Mobile Information Systems - Research Challenges on the Conceptual and Logical Level

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Abstract. This paper discusses new challenges and possible approaches for developing and evolving *mobile information* systems, with focus on *model-based approaches* on the conceptual and logical level. We have experienced these new challenges through several research and industrial projects on mobile solutions, usability and model-based approaches over the last years. We summarize the main challenges on how model-based approaches can support the development of mobile information systems that are to be used together with other types of systems, primarily in a professional setting and indicate upcoming research issues in this very dynamic area. We argue that this research area is also timely, because the underlying technological infrastructure are just becoming sufficiently mature to make feasible research on conceptual and logical, and not only on technical issues.

1 Introduction

Today, the PC is only one of many ways to access information resources and services. On one hand, traditional computing technology is becoming more mobile and ubiquitous and, on the other hand, traditional mass-media are becoming richer as in interactive TV. Whereas information services related to interactive TV is projected to become prominent in a few years, mobility is perhaps the most important *current* market and technological trend within information and communication technology (ICT), although the development of UMTS infrastructure goes more slowly than originally envisaged. With the advent of new mobile infrastructures providing higher bandwidth and constant connection to the network from virtually everywhere, the way people use information resources is predicted to be radically transformed.

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According to Siau [29], the essence of mCommerce is to reach customers, suppliers and employees regardless of where they are located and to deliver the right information to the right person(s) at the right time. To achieve this, a new breed of mobile information systems [17] must be developed. This paper will highlight some of the research challenges in this field that can be related to the conceptual and logical levels of information systems development.

2 Novel Aspects of Mobile Information Systems

Mobile computing systems entail end-user terminals easily movable in space, operable independently of particular locations and typically with wireless access to information resources and services. We will in this section first described the different dimension of mobility, before highlighting the specific aspects of mobile information systems to support the different mobility dimensions.

2.1 Dimensions of Mobility

Mobility can be *spatial*, *temporal* or *contextual* [13]. The spatial and contextual dimensions are the ones most commonly considered and will be focussed on here. (Spatial) mobility is primarily about *people* moving in space, having wireless access to information and services. Secondarily, mobility relates to all sort of things in the environment (parcels, cars etc.) with the possibility to interact with other devices and people.

People in general are getting increasingly mobile, both in connection to their professional and private tasks. The user of mobile information systems is characterised by frequent changes in context, given by:

- The *spatio-temporal context* describes aspects related to time and space. It contains attributes like time, location, direction, speed, track, and place.
- The *environment context* captures the entities that surround the user, e.g. things, services, temperature, light, humidity, and noise
- The *personal context* describes the user state. It consists of the physiological context and the mental contexts. The physiological context may contain information like pulse, blood pressure, and weight. The mental context may describe things like mood, expertise, anger, and stress.
- The *task context*. This context describes what the user is doing. The task context may be described with explicit goals or the tasks and task breakdown structures.
- The *social context* describes the social aspects of the user context. It may, for instance, contain information about friends, neighbours, co-workers and relatives. The role that the user plays is an important aspect of the social context. A role may describe the user's status in this role and the tasks that the user may perform in this role. The term *social mobility* [22] refers to the ways in which individuals can move across different social contexts and social roles, and still be supported by technology and services.

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- The *information context* – The part of the global and personal information space that is available at the time.

Luff and Heath [21] identify three types of mobility: Micro-mobility refers to how small artefacts can be mobilised and manipulated by hand. Local mobility involves real-time interaction between people and technology at the same location. Finally, remote mobility supports both synchronous and asynchronous collaboration among individuals who move around in distant physical locations. Several kinds of personal mobility have recently been identified in the literature. Kristiansen and Ljungberg [16] distinguish between *travelling*, *visiting* and *wandering*. *Travelling* is movement between different locations in a vehicle. *Visiting* is a prolonged period spent in one location before moving back to the original location or on to another one. *Wandering* is moving about — usually on foot — in the local area. To this, Esbjörnsson [6] adds *mobile work* proper, which is kinds of work where an essential aspect of the work process itself is mobility. Since mobile information systems is also relevant in non-working situations, we may extend this category to *mobility proper*, i.e., activities were mobility is an essential aspect of the activity itself, such as going on a hike or scenic tour or visiting an outdoor museum.

