communicate and interact with each other, the vision of “context aware” appliances [ELMM 99] and spaces [MIT] [Essa 99] [RoCa 00] – where dynamically configured systems of mobile entities by exploiting the available infrastructure and processing power of the environment – appears close to reality. We can hypothesize that the individual utility of mobile communication, wireless appliances and the respective mobile Internet services will be greatly increased if they were *personalized*, i.e. user centered and dynamically adapted to user preference, *location aware*, i.e. multimodal and multifunctional with respect to the environment [AAHL 97], and *time dependent*, i.e. if they were time dynamic and exhibited timely responsiveness. One revolution hence will be the evolution of context aware digital environments – often referred to as “smart appliances” or “smart spaces” – that intelligently monitor the objects of a real world (including people), and interact with them in a pro-active, autonomous, sovereign, responsible and user-authorized way. People will be empowered through a digital environment that is aware of their presence, sensitive, adaptive [Moze 99] and responsive to their needs, habits and emotions, as well as ubiquitously accessible via natural interaction [SATT 99].

The next generation embedded Internet hence will be characterised by the following basic elements: (i) *ubiquitous access*, (ii) *context awareness*, (iii) *intelligence*, and (iv) *natural interaction*. Ubiquitous access refers to a situation in which we are surrounded by a multitude of interconnected embedded systems, which are mostly invisible and weaved into the background of our surrounding, like furniture, clothing, rooms, etc., and all of them able to sense the setting and state of real world objects. The way how humans interact with the Internet will fundamentally change towards implicit, ubiquitous access. Context awareness

[RCDD 98] refers to the ability of the system to recognise and localise objects as well as people and their intentions. Intelligence refers to the fact that the digital surrounding is able to adapt itself to the people that live in it, learn from their behaviour, and possibly recognise as well as show emotion. Natural interaction finally refers to advanced modalities like natural speech- and gesture recognition, as well as speech-synthesis which will allow a much more human-like communication with the digital environment than is possible today.

It appears obvious that the notion of “context” is what will be the driving force for future applications and services using the Internet as the communication infrastructure. The context of an application is understood as “any information that can be used to characterize the situation of an entity”, an entity being “a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves” [Dey 01]. A key architecture design principle for context-aware applications (see e.g. [AAHL 99]) will be to decouple mechanism for collecting or sensing context information [SDOA 99] and its interpretation, from the provision and exploitation of this information to build and run context-aware applications [Schi 95]. To support building context-aware Internet applications, software developers should not be concerned with how, when and where context information is sensed. Sensing context must happen in an application independent way, and context representation must be generic for all possible applications [FBN 01].

2. Embedded Internet Enabling Technologies

From a technological viewpoint, a variety of challenges evolves towards the establishment of a “pervasive” Internet [HIR 01]. They concern a ubiquitous communication infrastructure for devices, the support for user interaction and user mobility, the provision of universal interfaces and the adaptation to individual user needs. One of the most important concerns is to design and develop software components that facilitate ad-hoc networking applications characterized by highly dynamic changes in the environment and the access modes or patterns, and their scalability with respect to the complexity of interactions and the number of involved entities or actors.

Ubiquitous access in an embedded Internet is promisingly implemented based on a continuous, wireless communication infrastructure involving broadband satellite systems, radio communication (e.g. GSM, GPRS, TETRA, DECT, EDGE, UMTS/IMT2000, G4, Bluetooth, HomeRF, IEEE802.11, HiperLAN, HomeCast, etc.), infrared (IrDA) and ultrasonic communication, wireless sensor networks, power line communications, wireline

communications and standards (USB, IEEE1394, HomePNA), etc. The primary challenge here lies in the maintenance of seamless connections as devices move between different areas of different network technology and network connectivity, as well as the handling of disconnects. While communication problems like routing and handover can be handled at the network level, others cannot be solved at this level as they relate to the interaction semantics at the application level [Else 99] [Arno 99]. Device heterogeneity and wide differences in hardware and software capabilities requires a communication infrastructure that maintains knowledge about device characteristics and manages coherent device interactions (e.g. among wearable devices, home appliances and outdoor appliances). Personal area network (PAN) technologies are supposed to address these issues.

