Towards a Coordination Framework for Pervasive Environments

Manfred Bortenschlager
Salzburg Research
Jakob Haringer Straße 5/III, A-5020 Salzburg, Austria
mborten@salzburgresearch.at

Gabriele Kotsis
Johannes Kepler University Linz
Altenbergerstraße 69, A-4040 Linz, Austria
gk@tk.uni-linz.ac.at

Marco Mamei
University of Modena and Reggio Emilia
Via Allegri 13, Reggio Emilia, Italy
marco.mamei@unimore.it

Abstract

The ongoing miniaturization of Information and Communication Technologies leads to novel ways of improving daily activities of users "existing" in and interacting with pervasive environments. Such environments are characterised on the one hand by a great multitude and diversity of occurring entities ranging from hardware and communication technologies to software and system architecture, and on the other hand by different and more challenging requirements than conventional, stationary systems. We argue that the demand for a thoroughly engineered integration of coordination mechanisms beneficially affects the behaviour of systems intended for pervasive environments. We take this assumption as the motivation for this UBICC Special Issue on *Coordination in Pervasive Environments*. In this preamble, we introduce an approach towards a reference framework proposing a configuration of essential elements necessary for coordination in pervasive environments. The articles presented in this Special Issue are categorised according to the elements of this framework.

Keywords: Pervasive Environments, Coordination Theory, Coordination Models, Context-dependence

1 PERVASIVE ENVIRONMENTS AND COORDINATION

Recent developments and technological advances in various fields influencing pervasive computing–like hardware, communication and networking, distributed systems, mobile middleware, embedded systems and sensors, information processing and -storage, materials, and human-computer-interaction–are leading to an omnipresence of information and services. The Internet and (mobile) telecommunication networks are converging to one vast and ubiquitously available information space accessible through such *pervasive environments* in an anytime, anywhere, anyhow manner. We are moving towards the "Internet of Things" [4] and we are shifting from the *one person is associated with one computer paradigm* to a one-to-numerous relationship.

The goal of pervasive computing is to create environments where networked devices provide unobtrusive connectivity, information, and services all the time, thus improving human experience and quality of life without explicit awareness of technology [11]. In such pervasive environments, the world around us is interconnected as a network of a multitude of intelligent devices that cooperatively and autonomously collect, process and transport information. Systems for such environments need to adapt to the associated context and activity [3].

One of the main conceptual difficulty to create pervasive computing applications is that we have direct control only on the individual entity's local activities, while the application task is often expressed at the global scale [17]. Bridging the gap between local and global activities is not easy, but it is possible: distributed algorithms have been designed for many tasks in both sensors network and MANETs (mobile ad-hoc networks), from tracking to information routing. However, most of these algorithms are closely tied to the application task and domain, making them difficult to generalize to solve also other tasks.

Accordingly, it would be fundamental to develop novel models and mechanisms to let individual components *coordinate* and *orchestrate* their activities in a flexible and general purpose way [17].

On the other hand, coordination–as a concept–is abstract and inter- and multidisciplinary. Nevertheless, people have a good intuitive notion about what coordination actually means [10]. It penetrates our daily lives and is omnipresent; and mostly becomes apparent when it is lacking or badly "implemented". The same or similar strategies or mechanisms may be applied to very diverse disciplines [10] such as computer science, social sciences, anthropology, biology, finance, sociology, psychology etc. Coordination may appear in many different facets such as direct or indirect coordination, collective or individual, intentional or unintentional, competitive or benevolent, centralized or decentralized, a priori defined or ad hoc determined, or under authoritarian control or autonomously conducted. However, the principal task of coordination is always to achieve a common, superior goal as effectively, fast, and economically as possible. In [12], coordination is said to be the "integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal". The interdisciplinary study of coordination (i.e. coordination theory) [10] tries to tackle this issue and to formalize this abstract concept of coordination. Malone and Crowston used a more formal approach to describe coordination theory as an interdisciplinary subject which comprises four entities [10]: goals, activities, actors, and interdependencies. This theory defines coordination as the "act of managing interdependencies between activities". Consequently, the challenge shall be to investigate and to elaborate accordant mechanisms to resolve the interdependencies, which is the key to improve coordination.