People also 'move' between different ways of organising their time. Hall [9] distinguishes between *monochronocity* and *polychronicity*. In the former, people seek to structure their time sequentially doing only one thing at a time, if possible according to a plan. In the latter, people accept — and maybe prefer — doing several things simultaneously, placing less importance on planned order. The new technologies seem to be increasing monochronicity in some situations and polychronicity in others. On the one hand, increased monochronicity appears in the interfaces of many contemporary enterprise systems, which often require business process steps to be carried out in strict sequence with little flexibility for individual variations of temporal order and few possibilities for carrying out several processes in parallel. Because mobile devices have small screen sizes and memories, monochronicity is strengthened, because it is less convenient to operate on several windows running different applications in parallel. On the other hand, the need for polychronicity is increased in many mobile settings. A larger proportion of work is today done by symbolic analyst [31], whose main work pattern is (often many parallel) knowledge intensive projects, both within and across organisational borders. Symbolic analysts such as consultants, reporters, and researchers will typically have many tasks going on concurrently, and will be interested in a lot of different information there and then, much of which can not be anticipated fully beforehand.

Thus mobile technologies inherently tend towards providing monochronic services, while at the same time they tend to place their users in contexts with polychronic demands.

2.2 Differences between Mobile and Traditional Information Systems

From an application point of view, mobile information systems differ from more traditional information systems [10,18,19,29]. We have grouped the differences within four areas:

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User-Orientation and Personalization: Mobile information systems often address a wider user-group, which means that user-interfaces should feature prominently and early in the design process and that user-interfaces often need to be extremely simple. The resulting user-interfaces often cannot presume previous acquaintance with computers at all, and input and output facilities may be severely restricted (no keyboard, small screen-size etc.) or based on new modalities (speech-recognition and –synthesis etc.). This means that *individualisation* of mobile information systems becomes increasingly important, both at the individual level where user-interface details such as commands and screen layout is tailored to personal preferences and hardware, and the work level where functions are tailored to fit the user's preferred work processes. Individualisation means both information systems that automatically *adapt* themselves to the preferences of the user, and systems that can be explicitly *tailored* by users through a specific user-interface.

Technological Aspects Including Convergence and Multi-channel Support: Mobile devices have severely limited processing, memory and communication capacities compared to other kinds of computers. Performance considerations therefore become increasingly important during design. Analytically-based predictive methods are necessary in order to assess a large number of design alternatives during design of mobile information systems.

Because the new mobile devices integrate functions that were previously offered by physically separate tools (*convergence technology*), they probably signal the arrival of a plethora of new types of applications. Mobile and other new technologies provide many different ways to offer the same or similar services to customers. For example, broadcast news in the future will be available through plain-old television, enhanced television, Internet TV, 3G mobile phone and numerous other information appliances (the door of the glove compartment in your car, your living-room wall etc.). At the same time as new channels to information is provided, existing channels such as traditional PCs over a LAN will still be used in combination with the mobile information systems, thus one need to support a multi-channel approach, where the same functionality and information resources is available across a large range of processing devices.

Methodology for Development to Ensure Organizational Return: Mobile information systems are radical and therefore reward increased focus on idea generation early during design. This also means that there are not always existing services or situations in which to anchor problem analysis efforts. Another effect of the radically new approaches enabled by the technological solutions is that the introduction of mobile information systems often spawns several other initiatives for changed information systems.

The mobile clients still develop rapidly, which means that idea generation should not be limited by currently available technologies. It also means that systems must be designed for change. There is little accumulated experience on how to design software for the new technologies. As a consequence, lightweight design techniques and early prototyping is the natural choice for practical development projects at the moment. In addition, research is needed on accumulating experience from early development projects and packaging this knowledge into comprehensive, integrated and model-

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based development methodologies. There is also a need for user-interface guidelines and standards for mobile solutions.