The dynamic interconnection of devices and discovery services [McGr 00] within PANs is approached with network technologies like MobileIP, IPv6, and coordination software systems [OZKT 01] like HAVI, Java/Jini, JXTA, Java wireless data, Java-Spaces, the Simple Object Access Protocol, Web-OS, XML-RPC, UpnP [ChLa 99], Salutation [Mill 99], Tspaces, etc. While service registration and discovery, lookup services, self organization, caching and differencing methods have working solutions today (see Table 1 for a comparison), context based networking [Esle 99] and the context based coordination of entities and activities must still be considered as research issues.

	Jini/Java	UPnP	Salutation	Tspaces
Originator	SUN Microsystems	primarily Microsoft	Industry / Academic consortium	IBM
Register / Announcing Presence:	Unicast/Multicast to Jini lookup service Lease expiry for up to date informations	SSDP Protocol, working with or without Proxy Service Unicast/Multicast HTTP - UDP	through a Salutation Manager (SM) works as a service broker	making Services available on the Tuple Space
Discovering other devices	Querying lookup services Optionally using an RMI proxy	SSDP (Simple Service Discovery Protocol) used to announce their presence as well as find other devices	queries on SM	Database indexing and query on the TupleSpace
Describing capabilities	Registration Information can have attribute pairs RMI interface with known methods	XML documentation is made available URIs are used	functional units which know features of a service	Java RMI Method invocation interfaces with known methods
Self configuration	not considered	DHCP or AutoIP multicast DNS	not considered, difficult because of transport independence	not considered
Invoking services:	Through the lack of device driver difficult, device must be Java enabled, RMI	Invoking Services via Browser, or direct API calls through applications	flexible, vendor specific, realised through SM	Java RMI framework
Security:	Java Security	not finished yet	allows user authentication	access controls by User
Transports:	TCP/IP – Proxies	TCP/IP – Proxies	transport independent	TCP/IP
Supported Devices	all kind of devices, mobile, household equipment	all kind of devices, mobile, household equipment	printer, FAX, telephone, Personal Digital Assistant , computer (of any size) but not limited to them	Printers, PDAs, Computers
Remarks	no self configuration makes it weak RMI Method invocation is difficult to handle + Security	self configuration is considered as the strongest feature of this technologie	advantages in the functionality of the SMs, problems with transport independence	enhancement of Linda TupleSpace concept

TABLE. 1 A COMPARISON OF CURRENT APPROACHES FOR COORDINATION IN THE INTERNET

A major enabling technology for an embedded Internet is the miniaturization of devices able to accept and to respond HTTP requests, i.e. the provision of WWW servers to be weaved into arbitrary fabrics of daily use objects. Figure 1 lists a collection of popular embedded webserver miniatures (like from HYDRA, Dallas Semiconductors, Tini, Boolean, etc.), envisioning the technological options for embedded Internet appliances.



FIGURE. 1 MINIATURIZED EMBEDDED AND ON-CHIP WEBSERVERS

New output technologies like light emitting polymers, foldable displays, laser diodes, electronic ink, electronic paper etc. together with new materials able to serve as sensors or input technologies for monitoring the environment (digital and analog), appliances like T-shirt computers, finger rings, hot badges, smart rooms and smart environments, interactive workspaces like smart walls, tables, chairs etc., spawn a whole new space for information appliance designs. Implicit input and output in an embedded Internet will generally be realized via sensor and actuator technologies, involving optical and opto-electrical (photodiodes, -conductors, charge coupled devices, light-emitting diodes and polymers, lasers, liquid crystals), acoustic (e.g. acoustic transducers, sonar transducers, surfaces acoustic wave devices), mechanical (metallic, silicon pressure sensors and accelerometers, solid-state displacement transducers, piezoelectric field-effect transducers), thermal (silicon transistor thermometers, diode temperature sensors, pyroelectric and quartz thermometers, integrated temperature transducers), magnetic (magnetoresistors, silicon depletion-layer magnetometers, magneto-injection transistors, MOS magnetic field sensors), chemical sensors, microwave sensors, environmental sensors, etc. A consequence of this multisensory input possibilities is the need for a “continuously present” interface, e.g. continually-worn sensors in a context-aware computing application [SSP 98], the integration of voice-vision-text technologies, gesture, eye- and body-movement recognition etc. (Figure 2 illustrates technologies enabling a “continuous” interface to an embedded Internet)