Coordination is significantly responsible for the effectiveness, performance and quality of complex systems. An explicit handling and a careful integration of accurate coordination mechanisms enables an enhancement of the overall system behavior and contributes to improvements in terms of flexibility, adaptability, maintenance, unobtrusiveness, and service quality.

Systems for pervasive environments are–as argued above–highly complex. Some of the major challenges system engineers have to face as argued in [6] are: *Discovery* (mutual discovery between devices and/or services), *Adaptation* (steady changes of a behaviour depending on context), *Integration* (combination of the physical world with pervasive technologies), *Programming Framework* (change in software paradigms and in development), *Robustness* (transparency regarding faults and failures), and *Security* (authentication, trust, and privacy issues). Also, in [6] the *Volatility Principle* is formulated as follows:

> *You should design ubicomp systems on the assumption that the set of participating users, hardware, and software is highly dynamic and unpredictable. Clear invariants that govern the entire systems execution should exist.*

These outlined considerations and the Volatility Principle show the particular constraints, dynamics and dependencies apparent in pervasive environments. We argue that an explicit study of coordination and related mechanisms will lead to beneficial results and will, eventually, help to improve information systems for such environments. This is what we want to address and explore in this Special Issue edition.

2 TOWARDS A COORDINATION REFERENCE FRAMEWORK

As mentioned in Section 1, Malone and Crowston defined coordination as the "act of managing interdependencies between activities" [10], where coordination management comprises four entities: *goals*, *actors*, *activities*, and *interdependencies*. We would like to slightly amend this concept by adding also *constraints* as we recognise that interdependencies are always constrained by specific aspects. Applications in pervasive environments are highly constrained due to the inherent dynamics and the resulting necessity of adaptations [11]. Hence, systems for applications in pervasive environments need to be able to process the dependence on different types of context–such as acting entity, activity, location, and time.

Coordination, furthermore, is intuitively dependent on communication: without communication–either direct or indirect–coordination is not possible. This has also been argued in [7] and has, for instance, been empirically examined in aircraft crew communication and coordination [5]. Pervasive environments are dynamic and deployed communication systems are prone to frequent disconnections. Hence, appropriate communication infrastructures are essential for pervasive systems.

According to [10], the key to improve coordination is an effective management, i.e., resolution, of the interdependencies. In order to accomplish this, coordination mechanisms are established and applied. These rules need to take into account the five entities of coordination stated above. Systems that shall support coordination need to encapsulate such coordination logics which embody the architectural glue between the communication infrastructure and the applications or the user, respectively.

We argue that appropriate applications for pervasive environments need to take into account a coordination model that comprises four essential elements.

1. **Communication.** The communication element

needs to be flexible and encapsulates techniques to address the specific characteristics of pervasive environments. Appropriate communication is the basis for all other elements.

2. **Coordination.** The coordination element comprises the logic and algorithms to resolve interdependencies.

3. **Application.** The application element subsumes system *actors*–such as software agents or sensors–conducting *activities* which are related to each other through *interdependencies* and inherent *constraints*. Moreover, this element provides the interface to the users who pursue to achieve a certain *goal*.

4. **Model.** The model element needs to provide appropriate entities and concepts to represent the relevant system data. Particularly in pervasive environments, this model must be able to handle, represent and process context information in a flexible way that is easily-understandable and manageable by the other components.

This reference framework for coordination in pervasive environments is also depicted in Figure 2 where the user is depicted as interacting with the framework through applications.

