ACADEMIA ENGELBERG

2nd Dialogue on Science – 15 - 17 October 2003
in Engelberg, Switzerland

Pervasive Computing connected > aware > smart

Alois Ferscha, Prof. Dr.

Department of Computer Science,

Johannes Kepler University Linz, Austria

Kontakt:

Altenberger Straße 69, A-4040 Linz

email: ferscha@soft.uni-linz.ac.at

We are facing the dawn of a new era in the information age: in the foreseeable future, the world will be full of invisible and at the same time omnipresent computer systems which, thanks to their communicating sensors, will be capable of reading their surrounding environment and taking autonomous actions (= Pervasive Computing).

The first quantum in this era, the "connectedness of things" is already technologically well-advanced. Challenges that remain are the "awareness" of these computer systems - i.e. mutual awareness between humans and things or between connected things - and consequently their "smartness", the invisible, unobtrusive, intelligent action of connected things taking place in the background.

Radically pushing computer technology into the background, embedded and concealed in everyday objects, and cultivated to assume routine activities, is nourishing the hope that "human lifestyles" can be regained through Pervasive Computing - at least from a technological point of view.

“*The most profound technologies are those that disappear.*
They weave themselves into the fabric of everyday life
until they are indistinguishable from it“
Mark Weiser, Scientific American, 1991 [16].

The term “Pervasive Computing”, which has crystallized in recent years from the integration of traditional core disciplines of computer science, describes the next generation of innovative informations technology, which merge with everyday working environments, are invisibly integrated into everyday objects, and form living spaces which respond intelligently to the presence of people and their habits, intentions and emotions. The roots of this field are embedded systems, distributed and real-time systems, wireless communication, sensor/actuator systems, multimedia, information logistics and in particular mobile computing [11]. Pervasive Computing technologies will radically change traditional information technologies (such as desktop computing) by providing the tiniest, embedded, spontaneously connected and wirelessly communicating systems which are operated not through classical input/output technology (keyboard/screen), but on the input side via sensors and on the output side via actuators. Both the trends in research and also industrial and business-related innovation barometers point clearly in the direction of “ubiquitous ambient intelligence” as the next challenge of information and communications technologies [1].

Embedding and Networking

Hardly any area in information technology has led to more significant advances in innovation and produced such technological potential over the last few years than distributed, embedded, mobile, multimedia, interactive and generally accessible multi-user systems, and no other area today makes higher integration demands on the various core disciplines of computer science than this field of information technology. Whereas it has hitherto been well-defined individual processor systems (PCs, workstations) with which the user interacted via keyboard and monitor with relatively low levels of demand on the time-specific behaviour of the system, today it is increasingly embedded, wirelessly connected information-processing systems, i.e. hardware/software systems which are “embedded” in an information-processing environment on the input side along with or instead of classical input devices via sensors (mainly electronic, but also optical, acoustic, magnetic, chemical, biometric, physiognomic, etc.) and on the output side via actuators (microcontrollers, multimedia emitters, monitoring and control units, motors, etc.). They pick up signals from different types of media, process them – often subject to strict specifications of time – and influence or monitor their environment accordingly. Instead of executing the kind of computing function which a conventional “program” does, embedded systems increasingly feature monitoring, control or regulating functions. Processing does not primarily involve the transformation of a quantity of input data into output data, but converts a quantity of input events (whose time-specific occurrence is often not predictable) into output events.

Mobility and Wireless Communication

It is precisely in the light of new information technologies, such as wireless communication (based for example on ultrasound, infrared or radio relay technologies), new optical, acoustic, biometric and (traditional) electromagnetic sensors, innovative output technologies and extremely high packing densities of electronic circuits, that the potential of embedded information systems is being increasingly revalued almost on a daily basis both in scientific and in business terms. The spectrum of technological feasibility is further extended by specialization (ASICs, PLDs and FPLDs, Custom ICs, Gate Arrays, etc.) and miniaturization (submicron technologies) in the construction of the microprocessor, digital signal processing and a wide availability of mature memory-based technologies (SRAM, EPROM, Antifuse), by the emerging diversity of mobile terminal devices (PDAs, SmartPhones, Active Badges, JavaCards, Tablets, NetBooks, Wearable Computers etc.), by the huge distribution of new mobile communication technologies (mobile IP, GSM, GPRS, UMTS), by the increasing use of multisensor and haptic input/output devices (magnetic and optical tracking systems and augmented reality systems), by the availability of global positioning technologies (GSM, GPS, dGPS), and not least by the establishment of distributed software architectures and middleware solutions (EJB, CORBA, etc.), all of which give rise to a “pervasiveness” of information technologies in almost all living spaces and areas on a scale not hitherto observed.

