Abstract

This thesis explores the domain of ubiquitous computing and relates situations of mobile work to Virtual Organizations (VOs). Motivated by the work performed by the MOWAHS project, this thesis aims to contribute in understanding virtual organizations, and in continuously assessing and improving the work processes within these.

Emerging technologies enable improved sensing of users, actions, wishes and requirements which can be utilized for facilitating situated activities in dynamic organizations. Taking an organizational approach to the subject we aim to describe new ways of coordinating actors automatically in these environments based on context information from the surroundings.

Through analysis of simple mobile work scenarios, we can extract knowledge of how different situations of mobile work demand coordination. This is used as method for identifying the importance of work process information in monitoring coordination. We provide an architecture proposition for a coordination module and suggestions to how context information of the work processes could be acquired and represented as knowledge to the organization.

Preface

This report is the result of work performed on the master thesis by Kristoffer Jacobsen at the Institute for Computer and Information Science (IDI), at the Norwegian University of Science and Technology (NTNU) during the Spring 2005. The project description was given by the Mobile Work Across Heterogeneous Systems (MOWAHS) project.

I would like to take this opportunity to thank my supervisor, PhD Fellow Carl-Fredrik Sørensen, for providing valuable and inspiring guidance and feedback through all phases of this research project. In addition, I would like to thank Morten Aabakken and Aker Verdal for help on providing one of the scenarios for our work.

Trondheim, July 2005

Kristoffer Jacobsen

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Part I

Introduction

Chapter 1

Introduction

This chapter gives an introduction to the thesis, and describes the background, motivation and problem definition for the research, along with a reading guide.

1.1 Background

The project description for this thesis was developed in cooperation with the research project MOWAHS[1] (MObile Work Across Heterogeneous Systems). The MOWAHS project is carried out jointly by the software engineering and database technology groups at the Department for Computer and Information Science (IDI), Norwegian University of Science and Technology (NTNU). The project is supported by the Norwegian Research Council.

The MOWAHS goals are threefold (as listed on the MOWAHS website):

G1) Helping to understand and to continuously assess and improve work processes in virtual organizations.

G2) Providing a flexible, common work environment to execute and share real work processes and their artifacts, applicable on a variety of electronic devices (from big servers to small PDAs).

G3) Disseminating the results to colleagues, students, companies, and the community at large.

One of the research challenges in MOWAHS is to provide an efficient and user-friendly environment for helping people in virtual organizations to perform and coordinate their work at their current location, time and device configurations.

The focus for this thesis will be to assist the MOWAHS project in achieving primarily the first goal, G1, providing a deeper understanding of what a virtual organization is and how it is organized, and partly G2 by studying enabling technologies.

[1] `http://www.mowahs.com`

1.2 Motivation

New ways of organizing businesses are continuously evolving with Information and Communication Technology (ICT) as an enabling factor along with increasing pace and globalization of the market. Individuals and businesses now collaborate from geographically dispersed locations in a much larger degree than before. The technology is enabling individuals to carry out their work anywhere, anytime, using ad hoc networking and wireless communication. This is referred to as **nomadic computing** [35]. As this concept of work matures in organizations, new challenges and issues emerge related to the computer interfaces and information systems the users interact with. The enormous growth in the number and type of devices connected to the Internet requires more flexible frameworks for working across heterogeneous systems.

Emerging technologies are enabling new ways of interacting with our surroundings, and may foster new ways of creating smart/intelligent environments that are able to autonomously adapt to multiple users simultaneously based on user preferences, and information and service needs (both stated and unstated). Such environments may enable cooperation and coordination between actors in dynamic environments in new and partly unpredictable ways. Situated activities can be better supported by increasing the ability of the organization to sense users, actions, wishes and requirements.

This affects the work processes in dynamic organizations, as objects and software are becoming actors and part of the organization. The intelligent objects can contribute with valuable context information to the organization, and possibly take actions on our behalf. The interaction and team-work in organizations consisting of both humans and computers, demand an innovative way of coordinating the activities. Support for both explicit and implicit coordination is desirable to improve the work processes in these environments, making the activities more efficient, increasing safety and possibly taking a step closer to the vision of **ubiquitous computing** [45].

1.3 Problem Definition

This project is a continuation of research on Virtual Organizations (VOs) performed during the fall 2004 [27]. The goal is to present a more extensive study of the concept of VOs and the challenges of coordinating actors in ubiquitous environments. The study will discuss scenarios in more depth (than the former project) and try to answer questions and key topics related to the research project MOWAHS. The following research questions have been identified as the foundation for this research:

RQ1) How can our knowledge of VOs be utilized in ubiquitous environments?

RQ2) How can we coordinate actors/roles in these environments?

RQ3) How can we represent core competencies as context?

RQ4) How can we represent organizational and process state as context?

1.4 Reader's Guide

This section is provided for the reader's convenience and briefly describes what the report contains and how it should be read. Table 1.1 outlines the main chapters in this report and indicates if a chapter is dependent on another. Reading the table, one can see that e.g. Chapter 7 is dependent on the information found in Chapter 1, Chapter 2 and Chapter 4.

Table 1.1: Overview of the report

Chapter	Chapter overview	Chapter dependency
1	Introduction	–
2	Research Method	–
3	Virtual Organizations	Chapter 1
4	Context	Chapter 1 and 3
5	Workflow	Chapter 1 and 3
6	Activity theory and Situated Actions	Chapter 1, 4 and 5
7	Problem Elaboration	Chapter 1, 2 and 4
8	Scenarios	Chapter 3, 4 and 7
9	Analysis	Chapter 7 and 8
10	Ontologies	Chapter 4 and 7
11	Coordination	All previous chapters
12	Architecture	All previous chapters
13	Discussion	All previous chapters
14	Conclusion	All previous chapters

Part I Introduction

Chapter 1: Introduction
This chapter contains background information about the project such as motivation, project context, problem definition and this reader's guide.

Chapter 2: Research Method
This chapter describes the work process and the methodologies used in the project. It motivates the choice of research methods, and relates them to software engineering.

Part II Central Concepts

Chapter 3: Virtual Organizations
This chapter introduces the concept of Virtual Organizations and relates it to mobile work.

Chapter 4: Context
This chapter introduces the concepts of context and context-awareness and discuss how one can acquire knowledge from the environment.

Chapter 5: Workflow
This chapter introduces the concept of workflow and presents the characteristics of workflow computer systems.

Chapter 6: Activity Theory and Situated Actions
This chapter introduces the concepts of activity theory and situated actions and relate them to context and workflow.

Part III Own Contribution

Chapter 7: Problem Elaboration
This chapter elaborates on the problem definition and introduces the contribution of this thesis.

Chapter 8: Scenarios
This chapter describes scenarios of mobile work taken from real-life work processes and facilitated with empirical studies.

Chapter 9: Analysis
This chapter presents a discussion of specific situations from the scenarios extracting knowledge on the need for coordination in virtual organizations.

Chapter 10: Ontologies
This chapter introduces ontologies and description logics, and discuss how they can be used for representing knowledge in ubiquitous computing.

Chapter 11: Coordination
This chapter discuss coordination of mobile work processes in ubiquitous computing environments and presents use cases and challenges related to it.

Chapter 12: Architecture
This chapter relates the work to the complementary studies within the MOWAHS project and present requirements for a coordination module of mobile work.

Part IV Discussion and Conclusion

Chapter 13: Discussion
This chapter evaluates the research method, discuss answers to the research questions and presents suggestions for future work.

Chapter 14: Conclusion
This chapter concludes the work and presents the key results of the research.

Part V Appendix

Appendix A: Glossary
This appendix presents a glossary of abbreviations and central terms used in the thesis.

Appendix B: OWL Code
This appendix presents short examples of OWL code illustrating the use of ontologies for representing and reasoning on context information.

Chapter 2

Research Method

This chapter provides an introduction to software engineering research, and discusses the research methods used in this thesis.

2.1 Introduction

Research in software engineering can be based on several different methods, usually answering empirical questions through controlled experiments. Different questions call for different research methods, because the nature of the research questions often constraint the methods that can be used to answer them. According to [48], there are four general categories of research methods:

Scientific method: Scientists develop a theory to explain a phenomenon; they propose a hypothesis and then test alternative variations of the hypothesis. As they do so, they collect data to verify or refute the claims of the hypothesis.

Engineering method: Engineers develop and test a solution to a hypothesis. Based upon the results of the test, they improve the solution until it requires no further improvement.

Empirical method: A statistical method is proposed as a means to validate a given hypothesis. Unlike the scientific method, there may not be a formal model or theory describing the hypothesis. Data is collected to verify the hypothesis.

Analytical method: A formal theory is developed, and results derived from that theory can be compared with empirical observations.

This thesis takes an analytical and engineering approach to answer the research questions. This is partly combined with field study of a mobile work domain thus also applying an empirical approach. The work process is described in the following with a literature study and scenario analysis as the main contributions.

2.2 Literature Study

Throughout the research on virtual organizations and central concepts related to mobile work processes, a literature study has been performed. It is an important process of gaining a better understanding of the problem domain. This study is a continuation of the state-of-the-art contribution in the pre-project [27] of this research project.

The background and resources for this part of the report are results of an extensive literature study of articles, journals, books, web pages, and forum discussions related to the concept of mobile work. In addition to using well known sites for accessing journals, magazines and other articles, a large number of publications have been made available through a shared bibliography in the MOWAHS project. The approach to this study has been to find the most cited authors and the most referred publications. In this way, we have been able to get an insight in which contributors that are most acknowledged and accepted among other researchers. We have been able to present a selection of contributions that reflect the research topics in a reasonably good way, after following innumerable links between the authors.

We have tried to balance the work of these acknowledged authors with a number of more specific research contributions to make the review of the domain as complete and consistent as possible. This approach to the literature study was chosen after conferring the experiences with software engineering research methods described by Glass et al. [21].

2.3 Scenario Analysis

Scenario analysis as a research method in software engineering, is mainly related to requirements engineering, as described in [43]. However, for the purpose of visualizing and extracting valuable knowledge of mobile work processes, scenarios are used as the foundation for this approach to VOs. This method of modeling a domain is a sort of use case modeling. In software engineering, scenarios are defined in the following way:

> "A scenario is a sequence of steps describing an interaction between a user and a system." [19]

The scenarios in this report focus on describing the different actors in the organization, their roles and responsibilities, and the rules of which the organizational entities act according to. The scenarios also aim to describe context dependencies in the work environments to identify which context information that is important to acquire and share within the organization. When describing the scenarios, we used qualitative methods to provide correct information and to secure consistency of our interpretation of the domain. These studies were carried out in good software engineering practice, as described in [41].

Part II

Central Concepts

Chapter 3

Virtual Organizations

This chapter introduces the concept of Virtual Organization (VO) and our knowledge of the domain.

3.1 Introduction

The term Virtual Organization was first introduced by Mowshowitz in [31]. Since then, there has been a lot of research on this type of networked organizations and how they will revolutionize the way we work in the 21st Century. There are numerous definitions of a VO because many authors and research groups use their own definition for their work. There exist various synonyms to the term Virtual Organization: Virtual Corporation (VC), Virtual Enterprise (VE) and Virtual Company (VCo) are all related to the same concept of cooperation between organizations or individuals. Davidow and Malone, presented in [15] one of the first extensive approaches to the subject. The focus for their conception of a *Virtual Corporation* relates to the concept of a *Virtual Product*. The ideal virtual product according to them, was a product or service that "is produced instantaneously and customized in response to customer demand."

The most widely cited definition of the term Virtual Corporation within the academic literature was provided by Byrne [11]:

> "A virtual corporation is a temporary network of independent companies - suppliers, customers, and even rivals - linked by information technology to share skills, costs, and access to one another's markets. This corporate model is fluid and flexible - a group of collaborators that quickly unite to exploit a specific opportunity. Once the opportunity is met, the venture will, more often than not, disband. In the concept's purest form, each company that links up with others to create a virtual corporation contributes only what it regards as its core competencies. Technology

plays a central role in the development of the virtual corporation. Teams of people in different companies work together, concurrently rather than sequentially, via computer networks in real time.” [11]

The definition mentions different attributes of the VO and these make the foundation to start talking about the formal characteristics of a VO.

3.2 Characteristics

The characteristics of a Virtual Organization as depicted in the literature were reviewed by Bultje and van Wijk in [8] and further discussed by Jacobsen in [27]. They are divided into two groups[1]: Key Characteristics (KC) and Other Characteristics (OC).

Table 3.1: Characteristics of Virtual Organizations

ID	Characteristic
KC1	Based on core competencies
KC2	Network of independent organizations
KC3	One Identity
KC4	Based on Information Technology
KC5	No hierarchy
KC6	Distinction between strategic and operational level
OC1	Small sized partners
OC2	Vague/fluid boundaries
OC3	Semi-stable relations
OC4	Dependent on opportunism
OC5	Shared risks
OC6	Based on trust
OC7	Shared ownership
OC8	Shared leadership
OC9	Shared loyalty
OC10	Dynamic network
OC11	Dependent on innovation
OC12	Geographical dispersed
OC13	No organization chart and meta-organization
OC14	Customer based and mass-customization
OC15	Lifespan of cooperation: temporary vs. permanent
OC16	Balance of power: equality of partners vs. core partners
OC17	Mission-overlap: partial vs. complete

[1]cf. Jacobsen [27] for more detailed descriptions of VO characteristics

3.3 Typology

The list of characteristics provided in Section 3.2 does no comply to every organization referred to as a VO in the literature. It is therefore reasonable to think that VOs exist in many different forms of business models.

3.3.1 Models of Virtuality

Burn et al. propose in [9] that organizations denoted as VOs can be related to one of six models of virtuality:

The virtual face: An easy way to describe a virtual face is that it is a cyberspace incarnation of a non-virtual organization. These kinds of VOs are usually created to add value by providing the same transactions and services to the customers over the Internet. For instance, web shops or newspapers on the web. Figure 3.1 shows a model of the virtual face, inspired by [10].

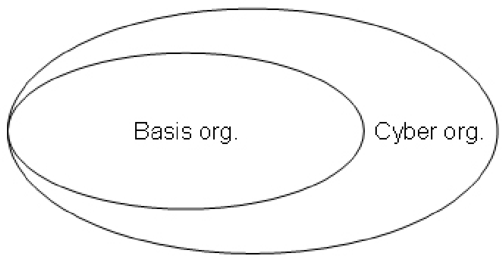

Figure 3.1: The virtual face

Co-alliance model: Shared partnerships where each partner brings approximately equal amounts of commitment to the VO are denoted as the Co-alliance model. The partners form a consortium, where the composition may change to reflect market opportunities or the core competencies of each member. The links within the co-alliance are usually contractual for permanent alliances, or by mutual convenience on a project by project basis. Figure 3.2 shows a model of the co-alliance, inspired by [10].

Star-alliance model: Coordinated networks of interconnected members, where each member reflects a core surrounded by satellite organizations, is the definition of a star-alliance model [10]. The core is normally a leading actor (star) in the market and supplies the members of the alliance with competency or expertise. Figure 3.3 shows a model of the star-alliance, inspired by [10].

Value-alliance model: Based on the value or supply chain, the value-alliance model gathers a range of products, services and facilities into one package.