3 COORDINATION IN PERVASIVE ENVIRONMENTS APPLIED

Many ongoing initiatives and research projects are related to coordination in pervasive environments [13, 14, 15, 16, e.g.]. One particularly interesting application area of coordination is group- or teamwork in pervasive environments. In many application scenarios, well-coordinated activities within such groups are a key factor for effectiveness. Collaboration of mobile users in pervasive environments is also referred to as acting in "nomadic workspaces". Nomadic workspaces are transparent virtual networks that shall permit users and programs to be as effective as possible in an environment of steadily uncertain connectivity, without significant changes of the manner in which they are used to operate. This shall be accomplished through transparent and context-dependent adaptations, which is the ability to automatically adjust the behaviour of the system according to the changing environments in such a way that the user is not significantly obstructed in his activities [8]. Appropriate infrastructures and architectures [1] are necessary that can handle these characteristics of pervasive environments in a transparent way.

A very typical such scenario is emergency management (EM). An emergency is a broad term which includes rapid natural and man-made hazards containing avalanches and railway accidents, slower creeping crisis such as drought, famine or disease and disaster events that have a different time lapse like floods or forest fires. Emergencies have severe consequences. Emergency management subsumes the activities necessary to prevent and relief such situations. Emergency management processes comprise the following phases [9]: *Risk assessment and planning* (strategic planning and establishment of recovery plans), *Mitigation* (a priori prevention and reduction of damages), *Preparedness* (preparing emergency operators by training), *Response* (the critical activities immediately following an incident), and *Recovery* ((i) short-term recovery: recovery of basic infrastructure, and (ii) long-term recovery: restoring all services to normal state).

Intra- and inter-organisational management–i.e., coordination–of teams is vital to resolve emergency situations as fast and safe as possible. Team members and (sometimes complex) configurations of teams are working collectively on one or more interdependent tasks. This represents a mobile, collaborative work environment and a representative field of application for coordination in pervasive environments.

The EU research project WORKPAD[1] aims at developing an innovative software infrastructure for supporting collaborative work of human operators in emergency scenarios. In such scenarios, different teams and team members shall be coordinated by a context-aware and P2P-based infrastructure that adaptively monitors and manages the work-flows always relative to the current situation on site. The teams are provided with context-dependent information coming from a back-end grid infrastructure that semantically integrates various data sources. The WORKPAD system architecture addresses all four elements identified in Section 2 which seem to be necessary for building well-coordinated pervasive information systems. Thus, WORKPAD could be seen as a first instantiation of the coordination reference framework we introduced in this paper.

[1] See `http://www.workpad-project.eu`.
[2] See `http://mowi.salzburgresearch.at/wetice`

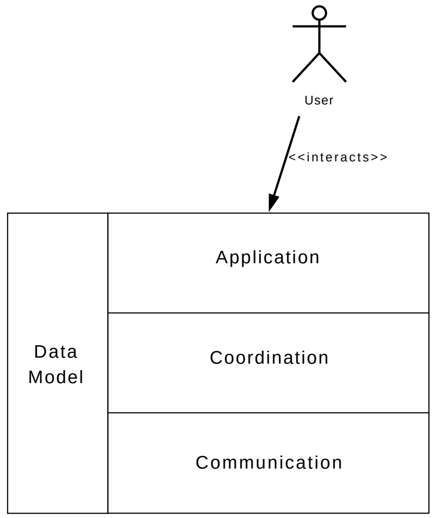

Figure 1: Coordination Reference Framework

4 DETAILS ABOUT THIS SPECIAL ISSUE

This UBICC Special Issue is based on the International Workshop on *Interdisciplinary Aspects of Coordination Applied to Pervasive Environments: Models and Applications (CoMA)*[2] which was held at the *16th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE)* from June 18 till June 20, 2007 in Paris, France. Selected papers were resubmitted in an extended version and peer-reviewed.