FIGURE. 2 NEW MATERIALS FOR A “CONTINUOUSLY PRESENT” INTERFACE

3. Identification, Localisation, Coordination

To build context aware applications [SDA 99], the adoption of a world model representing a set of objects and their state in a real world (or at least the subworld essential for the specific application) is the common software engineering approach suggested in the literature [DSA 99] [DSAF 99a] [DSAF 99b]. What makes an application context aware is the ability to interact with objects in the real world, requiring adequate models and representations of the objects of interest, and the possibility to sense, track, manipulate and trigger the real objects from within the world model. Several frameworks for such world models have appeared recently [PRM 99] [KBMB 00] [KHCR 00] [FCE] [HP] identifying *persons*, *things* and *places* as the primary abstract classes for real world objects. People living in the real world, acting, perceiving and interacting with objects in their environment are represented in a “virtual world” by “virtual objects” or “proxies”. Proxies of persons, things and places are linked to each other in the virtual world, such that this “linkage” is highly correlated with the “linkage” of physical persons, things and places in the real world. A context-aware application [BBC 97] now monitors the state and activity of the real world objects via *set of sensors*, *coordinates* the proxies according to the rules embodied in the application, and notifies, triggers [Brow 98] or modifies the real world objects via a *set of actuators*.

We claim that a context-aware application can only be “intelligent” about an object it can (i) *identify*, (ii) *localize* and track, and (iii) *coordinate* with respect to the other objects around. Identification (sensing the identity of or recognizing a real world object), localization (sensing its position and possibly its movement in space) and coordination (relating it semantically to other objects and behavioural rules) are the central issues for embedded Internet applications,

and, moreover, are essential to all context-aware applications. They are among the few aspects that are fundamentally different from conventional WWW applications.

A plenty of ready-to-use technologies for the automated recognition (identification) of real world objects can be accounted: technologies based on optical (barcode and OCR), magnetic (SmartCard), ultrasonic (Active Badge and iButton) sensors, voice and vision based systems, biometrical systems (fingerprint, retina, face recognition), etc.. Many of those are also suitable for short distance positioning and tracking (localization), and are already in use for locator services in many different fields of application. Global positioning technologies based on GSM, GPS, dGPS extend the range of options for long distance localization.

An identification and localization technology with a certain appeal for embedded Internet applications is radio frequency identification (RFID) which is based on radio or electromagnetic propagation, i.e. the ability to allow energy to penetrate certain physical objects and read a tag that is not necessarily visible. Objects can be identified remotely, either in the form of reading an identity code, or more simply just checking for the presence of a tag. An RFID system consists of a tag (or transponder), and a reader device. The transponder as a passive component responds by replying to an interrogation request received from an interrogator. The reader as an active component induces an interrogation request, and receives back some data from the transponder (such as an identity code or the value of a measurement) with virtually zero time delay. Different frequencies of the radio system of the reader result in different reading ranges (10cm to 1m) and properties of the system. Commonly available tags have an operating frequency in the range from 60 kHz to 5.8 GHz, 125 kHz and 13,56 MHz being the most prominent frequencies in use today. The reason why transponders have recently started to become major players in the field of electronic identification is their contact-less and powerless operation (no power supply needed in the tag), low cost packaging, “unlimited” lifetime, ISO standard compliance (14443 A/B and 15693-2), a wide choice of qualified packaging (Smart Cards, tags, inlets, smart labels, etc.), short range operation, proximity and vicinity communication with one and the same technology, cryptographic security (i.e. the protection against unauthorised product copies or data modification), and, last but not at least, low investment level for contact-less technology integration.

Coordination [OZKT 01] finally, is the concern of software frameworks providing concerted but autonomous components for object representations of real world persons, things

and places. Metadata models like the RDF (Resource Description Framework) [RDF 00] for the definition and description of abstract object classes and the operations required by a applications have been successfully applied in context-aware embedded Internet applications [FBN 01]. Generally, such frameworks provide an abstract specification (or a model) of the set of relevant objects and the semantics of the operations to be supported by the application. Concrete implementations by exploiting the mechanisms of inheritance and reuse realize the (i) creation and management of virtual representations of physical objects, (ii) mechanisms for sensing (including identification, localization and tracking) and manipulating such objects, and (iii) mechanisms for the coordinated invocation of object methods.