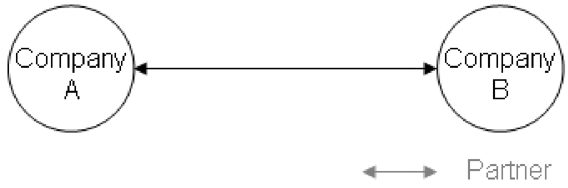

Figure 3.2: Co-alliance model

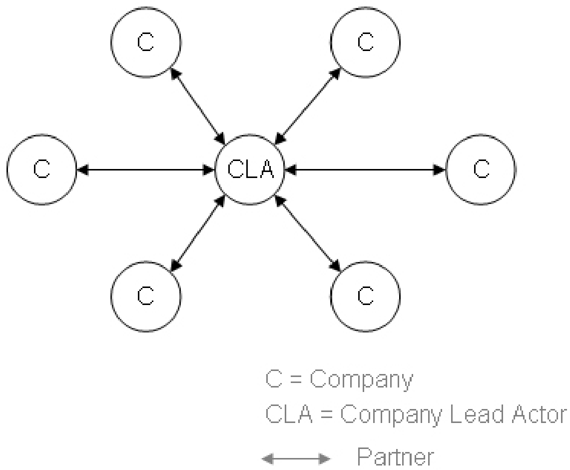

Figure 3.3: Star-alliance model

The coordination is normally provided by the general contractor, but participants may also come together on a project by project basis. In cases where longer term relationships have been developed, the value alliance tends to adopt the form of constellations, with complex strategic relations between the suppliers and the companies in the value chain. Figure 3.4 shows a model of the value-alliance, inspired by [10].

Market-alliance model: Like the value-alliance model, the market-alliance also brings together a range of products and services and facilities into one package. In this case, they may be offered separately by individual organizations, and the market-alliance exists primarily in cyberspace. The concept of virtual communities could also be related to this model. Figure 3.5 shows a model of the market-alliance, inspired by [10].

Virtual broker: The virtual broker can be described as a designer of dynamic networks. Virtual brokers seek strategic opportunities either as third-party value-added suppliers or as a kind of information broker of specific business information services. This is the most flexible purpose-built VO that is actually created to fill a window of opportunity and is dissolved when that win-

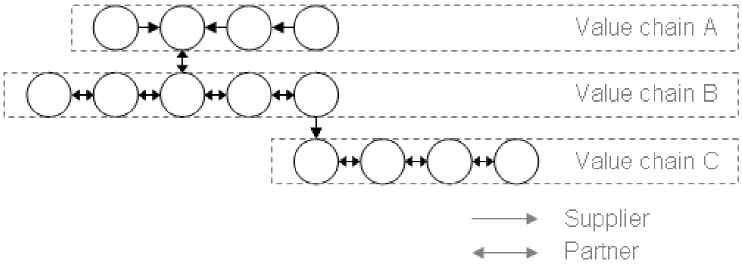

Figure 3.4: Value-alliance model

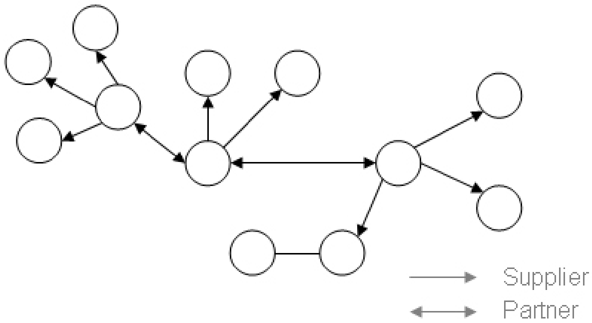

Figure 3.5: Market-alliance model

dow is closed. When Miles and Snow [30] introduced the concept of dynamic networks, they suggested that this kind of network needed a coordinator, a net-broker. In Snow et al. [42], three netbroker roles; architect, lead operator and caretaker have been identified. Responsible for respectively the selection of suitable partners and web members, the overall project management and maintenance, and supporting the process of "learning to cooperate and cooperate to learn". Figure 3.6 shows a model of the virtual broker, inspired by [10].

3.3.2 Dynamic Organization

The literature on virtual organizations presents different typologies for VOs [8][34]. The typologies are mainly defined based on lifespan of cooperation and strength in organizational links.

In the context of this thesis, we focus on the dynamic view of VOs, with the interpretation of a VO as a temporary network of modules: organizations, companies or

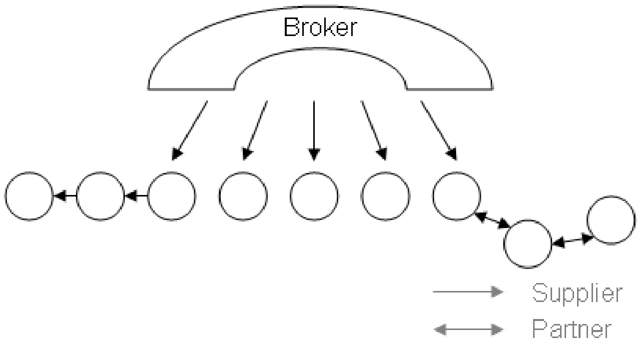

Figure 3.6: Virtual broker

individuals. This corresponds to what Bultje and van Wijk refer to as dynamic VO in [8] and what Palmer and Speier refer to as temporary VOs in [34].

Figure 3.7 shows the concept of the dynamic organization, presented in the VO model approach by [36]. It depicts three layers: a universe of modules, a dynamic web of modules with common purpose, and a dynamic organization with the dynamic web responding to a market opportunity or demand.

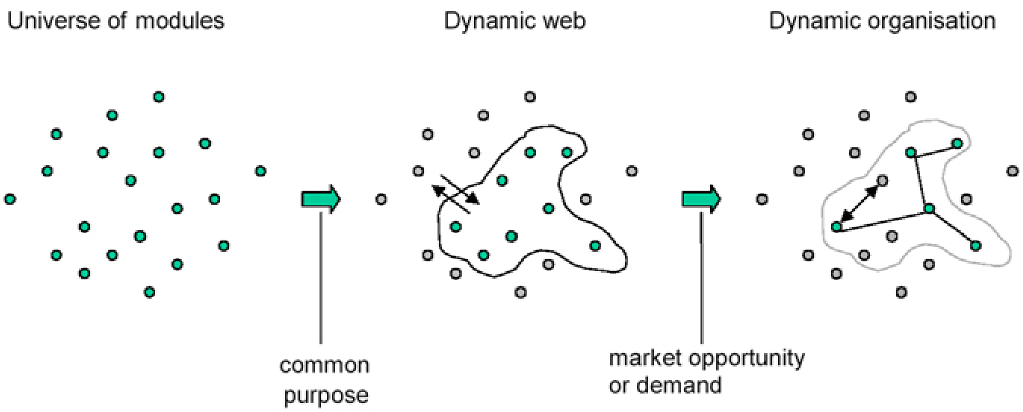

Figure 3.7: Dynamic Organization

3.4 Mobile Ad Hoc Virtual Organizations

Our previous research [27] shows that mobile work processes follow the model of the dynamic organization in ubiquitous computing environments. As an extension of the VO typology we introduce the **Mobile Ad Hoc Virtual Organization** (MAHVO), which can be characterized as:

> "temporary dynamic networks of independent actors with complementary core competencies, working towards a common goal in a nomadic environment. The cooperation is based on Information and Communication Technology (ICT) as the main facilitator for sharing knowledge and fostering trust."

Related to the models of virtuality in Section 3.3.1 the MAHVO can be depicted as a kind of decentralized broker. This concept combines the virtual broker with the star-alliance model and describes how the environment can participate in the organization on the same level as a regular actor or with a coordinating role. Figure 3.8 shows the concept of a decentralized broker.

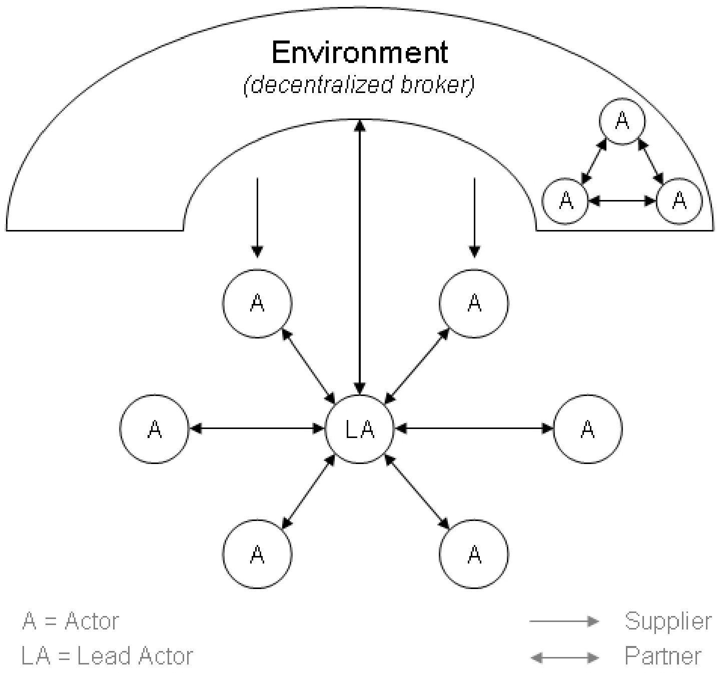

Figure 3.8: Decentralized broker

The model aims to describe how an environment, with intelligent sensors or computers participating as actors, supports coordination of activities in the VO. The environment collaborates with structures of ad hoc alliances, modeled as a star-alliance, and contributes both as regular actors, and as suppliers in the sense of supporting formation, knowledge sharing, and coordination. According to the role and influence of the surroundings in the VO, the environment can also in some cases be considered a lead actor, possibly taking initiative to the formation of a VO.

The participation of the technological actors in the organization may also be disbanded, either because there is no longer a need for technological support, or possibly due to disrupting signals or loss of connection. The role of each actor can change from actor to lead actor and back again, and also be disposed when its intentions and/or goals have been fulfilled. The different roles may appear again in the organization as fits the activities and work processes, like in the traditional VOs. This dynamic characteristic of the organization demands for a management of which actors that are to be included and disbanded from the organization. As computers in the environment has part of the coordinating responsibility, they have to take into account the needs of the organization and the competencies of the available actors. Furthermore, they need to take actions and apply roles based on an opportunistic model to make the work processes as efficient as possible.

This identifies new challenges to the enabling technologies in VOs, with regards to cooperation and competition. Two computerized actors are cooperative if they have complementary roles, which means that they make more profit working together than by working individually. Conversely, the actors are considered competitive if they have the same role, which means that the profit created by the one actor is negatively affected by the appointment of the other actor. An opportunistic model and machine-learning of behaviors and strategies can contribute in meeting this proposed challenge.

Chapter 4

Context

This chapter introduces the concepts of context and context-awareness, and relate them to ubiquitous and pervasive computing.

4.1 Introduction

Ubiquitous computing is the term for integrating computation into the environment, rather than having computers which are distinct objects. The concept was described by Mark Weiser, who provided his visions of the future in [45]. It is sometimes also referred to as pervasive computing. Figure 4.1 from [29] presents the different dimensions of ubiquitous computing.

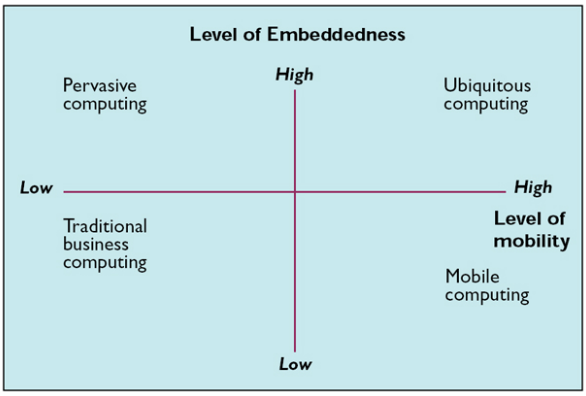

Figure 4.1: Dimensions of ubiquitous computing

One of the ultimate goals of ubiquitous computing is to enable devices to sense changes in their environment and automatically adapt and act according to these changes based on our needs and preferences. This future environment is also referred to as proactive computing[1], and it is predicted to be the next era of computing. As

[1] http://www.intel.com/research/exploratory

the number of devices in our surroundings increase, it will become impossible to interact directly with each one of them.

The vision of this future scenario requires a lot of development in technology, machine learning and artificial intelligence. However, one of the first steps is to integrate lots of sensors and actuators in the physical environment.

Schilit et al. [40] claim that the aspects of context are where you are, who you are with, and what resources are nearby. They define context to be the changing environment. The environment is composed by the following views:

- Computing environment: e.g., available processors, devices accessible for user input and display, network capacity, connectivity and costs of computing.
- User environment: e.g., location, collection of nearby people and social situation.
- Physical environment: e.g., lighting and noise level.

4.2 Context-Awareness

Dey and Abowd [16] find the definitions of context to be too specific, and present their apprehension of context as the whole situation relevant to the applications and its set of users. They propose the following definition of context:

> "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." [16]

Dey and Abowd [16] characterize certain types of context as more important than others: **location**, **identity**, **activity** and **time**. In other words information about the user's environment: where, who, what and when. This extends the definition of Schilit et al. [40] by adding activity and time information, and give us a more complete view for using context in relation to coordination and work processes.

Truly ubiquitous and pervasive computer systems are dependent on operating and acting according to the environment they are in. In the literature, context-awareness is often synonymous with the terms: adaptive, reactive, situated and context-sensitive. Dey and Abowd [16] define a context-aware system in the following way:

> "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the users task." [16]

Ubiquitous computing is making objects in the environment intelligent and contributors of valuable context information available for other entities in the environment. This is referred to as sentient objects [17]. In the sentient object model, context-awareness is defined as:

> "The use of context to provide information to a sentient object, which may be used in its interactions with other sentient objects, and/or the fulfilment of its goals." [17]

4.3 Context Acquisition

The key to acquiring context information from the environment is the sentient objects as described previously. These objects may vary from primitive sensors to more advanced context information services. Satyanarayanan [39] introduces the concept of **smart dust** involving small intelligent sensors with very low production costs. This makes it possible to spread large amounts of sensors into the environment like dust, and taking us a step closer to Weiser's vision of ubiquitous computing. The smart dust sensors contain the actual sensing hardware, wireless connectivity, a small memory, a small CPU and a small battery. The sensor can be deployed into the environment, self-configure and react to the environment, contributing in sending primitive context data such as temperature and humidity. When the battery is depleted the sensors are discarded having served their purpose.

The described way of embedding sensors into the environment are called immersive sensing. This way of acquiring context information must be complemented with non-immersive sensing such as video surveillance, motion detectors and other context services. This kind of sensors are referred to as **brilliant rocks** in [39] and has greater processing power and self- and environmental awareness than the smart dust.

Figure 4.2 from [24] shows a sensor network hierarchy. The lowest level relating to *smart dust*, and the higher levels representing *brilliant rocks*.