UBICC Special Issue Guest Editors

Manfred Bortenschlager
Affiliation: Salzburg Research / Mobile and Web-based Information Systems Group
Address: Jakob Haringerstr. 5/III, A-5020 Salzburg, AUSTRIA
Email: `mborten@salzburgresearch.at`
Web: `http://www.salzburgresearch.at`
Credentials: Manfred Bortenschlager is researcher at the Mobile and Web-based Information Systems Group of Salzburg Research. His research interests are focused on coordination models and mechanisms for pervasive information systems applied to telecooperative applications. He concentrates on coordination theory, P2P networks, agent technology, and space-based computing. He is involved in several national and international (applied) research projects related to above mentioned topics. Currently, Manfred conducts his PhD studies at the Telecooperation Department at the Johannes Kepler University Linz on coordination architectures for pervasive environments.

Gabriele Kotsis
Affiliation: Johannes Kepler University Linz / Department of Telecooperation
Address: Altenbergerstr. 69, A-4040 Linz, AUSTRIA
Email: `Gabriele.Kotsis@jku.ac.at`
Web: `http://www.tk.uni-linz.ac.at`
Credentials: Gabriele Kotsis received her masters degree, her PhD and the venia docendi in computer science from the University of Vienna. Since December 2002 she is holding a full professor position at the Telecooperation Department at the Johannes Kepler University Linz. Her research interests include performance management of computer systems and networks, workgroup computing, mobile and internet computing, telemedia and telecooperation. Prof. Kotsis is author of numerous publications in international conferences and journals and is co-editor of several books. Since April 2003 she is president of the Austrian Computer Society.

Marco Mamei
Affiliation: University of Modena and Reggio Emilia / Agents and Pervasive Computing Group
Address: Via Allegri 13, Reggio Emilia, ITALY
Email: `marco.mamei@unimore.it`
Web: `http://www.dismi.unimo.it/Members/mmamei`
Credentials: Marco Mamei is an assistant professor at the Università of Modena and Reggio Emilia, where he received the PhD in computer science. His current research interests include distributed and pervasive com-

puting, swarm intelligence, and multiagent systems. He is a member of the IEEE and AIIA.

List of Accepted Papers

The following papers are presented in this Special Issue edition. The indications in the square bracket denote how we would classify this paper with regard to the coordination reference framework we presented in Section 2 (see also Figure 2), or to which element this paper contributes to, respectively.

1. **Registering and Discovering Semantic Web Services in a Federated Directory System** by *Michael Schumacher, Alexandre de Oliveira e Sousa, Ion Constantinescu, Tim van Pelt, and Boi Faltings*
   In this work, the design and implementation of the distributed directory for semantic (Web) services (WSDir) is described. The typical use of this directory system is in a context where ubiquitous business services should be flexibly coordinated and provided to the mobile user in dynamically changing environments. WSDir has been applied and evaluated as a backbone in the trials of an eHealth emergency application where agents are in charge of Web service coordination. **[Model, Coordination]**

2. **Integration of XVSM Spaces with the Web to Meet the Challenging Interaction Demands in Pervasive Scenarios** by *eva Kühn, Johannes Riemer, Richard Mordinyi, and Lukas Lechner*
   This paper proposes to overcome shortcomings of present web infrastructures and architectures–such as inflexibility and the inability of server-side push information delivery–by integrating the XVSM space-based computing (SBC) technology. By this, the inherent decoupling mechanisms of SBC can be exploited where the HTTP protocol is used to transport space operations providing improved behavior of Web-based information delivery to mobile users **[Communication]**.

3. **A Bayesian Approach for Disconnection Management in Mobile Ad-hoc Networks** by *Massimiliano de Leoni, Shah Rukh Humayoun, Massimo Mecella, and Ruggero Russo*
   As the communication medium is an essential prerequisite for coordination, this paper deals with an algorithm to avoid imminent disconnections between entities connected through a MANET configuration. A predictive technique to estimate possible disconnections in such mobile scenarios was proposed and empirically evaluated. **[Communication]**