Security and Other Quality Aspects: Mobile information systems pose new challenges to information systems security, for instance by rendering traditional firewall thinking unusable. Exacerbating a problem already introduced by the emergence of wireless LANs, mobile communications can in principle and easily be wiretapped by anyone. In addition, the mobile devices themselves are easily stolen, lost etc., sometimes without the loss being identified immediately.

Whereas these challenges to traditional software design are not new when seen in isolation, the emerging generation of new information and communication technologies increases their importance because (1) each challenge is *amplified by* the new technologies and (2) the new technologies *combine the challenges* in ways that are not yet understood.

3 Background on Our Structuring of the Research Area

We have for many years been engaged in the areas of information systems analysis and design methods, their application, evaluation and engineering in general, and has followed the development from mainframe to client-server, ERP, and web-applications. It is on this basis that we address research challenges within mobile information systems.

In our community, a distinction has traditionally been drawn between issues on the conceptual, logical, and physical level.

Conceptual Level: On the conceptual level the IS-problems are looked upon regardless of what part of the current or future IS in the broad sense that is (or is to be) supported or automated by information technology. Thus a conceptual data model for instance map the relationship between concepts as they are perceived to be by humans in the real world (normally within organisation). This level is by some also called the essential level.

Logical Level: On the logical level, it is taken into account that one is dealing with information technology, but without being overly constrained with detailed aspects of the concrete implementation technology. Data models for instance on this level would take into account e.g. the structuring and relationship of data in several relational tables.

Physical Level: Finally, at the physical level, all implementation details are regarded, including for a database e.g. things like physical indexes, tablespaces etc.

We have structured the main research issues and areas in connection to mobile information systems in the same way. For this paper, we focus specifically on aspects on the conceptual and logical level. Our focus is on the support of model-based approaches. The common approach is to not follow modeling-based approaches. Although most software engineers are aware of model-based methodologies and

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many companies claim to base their development processes on them, model-based methodologies are seldom followed in great detail in practise. In fact, in most real software engineering projects, if at all used, semi-formal modelling techniques mainly play a role during the initial development stages. Also most current multi-channel approaches do not focus on the use of rigorous model-based techniques. The Oxygen Project [4], developed at MIT, focuses on the concept of "pervasive computing" from a technical point of view introducing a novel network technology in which mobile devices can recognise each other, and dynamically configure their interconnection in order to form "collaborative regions". Odyssey [25] defines a platform to manage adaptive applications for different mobile devices using mobile agents. The Portolano Project [7] investigates the emerging field of invisible computation. It envisions a user interface that combines the data gathered from location sensors, identification tags, and on-line databases in order to determine user intents rather than relying on user commands. In contrast to these projects that focus on automating the support by partly guessing what the worker is interested in, the Ninja Project [8] aims at developing a software infrastructure for the next generation of Internet applications which is more open for adaptation in use, although not taking full benefit from a model based approach.

4 Research Challenges for Mobile Information Systems

We below highlight main research areas on mobile information systems at the conceptual and logical levels, structure according to the four areas described in section 2 as applicable.

4.1 Conceptual Level

User-Orientation and Personalization: Traditionally, support for workers in actually performing its processes has not been provided. Functions of the mobile information system should be tailored to fit the user’s preferred work processes, which typically involve other persons as well. To support group and teamwork, awareness of the status of knowledge resources is increasingly important in a mobile setting. Given that knowledge resources both include individuals and technology that can be mobile, one should look into interactive systems to improve group performance. Peter Wegner's interaction framework [32] was triggered by the realization that machines involving users in their problem solving, can solve a larger class of problems than algorithmic systems computing in isolation. The main characteristic of an *interaction machine* is that it can pose questions to human actors (users) during its computation. The problem solving process is no longer just a user providing input to the machine which then processes the request and provides an answer (output), it is a multi-step conversation between the user and the machine, each being able to take the initiative. A major research question in this area is how to specify and utilize interaction machines on a multi-channel platform. To enable interaction machines, process support technology is a natural choice. Process support technology is typically based on process models, which need to be available in some