4.4 Context Representation

Context representation may occur in several ways ranging from real-time augmented sensing to regular database storage of information. When discussing context representation it is reasonable to separate between storing information and sharing information with the user. The first part can be realized using databases or knowledge bases enabled through various formatted documents i.e. XML[2]. The second part has more varieties to it. While machines and robots will have special interfaces for communication and sharing of information with a defined syntax, the humans

[2] XML: eXtensible Markup Language

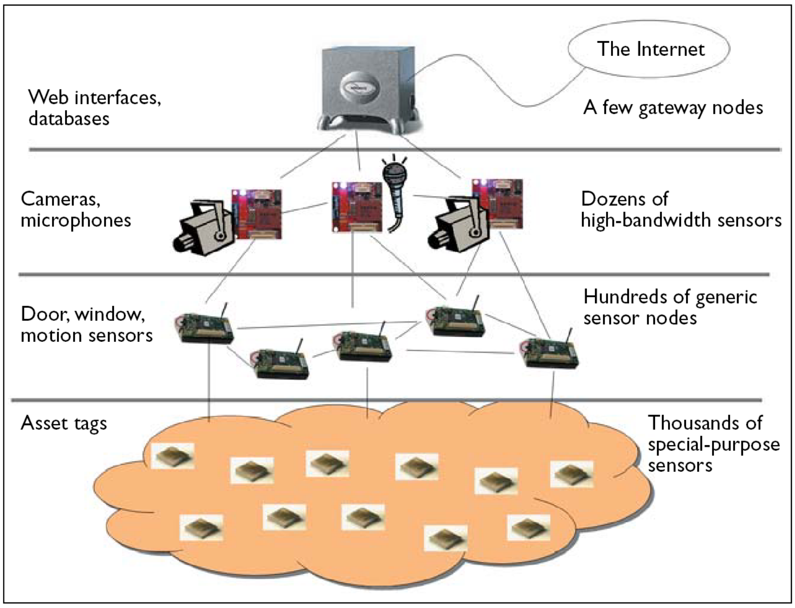

Figure 4.2: Hierarchy of Sensor Networks

may need several channels of context input from the environment for correct interpretation. The large selection of mobile devices with well developed features such as graphical displays and wireless network connectivity enables advanced user interfaces for representing information and customized mobile computer systems. Because the human workers may be occupied and not capable of operating a common mobile device such as a cellular phone or PDA[3], new and alternative ways of communication are being developed. The concept of **wearable computing** was founded by Steve Mann in 1995 through the development of a prototype wearable computing device with a head-mounted display. The state-of-the-art in wearable computing networks is presented by Ashok and Agrawal in [4], discussing various technology for ad hoc communication and advanced user interfaces for mobile work.

The key challenge in this research project is however to identify possibilities of acquiring and representing context within the computer systems for organizing and coordinating the mobile work processes. The focus is on filtering and reasoning on available context information, possibly deducing new knowledge about the work environment to create a safer and more efficient execution of activities.

[3]PDA: Personal Digital Assistant

Chapter 5

Workflow

This chapter introduces the concepts of workflow and workflow management systems, in addition to several related concepts.

5.1 Introduction

Workflow can be described as a collection of tasks that are completed by multiple resources. More specifically it is execution of defined business processes which may vary from milliseconds to several months. Dealing with mobile work processes executing in highly dynamic environments the time scope is normally limited to seconds. Figure 5.1 shows an example workflow of an order processing.

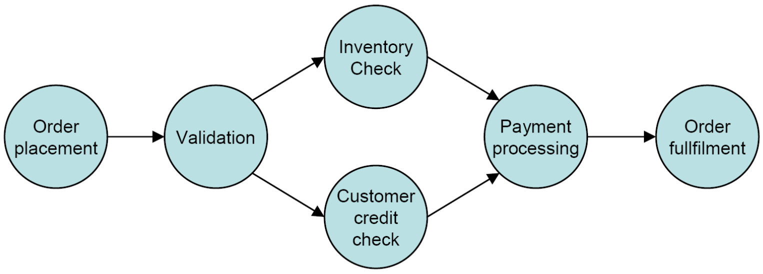

Figure 5.1: An example workflow

5.2 Terminology

The current workflow terminology has been developed and standardized by the Workflow Management Coalition[1] (WfMC), a non-profit, international organization

[1] `http://www.wfmc.org`

of workflow vendors, users, analysts and university/research groups. They define workflow as:

> "The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules." [14]

Figure 5.2 from [14] and revised by [33] shows the basic workflow terminology and the relationships between the concepts. Definitions of all the terms can be found in Appendix A.

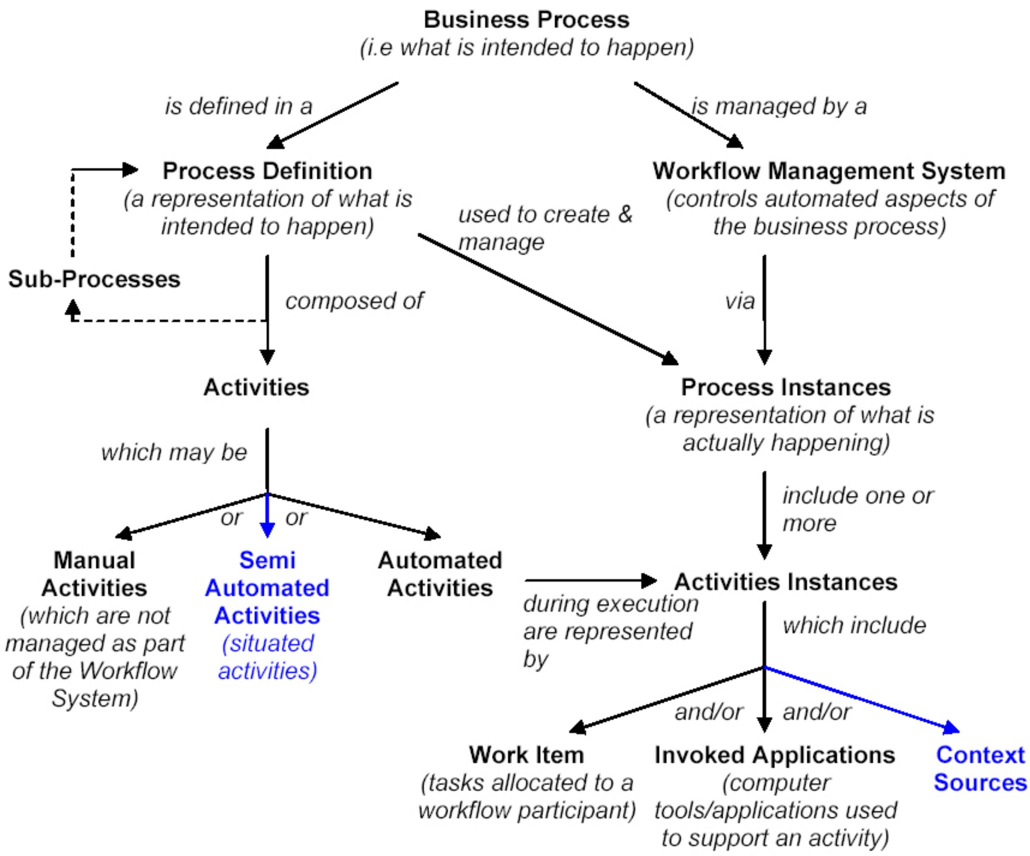

Figure 5.2: Relationships between basic workflow terminology

5.3 Workflow Systems

The Workflow Management coalition defines a workflow system as:

> "A system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines,

which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of IT tools and applications." [14]

There are several types of workflow systems that support different kinds of work. They can be classified into four different categories [3]:

Production: Automation and management of a large number of similar tasks to optimize productivity. Human input is reduced to only handling exceptions to pre-determined work processes.

Administrative: Many process definitions running concurrently, often involving a large number of employees. Process definitions are often created using forms, limiting the use to non-complex work processes.

Collaboration: Work processes with teams working towards common goals. Process definitions are not rigid and can be amended frequently.

Ad-Hoc: Allows users to create and amend process definitions quickly to meet immediate circumstances. This maximizes flexibility in environments where throughput and security are not major concerns.

Figure 5.3 from [25] shows the characteristics of a Workflow System.

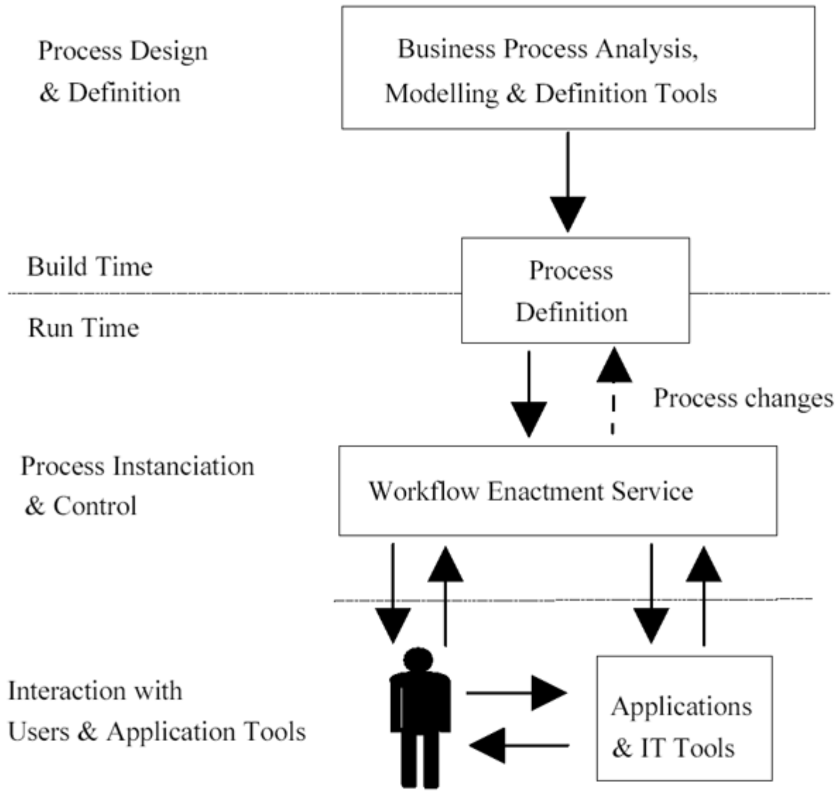

Figure 5.3: Workflow System Characteristics

Chapter 6

Activity Theory and Situated Actions

This chapter introduces the concepts of situated actions and activity theory, and relates them to context and workflow.

6.1 Introduction

Activity theory is both a formal theory of human work activities and a philosophical framework for studying human work practices [44]. When discussing mobile work processes and coordination it is interesting to combine the concepts of activity theory and situated actions. Dynamic organizations in ubiquitous computing environments involve huge amounts of situated work and possible need for coordination of actors and activities. Planning is an important part of work processes, and the concept of dynamic planning *in situ* is described in the following.

6.2 Activity Theory

When discussing activity theory it is important to look at building blocks of an activity. The human activity has three basic characteristics [6]:

- activities are directed towards a material or ideal object which distinguishes one activity from another.
- activities are mediated by artifacts (tools, languages, etc.).
- activities are social within a culture.

Activity theory states that human activity is a hierarchy of three levels, as shown in Figure 6.1 [28]. Activities are realized through the use of actions, which are carried out by operations. The motive for an activity stems from the reflection of and expectation to, a material or ideal object. Actions result in objective results. Humans have anticipations for results of an action, and these anticipations form the goals for a human performing an activity. An activity exists as one or more actions, but the activity and action are not identical. The conditions of a concrete situation govern how an action can be performed. This means that actions are realized through a series of operations, where each operation is adapted to the physical conditions of the action. At all three levels activities are guided by anticipation.

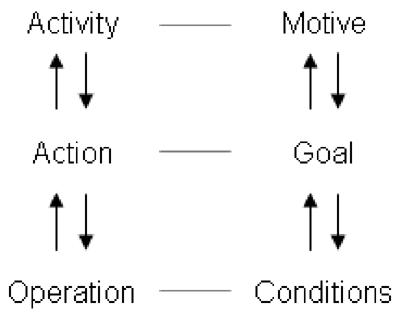

Figure 6.1: Hierarchical levels of an activity

Nardi [32] states that activities are composed of subject, object, actions, and operations. In ubiquitous computing environments activities themselves become context, and for the purpose of organizing mobile work processes this is key context information. This is acknowledged by the research of Dey et al. [16].

Adams et al. [1] have derived ten principles (P1 ... P10) from activity theory that help the understanding of work practices. These principles reflect an interpretation of central themes in activity theory, and will be further discussed in relation to context representation in the next part.

P1 Activities are hierarchical: An activity consists of one or more actions. Each action consists of one or more operations.

P2 Activities are communal: An activity almost always involves a community of participants working towards a common objective.

P3 Activities are contextual: Contextual conditions and circumstances deeply affect the way the objective is achieved in any activity.

P4 Activities are dynamic: Activities are never static but evolve asynchronously, and historical analysis is often needed to understand the current context of the activity.

P5 Mediation of activity: An activity is mediated by tools, rules and divisions of labor.

P6 Actions are chosen contextually: A repertoire of actions and operations is created, maintained and made available to any activity, which may be performed by making contextual choices from the repertoire.

P7 Actions are understood contextually: The immediate goal of an action may not be identical to the objective of the activity of which the action is a component. It is enough to have an understanding of the overall objective of the activity to motivate successful execution of an action.

P8 Plans guide work: A plan is not a blueprint or prescription of work to be performed, but merely a guide which is modified depending on context during the execution of the work.

P9 Exceptions have value: Exceptions are merely deviations from a preconceived plan. Deviations will occur with every execution of the plan, and give rise to a learning experience which can then be incorporated into future executions.

P10 Granularity based on perspective: A particular piece of work might be an activity or an action depending on the perspective of the viewer.

6.3 Situated Actions

Situated action models emphasize the emergent, contingent nature of human activity, the way activity grows directly out of the particularities of a given situation [32]. Most modeling approaches in cognitive science of human behavior rely heavily on plans to achieve the objective of an activity, and represent only carefully planned activities. Situated actions depend on the environment as an important contributor to shaping activities. This is an important factor when organizing mobile work processes, and a definitive characteristic of organizations in ubiquitous computing environments.

As described above, plans have traditionally been looked upon as the opposite of situated actions, but Bardram [6] discuss how plans can be made out of situated actions an realized *in situ*. This is referred to as **situated planning**, and involves planning while executing and the ability to modify a plan based on occurring events. Bardram [6] characterizes it as the building, altering, sharing. executing and monitoring of plans within cooperative work activities. Based on activity theory he provides the following definition of a plan:

> "A cognitive or material artifact which supports the anticipatory reflection of future goals for actions, based on experience about recurrent structures in life." [6]

Situated actions and situated planning relates to our model of the Mobile Ad Hoc Virtual Organization described in Section 3.4 and the view on the environment as an important actor.

Part III

Own Contribution

Chapter 7

Problem Elaboration

This chapter gives an introduction to the contribution of this research project and elaborates on the problem definition.

7.1 Introduction

This research project is focused on the use of context information and knowledge in organizing mobile work processes in ubiquitous computing environments. The contribution of this thesis aims to discuss the challenges of managing the different actors and activities involved in complex dynamic organizations, and provide new ideas and opportunities on the concept of context in dynamic organizations.

Sørensen et al. [12] provide a view on work processes in a mobile setting by distinguishing between work in a mobile environment and mobile work. Their definitions are based on context-sensitivity:

Work in a mobile environment: Work processes performed in a mobile environment *independent* of context information extracted from the physical environment. That is, mobility is *not necessary* to accomplish the process goals.

Mobile work: Work processes performed in a mobile environment *dependent* of context information extracted from the physical environment. That is, mobility is *necessary* to accomplish the process goals.

Their definition of mobile work is the foundation of our research, and emphasizes an important aspect of mobile work processes. The mobility is a key factor to the achievement of the process goals. Sørensen et al. [12] propose that mobile work and the local working environment can mutually influence each other in different ways. Mobile work can change the state of the environment, and the state or change of state in the environment can:

- initiate activities that must be performed.
- control start, duration, delay, stop, and termination of activities.
- control which activities to be performed.
- change the content or goal of an activity.
- initiate exceptions in the current activities.