4. **Coordinating Knowledge in Pervasive Environments** by *Lyndon Nixon, Robert Tolksdorf, Alan Wood, and Ronaldo Menezes*
   The authors introduce the Semantic Web Spaces prototype, which represents a new coordination model and API based on Linda and tuple spaces. They extend the classic tuple space approach by arguing for the coordination of *knowledge*. Novel concepts are required to solve problems of knowledge coordination. This work contributes a new API including the use of *scopes* and *fading* to provide a measure for the relative strength of knowledge claims in the system (i.e., how much clients can "believe"). **[Coordination]**

5. **Enabling Collaborative eHealth Through Triplespace Computing** by *Lyndon Nixon, Elena Simperl, Dario Cerizza, Emanuele Della Valle, and Reto Krummenacher*
   Triplespace computing is a new semantic tuple space paradigm which shall revolutionize machine-based communication just as the Web's persistent publication paradigm and simple interaction pattern revolutionized human communication. To make Triplespace computing a reality, the authors align communication models (i.e., Linda and tuple spaces) to the knowledge-centered approach (i.e., RDF and reasoning). A decentralized architecture supports emergent coordination of intelligent agents or services. The approach is applied to the eHealth domain, where knowledge is represented as RDF graphs. **[Application, Model]**

6. **Mediating Agents' Activities in Situated Multiagent Systems** by *Danny Weyns and Tom Holvoet*
   This paper focuses on the importance of engineering the environment in which agents are embedded. The authors argue that for many particular applications in pervasive environments it is more beneficial to encapsulate the coordination logic within the environment rather than in the coordinables (i.e., agents in this case). Three types of laws integrated in the environment are described: perception, action, and communication laws. **[Coordination]**

7. **Context-aware Coordination in the Sensor's Continuum** by *Nicola Bicocchi, Gabriella Castelli, Alberto Rosi, and Franco Zambonelli*
   This paper introduced an infrastructural approach

to exploit service invocation based on a “sensor’s continuum” with a particular focus on modeling context data (the W4 model). With this, the authors pursue the *Ubiquitously Browsing the World* vision [2] which shall be enabled by the provision of context-aware coordination of ubiquitous services. **[Model]**

8. **Smart Environments as Agents Workspaces** by *Andrea Omicini, Alessandro Ricci, and Giuseppe Vizzari*
   The paper describes an approach based on agents and artifacts used to model and design pervasive environments. The authors refer to “Smart Environments” that are specific work areas supporting the interaction among actors, and between actors and resources in order to facilitate work activities. This work tries to stress the relevance of social aspects that are sometimes overlooked in pervasive research. **[Model, Coordination]**

9. **SCOMET: A Middleware for Collaborative Working Environments in MANETs** by *Marcel Arrufat, Gerard Paris, Pedro Garcia Lopez, and Antonio F. Gomez Skarmeta*
   SCOMET represents a peer-to-peer based middleware for collaborative applications building up on MANET environments. This middleware can transparently be deployed over several network configurations and offers services to higher layers such as publish/subscribe or group management, which can be exploited for CSCW applications, for instance. **[Communication]**

List of Reviewers

The following people constituted the program committee and provided the very valuable review comments to paper authors:

Giacomo Cabri (University of Modena and Reggio Emilia, Italy)

Paolo Ciancarini (University of Bologna, Italy)

Schahram Dustdar (Vienna University of Technology, Austria)

Pedro García López (Universitat Rovira i Virgili, Spain)

Christine Julien (University of Texas, USA)

Gabriele Kotsis (Johannes Kepler University Linz, Austria)

Massimiliano de Leoni (University of Rome La Sapienza, Italy)

Marco Mamei (Università di Modena e Reggio Emilia, Italy)

Massimo Mecella (University of Rome La Sapienza, Italy)

Francesco de Mola (University of Modena and Reggio Emilia, Italy)

John Nealon (Oxford Brookes University, UK)

Wee Keong Ng (Nanyang Technological University, Singapore)

Andrea Omicini (University of Bologna, Italy)