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form for people to change them to support their emerging goals. Thus interactive models should be supported [11,12]. The outset for this thinking is that models can be useful tools in a usage situation, even if the models are changing and are partly incomplete and inconsistent. The user is included as an interpreter and changer of the models, based on underlying interaction machines. Emergent workflow systems [11] represent a different approach to static and adaptive workflow systems with respect to their use of models. They target very different kinds of processes: Unique, knowledge-intensive processes where the structure emerges. It can be argued that this is not specific for mobile information systems utilizing GPRS and UMTS networks, but this area will be even more pronounced in such systems since future information appliances (and a multitude of services across the network) will be always available (and thus more likely to be used in an emergent or ad-hoc fashion). Awareness mechanisms are linked to our emergent workflow systems, and should be enriched with supporting giving notice of the additional changes in context.

Approaches such as ServiceFlow [34] points to the need for such flexible solutions, although not taking a model-based approach. In the ongoing EXTERNAL-project [20], we are involved in developing such a model-based approach that enables the change and adaptation of instance-models by the users themselves. The operating environment is currently available through a traditional web-interface using a PC, but we have started to experiment with PDAs as clients.

Methodology for Development to Ensure Organizational Return: Siau [29] highlights as an important application-oriented research area the development of mCommerce business models. Within eCommerce, many new business models have appeared. The mobile environment in which mCommerce applications reside will require further adaptations of these models. In order for mCommerce to succeed, it is vital to ensure that all the related applications and services can be accessed with ease and little cost. Thus, in addition to externalize the business models in an computing independent way, it is important to integrate these models with the internal enterprise models and enterprise architecture, to be able to pinpoint the links to e.g. internal systems for the efficient billing of services provided

Requirements Engineering for business solutions have so far primarily dealt with the elicitation, specification, validation, management and change to information systems to be accessed through PCs and workstations [17]. As multi-channel solutions including also mobile front-ends are applied in more and more situations, additional challenges will meet those that specify the requirements to these applications. The traditional view of requirements engineering [15], where a requirement specification is developed early in a project, and then undergoes only minor changes under development and further system evolution, only partly applies. Rather it will be important to deal with unstable, unclear, and inconsistent user requirements that evolve and emerge through actual use.

Security and Other Quality Aspects: To enhance social mobility, organisations and industries need to develop "social ontologies", which define the significance of social roles, associated behaviour and context [22]. These ontologies would need to be available as explicit models to be useful for the development and ensuring necessary security of the mobile information systems.

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4.2 Logical Level

User-Orientation and Personalization: The new separation between content and medium found in mobile information systems serves as a major challenge. Design of new systems need to take a minimum set of assumptions about physical devices to provide a maximum level of personalisation. *Personalisation* of mobile information systems becomes increasingly important, where user-interface details such as commands and screen layout is tailored to personal preferences and hardware using information about the current context and context trace [27] of the user. Personalisation here means both information systems that automatically *adapt* themselves to the preferences of the user, and systems that can be explicitly *tailored* by users through a specific user-interface. Generally the context should be explicitly modeled to be able to keep an overview of, analyze, and simulate the multitude of possibilities open for adapting to the context, and the use of context traces. For the more general use of mobile applications, it is also important to be able to adapt these systems to the user at hand, thus making a case for simple user-models to guide the adaptation.

Recently, work within user interface modeling has focused increasingly on mobile user interfaces [5,23,26]. This is often done to facilitate some level of common models for the mobile user interfaces and more traditional ones. A central element in this is the development of model-based approached that are powerful enough to be used as a basis for the development of user-interfaces on the multitude of platforms needed, but still general enough to represent the commonalties in a single place. One approach is to define user-interface patterns with general usability principles as powerful building blocks. Several other researchers have examined how patterns can be used in usability-oriented work [1,30,33] and have described how patterns can fit into all the different phases of a usability-engineering life-cycle.

A main challenge for model-based approaches for developing multi-interfaces is to have a set of concepts that are, on the one hand, abstract and general enough to express specifications across a number of quite different platforms and, on the other hand, powerful and expressive enough to support mapping to different platforms. Thus, there is a need to combine generalization and specialization. A model-based technique that is abstract enough to be able to describe user interfaces with significant differences may run the risk of being banal. By this we mean that the model is not able to describe a sufficient number of aspects of the user interfaces in a way that renders it possible to transform the models to concrete user interfaces without adding so much additional information to the mapping process for each platform, that the interfaces might as well have been developed from scratch on each platform (Nilsson, 2002). A model based approach for such system might also prove efficient when needing to run the system on new mobile devices.