This raises lots of different challenges to organizing the mobile work processes which will be addressed in this research. The term mobility will be related to the dynamics of virtual organizations, and the importance of context will be discussed on different mobile work scenarios.

7.2 Challenges

Mobile work, according to the definition in Section 7.1 is affected by the context information in the surrounding environment. This may require large amounts of data to be sensed and processed to enable efficient work processes. More important is to filter the data to decide which information is relevant and important and which is not. An important issue in this case is how to translate the context information into knowledge of events that affects the organization. Computerizing the process design and context sensing is a giant leap towards the vision of ubiquitous computing. However, it requires development of flexible frameworks for coordination of activities in ubiquitous computing environments, among other issues.

The traditional view on workflow systems performing the process design in build time before executing the work processes in run time needs to be adapted to support mobile work. Figure 7.1 adapted from [25] illustrates the challenge of making the workflow system more flexible and adaptive by performing business process modeling in run time.

The mutual influence of mobile work and the local working environment call for new methods to support planning and executing activities in ubiquitous computing environments. It is also important to develop new ways of coordinating all the actors involved in the dynamic organizations. This is particularly challenging in the organizations where the environment is an important actor to achieving the goals of the organization. However, the key challenge is how to identify and use the relevant context in design and enactment of mobile work processes.

The research will be focused on utilizing our knowledge of Virtual Organizations (VOs) when discussing the importance of context information in mobile work. This will mainly be related to the representation of core competencies and the process state or environment as context in the organization.

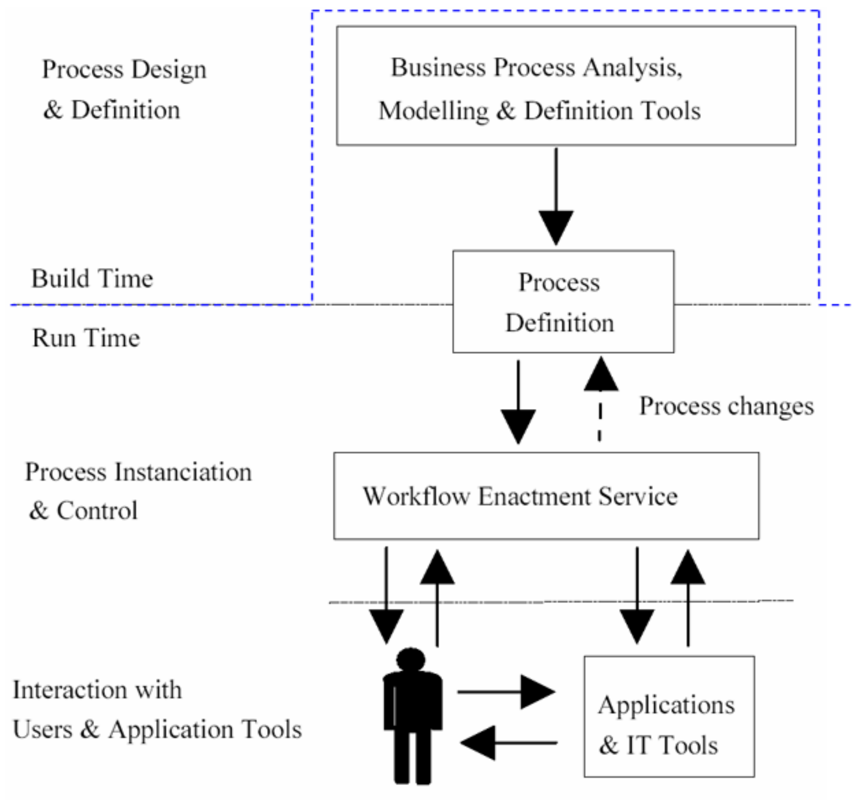

Figure 7.1: Process design in run time

7.3 Scenarios

The scenarios used in this research project are directed to highly context-sensitive work environments. The motivation for including them are to discover opportunities and challenges in such organizations by examining real-life mobile work processes. The selection of scenarios are also categorized on their degree of pre-planned actions and influence of context to further focus our investigation on the most dynamic organizations. The classification of the scenarios into the different categories is assessed by the experience and analysis from the pre-project of the research [27]. The ultimate goal is automation and to increase efficiency of the work processes. The focus is both on reducing costs and increasing the safety of the work environment.

7.4 Analysis

The analysis of the scenarios is an important part of contributing new ideas and suggestions to the research questions addressed by this thesis. Based on the contribution and discussion of the scenarios, the different concepts and theories presented in the first part of the report will be further examined and evaluated related to mobile work. The motivation for this work is the attempt to fuse and relate the different concepts to each other, possibly achieving synergies and new knowledge on supporting mobile work.

7.5 Architecture

The architectural proposal will conclude the own contribution of the research project. The aim is to incorporate the knowledge derived from studying organization of mobile work processes into a high-level software design. The described computer system will be related to the research questions in this thesis, and also evaluated against the challenges in implementing a context-aware system identified by Satyanarayanan in [38]. The challenges are listed below (C1 ... C12). According to Satyanarayanan [37], a pervasive computer system has to be context-aware.

C1: How is context represented internally?

C2: How is this information combined with the system and application state?

C3: Where is context stored?

C4: Does it reside locally, in the network, or both?

C5: How frequently does context information need to be consulted?

C6: What is the overhead of taking context into account?

C7: What techniques can one use to keep this overhead low?

C8: What are the minimal services an environment has to provide to make context-awareness feasible?

C9: Is historical context useful?

C10: What are the relative merits of different location-sensing technologies?

C11: Under what circumstances should one be used in preference to another?

C12: Should location information be treated just like any other context information, or should it be handled differently?

Chapter 8

Scenarios

This chapter presents different scenarios of mobile work and discusses issues related to the use of context in such work environments.

8.1 Introduction

The scenarios in this thesis are focused on providing reference work processes for the discussion of dynamic organizations in ubiquitous computing environments. The presentation of the different scenarios are divided in specific focus areas: description, actors, roles, activities and a discussion of context dependency. The scenarios are categorized based on their degree of pre-planned activities to give a broader perspective of the discussion. This serves as a measure of the dynamics and variation in the organization. Table 8.1 shows the categorization and choice of scenarios.

Table 8.1: Categorization of scenarios

Categorization	Description	Scenario
Fully pre-planned	Production or assembly line	Shipyard
Semi pre-planned	Strict routines with necessary ad hoc execution	First response
Not pre-planned	Very dynamic organization with ad hoc operation	Traffic

The motivation for including the different scenarios is to show the varieties of mobile work. The first scenario shows how even production and assembly line work require improved coordination when operating in an ubiquitous computing environment. The subsequent scenarios describe work processes already operating in highly context-sensitive environments, motivating for better coordination to increase efficiency towards achieving their goals and at the same time possibly improving safety of the actors involved.

8.2 Shipyard

This scenario is based on a field study of the Norwegian shipyard Aker Verdal. It is a shared study within our research group on mobile work, and it is included in this thesis because of the high relevance towards ubiquitous computing in production work environments.

8.2.1 Description

The shipyard has two main assembly lines on producing offshore installations: steel plate processing and steel pipe processing. The latter is presented in our research as an example of the organization of such production. Figure 8.1 shows a simplified workflow model of the steel pipe production at Aker Verdal.

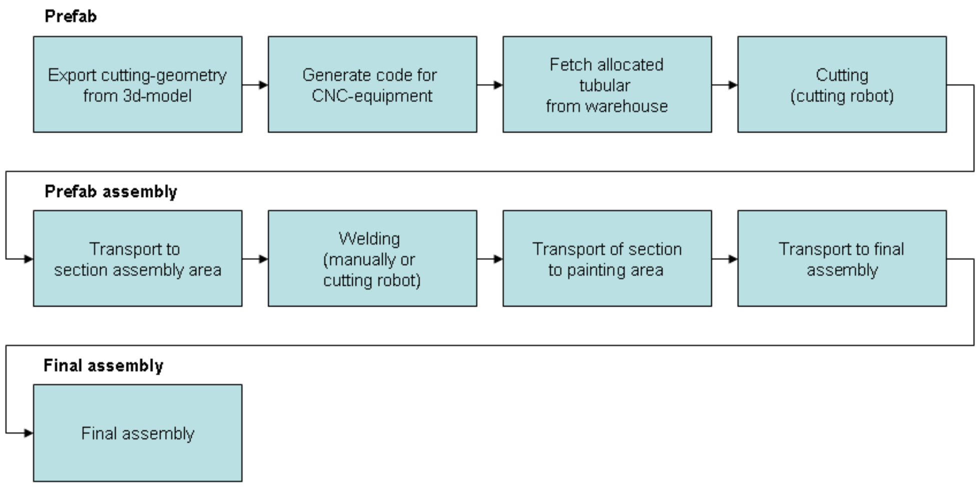

Figure 8.1: Simplified Structural Tubular Workflow

The work process of steel pipe production consists of three main phases: prefabrication, prefabrication assembly, and final assembly.

Prefabrication is the first phase of the structural tubular work process. Cutting information from a 3D-model is exported to cutting geometry, and code is generated for the CNC-equipment[1]. Allocated tubular is fetched from a warehouse for processing by a cutting robot. The cutting robot performs the cutting, supervised by a human worker.

In **Prefabrication assembly**, the tubular is transported to the section assembly area. Welding is performed by a welding robot, supervised by a human worker who also performs a visual inspection of the weld. The assembled section is then

[1] CNC: Computer Numerically Controlled, computer controlled machine tools for the purpose of manufacturing complex parts repeatedly

transported to the painting area. The section needs to be painted to withstand corrosion and the work is performed by a painting robot. The painted section is then transported to the area for final assembly.

In **Final assembly**, the section is assembled into a large steel structure as shown in Figure 8.2.

Figure 8.2: Assembled Steel Jackets at Aker Verdal

Between each of these processing steps there may be times when the tube is placed in storage rather then immediately being transported to the next processing entity.

8.2.2 Actors

The scenario involves the following actors: Work place supervisors, transport personnel, operation facilitators controlling the machines, welding robots, cutting robots, painting robots. There is a mix of humans and machines. Due to heavy machinery and the presence of various technological actors, this organization can be characterized as operating in a hazardous environment.

8.2.3 Activities

The work environment is a traditional assembly line production plant, including a warehouse and different specialized stages of assembling parts for the final product. This involves a separation of work environments into different locations and several transportation activities between them. Except from the different transportation stages in the workflow in question, the production environments are quite different and with individual needs for coordination and automation.

8.2.4 Roles

The roles in this organization are supervisors overlooking several steps of the work process, specialized working robots, specialized human workers, and a variety of maintenance personnel. In a production organization, almost all the actors complement each other with core competencies, hence coordination meets less challenge of competitive behavior. When organizing mobile work processes in these less dynamic environments, the focus should be on making the workflow more efficient and the local work environment safer. Increasing the amount of automation in the work process, for instance by applying more specialized robots and machines, will require improved coordination among the actors.

8.2.5 Context Dependency

The context dependencies in this scenarios is mainly related to supervision of work according to the planned execution of activities. The operation is executed according to a planned workflow with a scheduled timetable. Table 8.2 lists some of the important context information that this operation is dependent on.

Table 8.2: Shipyard - context dependency

Context type	Description
Location	- Where are the actors? - Where are the materials?
Identity	- Which actors are present? - What role are they possessing?
Activity	- What has already been done? - What needs to be done?
Time	- Is the production following the scheduled timetable? - When will requested resources or materials arrive?

8.3 First Response

This scenario is related to the course of events at the scene of a traffic accident when organizing a rescue operation. Due to the worked in line of actions with an ad hoc execution, the scenario is characterized as having semi pre-planned activities.

8.3.1 Description

The organization of the rescue action is initialized either by one of the involved, possibly injured, eyewitnesses, or the first person to arrive the site of the accident.

The line of actions described in this example starts when this initializer evaluates the condition of the patients and performs an emergency phone call. This involves the rescue party in the organization, and the following procedure of operation is well-known to all participants.

8.3.2 Actors

The scenario involves the following actors: the injured persons, the rescue initializer, the coordinator at the emergency call center, the policemen blocking the road to prevent more accidents and leading the on-site operation, the firemen putting out any fires and helping to release the injured from the car wreck, the ambulance personnel medically treating the injured, spectators and eyewitnesses.

8.3.3 Activities

The activities involved in this scenario are listed below related to the actor normally performing the activity. The list of activities is a suggestion based on experience with these work processes to illustrate the level of involvement of the different actors in the organization.

First arrival
- Get an overview of the situation
- Secure the scene to prevent further accidents
- Check the health condition of the people involved
- Secure injured people
- Prioritize first-aid if necessary
- Call for emergency assistance

Alarm central
- Receive emergency calls
- Help to organize emergency scene until trained personnel arrives
- Alarm police, ambulance, fire department etc.

Police
- Organize the traffic
- Investigate the accident

Ambulance personnel
- Take over patient treatment and first-aid
- Prepare people to be moved to the ambulance
- Bring people to the hospital
- Inform the hospital about which people and injuries are expected on arrival

Fire department
- Stop any fires

- Cut open wrecks to save people
- Secure the scene for any dangerous liquids, gases, etc.
- Clean up the scene when the wrecks are removed

Crane vehicle personnel
- Prepare the damaged vehicles to be removed
- Move the vehicles to the police and/or repair shop

8.3.4 Roles

In this scenario, the roles are almost completely defined in advance. The actors contributing with their core competencies on the site of the accident, are highly trained personnel with exercised skills for handling this kind of operation. The special case in this scenario is the role as the initiator. This person is normally expected to know the procedure of first aid and where to call for assistance. This is an abstract set of rules that is considered common knowledge. However, the stress related to this scene result in a improvised handling of the situation, and a pragmatic behavior towards the rules.

8.3.5 Context Dependency

Mobility along with certain context information is necessary to achieve the process goals in this scenario. As described in the section above, the initiator has an important role in the organization. When calling the alarm central the initiator describes the situation and important detailed context information asked for by the call operator. Based on the received information required emergency personnel are given instructions to approach the situation and perform their specific tasks on site. Their specific tasks on site are somewhat pre-planned, so the most important information is the location and the degree of seriousness of the situation. The alarm central holds the line to maintain contact with the scene of the accident until the emergency resources arrive. Table 8.3 lists some of the important context information that this operation is dependent on.

8.4 Traffic

This scenario is related to an arbitrary segment of normal traffic. It contains a discussion on how each actor behaves and adapt to the traffic.

8.4.1 Description

Describing traffic as an organization is a complex matter. Thus, this scenario describes a segment of traffic and the possible actors in this organization. The boundaries can be set by a geographically limited area of operation for the scenario, by following the operation of a single actor, or by looking at situations where multiple actors need to cooperate. Taking the first approach, the organization is established when a vehicle enters the area, and ends when there is no traffic in the area. The superior goal of the participants in this organization is to get from A to B in a secure and effective way. This requires each actor to follow a set of rules and cooperate with the other actors to handle any situation that may arise. There are often a great diversity of actors appearing in this organization, each with a set of individual goals in addition to the superior organizational goal.

8.4.2 Actors

The scenario involves the following actors: regular drivers, professional transport workers, pedestrians, cyclists, emergency vehicles, police patrols, public transport and taxies.