4. A Context-Aware Application Scenario

As an example, we demonstrate the co-influence of hardware and software engineering issues in a scenario of a “context-aware luggage” framework: An embedded PC has been integrated into an off-the-shelf suitcase (see Figure 3), executing a standard webserver together with a TCP/IP stack over an integrated IEEE802.11b WLAN adaptor. A miniaturized RFID reader is connected to the serial port of the server machine, an RFID antenna is integrated in the frame of the suitcase so as to enable the server to sense RFID tags contained in the suitcase. A vast of 125KHz magnetic coupled transponders are used to tag real world objects (like shirts, keys, PDAs or even printed paper) to be potentially carried (and sensed) by the suitcase. The suitcase itself is tagged and possibly sensed by readers integrated into home furniture, car or airplane trunks, conveyor belts etc. so as to allow for an identification and localization at any meaningful point in space of the application.

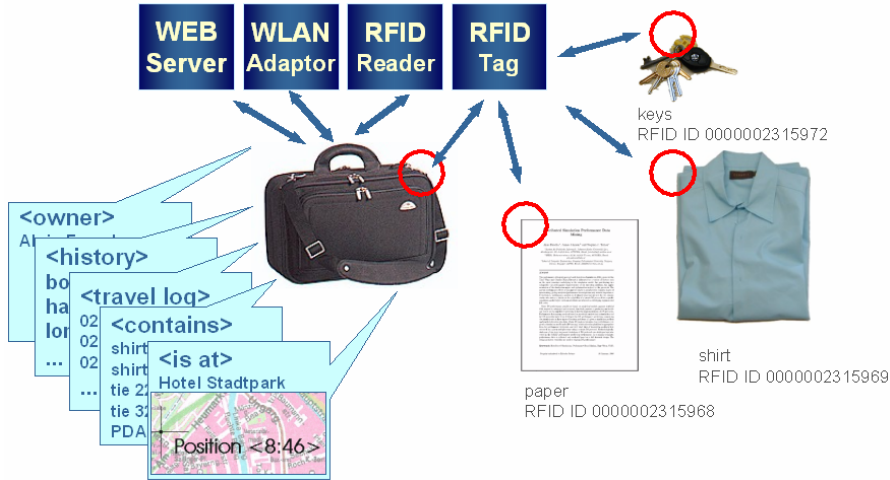


FIGURE. 3 “CONTEXT-AWARE LUGGAGE” AS AN APPLICATION INSTANCE OF THE CONTEXT FRAMEWORK

In our context framework, an application specific abstraction of the real world is generated from three generic classes for persons, things, and places. The reification of real world objects and their relation among each other is expressed in a framework RDF. The person object represents the concepts about a person that are necessary to link their physical properties and activities to the virtual world. The thing object encapsulates the basic abstraction for objects relevant to the application and has instances like shirt, bag, etc. The place object is used to represent the essential features of a physical location like an office room or a waiting lounge. Places, things and persons may be related in a manifold of ways. The RDF in Figure 4 sketches quite a few relations of our context framework: The *owner* relation expresses ownership of a real world object by another, the *contains* and *is_in* relations expresses geometrical containment of an object within another one, the *contained* and *was_in* relations trace the history of containment into RDF bags, the *containable* attribute defines whether an object may contain another one, the *controllable* attribute allows to prevent or enable the modification of an object RDF by the object itself, etc. The unique ID associated with every real world object is the ID encoded in its RFID tag. It is sensed by the RFID reader which triggers a script to update the involved object RDFs (Inserting e.g. the shirt into the suitcase would cause the RFID reader to identify the shirt tag and update (among others) both the shirts RDF relation *is_in*, as well as the suitcases RDF relation *contains* by cross-referring URIs. Figure 4 left presents a snapshot of an RDF of the suitcase after some insert operations.