Intelligent Information Technologies

This presence of information technology, which is not necessarily obvious, but is omnipresent, is the subject of a research challenge currently seen crystallizing in the literature under various titles such as “pervasive computing”, “ubiquitous computing”, “calm computing”, “invisible computing”, “hidden computing”, “ambient intelligence” etc. In this diversity of terms, “Pervasive Computing” is best able to convey the basic principle: smart information technology which is reduced to function and detached from devices and which is no longer recognizable as technology, but acts proactively and largely autonomously as supporting background assistance. Whereas “mobile computing” is still motivated by the support of geographically mobile users and mobile end devices, “pervasive computing” sees itself confronted with an omnipresence of highly heterogeneous communication or information media, from which “mobile services” are made available. The main features of this “pervasive computing” are the connectedness of components and services, the interaction of components (and users) with each other, and the control and coordination of these interactions – in technical hardware and software detail then accordingly also the identity and authentication of components, the offering and location of services, the coordination of local activities, fault tolerance, scalability, safety, self-configuring functionality, adaptivity, awareness of surroundings and context relatedness, autonomy, sovereignty, preparedness for interaction, trigger option, etc. These technologies make huge demands on the performance capability of software and their development methods: the new software generation must be built on component technology in order to ensure requirements regarding quality, availability, reliability, time-to-market, maintainability and portability with reasonable use of financial resources. The questions of self-organization, deduction and planning, (independent) adaptability, knowledge representation and knowledge management, heuristic problem-solving, fuzzy methods and algorithms, decisions taken amid uncertainty, and process development and optimization place a central role in terms of the design of smart information technology.

Computational Perception

An essential prerequisite for the design and realization of smart systems and environments is the ability to recognize, localize, perceive and predict the activities and behaviour of actors or objects. To visualize cognitive functions that have hitherto been the preserve of humans also in information-processing systems, to embed them in industrial or business processes, and to be able to integrate them into technical systems, it requires a formalization of the human perception process and the provision of a corresponding methodological and technological apparatus. Computer-based seeing [2] and comprehension of language are undoubtedly the most important examples of the IT implementation of artificial cognitive performance in technical systems, and research in these areas is also at its most advanced. Furthermore, multisensor systems of perception which, in addition to visual and auditory stimuli, are also geared to kinaesthetic, olfactory, and atmospheric perception are the subject of research on "computational perception". The nature and quality of how we interact with computer systems in the future depends essentially on how machines or programs perceive the world and how they proceed with this perception. The aim of so-called "context-based" applications is the inclusion of all information about the ambient environment that is capable of being picked up by multimodal sensors, and the use of this context information to regulate and monitor the behaviour of the system itself. Context-based applications require the integration of profound methods of computational perception (computer vision, acoustic and speech recognition, perception of place and time, and perception of odour, temperature, movement, acceleration etc.), and will supersede today's forms of embedded computer systems, human-machine interaction, and (traditional) autonomous systems in robotics.

Context Sensitivity

The ability of a system to recognize and determine objects and acting persons and their intentions is described as context sensitivity (or context awareness). The context of an application is defined in the literature as any information which can serve to characterize the situation of an entity [3]. An entity may be a person, a place or an object which is considered relevant for the interaction between the user and the application, including the user or application himself or itself. A fundamental design principle in the development of context-based applications is the determination, collection, aggregation and interpretation of sensor data, as well as the appropriate treatment and preparation of the information obtained from the data for the application concerned.