8.4.3 Activities

The activities described in this scenario are limited to some activities and basic operations executed by the drivers, for the purpose of discussing coordination and adaptation in later chapters. This includes regular drivers, professional transport, emergency vehicles, public transport and taxies. The different driving activities are composed by a complex set of driving actions and operations executed as an ad-hoc plan based on the context information available.

Driving activities
- Driving from location A to location B
- Finding the shortest route
- Analyzing the map

Table 8.3: First response - context dependency

Context type	Description
Location	- Place of accident - Weather conditions or other location specific challenges - Relative distance to emergency resources
Identity	- Who is involved in accident? (patient records) - Other actors
Activity	- What has already been done? - What needs to be done?
Time	- When did the accident occur? - Estimated time of arrival

Driving actions
- Normal driving (autopilot)
- Changing lane
- Overtaking
- Highway arrival
- Highway exit
- Roundabout
- Parking

Driving operations
- Speed up
- Break down
- Turn left
- Turn right
- Blink lights
- Honk the horn
- Look around

8.4.4 Roles

There is a wide diversity of roles in this scenario, police patrols managing the traffic, professional actors working in the traffic, and regular drivers more or less casually present. They all act according to a set of rules, and are expected to know their rights and responsibilities as a results of their training. However, individuals acting pragmatic towards the rules, as a results of cultural differences, driving under the influence of alcohol, or simply by choice, may call for pragmatic actions by the individuals nearby in order to adapt to the situation and prevent an accident.

8.4.5 Context Dependency

In this scenario, mobility along with certain context information is necessary to achieve the process goals. Each actor in the organization adapts to the situations that arise in the environment. Their mutual understanding and trust towards the traffic rules contribute in a great extent in organizing the work processes and maintaining a low need for superior coordination. However, due to the dynamic structure and variety of actors there is a strong demand for situated coordination. This is also closely related to the fact that most of the actors have different goals and motivations for appearing in this environment. These issues will be further discussed in the next chapter. Table 8.4 lists some of the important context information that this operation is dependent on.

Table 8.4: Traffic - context dependency

Context type	Description
Location	- Position on the road network - Weather conditions or other location specific challenges - Distance to the other vehicles and speed
Identity	- Who is part of the organization? (roles and goals) - Other actors
Activity	- What has already been done? - What needs to be done? - What are the other actors doing? (possibly interfering)
Time	- Time specific conditions (rush-hour) - Are the actors in a hurry?

Chapter 9

Analysis

This chapter presents a discussion of special situations from the scenarios described in the previous chapter.

9.1 Introduction

The scenarios presented in the previous chapter give us valuable descriptions of mobile work processes and their organization. The organization of work in these scenarios is not always obvious because it does not naturally correspond with the common view of an organization. However, when viewed upon as a virtual organization one can identify several characteristics of traditional organizations and apply our knowledge of these into ubiquitous computing environments. Situations from the scenarios substantiate the organizational view and provide an introduction to start discussing the challenges of automation and coordination.

Context information is essential when organizing mobile work, and the scenario descriptions emphasize the role of such information in ubiquitous computing environments. In most situations it is the same set of context information that is necessary for a smooth operation and a common understanding between the actors in the organization. The following discussion is an attempt to identify the elements that constitute this *superset* of context information that is necessary for coordinating actors in ubiquitous computing environments.

9.2 Situations

In this section we analyze situations from the discussed scenarios and relate them to challenges of coordination.

9.2.1 Shipyard

In work environments involving both humans and robots or heavy machinery it is critical to have context-awareness. More specifically, the actors need to take necessary precautions of how they move and act according to the other actors. The human workers need to know which machines are present and the consequences of acting irresponsible towards them. The latter means knowing how to behave around these machines, and this is where coordination plays a major role. The human intuitive coordination pattern (taught through experience, knowledge acquired from others etc.) creates a memory that is the foundation for our motor behavior. This pattern can be transferred to machines by training the mechanisms for such learning, and adapt the knowledge to typical patterns in real-life work situations. No situations will be identical, however resembling enough to apply the same reaction pattern with small adjustments. As a first step one can assign simple knowledge rules to the machines of how the interpret certain context information. For instance, heavy machinery can automatically shut down if humans approach too near, or in some way communicate their presence to the other actors. This concept has been examined in various machinery research as machine cells or manufacturing cells.

In addition to enabling a safer work environment, context-awareness in production areas can lead to a higher efficiency of work. By monitoring the work environment and taking actions based on occurring events or predictions, it is possible to create an adaptive workflow. This involves anything from understanding when and where certain resources will be needed, to arranging the work environment according to priorities of more important or operation-critical actors and activities. This is related to how it is done in an operating system with key processes or with certain uniformed vehicles in the traffic.

9.2.2 First Response

The first response scenario is very interesting due to its time-critical operation. The organization on the scene of the accident is a complex and dynamic structure. It is instantiated just after the accident when the initiator calls the alarm central. The caller describes the situation to the person at the central, giving the necessary context information. Number of persons involved, their condition, time and place of accident etc. Based on the information from the caller, the alarm central starts a rescue operation and appoints the necessary resources and emergency personnel to the organization. The alarm central has strict routines of operation as to which information they need from the caller to make their decisions. It is their job to get the most realistic picture of the situation to appoint the necessary resources based on the location and the seriousness of the situation. The alarm central keeps contact with the person on site until the emergency personnel arrives.

The most important context information is a description of the situation and the available resources for the operation. This information flow today is supported by the information and communication technology used to coordinate such operations. However, to improve the workflow and enable automation of coordination, the context needs to be organized in some sort of templates that are common for the application area of emergency operation. For instance, the required information from the scene obtained through the phone call can be automatically sensed and the caller may then concentrate on helping the injured and securing the site. This is partly supported by the computer systems, where the location of the caller can be obtained through locating the coordinates from which the device (i.e. cellular phone) is transmitting signals. If the situation can be related to a certain workflow template, the resources (core competencies) can be assigned to the organization based not only on the primary factors availability and proximity, but on secondary factors such as experience with similar situations and knowledge on local conditions.

When the resources arrive on the site there is a well-known line of work and responsibilities according to their role in the organization. This scenario is special through the communication of roles to the other actors. The actors are very recognizable due to their vehicles and uniforms, which improves the workflow and communication in the organization. Everyone knows who to address with certain issues because they know the other actors responsibility and line of actions. This way of representing knowledge of roles and expected behavior can be transferred into other work environments to improve situated actions.

9.2.3 Traffic

The traffic scenario is by far the most dynamic organization in this research project, and it has several characteristics that are interesting to analyze in relation to situated actions and coordination. The traffic pattern in itself is interesting to view as an organization where new actors enter and leave continuously. However, for the purpose of this research, the key knowledge to extract from this scenario is the way the different actors behave according to their roles and goals. More specifically it is interesting to learn the patterns of how the actors interact and perform implicit coordination according to the traffic rules and their common goal of safe operation.

The purpose of including and analyzing this scenario is not for implementing and enabling autopilots in the traffic, but rather to observe the patterns of operation and try to apply this knowledge to other application areas and work environments. With respect to coordination it is especially interesting to observe the workflow of these organizations and how well they operate according to a strict set of rules. The different actors may interpret the rules independently, however they all have a common understanding of taking precautions to prevent accidents, avoid violations of the law or damage to their vehicles due to their conscience and in many cases the potential cost of repair.

The security of operation in traffic can hopefully be further improved by developing new ways of using context information to support interaction between the actors. For instance the technology can be an augmentation of the human sense perception enabling the actors to operate more safely and cost effectively. This is partly supported today through radio messages and niche products such as map applications. The future applications could support more time critical sensing operations such as registering sudden activation of break lights on a car a few cars in front with no line of sight. This would have to be supported with a reasoning tool identifying whether this event is relevant for the actor, for instance if the distance between the cars is minimal and the speed is high.

Another characteristic of this environment is the exceptions to the traffic rules for specific actors such as emergency vehicles, and the knowledge that some vehicles cannot act as dynamic i.e. large trailers or buses. Implicit coordination with these actors demands for different behavior than usual, and is a challenge when enabling automation of mobile work.

9.3 Summary

The situation analysis of different work environments helps us see the big picture of mobile work and identify specific characteristics of using context information for organizing work processes. It is also valuable to apply our knowledge to certain application areas for the purpose of evaluation at a later phase of the research. The main goal is to develop a general framework for organizing mobile work processes in ubiquitous computing environments and identify the necessary context information and best practice for representing knowledge in such organizations.

Chapter 10

Ontologies

This chapter introduces the concept of ontologies and discuss their usability in ubiquitous computing environments.

10.1 Introduction

The concept of **ontologies** has its foundation in the vision of **The Semantic Web**.

> “The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.” [7]

Ontologies are referred to as the shared understanding of some domains, often conceived as as a set of entities, relations, functions, axioms and instances. In ubiquitous computing environments new entities may enter the environment at any time, and these entities have to interact with the existing entities. The interaction must be based on common, well-defined concepts to prevent misunderstanding between the actors in the organization. The actors must have a common understanding of the various terms and concepts used in the interaction.

10.2 Context

Mobile work processes are dependent on context, and the actors and the environment have a mutual influence on each other as described in Section 7.1. The ontologies can be used to concisely describe the various concepts used in the work environment enabling semantic inter-operability between the different entities. Context information and knowledge can be described with a semantic vocabulary so that the different actors can access the necessary information in their own ”language”. For instance, in the first response scenario the representation of location can be described as GPS[1] coordinates or possibly with a semantic translation to which high-way and even relative distance to well-known sights or buildings. The phrase "well-known" is especially interesting because it can be viewed upon as personalization or customization of information to the user with an individual semantic representation.

Context information in ubiquitous computing environments has a number of characteristics that complicates the operation of mobile work:

Great variety: The definition of context includes any information that describes physical objects, users, activities and environmental conditions. This results in large amounts of data and complicates the work of identifying and deducing the important information.

Different sub-domains: The relevance and importance of information varies related to the other context information. For instance, location information may be important in some situations and totally irrelevant in others.

Inter-relativity: Different context information may be inter-related in several dimensions. For instance, location may be closely related to the activity being performed and who is in charge of the operation.

Inconsistency: Context information may be inconsistent due to the highly dynamic nature of the environment and imperfect sensing. For instance, in the traffic scenario the different actors are moving quickly causing the location context to be out-of-date. This could be supported by implementing dead-reckoning, which is prediction of future position based on present position, speed and direction, both topological and geographical.

Ontologies have the properties for supporting the challenges identified above, and can be used for representing context information from the environment in mobile work.

10.3 Context Reasoning

Another important feature when using ontologies in ubiquitous computing environments is the ability to support automated context reasoning based on various types of context and their properties. Context can be processed with logical reasoning mechanisms. The use of context reasoning has two important areas of application:

- checking the consistency of context.
- deducing high-level, implicit context from low-level, explicit context.

[1]GPS: Global Positioning System

The use of ontologies as a specification of a domain enables consistency checking of all context information available, and by using semantic rules the low-level context can be translated into high-level information. This also involves identifying events based on low-level information. For instance, information about weather conditions and temperature may not be relevant unless it exceeds a certain defined limit or degree of Celsius. Then it may be be reported semantically as an incident of overheating.

Different reasoning methods can meet the challenges described in Section 10.2 and contribute into making the information accessible to all the relevant actors in the organization. When introducing context reasoning in ubiquitous computing environments new challenges arise such as performance on devices with limited resources and dealing with time-critical applications. These issues among others will be further discussed in the next chapter.

10.4 OWL - Web Ontology Language

OWL is one of the emerging Semantic Web languages that are endorsed by the W3C[2] for building ontologies [46]. The OWL language builds on the DAML+OIL language [26] and both are layered on top of the standard RDF/RDFS triple data model (i.e. subject, predicate, and object) [47]. OWL has the capability of sharing information between the actors in virtual organizations and enable inter-operability between them through:

- formalizing a domain by defining classes and properties of those classes.
- defining the actors and asserting properties about them.
- reasoning about these classes and actors.

OWL provides three increasingly expressive sub-languages designed for use by specific communities of implementers and users [46]:

OWL Lite supports those users primarily needing a classification hierarchy and simple constraints. For example, while it supports cardinality constraints, it only permits cardinality values of 0 or 1. It should be simpler to provide tool support for OWL Lite than its more expressive relatives, and OWL Lite provides a quick migration path for thesauri and other taxonomies. OWL Lite also has a lower formal complexity than OWL DL, see the section on OWL Lite in the OWL Reference for further details.

OWL DL supports those users who want the maximum expressiveness while retaining computational completeness (all conclusions are guaranteed to be computable) and decidability (all computations will finish in finite time). OWL

[2]The World Wide Web Consortium: http://www.w3.org

DL includes all OWL language constructs, but they can be used only under certain restrictions (for example, while a class may be a subclass of many classes, a class cannot be an instance of another class). OWL DL is so named due to its correspondence with description logics, a field of research that has studied the logics that form the formal foundation of OWL.

OWL Full is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. For example, in OWL Full a class can be treated simultaneously as a collection of individuals and as an individual in its own right. OWL Full allows an ontology to augment the meaning of the pre-defined (RDF or OWL) vocabulary. It is unlikely that any reasoning software will be able to support complete reasoning for every feature of OWL Full.

The most appropriate sub-language of OWL in ubiquitous computing environments would be a combination of OWL Lite and OWL DL, for respectively representing the context information and providing context reasoning based on rules described as description logic.

OWL is also used as the language for defining ontologies in the research project CoBrA [13] to share contextual knowledge with other agents and enabling it to reason about context. Their collection of ontologies called COBRA-ONT is expressed in OWL for describing information in an intelligent meeting room.

10.5 Description Logics

OWL is a logic, or a family of logics. It is used as a method for knowledge representation (KR), with axioms, inference and modeling of theoretic semantics [5]. There is a trade-off between expressive power and decidable inference that needs to be taken into account. Description logics (the family of DLs) are various sub-sets of First Order Logic (FOL), with a variable free syntax: C vs. C(x)

10.5.1 Implementing Logics

The basic building blocks of DLs are:

- atomic concepts - Female, Person, Woman
- atomic roles - hasChild, hasFemaleRelative

Particular languages supporting DL are mainly characterized by:

- set of constructors for building complex concepts and roles from simpler ones.

- set of axioms for asserting facts about concepts, roles and individuals.

Table 10.1 shows the class constructors in OWL implementing the basic knowledge representation formalisms. Table 10.2 shows the axioms in OWL for asserting facts about concepts, roles and individuals.