Robert Tolksdorf (Freie Universitaet Berlin, Germany)

Simon Vogl (Research Studios Austria, Austria)

Eiko Yoneki (University of Cambridge, UK)

Franco Zambonelli (Università di Modena e Reggio Emilia, Italy)

5 SUMMARY AND FUTURE CHALLENGES

The focus of the UBICC Special Issue edition was to explore several aspects of *Coordination in Pervasive Environments*. During the course of this work we tried to develop a reference framework for systems that deal with coordination in pervasive environments. The main four building blocks are *(i)* Communication, *(ii)* Coordination, *(iii)* Application, and *(iv)* Data Model. With regard to pursuing this field of research fruitfully, we identified–based on the paper contributions and the preceding CoMA workshop–the following potentially relevant future research challenges:

- Better understanding and tackling the specific requirements of pervasive environments
- Supporting and exploiting the shift from data-based coordination to knowledge-based coordination
- Developing expressive concepts for modeling context to allow for context-dependent coordination
- Reasoning about where to encapsulate the coordination logic (e.g., coordinables versus environment)
- Integrating and exploiting semantics in coordination systems explicitly (more emphasis ontology engineering for coordination)
- Adopting more user-centered approaches

Some presented works, in fact, are complementary and collaborations and future joint (research) initiatives, reasoning about the discussed issues and problems, might result in generating new ideas and further contributions to improve coordination in pervasive environments.

Acknowledgements. This work is supported by the European Commission through the FP6-2005-IST-5-034749 project WORKPAD[3].

References

[1] M. Bortenschlager, G. Castelli, A. Rosi, and F. Zambonelli. A context-sensitive infrastructure for coordinating agents in ubiquitous environments. *Special Issue on Engineering Environments for Multiagent Systems of International Journal on Multiagent and Grid Systems*. To appear.

[2] G. Castelli, A. Rosi, M. Mamei, and F. Zambonelli. Browsing the World: Bridging Pervasive Computing and the Web. In *International Workshop on Ubiquitous Information Systems*, Muenster, Germany, 2006.

[3] S. K. Das and M. Conti. The Pervasive and Mobile Computing Journal, 2008. `http://www.elsevier.com/locate/pmc`.

[4] N. Gershenfeld, R. Krikorian, and D. Cohen. The Internet of Things. *Scientific American*, 291(4):76–81, October 2004.

[5] B. Kanki and H. F. S. Lozito and. Communication indices of crew coordination. *Aviation, Space, and Environmental Medicin*, 60:56–60, 1989.

[6] T. Kindberg and A. Fox. System software for ubiquitous computing. *IEEE Pervasive Computing*, 1(1):70–81, 2002.

[7] M. Klein. Coordination science: Challenges and directions. In *Coordination Technology for Collaborative Applications*, pages 161–176, 1996.

[8] L. Kleinrock. Nomadic Computing - An Opportunity. *SIGCOMM Comput. Commun. Rev.*, 25(1):36–40, 1995.

[9] S. Leitinger. Comparision of GIS-based Public Safety Systems for Emergency Management. In *24th Urban Data Management Symposium, UDMS*, 2004.

[10] T. W. Malone and K. Crowston. The Interdisciplinary Study of Coordination. *ACM Comput. Surv.*, 26(1):87–119, 1994.

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

[12] B. Singh. Invited Talk on Coordination Systems, 1989. Organizational Computing Conference, November 13-14, Austin, Texas.

[13] The CASCADAS Project, 2008. `http://www.cascadas-project.org`.

[14] The CASCOM Project, 2008. `http://www.ist-cascom.org`.

[15] The POPEYE Project, 2008. `http://www.ist-popeye.org`.

[16] The TripCom Project, 2008. `http://www.tripcom.org`.

[17] F. Zambonelli and V. Parunak. Towards a paradigm change in computer science and software engineering: a synthesis. *The Knowledge Engineering Review*, 18(4), 2004.

[3] See http://www.workpad-project.eu