In addition to the purely information-related logistical problems (providing the "right data" at the "right time" on the "right scale" in the "right place"), new challenges are posed from the viewpoint of modelling and data management. Explained by the typical architecture of context-sensitive applications widely dislocated applications generally have to be locally detected at the level of the sensor hardware and condensed to interpretable data in terms of the application concerned. Technical difficulties in the detection of sensor data lie in the often substantial limitation of sensor resources (memory capacity, computing performance, communication medium and bandwidth, etc.), in the management of differing data rates, the differing level of data, the susceptibility to failure of sensor nodes (e.g. when they have their own energy supply), the mobility of sensors, the synchronization of sensor data flow from different sources and the integration of time-controlled and event-controlled sensor data. Both push and pull approaches may be considered for sensor data management. One modelling challenge lies in the interpretation of sensor data in terms of the semantics of the application, often referenced in the literature as "context modelling". Whereas early approaches modelled contexts using simple key values, more recent studies have been pursuing metadata approaches (e.g. ConteXtML, RDF [10]), object-oriented models (e.g. the person/place/thing [7]) through to logic-oriented approaches in which context is presented and processed as facts in rules-based systems. A difficulty here is the potentially large diversity of contexts to be modelled (geographical context for e.g. "location-based service", time context, physical context, social context, organizational context, user context, etc.) with very different requirements with respect to the data models concerned. Linked to the selection of context representation and of memory model is the question of context dissemination, for which not only the sensors but also the actuators (which exert a controlling influence on the whole system) offer peer-to-peer strategies based on their dislocation. In order to be able to implement proactive context-based system behaviour, i.e. to be able to realize applications which are adaptable to foreseeable future situations, a predictive component for anticipated context states presents itself for status-based context models. System control is based in this case not on the last identified context state (reactive), but on a future context state which is already predictable (proactive). Context-sensitive software frameworks realize the control of actuators in most cases via a rules-based system (ECA rule systems) or active databases.

Smart Things – Smart Spaces

The technological possibilities offered by end devices of the most diverse forms and functions for communication, interaction, and archiving and retrieval of knowledge represent a particular consolidation of “Pervasive Computing”. This proceeds along paths laid down by the categories “smart things” (portable, mobile end devices with special functions) and “smart spaces” (fixed installation which provides intelligent background assistance). Subjects of investigation here are smart phones and organizers, smart gadgets, universal information appliances, mobile internet appliances, embedded web servers and browser, smart displays, walls and rooms, smart home and home networking, right through to wearable computing, e-textiles and smart clothing [13]. Latest results from the area of materials research (light-emitting polymers, piezo-electric and pyroelectric materials) and high-grade miniaturization of radio modules (Bluetooth as pioneer) prompt a “spatially” even narrower network concept of the “personal area” (compared for example with the IEEE 802.15 standard): “near body networks” pose new challenges and potentials for implicit person-to-person systems of cooperation. In the technical software realization of such systems the primary focus is on increasingly conceptual questions of interaction [8], [14], and coordination.

Interfaces everywhere, natural interfaces

The systematic inclusion of human senses that lie outside the powers of audiovisual perception and thus replacement of the conventional means of interaction (keyboard, mouse, screen) pose the central challenge behind this consolidation of pervasive computing. Even speech processing and the recognition and processing of image data cover only a part of the possible spectrum of human-machine interaction in context-based applications. Additional factors to be considered include gestures/facial expressions, emotions, habits, forgetting and force feedback. User interfaces which are embedded in the infrastructure (interfaces everywhere), which are linked to susceptible objects, which integrate physical and virtual artefacts (tangible interfaces, graspable user interfaces) [6] and which reproduce digital information on tangible and manipulable objects of everyday life, etc. open up new possibilities of interaction with cooperative applications. Our preliminary shows that a separation of the system inputs and outputs from traditional I/O devices is not only possible, but is also often even more efficient as an implicit I/O realized via tangible interfaces than an explicit I/O.