10.5.2 Knowledge Bases

DL Knowledge Bases (KB) are normally separated into two parts:

TBox is a set of axioms describing structure of domain (i.e., a conceptual schema).
- Concept inclusion $C \sqsubseteq D$
- Concept equivalence $C \equiv D$
- Role inclusion $R \sqsubseteq S$

Table 10.1: OWL - Class constructors

Constructor	DL Syntax	Example	FOL Syntax
intersectionOf	$C_1 \sqcap \cdots \sqcap C_n$	Human $\sqcap$ Male	$C_1(x) \wedge \cdots \wedge C_n(x)$
unionOf	$C_1 \sqcup \cdots \sqcup C_n$	Doctor $\sqcup$ Lawyer	$C_1(x) \vee \cdots \vee C_n(x)$
complementOf	$\neg C$	$\neg$Male	$\neg C(x)$
oneOf	$\{x_1\} \sqcup \cdots \sqcup \{x_n\}$	{John} $\sqcup$ {Mary}	$x = x_1 \vee \cdots \vee x = x_n$
allValuesFrom	$\forall P.C$	$\forall$hasChild.Doctor	$\forall y.P(x,y) \rightarrow C(y)$
someValuesFrom	$\exists P.C$	$\exists$hasChild.Lawyer	$\exists y.P(x,y) \wedge C(y)$
maxCardinality	$\leqslant nP$	$\leqslant$1hasChild	$\exists^{\leqslant n} y.P(x,y)$
minCardinality	$\geqslant nP$	$\geqslant$2hasChild	$\exists^{\geqslant n} y.P(x,y)$

Table 10.2: OWL - Axioms

Axiom	DL Syntax	Example
subClassOf	$C_1 \sqsubseteq C_2$	Human $\sqsubseteq$ Animal $\sqcap$ Biped
equivalentClass	$C_1 \equiv C_2$	Man $\equiv$ Human $\sqcap$ Male
disjointWith	$C_1 \sqsubseteq \neg C_2$	Male $\sqsubseteq$ $\neg$Female
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$	{President_Bush} $\equiv$ {G_W_Bush}
differentFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$	{John} $\sqsubseteq$ $\neg${Peter}
subPropertyOf	$P_1 \sqsubseteq P_2$	hasDaughter $\sqsubseteq$ hasChild
equivalentProperty	$P_1 \equiv P_2$	cost $\equiv$ price
inverseOf	$P_1 \equiv P_2^-$	hasChild $\equiv$ hasParent$^-$
transitiveProperty	$P^+ \sqsubseteq P$	ancestor$^+$ $\sqsubseteq$ ancestor
functionalProperty	$\top \sqsubseteq 1P$	$\top \sqsubseteq \leqslant$1hasMother
inverseFunctionalProperty	$\top \sqsubseteq 1P^-$	$\top \sqsubseteq \leqslant$1hasSSN$^-$

- Role equivalence $R \equiv S$
- Role transitivity $R^+ \sqsubseteq R$

ABox is a set of axioms describing a concrete situation (data).
- Concept instantiation $x \in D$
- Role instantiation $< x, y > \in R$

This separation has no logical significance, but it may be conceptually and implementationally convenient. An OWL ontology maps to a DL Knowledge Base $\mathcal{K} =< \mathcal{T}, \mathcal{A} >$

Another important feature is the inference tasks one can perform on the knowledge base. These are listed below:

Knowledge is correct - captures intuitions
- C subsumes D w.r.t. $\mathcal{K}$ iff for every model $\mathcal{I}$ of $\mathcal{K}$, $C^I \sqsubseteq D^I$

Knowledge is minimally redundant - no unintended synonyms
- C is equivalent to D w.r.t. $\mathcal{K}$ iff for every model $\mathcal{I}$ of $\mathcal{K}$, $C^I = D^I$

Knowledge is meaningful - classes can have instances
- C is satisfiable w.r.t. $\mathcal{K}$ iff there exists some model $\mathcal{I}$ of $\mathcal{K}$ s.t. $C^I \neq \emptyset$

Querying knowledge
- x is an instance of C w.r.t. $\mathcal{K}$ iff for every model $\mathcal{I}$ of $\mathcal{K}$, $x^I \in C^I$
- $< x, y >$ is an instance of R w.r.t. $\mathcal{K}$ iff for every model $\mathcal{I}$ of $\mathcal{K}$, $(x^I, y^I) \in R^I$

Knowledge base consistency
- A knowledge base $\mathcal{K}$ is consistent iff there exists some model $\mathcal{I}$ of $\mathcal{K}$

Chapter 11

Coordination

This chapter presents the concept of coordination of mobile work and operationalize the approach towards mobile work processes.

11.1 Introduction

The need for coordination of mobile work varies with the activities and the local execution environment. In the scenarios described previously, the need for coordination is mainly related to emergent behaviors and situated actions, thus the support of coordination in ubiquitous computing environments can be looked upon accordingly. Along with automation of coordination in such environments, and the dissemination of machines and intelligent objects, a transition of implicit coordination towards explicit coordination may be required to secure the enactment of the work processes and the actors involved. This is especially important for non-human actors, since they are not capable of implicit decisions without sophisticated artificial intelligence. The challenge is how to evaluate different aspects of the world as important. Humans tend to ignore non-important events, presence, and activities if they are not directly involved or committed to the activities of others. This information filtering can be enabled for non-human actors if the context information can be related to a set of rules as a reasoning template for the different situations of work.

In a process of coordination supported by computer systems, the technology needs to have focus on **accountability**, **dependability** and **usability**. The relevance of these issue are described below.

Accountability: All actors, including computers, must be aware of their responsibilities and roles in the organization. Communication and understanding of their role and intentions for participating in the organization are essentials for a successful collaboration.

Dependability: The actors have shared risks in these environments, and are dependent of the system to not put their safety at risk when performing operations in the organization. It is also important to ensure that the non-human actors in the organization have shared loyalty towards the goal of the operation.

Usability: The use of computers in these work environments are only making the work processes more efficient if the usability is adequately developed for the user and the environment. Context information can increase the usability by providing individually adapted information, and arranges for a more customized coordination approach to each actor in the organization. Blue-collar workers are often not capable of operating regular mobile units, because their hands and other senses are focused and involved in carrying out their work. This demand for new and alternative ways of communicating.

11.2 Coordinating Operations

Mobile work requires some sort of coordination in a wide range of situations, from altering plans of operation to assigning resources to meet the demand of the organization. To create safe enactment and automation of mobile work processes it is important to identify the different coordination needs in ubiquitous computing environments. A set of simple operations demanding coordination is described below.

Request for resources: The organization requests resources available to the organization. Necessary information include role specification with a set of required characteristics and objective of operation. This process may be supported by a coordination service trying to find the best available resources for the organization. The selection should be based on policies for building a *contract* described in Jacobsen [27], involving a mutual awareness of responsibilities and privileges.

New actor enters the organization: The organization needs to identify the new actor and which role to assign. Necessary information include core competencies (available resources), previous role in equivalent working situation and possible motive for joining the organization. At the same time the new actor needs to identify the state of the working situation and gain a common understanding of the work being done and more specifically the responsibility the assigned role involve. A role is normally assigned by the environment and how the other actors regard the new arrival. The exception to this is when an actor intentionally takes a role in an organization overriding the existing policies or simply when there is no form of coordination present. A solution to cover these situations is to assign a role to every actor that enters the local execution environment simply marking non-involved actors as non-involved or with no specific privileges or responsibilities besides having to indulge privileged actors in the organization i.e. emergency vehicles.

Hand over resources: The organization hands over (gives up) resources if a request is made from outside the organization and/or its goals have been met. Identifying when the actors' goals of operation are fulfilled call for a way of monitoring the state of the work environment. When an actor has finished all planned or delegated activities, the monitoring service should disband the resource if there is a demand for its core competencies elsewhere or find an appropriate complementary role in the existing organization.

11.3 Digital Uniforms

The experience with mobile work processes and virtual organizations shows that roles are the most effective way of communicating core competencies and knowledge within the organization. The concept of **digital uniforms** emerged when analyzing the scenario of first response in Section 9.2.2. When identifying police or emergency personnel with uniforms and decorated vehicles one can extract knowledge of their role in the organization and their core competencies. The idea is to transfer this way of representing roles into other work environments such as production or assembly-line work. The concept can be related to **affordance** used in cognitive psychology, which was introduced by Gibson [20] and defined in the following way:

> "An affordance is a property of an object, or a feature of the immediate environment, that indicates how that object or feature can be interfaced with. The empty space within an open doorway, for instance, affords movement across that threshold. A couch affords the possibility of sitting down on it."

Role affordance indicates how the actor or resource can be interfaced with, in the same way the police uniform indicates control and supervision on the site of the accident and the file extension indicates the use of a file within a file system on a computer. The role knowledge can be treated as context information in the organization and stored in a knowledge base describing the attributes and reasoning rules related to the specific role.

11.4 The Future Shipyard

Taking the shipyard scenario a step further, we can describe the future operation of an emergency within the production area. More specifically, a machine is dangerously overheated which cause the human workers in the area to be in an endangered situation.

The machine in question automatically sends request for assistance when the temperature exceeds the safety limit. The limit is defined according to standards for such environments digitally uploaded from the web. The request is made from a template for irregular behavior, and is automatically routed to the actors with the role as machine supervisors. The system also performs investigation of the incident. If there are no evident answers, the system provides a calculated outline of the situation with possible reasons for the emergency. Based on situational information from the machine and the environment, the coordination system reason on possible lines of action.

At this point there are a lot of factors influencing the decision-making for coordination. The safety of human workers needs to be prioritized, and if they are evacuated, the machine can take actions for self-repair. The costs related to full shut down may affect the workflow in a destructive manner, and the chain of cause and effect needs to be analyzed by the system. The self-repair mechanisms should be related to templates securing consistency and providing previously simulated workflow. In this way the system can provide the most cost-efficient operation and at the same time securing the work environment.

In most cases, the self-repair will be performed without even notifying the supervisors, just by registering the events. Logging of activities may be the foundation for a training set improving the situation templates by simulation.

The situation involves a lot of work *behind the scenes*, including the coordinating operations described in Section 11.2. The request for resources is obvious, but as the helping actors (both human and machines) are included in the operation they need to be assigned complementary roles according to their competencies in this organization. This turns the system into an alarm central from the first response scenario in Section 8.3. Continuously monitoring the situation is important to identify new risks and keeping track of the progress.

When an incident such as this happens, the system should reset parts of the organization by assigning new roles to each of the affected actors. Building knowledge of these situations in the organization will help reducing the time of operation when the incident happens. Time may be critical both in terms of the safety of actors, and ultimately the cost of down-time in production.

11.5 Limited Resources

Maintaining a knowledge base, managing context information and reasoning over such information are resource-demanding processes. In ubiquitous computing environments it is important to keep in mind the challenges of mobile computing related to i.e. power and performance [18]:

- Communication
- Mobility
- Portability

Mobile devices have been the core of many existing context-aware systems for years. However, they often hinder the functionality in their respective systems. Limited computational resources make it difficult to build more advanced and complex system behaviors, and require a more intricate infrastructure and computing architecture. There are four constraints that are especially important to take into consideration.

Battery power: Most mobile devices are not designed to support sophisticated sensing hardware due to their battery constraint. The integrated sensors in such hardware are limited and only support basic context sensing. As the development in technology progress, the battery power on laptops and wearable computers will be become less of a constraint. However, the usability will always have to be taken into consideration as a laptop with multiple sensors may be in conflict with the convenience of use. Distribution of sensing to the environment deliberates the mobile device from the most basic services by utilizing resources with more available power.

Information storage: The knowledge in acquired context information often needs to be stored to reduce the computational costs of reacquisition. Most mobile devices have limited disk space for storing information, and therefore the first challenge is to be selective of which information needs to be stored. Second, due to possible inconsistency in sensed context information the knowledge needs to be maintained. The latter point is the most demanding, as information storage is becoming less of a constraint due to developments in technology. Responsibilities for managing historical information need to be delegated and coordinated through separation of concerns in the computer system.

Computing power: Both knowledge management and context reasoning are computation intensive processes. Mobile devices often lack CPU power and memory, and therefore should be processing only primitive context. If one choose to balance the computing power by performing more intensive reasoning on stationary computers the communication constraint will increase considerably. However, scalability is probably a bigger challenge when dealing with an intelligent environment potentially consisting of thousands of sensors capable of acquiring new information every second.

Communication: Ubiquitous computing environments are highly dynamic, and to provide secure and effective communication the actors needs to have knowledge about the other actors and the available sensors in the environment, and a common understanding of how they can interact.

Chapter 12

Architecture

This chapter relates the research to an architecture for adaptive mobile work processes under development within the research project MOWAHS.

12.1 Introduction

Adaptive Mobile Work Processes has been widely investigated within the research project MOWAHS. However, in terms of software design and implementation most of the work have been related to the managing and sensing of context information related to the surrounding environment. The goal in this report is to apply our acquired knowledge of the virtual organization domain into a software engineering component dealing with coordination and organization of mobile work processes. The coordination component will be looked upon in relation to a context-aware workflow system under development and the design will be discussed accordingly.

12.2 Architecture

The architecture proposition is specified in Hauso and Røed [22] and developed in the MOWAHS project. Figure 12.1 shows an overview of the architecture.

The scope of this report is mainly related to the **Cooperative Workflow Integration Service** (CWIS) component of the user client which will be responsible of coordination and organization of mobile work processes. The other main components of the user client **Workflow Context Integration Service** (WCIS) and **Fragment Workflow Enactment Service** (FWES) are covered in Hauso and Røed [23].

The Workflow Context Integration Service manages and distributes data gathered from different context services, and integrates the Fragment Workflow Enactment Service with the context-services and actuator-services.

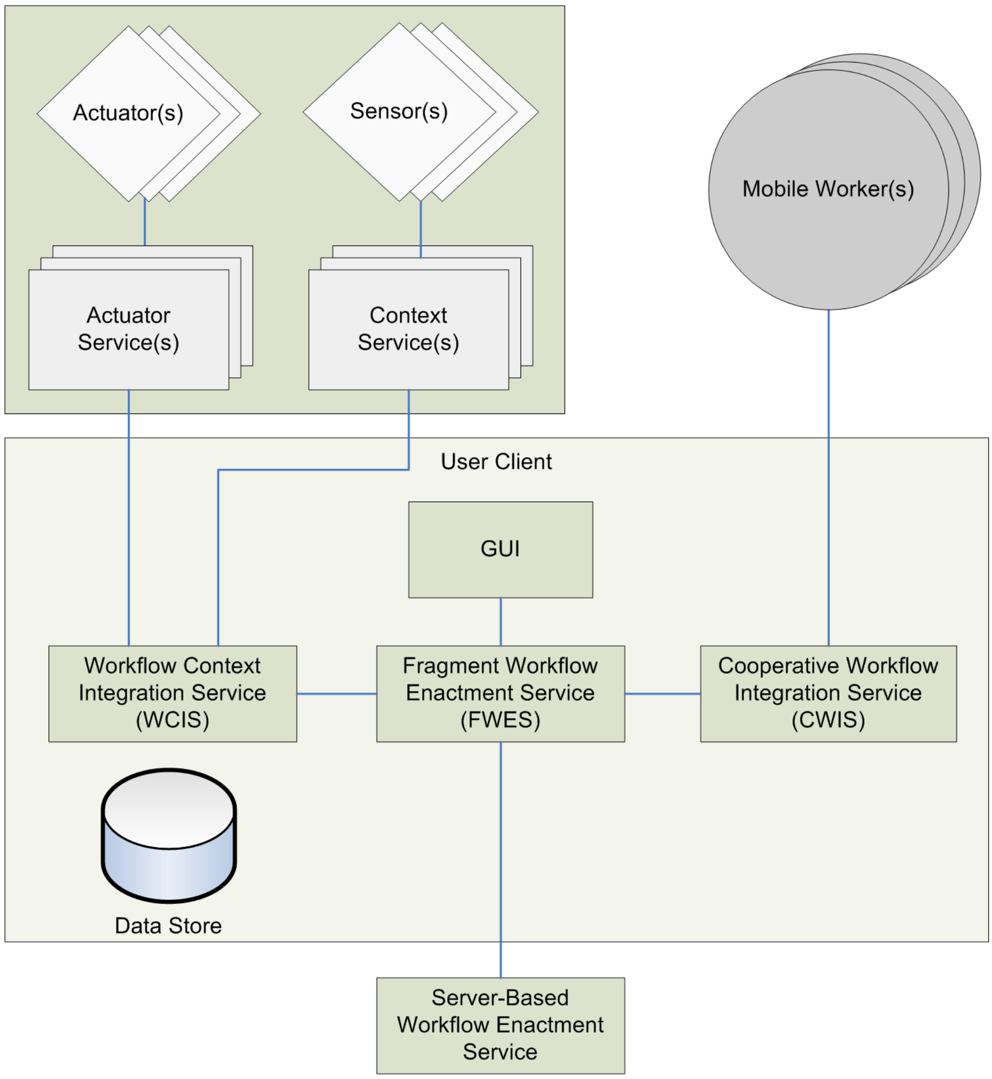

Figure 12.1: Architecture Overview

The Fragment Workflow Enactment Service is an extension of a standard workflow enactment service capable of executing workflow process fragments in addition to standard workflow processes.