Technological Aspects Including Convergence and Multi-channel Support: There are currently (and will be for the foreseeable future) a multitude of competing technologies for providing the underlying infrastructure for distributed and mobile applications. A central element when addressing this is the development of model based specification techniques that are powerful enough to be used as a basis for the development of systems on a large number of technical platforms, but still general enough to represent the commonalties at one place only. The current major initiative

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within OMG, on Model-driven architectures (MDA), where both platform independent and platform specific modeling notations including refinement techniques are specified, highlights the current industry-focus on such an approach. In connection to this, it is interesting to note how meta-modeling techniques and domain-specific modeling (DSM) have found a special application for the design of mobile phone software [14]. Mobile information systems can be argued as a particular good area for using domain-specific modeling:

- The software (on the client side) is partly embedded, needing higher reliability than traditional software, which can be supported by restricting choices through adding modeling rules and code-generation.
- You need many, very similar variants of the same application.
- There are a number of standards to adhere to, and the technology and standards change rapidly. One wants to define e.g. GSM only once, and use this definition in a range of product. When necessary one would like to plug in e.g. UMTS or US analog system in its place

Several approaches to customize the presentation of the contents of distributed information systems wrt. the terminal device are reported. A literal translation from the web to wireless is inadequate. Merely squeezing data into small screens detracts from the user experience on mobile devices [2]. Most of the proposals concentrate on the generation of HTML pages for the web, and WML pages for WAP. Nowadays, the research interest is devoted to the automatic generation of multi-channel access systems. The most prominent approaches for the development of multi-channel interfaces can be summarized as follows:

- Terminal-independent form management such as XForms
- Vocal services such as using VoiceXML
- Transcoding: Several automatic transcoding tools have been developed to convert HTML documents into new languages, such as WML or HDML.
- Common languages such as XHTML Basic
- Comprehensive multi-channel language for a virtual universal device that includes all the characteristics of the devices through which the developed service should be accessed. CDI-ML and MaxML represent this approach.
- Finally WebML is a conceptual model for specifying data-intensive Web sites. WebML includes a structural model, to describe data, and a hypertext model, to describe how data are organized in pages and the navigation among pages. Generative techniques allow sites to be produced automatically even in a multi-channel context; also personalisation facilities are provided.

Methodology for Development to Ensure Organizational Return: Mobile information systems are often radical and therefore reward increased focus on idea generation early during development phases. This also means that there are not always existing services or situations in which to anchor problem analysis efforts, e.g., using As-is analysis as a starting point for To-be design [28]. Technology in the field still develops rapidly, which means that idea generation should not be limited by currently available technologies. It also means that systems must be designed for change. Applications of the new technology call for highly distributed systems that comprise new user-interface systems on the client side, new and existing back-end

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systems, as well as new bridging systems (which port information between other systems.) The new technologies therefore highlight the need for principled, long-term IS-architecture management and for integrating architecture management with software development methodologies. Often there is a need to interface to existing enterprise systems and architectures to enable the new workflow. Another aspect is how to integrate the user-interface models discussed above with other parts of the requirements and design model, for instance the entity model, process model and goal model. On both the process and the user-interface side, the challenges can be attacked by extending existing approaches to modeling, although research is needed to investigate both which techniques that should be extended and how they could be best adapted to the new problem areas. Looking at the architecture for general existing mobile information systems framework and solutions [3], we notice that the generic architecture is geared towards the modeling of data, business processes and tasks, events and behavior, rules, user interfaces and general context information.