People in the foreground – information technology in the background

The aim of pervasive computing lies in the conception, design and development of systems which provide enrichment for people not only in every situation of their daily lives through the possibilities offered by the digital information world that invisibly surrounds them and but also in scope for action which will be at their disposal. The challenge here lies in the accumulation of artefacts – e.g. objects of daily use – with added functionality which are easy to use and can be intuitively operated and which respond to people autonomously and intelligently depending on the situation. The creation of objects and environments which provide people with access to the digital resources around them is also attended by a number of challenges:

- ***Omnipresent access:*** ensuring access to relevant information content based on wireless communication technologies regardless of time and place.
- ***Context sensitivity:*** system behaviour that takes account of the present and where applicable also the anticipated future situation if an artefact or of the user and acts on it accordingly in a plan-based manner (intelligently).
- ***Security and privacy:*** in the future application forms of pervasive computing, systems will sensorily detect their surrounding environment with an increasing degree of autonomy (and without activation by the user). There is already a demand in information technology ethics for procedures and methods that place data access in the sovereignty of the data owner and make data secure to use.
- ***Natural interaction:*** miniaturization and invisible integration of technology for the design of artefacts that serve both as representation and as control and regulating mechanism for the digital information associated with them. The natural interaction with an artefact must at the same time enable the data which it represents to be manipulated [15].

[1] J. Bohn, V. Coroama, M. Langheinrich, F. Mattern, M. Rohs: Allgegenwart und Verschwinden des Computers - Leben in einer Welt smarter Alltagsdinge. In: Ralf Grötker (Ed.): *Privat! Kontrollierte Freiheit in einer vernetzten Welt*. Heise-Verlag, pp 195-245, 2003

[2] J. L. Crowley, J. Coutaz, F. Berard: Perceptual user interfaces: Things That See. *Communications of the ACM*, Vol. 43, Nr. 3, pp. 54-64, 2000.

[3] A. K. Dey: Understanding and Using Context. Personal and Ubiquitous Computing, *Special Issue on Situated Interaction and Ubiquitous Computing*, 5(1), 2001.

[4] A. Ferscha: Collaboration and Coordination in Pervasive Computing Environments. Proceedings of the 12th International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE 2003), IEEE Computer Society Press, 2003.

[5] L. Gong: Peer-to-Peer Networks in Action. *IEEE Internet Computing,* Vol. 6, No. 1, pp. 36-39, 2002.

[6] Gorbet, M.G., Orth, M., Ishii, M.: Triangles: Tangible Interface for Manipulation and Explo-

ration of Digital Information Topography. *CHI 1998*, pp. 49-56, 1998.

[7] T. Kindberg, J. Barton, J. Morgan, G. Becker, I. Bedner, D. Caswell, P. Debaty, G. Gopal, M. Frid, V. Krishnan, H. Morris, J. Schettino, B. Serra, M. Spasojevic: People, Places, Things: Web Presence for the Real World. *WWW'2000*, 2000. http://cooltown.hp.com/dev/wpapers/WebPres/WebPresence.asp

[8] R. Milner: Elements of Interaction: Turing Award Lecture, *CACM*. Vol. 36, No. 1, pp.78-89, 1993.

[9] A. Omicini, F. Zambonelli, M. Klusch, R. Tolksdorf (Eds.): Coordination of Internet Agents. Models, Technologies, and Applications. Springer-Verlag, Berlin, 2001.

[10] O. Lassila, R. R. Swick: Resource Description Framework (RDF): Model and Syntax Specification. Recommendation, World Wide Web Consortium, 1999. http://www.w3c.org/TR/REC-rdf-syntax/.

[11] M. Satyanarayanan: Pervasive Computing: Vision and Challenges. *IEEE Personal Communications*, pp. 10 – 17, 2001.

[12] A. K. Dey. *Providing Architectural Support for Building Context-Aware Applications*. PhD thesis, Georgia Institute of Technology, 2000.

[13] A. Schmidt, K. Laerhoven: How to Build Smart Appliances?, *IEEE Personal Communications*, Vol. 8, No. 4, pp. 66-71, 2001.

[14] P. Wegner: Why Interaction is more powerful than algorithms. *CACM*, Vol. 40, No. 5, pp. 80-91, 1997.

[15] P. Wellner, W. Mackay, R. Gold: Computer Augmented Environments: Back to the Real World. *CACM*, Vol. 36, No. 7, 1993.

[16] M. Weiser: The Computer of the Twenty-First Century. *Scientific American*, pp. 94-100, 1991.