12.3 Knowledge Representation

This section elaborates on the system architecture and describes how the knowledge can be stored and automatically updated according to the local execution environment.

12.3.1 Organization

The Mobile Ad Hoc Virtual Organizations are based on presence and situated work, and the formation of such dynamic organizations are either based on a demand or an opportunity to solve a common goal in a multi-actor environment. Due to the characteristics of situated work the organization of the mobile work processes must be designed according to situations. As previously discussed, the coordination needs in different situations will vary according to the participating actors and the available context information. By relating the organization to situations one can design templates to support different variations within a specific situation domain. The **situation templates** appear as world models in the coordination system, including knowledge of the organization such as participating actors and their roles, goals of operation and the involved activities, constituting enough knowledge to build a common understanding of the mobile work.

The monitoring of organizational state and work process should be closely related to the actors and the partnering of complementary resources. There are several questions that need to be answered to get an overview of the organization:

- Which actors are part of the organization?
- Why are they engaged in the work?
- How long do they need to be part of the organization?
- What has been done so far?
- What needs to be done?
- What can possibly threat the progress of work?

The latter question is particularly interesting and creates the foundation for studying **smart risk management**. This is basically context-aware risk analysis of mobile work, and could include advanced reasoning on the consequences of sensed events based on probabilities attached to the situation templates. As the number of machine workers increase, this may be a good way to determine the appropriate activities for such actors. If smart risk management is included in the coordination of mobile work, one can not only enable safe execution of activities, but analyze the state of the organization related to safety and time efficiency. Through monitoring risk it is possible to determine the probability of dangerous incidents or critical time delays of operation. Pro-actively actors can be notified of the relevant risks and the system can be prepared to handle coordination (pre-organized work processes) in such situations.

12.3.2 Actors and Roles

The most important foundation of the organizations are the actors and their roles. If all the actors have complementary core competencies the process towards a common goal is much more likely to succeed. When organizing mobile work processes it is therefore desirable to assign actors that complement the organization leading to a group of cooperative rather than competitive resources.

In the models of virtuality described in Section 3.3.1 the coordinator in the virtual broker is identified to have three roles; architect, lead operator and caretaker. Responsible for respectively the selection of suitable actors, the overall project management and maintenance, and supporting the process of "learning to cooperate and cooperate to learn". These are important aspects of coordinating mobile work and can be transferred into software engineering for automating coordination in ubiquitous computing environments.

Different ways of improving human collaboration with technology have been provided within the domain of Computer Supported Cooperative Work (CSCW) throughout the years. However, in ubiquitous computing environments the support for **spontaneous collaboration** with peer-to-peer applications forming ad hoc wireless networks is an emerging technology as described by Wang et al. [2]. The approach to supporting spontaneous collaboration is individual profiles determining the areas of interest and competencies of the actor. If an actor with matching competencies appears, the user is notified of its presence and presents different possibilities of initiating contact with the person concerned. Using profiles for representing core competencies has some challenges to it, such as out-dated profiles and the fact that all actors need to be equipped with both a mobile device and the application.

The concept of spontaneous collaboration is in fact a way of creating small mobile ad hoc virtual organizations, and the technology could be used on larger dynamic organizations for the selection of partners. At a production plant, such as the shipyard, the **competency profiles** could be used as a way of describing the available resources to the organization. While engaged in the virtual organization, the focus should be on representing roles, responsibility and privileges to facilitate autonomous coordination.

12.3.3 Knowledge Reasoning

Appendix B is included for the purpose of showing the application of OWL into knowledge representation of mobile work. The appendix contains basic examples of how context can be represented as ontologies and how the system can provide new knowledge based on advanced context reasoning. To improve understanding the code examples are related to the shipyard scenario.

12.4 Specification

This section describes the requirements specification of a coordination component and the responsibility of this component in a workflow system. The requirements are partly based on the research of Nguyen and Nødtvedt [33] within the MOWAHS project, including some requirements universal for all context-aware systems.

In the architecture described previously, this kind of component is referred to as the Workflow Context Integration Service intended for management and coordination of activities in a multi-actor environment. The coordination in question has been described as sending the state of the currently executing activity to relevant actors and possibly prepare other users for new activities to be started within a time limit. Based on our research on mobile work processes, the concept of coordination in ubiquitous computing environments will be further improved.

12.4.1 Managing Context

Managing context information is a very important part of coordinating mobile work processes. It involves three main functionalities: context acquisition, context reasoning and context sharing. These functions take care of respectively managing sensed data and information from context services, reasoning on available context information and distributing the knowledge of context to the participants in the organization. The functional requirements of this component is described below, divided into three groups corresponding to the main functionalities.

Context Acquisition

F1) Support discovery and look-up of context sources. Must be able to handle a large number of different context sources in a distributed and ad-hoc network.

F2) Support polling and subscribing mechanisms for context information retrieval from context sources and services.

F3) Support filtering of context data based on rules to translate into a common domain syntax.

F4) Support feedback and contextual updates from mobile workers.

Context Reasoning

F5) Support deducing of high-level implicit context information from low-level context data.

F6) Support reasoning on domain consistency in knowledge base.

F7) Support reasoning on knowledge correctness and redundancy.

Context Sharing

F8) Support semantic knowledge translation to all mobile workers.

F9) Support identification of significant events for the individual roles in the organization based on rules.

F10) Support broadcasting of organizational knowledge.

F11) Support updating of situation-specific domain knowledge.

12.4.2 Monitoring Coordination

Monitoring coordination in ubiquitous computing environments reflects the process of identifying coordination needs in mobile work situations and monitoring the organizational state. This involves tracking the actors and roles in the organization and monitoring the execution of activities in the mobile work processes. The functional requirements of this component is described below.

F12) Support identification of coordination needs based on events and the organizational state.

F13) Support high-level monitoring of work processes with time control.

F14) Support dismissal of coordination when the demand has been met.

F15) Support organizational learning based on patterns in coordination.

F16) Support risk analysis before activating forced coordination.

12.4.3 Performing Coordination

Performing coordination in mobile work has multiple dimensions to it, and all the described components combined constitute the concept of coordination in these organizations. However, this component is related to the actual coordination of actors in specific situations of mobile work as identified in the scenarios. This include the coordinating operations described in Section 11.2 among others. The functional requirements of this component is described below.

F17) Support role assignment based on demand and available resources.

F18) Support priority handling based on role description.

F19) Support situated planning of activities based on templates.

F20) Support activity delegation based on situated plans and events.

F21) Support forced coordination in specific situations.

12.4.4 General Requirements

This section describes the general requirements of the system applicable to all components. The list is divided into the following categories: mobility, performance and storage.

Mobility

F22) Support for physical mobility and network mobility.

F23) Support handling of unreliable communication.

F24) Support for disconnected operations and asynchronous communication.

F25) Support for session mobility.

Performance

F26) Support balancing of performance with power, outsourcing heavy reasoning tasks to stationary computing resources.

F27) Support time constraints on reasoning, enabling deduced knowledge in finite time.

Storage

F28) Provide persistent storage of rules, situation templates and domain specific role-knowledge.

F29) Support central storage of situation templates and domain knowledge.

12.4.5 Non-Functional Requirements

This section describes the non-functional requirements of the system applicable to all components.

N1) High level of responsiveness. The system must be able to respond quickly to changes in the environment, for instance when organizing emergency work processes, and should therefore support multi-threaded services.

N2) Separation of concerns. The system should provide a clear separation of concerns between the components to improve flexibility and adaptability to a large variety of mobile work situations.

12.5 Design

This section describes a high-level design of the Coordination Module based on the requirements specification.

12.5.1 Overview

Figure 12.2 shows the overview of the coordination module interacting both with context contributors and mobile workers.

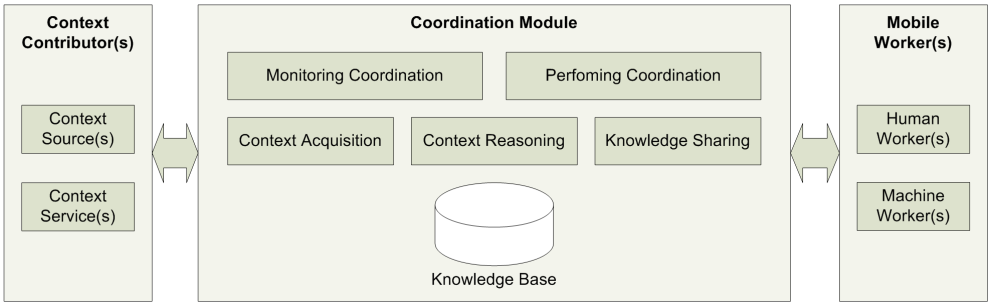

Figure 12.2: Coordination Module Overview

The coordination module design consists of separate components meeting the requirements described previously. The foundation of this module is a **Knowledge Base** consisting of situation templates and instances describing the immediate environment.

The **Context Acquisition** senses and manages context from the environment, while the **Context Reasoning** provides new implicit context information as organizational knowledge. The **Knowledge Sharing** distributes knowledge and semantic context information to the actors in the organization.

Furthermore, **Monitoring Coordination** is responsible for identifying events leading to coordination need, while **Performing Coordination** is responsible for solving coordination tasks in the organization, dealing with competitive resources and sending actuation orders to mobile workers.

The **Mobile Workers** may in fact appear as important context contributors in addition to carrying out the mobile work processes, so their behavior and feedback to the system will be handled as context acquisition.

12.5.2 Description of Components

The design of the coordination module is described in three layers with the knowledge base as the foundation, the context management components in the middle, and the two coordination components using interfaces from the context management components.

Knowledge Base
The knowledge base consists of ontologies describing all instances of context, and templates to describe the rules to which the work is organized in different situations.

Context Acquisition
The context acquisition component includes interfaces for acquiring context information from the environment and actors in the organization. The context information is either *active* (requested by an actor or the system), or *passive* (broadcasted to the system). The component needs interfaces for both kind of context acquisition. The active information is prepared semantically for the actor who made the request, while passive information is analyzed to determine whether it is important or not for the organization, and is used to update the world model.

Context Reasoning
The context reasoning component includes several inference methods supported by the ontology language, and interfaces for customizing rules related to the situations. These can be used by other components in the system to deduce new knowledge, monitor the organization and perform custom analyzes on the knowledge base.

Knowledge Sharing
The knowledge sharing component includes interfaces for communicating messages from the coordination module to the environment and mobile workers. This can be used to transmit actuation orders, sharing organizational knowledge, and provide feedback to mobile workers (i.e. responses with context information).

Monitoring Coordination
The monitoring coordination component uses interfaces from the context management layer to perform its tasks. This involves monitoring the organizational and process state, based on situation templates from the knowledge base, and continuously supervising the dynamics and progress of the mobile work processes. The monitoring of activities and workflow fragments may be partly supported by available workflow services (cf. the CAGIS[1] project).

Performing Coordination
The performing coordination component also uses interfaces from the context management layer to perform its tasks. It is requesting necessary information from the knowledge base, solving coordination operations, and performing coordination by distributing information and orders to the mobile workers in the organization. Any changes and organizational restructuring are reported to the monitoring coordination component which updates the state of the organization and new knowledge in the knowledge base.

[1]Cooperative Agent in Global Information Space: `http://www.idi.ntnu.no/~cagis/`

Part IV

Discussion and Conclusion

Chapter 13

Discussion

This chapter evaluates the work in this thesis and provides ideas and suggestions for future work.

13.1 Evaluation of Research Questions

The research questions have been partially answered through the literature study and the discussions of an architecture supporting coordination in ubiquitous computing environments.

13.1.1 RQ1

How can our knowledge of VOs be utilized in ubiquitous environments?

The organizational approach to examining mobile work seems to be appropriate in the way the dynamic characteristics of a virtual organization fits the formation of cooperative groups in a mobile setting. The most important knowledge from the virtual organization domain is the way actors with complementary skills join together in an effort towards a common goal. The organization view provides insights to how the roles in ubiquitous environments should be handled and suggestions for coordination.

13.1.2 RQ2

How can we coordinate actors/roles in these environments?

The study of mobile ad hoc virtual organizations has shown different situations where coordination is needed to improve the mobile work processes. The different kinds of required coordination laid the foundation for discussing automated coordination methods. This research provides suggestions to which functionalities such a system should support, with focus on the selection of partners, coordinating activities and handling critical situations.

The coordination of actors and roles in ubiquitous computing environments should be related to situations which demands coordination, and performed from an organizational view. Firstly, knowledge from virtual organizations shows that it is important to have an overview of the individual core competencies and motives for taking part in the mobile work. It is important to monitor when the different actors' goals have been met and take actions accordingly to disband them from the organization. Secondly, complementary roles should be assigned to all actors in the organization, using them as key information in coordinating operations related to rules and privileges associated with the specific roles through digital uniforms.

13.1.3 RQ3

How can we represent core competencies as context?

The study of context in these organizations has a main focus on the actors and their roles. Support of VO formation should take into account the core competencies and available resources. Different approaches to representing this kind of knowledge is discussed including competency profiles derived from spontaneous collaboration.

Using profiles for representing the competencies of an actor can enable software to acquire relevant skills and resources based on the demand from the organization. This presents various possibilities, such as autonomous adaptation of profiles according the characteristics of the organization the actor is approaching. More specifically, the competencies may have to be translated to the syntax of the situation to prevent incompatibility. This can be solved by running a situation-specific reasoning engine. All reasoning tasks will propose challenges to performance, which is not addressed in detail in this thesis.

13.1.4 RQ4

How can we represent organizational and process state as context?

Monitoring the organizational and process state is a challenging issue due to the dynamics of the actors and their goals. The organizational scope is limited to specific situations, each described by situation templates in a knowledge base used for coordination. The templates will be based on ontologies describing a world model within a situation domain.

The advantages of using such an approach is the ability to use the nature of reasoning on the consistency of information in addition to representing context with an expressive syntax. Among the challenges, are keeping the information up to date, and track the individual actors' motives and contribution to the work. The idea of including smart risk management will, based on sensed context information, enable probabilistic prediction of events and occurrences leading to threat of progress.

13.1.5 Summary

This section summarizes the evaluation of the research questions. Table 13.1 shows an overview of which sections in this thesis that are important in reviewing the research questions.

Table 13.1: Evaluation of Research Questions

Research Question	Reviewed in
RQ1	Section 3.4, 6.3, 9.2 and 12.3
RQ2	Section 3.4, 9.2, 11.2, 11.4 and 12.3
RQ3	Section 9.2, 11.2, 11.3 and 12.3
RQ4	Section 10.3, 11.2 and 12.3

13.2 Evaluation of Architecture

The described architecture is included in our research project to show a way of organizing software components to meet some of the challenges to supporting mobile and smart work processes.