Security and Other Quality Aspects: An important aspect is the dependability of the systems made. Laprie defines dependability as the “ability to deliver service that can justifiably be trusted” and identifies six dependability attributes: availability, reliability, safety, confidentiality, integrity and maintainability. Model-based development will in general be able to support dependability analyses, i.e., use of methods, techniques and tools for improving and estimating dependability, e.g., risk analyses, probabilistic safety assessment, testing, formal walkthrough, simulation, animation, exhaustive exploration and formal verification. Many of the dependability areas will be even more complex in mobile information systems than in traditional business systems. As an example, consider new issues arising in connection to security and privacy. The same device will often be used as a personal tool across the user's commitment to many different organizations and projects, and one must assure that data does not “leak” across different domains. Another area of concern is the users (lack of) control over the context traces they leave behind when they use location-based or other context-based general services.

5 Conclusion and Future Work

We have in this overview paper highlighted research areas for mobile information systems on the conceptual and logical level. We have primarily focused at the use of modelling-oriented tasks and approaches for business, process, requirements and design models. Although our focus is on user-oriented and traditionally 'early' phases of system development, the need for rapid and continuos development of new releases of a number of different variants brings forward a higher degree of reuse and integration of models of different nature. A major research question in connection to these areas is to what extent existing modelling-techniques based on e.g. UML can be applied, when these techniques should be extended, and when they need to be replaced all together due to the changes of the possibilities and limitations of the underlying infrastructure.

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References

1. Borchers, J. *A pattern approach to interactive design*. New York: John Wiley & sons, Inc. 2001.
2. Billsus, D, Brunk, C. A., Evans, C. Gladish, B., and Pazzani, M. Adaptive interfaces for ubiquitous web access. In Communications of the ACM Volume 45, No. 5, May pp. 34-38, 2002.
3. Celesta Universal mBusiness Platform (http://www.celesta.com/pdf/products/mBusiness_Platform.pdf), June 6, 2001.
4. Dertouzos et al, The future of Computing, Sc. Am. 1999.
5. Eisenstein, J. , Vanderdonckt, J., and Puerta, A. *Applying Model-Based Techniques to the Development of UIs for Mobile Computers*. In "Proceedings of ACM Conference on Intelligent User Interfaces IUI'2001"
6. Esbjörnsson, M. "Work in Motion: Interpretation of Defects along the Roads", Proc. IRIS24, Bjørnestad, S., Moe, R., Mørch, A., Opdahl, A. (Eds.), Univ of Bergen, Norway, 2001.
7. Esler et al. Data-centric Networking for Invisible Computing: The Portolano Project, 5th ACM/IEEE Conf. on Mob. Comp. and Netw. 1999
8. Fox et al, Adapting to Network and Client Variation Using Active Proxies: Lessons and Perspectives, IEEE Pers. Comm., 1998
9. Hall, E.T. Beyond Culture. Anchor Books, Doubleday, 1976
10. Hirsch, R., Coratella, A., Felder, M., and Rodriguez, E. A Framework for Analyzing Mobile Transaction Models. Journal of Database Management: 12(3) July-September, 2001.
11. Jørgensen, H.D., and Carlsen, S. (1999) Emergent Workflow: Integrated Planning and Performance of Process Instances, Proceedings Workflow Management '99, Münster, Germany.
12. Jørgensen, H.D. (2001) "Interaction as a Framework for Flexible Workflow Modelling", Proceedings of GROUP 2001, Boulder, Colorado, October 2001.
13. Kakihara, M., and Sørensen, C., "Mobility Reconsidered: Topological Aspects of Interaction", Proc. IRIS24, Bjørnestad, S., Moe, R., Mørch, A., Opdahl, A. (Eds.), Univ of Bergen, Norway, 2001.
14. Kelly, S., and Tolvanen- J-P. Visual Domain-specific modelling: Benefits and Experiences of Using Metacase Tools, Metacase Consulting, 2001.
15. Kotonya, G.. and Sommerville, I. Requirements Engineering: Processes and Techniques, Wiley, 1998.
16. Kristiansen, S., and Ljungberg, F., "Mobility — From stationary to mobile work", chapter 6 in Planet Internet, Braa, K., Sørensen, C. & Dahlbom, B. (Eds.), Studentlitteratur, Lund, 2000.
17. Krogstie, J. Requirement Engineering for Mobile Information Systems. Proceedings of REFSQ'2001 Interlaken Switzerland, 2001.
18. Krogstie, J., Brandtzæg, P.B. , Heim, J.. and Opdahl, A.L. Usable mCommerce Systems: The Need for Modeling-Based Approaches. To be published in Lim, Ee-P.and Siau, K. Advances in Mobile Commerce Technologies, IDEA Group Publishing, 2002.
19. Kvalsøren, G.M.; Langeland, P.F.; Moe, R.E.; Opdahl, A L.; Solberg, J.O.; Thornquist, B., and Wikenes, M. Early Design of Enhanced ETV Services. I: Bjørnestad, Solveig; Moe, Richard Elling; Mørch, Anders I. og Opdahl, Andreas Lothe, red. Proceedings of IRIS24: The 24th Information Systems Research Seminar in Scandinavia,Bergen, Norway: Institutt for informasjonsvitenskap, UiB; s. 465-478 Ulvik, 11. - 14. aug, 2001.