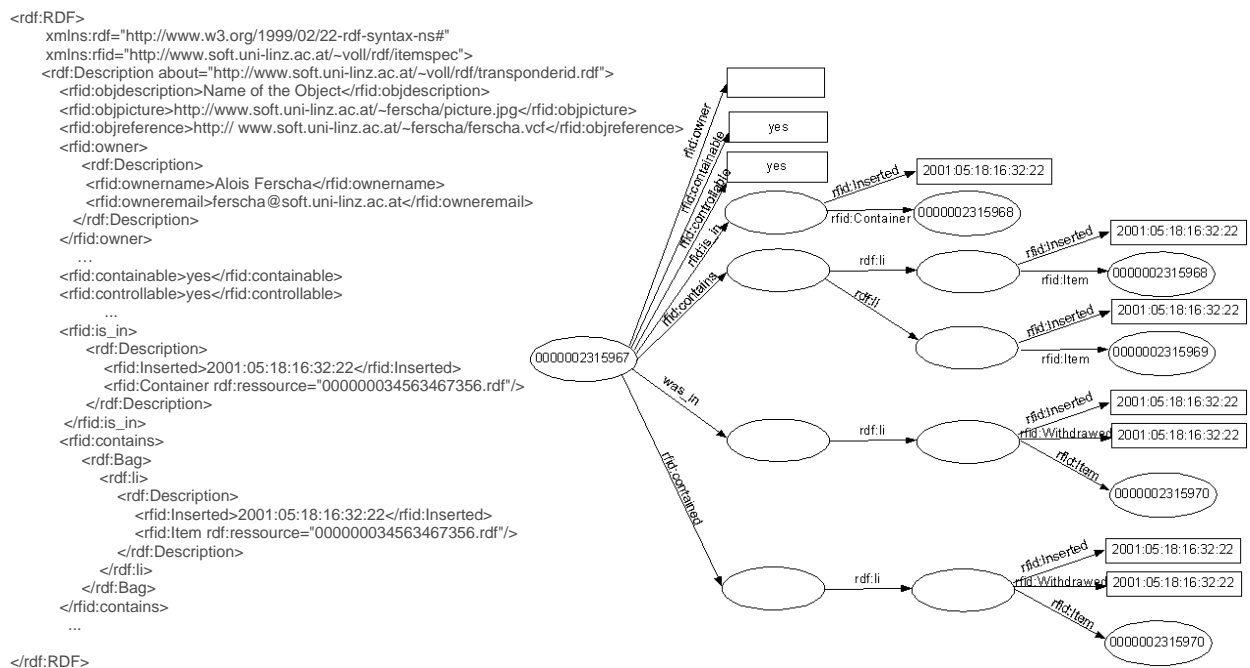


FIGURE. 4 RDF RELATING REAL WORLD OBJECTS WITH THEIR VIRTUAL REIFICATIONS

5. Conclusions

Technological trends in mobile and pervasive computing have created new requirements for the **automated configuration** and **operation** of Internet applications. Central to those is the notion of “**context**”, preliminarily defined [DeAb 99][Dey 01] as any information that can be used to characterize the state or situation of an entity – a person, a thing or a place – and the spectrum of its behaviours. Software architectures and frameworks for context-aware applications [UKC] thus must be concerned with (i) abstract representations of context, (ii) sensing, collecting, interpreting and transforming of context information and (iii) disseminating and making appropriate use of context information to impact the behaviour of the application. The methodological approach today is to employ standardized Web-metadata modelling (like SGML, XML, RDF) to solve (i) [CaDe 00], integrated electrical, chemical, magnetic, optical, acoustic etc. multi-sensor systems for (ii), and integrated multi-actuator systems involving data processors, controllers, motors, filters, etc. for (iii). Given today’s Internet as the network level communication infrastructure, ubiquitous access to this infrastructure demands technological solutions for the “spontaneous” discovery and configuration of devices and services, the selection of meaningful services offered by autonomous software components, the automatic adaptation to mobile and sporadic availability, the interoperability across manufacturers, platforms and services and the scalability with respect to the number of involved activities and entities. On top of **ubiquitous access**, **context-awareness** and issues of **intelligence** (learning, memorizing, planning, forgetting) and knowledge processing are essential for the provision next generation Internet applications. A very important aspect is the way how humans **interact** with those applications: requirements towards pro-active (rather than reactive) responsiveness, towards implicit (rather than explicit) input-output and towards continuously (in time and space) available, “naturally occurring” interfaces [CCB 00] will drive their development. The “linking” of real world contexts with their virtual counterparts poses three fundamental problems to be solved in a “co-investigation” of the spectrum of options in hardware for sensors and actuators, and software framework designs are related to (i) *identification* – the automated recognition of the identity of entities – (ii) *localization* and tracking of those entities as they change state in space and time, and (iii) *coordination* – i.e. to bring the autonomous activities of virtual entities to a concerted action that represents the application.

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