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Published version can be found at http://link.springer.com/chapter/10.1007/978-3-540-45275-1_11

20. Lillehagen, F. , Dehli, E. , Fjeld, L., Krogstie, J., and Jørgensen, H.D. Active Knowledge Models as a Basis for an Infrastructure for Virtual Enterprise PRO'VE 2002 - 3rd IFIP Working Conference on infrastructures for virtual enterprises. Sesimbra, Portugal, May 2002.
21. Luff, P., and Heath, C. Mobility in collaboration. In: *Proceedings of the CSCW'98*, Seattle, USA, 305-314, 1998.
22. Lyytinen and Yoo. The Next Wave of Nomadic Computing: A Research Agenda for Information Systems Research, Accepted for publication in Information systems research, 2002.
23. Muller, A., Forbig, P., and Cap, C. *Model Based User Interface Design Using Markup Concepts*. In "Proceedings of The Eighth Workshop on the Design, Specification and Verification of Interactive Systems, 2001.
24. Nilsson, E.G. Combining compound conceptual user interface components with modelling patterns – A promising direction for model-based cross-platform user interface development. In 9th International Workshop on the Design, Specification and Verification of Interactive Systems, Rostock, Germany, June 12-14, 2002.
25. Noble et al. Agile Application-Aware Adaptation for Mobility, 16th SOSP, 1997.
26. Pribeanu, C., Limbourg, Q., and Vanderdonckt, J. Task Modelling for Context-Sensitive User Interfaces. In "Proceedings of The Eighth Workshop on the Design, Specification and Verification of Interactive Systems, 2001.
27. Rahlff R., Rolfsen, R.K., and Herstad, J.*"Using Personal Traces in Context Space: Towards Context Trace Technology"***,** Springer's Personal and Ubiquitous Computing, Special Issue on Situated Interaction and Context-Aware Computing, Vol. 5, No. 1, 2001.
28. Rolland, C.,and Prakash, C., "Bridging the Gap Between Organisational Needs and ERP Functionality", RE Journal 5(3):180–193, Springer, 2000.
29. Siau, K., Lim , E.-P., and Shen, Z. Mobile Commerce: Promises, Challenges, and Research Agenda Journal of Database Management: 12(3) July-September, 2001.
30. Sutcliffe, A., and Dimitrova, M. *Patterns, claims and multimedia.* Paper presented at the INTERACT'99 7th International Conference on Human-Computer Interaction, Edinburgh, UK, 1999.
31. Thompson and Warhurst. Workplaces of the Future, Macmillan Business, 1998.
32. Wegner, P. Why interaction is more powerful than algorithms, Communications of the ACM, vol. 40, no. 5, 1997.
33. Welie, M. v., and Trætteberg, H. *Interaction Patterns in User Interfaces.* 7th. Pattern Languages of Programs Conference, Allerton Park Monticello, Illinois, USA, 2000.
34. Wetzel, I., and Klischewski, R. Serviceflow beyond Workflow? Concepts and Architectures for Supporting Interorganizational Service Processes. In Pidduck, A. B., Mylopoulos, J. Woo, C. C., and Ozsu, M. T. (Eds.) Proceedings from CAiSE'14, Toronto, Canada, 2002.

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