The discussions around the software design partly meet the challenges in implementing context-aware computer systems described in Section 7.5. The main focus has been on meeting the challenges dealing with knowledge representation and methods for reducing the overhead of context information (C1-C7). The frequency of context information consultation has been related to monitoring coordination. The minimal services an environment has to provide (C8), and the importance of historical context (C9), are discussed throughout the thesis focusing on extracting the most important context information in mobile work, and analyzing context dependencies in different scenarios. The last challenges, related to location (C10-C12), have not be discussed in detail beyond describing the need for location information.

The choice of using ontologies to describe the situation domains and first order logic, carries with it some limitations to the system. The fact that the reasoning engine deduce new knowledge, and at the same time ensures consistency and correctness of information, leads to a lot of information needed to be stored in the knowledge base. This could be a negative aspect when important information are extracted in time-critical operations. The domains could be represented with less information in a custom defined XML scheme, however not incorporating the inference tasks provided by the ontology language. It is critical that the information is correct, and interpreted correctly by the different actors in the organization. The use of reasoning mechanisms are therefore valuable to enable safe enactment of mobile work processes.

The context management components are necessary to support the responsibilities of the monitoring and performing coordination components. The thesis provides suggestions to how these coordination components should function on a conceptually basis. The descriptions and requirements are based on the organizational approach which are the foundation of the research project.

The design could be adapted to integration with the proposed architecture described in Section 12.2 implementing an interface for interpreting the workflow fragments in XPDL[1] format. However, the focus in our architectural approach has been to describe the fundamental requirements that need to be supported by a coordination module for mobile work processes, and incorporating the virtual organization mind into the software design. It has been more feasible to describe such a system independent of the previously proposed architecture, based on the conditions for our research project.

13.3 Evaluation of Research Method

The use of empirical methods has proven valuable in this research project, through the field study and exploration of different mobile work domains. The engineering approach has been used in a small scale as validation of the proposed technology for representing knowledge in the virtual organizations. The analytical method has helped us in transferring the knowledge of organizational structures to the mobile work situations.

The literature study provided a deeper understanding of ubiquitous computing and what it means for a system to be context-aware. Furthermore, workflow and activity theory provided insights to work processes and the basic prerequisites of planning and execution of activities.

The scenario analysis points out specific situations of mobile work that emphasizes the need for coordination in ubiquitous computing environments. This has lead the research to a situation-based view on mobile work and virtual organizations. The scenarios presented in this thesis also act as application examples for new technology and the modeling of knowledge.

The architectural proposal is included as a discussion of the theoretical knowledge derived from our research. The suggestions to software engineering solutions of coordinating mobile work complements the work performed by fellow participants of the MOWAHS project. The results of this thesis should provide new ideas to the mobile work domain and suggestions for future work is presented in the next section.

[1]XPDL: XML Process Definition Language

13.4 Future Work

This section presents suggestions for future work continuing the research in this thesis and summarizing emerged concepts for further examination.

Situation Templates
There should be developed example situation templates as ontologies to test context reasoning and updating of world models in dynamic environments. This could be integrated with the existing architecture provided through the MOWAHS project implementing coordinating operations described in this thesis.

Smart Risk Management
The idea should be further examined involving design and prototype development to evaluate the concept, and find the best practice for using probabilities and prediction in ubiquitous computing environments.

Digital Uniforms
The idea of role affordance towards actors operating in ubiquitous computing environments will support spontaneous collaboration and facilitate the formation of virtual organizations. The concept should be further developed, and different technologies for implementation may be evaluated for a prototype.

Social Aspects
The social implications of using automated coordination of mobile work should be examined thoroughly, taking into account negative organizational effects on dynamics and the mobility of operation.

Chapter 14

Conclusion

This chapter presents the conclusions of the research and summarizes the discussions provided through the thesis.

14.1 Mobile Work as Context

Throughout the research project we have explored different aspects of facilitating mobile work with context information. The approach has been from an organizational perspective using knowledge of virtual organizations as the foundation for analyzing mobile work processes in a multi-actor ubiquitous computing environment.

When we look at mobile work as virtual organizations, the constellations or partnering of different actors with core competencies are situation specific. This means that their contribution to the organization and their goals of operation are adapted to a certain occurrence of situated actions. The role of the actor is determined by the organization based on a demand for resources or filtered out as a result of competitive motives. The role of the participating actors in the organization is the key knowledge in organizing mobile work processes, and is the foundation for automated coordination in these environments.

14.2 Coordination of Mobile Work

This thesis has aimed to discuss how mobile work processes can be coordinated by looking at the work situations as virtual organizations with corresponding organizational characteristics. Based on the analysis of simple mobile work scenarios we have extracted knowledge of how different situations demand coordination. Furthermore, we have identified the importance of work process information in monitoring coordination needs, and provided suggestions to how such information could be acquired and represented as knowledge to the organization.

The final part of the contribution is an architecture proposition for a coordination module for mobile work processes. By using ontologies we can transfer the semantic web into ubiquitous computing and enable efficient ways of reasoning on context information and take actions based on rules of description logics. Specific situations will be facilitated by situation templates for monitoring the virtual organizations of mobile work.

Digital uniforms have been proposed as a new concept of supporting both implicit and explicit coordination of mobile work. Role affordance can be enabled by assigning a digital uniform to all actors (both humans and machines) in the organization. The uniform indicates how the actor or resource can be interfaced with, and its privileges and responsibilities can be intuitively interpreted by the other actors in the organization in the same way the police uniform indicates control and supervision in the first response scenario.

The aim has been to provide some new ideas to the field of pervasive and ubiquitous computing, and contributing in coupling the research areas of virtual organizations to ubiquitous computing. There are still several challenges related to mobility and limited resources, and before ubiquitous computing can be truly realized one have to take into account the social aspects of enabling these technologies. However, by providing specialized prototypes and discussing important issues of mobile work, we can assess and improve work processes in certain work environments acting as pilot scenarios for the future.

Part V

Appendix

Appendix A

Glossary

Actuator: An object that can perform some action. It may be a physical object, an application invocation, or something more abstract like a workflow activity.

Activity: A description of a piece of work that forms one logical step within a process. An activity may be a manual activity, which does not support computer automation, or a workflow (automated) activity. A workflow activity requires human and/or machine resources(s) to support process execution; where human resource is required an activity is allocated to a workflow participant.

Affordance: An affordance is a property of an object, or a feature of the immediate environment, that indicates how that object or feature can be interfaced with. The empty space within an open doorway, for instance, affords movement across that threshold. A couch affords the possibility of sitting down on it.

Business Process: A set of one or more linked procedures or activities which collectively realize a business objective or policy goal, normally within the context of an organizational structure defining functional roles and relationships.

MOWAHS: MObile Work Across Heterogeneous Systems.

Ontology: An ontology is the product of an attempt to formulate an exhaustive and rigorous conceptual schema about a domain. Typically a hierarchical data structure containing all the relevant entities and their relationships and rules within that domain.

OWL: Web Ontology Language.

Process Definition: The representation of a business process in a form which supports automated manipulation, such as modeling, or enactment by a workflow management system. The process definition consists of a network of activities and their relationships, criteria to indicate the start and termination of the process, and information about the individual activities, such as participants, associated IT applications and data, etc.

Process Instance: The representation of a single enactment of a process, or activity within a process, including its associated data. Each instance represents a separate thread of execution of the process or activity, which may be controlled independently and will have its own internal state and externally visible identity, which may be used as a handle, for example, to record or retrieve audit data relating to the individual enactment.

Sentient Object: Mobile, intelligent software component which is able to sense its environment via sensors and react to sensed information via actuators.

Ubiquitous Computing: An environment where computers are integrated seamlessly into the environment, are aware of their surroundings, and can adapt their behavior accordingly.

Workflow: The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.

Workflow Management System: A system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of IT tools and applications.

Appendix B

OWL Code

This appendix presents examples of OWL code referenced from the report to show how the language can be used. To improve the understanding all examples are related to the Shipyard scenario described in Section 8.2.

B.1 Representation of Location

The example of representing location in OWL is shown in Listing B.1. The class `Location` is defined as a subclass of `ContextEntity`. Further we have defined two functional properties related to position coordinates, respectively `longitude` and `latitude`.

Related to the Shipyard scenario we have defined two subclasses of `Location` which are disjoint to each other, `InsideProductionArea` and `OutsideProductionArea`. Finally we have defined a transitive property `locatedIn` which shows a relation between an `Entity` (i.e. human, machine, thing) and a `Location`.

Listing B.1: Location Representation

```
<owl:Class rdf:ID="ContextEntity"/>

<owl:Class rdf:ID="Location"/>
    <rdfs:subClassOf rdf:resource="#ContextEntity"/>
</owl:Class>

<owl:ObjectProperty rdf:ID="longitude">
    <rdf:type rdf:resource="functionalProperty">
    <rdfs:domain rdf:resource="#Location">
    <rdfs:range rdf:resource="xsd:double">
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="latitude">
    <rdf:type rdf:resource="functionalProperty">
    <rdfs:domain rdf:resource="#Location">
    <rdfs:range rdf:resource="xsd:double">
```

```
</owl:ObjectProperty>

<owl:Class rdf:ID="InsideProductionArea">
    <rdfs:subClassOf rdf:resource="#Location"/>
    <owl:disjointWith rdf:resource="#OutsideProductionArea"/>
</owl:Class>

<owl:ObjectProperty rdf:ID="locatedIn">
    <rdf:type="owl:transitiveProperty"/>
    <rdfs:domain rdf:resource="#Entity"/>
    <rdfs:range rdf:resource="#Location"/>
    <owl:inverseOf rdf:resource="#contains"/>
</owl:ObjectProperty>
```

B.2 Reasoning on Location

Following the previous example we describe an example of context reasoning on location shown in Listing B.2. The class `Actor` is defined as a subclass of `ContextEntity`. Further we have defined two subclasses of `Actor`, respectively `Human` and `Machine`. We have also two instances of actors, one `Human` and one `Machine`, both located in `WeldingRoom`. The `WeldingRoom` is an instance of a `Room` and is located in `InsideProductionArea`.

Listing B.2: Location Reasoning - Explicit Context

```
<owl:Class rdf:ID="Actor"/>
    <rdfs:subClassOf rdf:resource="#Entity"/>
</owl:Class>

<owl:Class rdf:ID="Human"/>
    <rdfs:subClassOf rdf:resource="#Actor"/>
</owl:Class>

<owl:Class rdf:ID="Machine"/>
    <rdfs:subClassOf rdf:resource="#Actor"/>
</owl:Class>

<Human rdf:ID="IdentifiedHuman">
    <locatedIn rdf:resource="#WeldingRoom"/>
</Human>

<Machine rdf:ID="WeldingRobot">
    <locatedIn rdf:resource="#WeldingRoom"/>
</Machine>

<Room rdf:ID"WeldingRoom">
    <locatedIn rdf:resource="#InsideProductionArea"/>
</Room>
```

Based on the explicit context described above one can perform context reasoning to provide new implicit context. Listing B.3 shows an example of possible results from context reasoning. Since the `WeldingRoom` is located in `InsideProductionArea`, the actors located in the `WeldingRoom` is therefore also located in `InsideProductionArea`. The instance of `Building` named `InsideProductionArea` is now known to contain a `WeldingRoom` and two actors `IdentifiedHuman` and `WeldingRobot`. More specifically the `WeldingRoom` contains the two actors.

Listing B.3: Location Reasoning - Implicit Context

```
<Human rdf:ID="IdentifiedHuman">
    <locatedIn rdf:resource="#InsideProductionArea"/>
</Human>

<Machine rdf:ID="WeldingRobot"/>
    <locatedIn rdf:resource="#InsideProductionArea"/>
</Machine>

<Building rdf:ID="InsideProductionArea">
    <contains rdf:resource="#WeldingRoom"/>
    <contains rdf:resource="#IdentifiedHuman"/>
    <contains rdf:resource="#WeldingRobot"/>
</Building>

<Room rdf:ID="WeldingRoom">
    <contains rdf:ID="#IdentifiedHuman"/>
    <contains rdf:ID="#WeldingRobot"/>
</Room>
```

B.3 Advanced Context Reasoning

The example of more advanced context reasoning based on description logics is shown in Listing B.4. If the `WeldingRoom` contains an instance of `Human` and an instance of `Machine`, reasoning with the knowledge base can determine new and more advanced context information such as activity, the role of an actor or even the estimated time of finishing the work process. This kind of reasoning is based on user defined rules adapted to the specific situation.

If there is a `Human` present in the `WeldingRoom` in addition to the `Machine`, **and** the `WeldingRobot` is *Active*, the activity can be identified as *Welding*. This is possible to deduce if the knowledge base contains a rule stating that the `WeldingRobot` needs to be *started* **and** *operated* by a `Human`. Further we can deduce the role of the `Human` based on the same rule, that the `IdentifiedHuman` has the role of *operationSupervisor*. As an additional enhancement of the ontology, one can register the *time* when the `WeldingRobot` turned *Active*, and based on a set of normal execution schedules in the actual production environment it is possible to deduce an estimated time of finishing the activity.

Listing B.4: Activity Reasoning

```
<Activity rdf:ID="Welding">
    <owl:intersectionOf rdf:parseType="Collection">
```

```
        <Human rdf:ID="IdentifiedHuman">
            <locatedIn rdf:resource="#WeldingRoom"/>
        </Human>
        <Machine rdf:ID="WeldingRobot">
            <owl:Restriction>
                <owl:hasValue rdf:resource="#Active"/>
            </owl:Restriction>
        </Machine>
    </owl:intersectionOf>
</Activity>
```

Bibliography

[1] Michael Adams, David Edmond, and Arthur H. M. ter Hofstede. The application of activity theory to dynamic workflow adaptation issues. In *The Seventh Pacific Asia Conference on Information Systems (PACIS-2003)*, pages 1836–1852, 2003.

[2] Alf Inge Wang and Carl-Fredrik Sørensen and Thomas Fossum. Mobile Peer-to-Peer Technology used to Promote Spontaneous Collaboration. To be published.

[3] Rob Allen. Workflow: An Introduction. In Rob Allen, editor, *Workflow Handbook 2001*, pages 15–38. WfMC, 2001.

[4] Roy L. Ashok and Dharma P. Agrawal. Next-Generation Wearable Networks. *Computer*, 36(11):31–39, November 2003.

[5] Franz Baader and Werner Nutt. Basic description logics. In *The description logic handbook: theory, implementation, and applications*, pages 43–95. Cambridge University Press, 2003.

[6] Jakob E. Bardram. Plans as Situated Action: An Activity Theory Approach to Workflow Systems. In *5th European Conference on Computer Supported Cooperative Work*, Lancaster University, UK, 7-11 September 1997. Kluwer Academic Publishers.

[7] Tim Berners-Lee, James Hendler, and Ora Lassila. The semantic web. *Scientific American*, 284(5), 2001.

[8] René M. Bultje and Jacoliene van Wijk. Taxonomy of Virtual Organisations, based on definitions, characteristics and typology. *VoNet: The Newsletter @ http://www.virtual-organization.net*, 2(3):7–20, 1998.

[9] Janice Burn, Peter Marshall, and Martyn Wild. Managing knowledge for strategic advantage in the virtual organisation. In *SIGCPR '99: Proceedings of the 1999 ACM SIGCPR conference on Computer personnel research*, pages 19–26. ACM Press, 1999.

[10] Janice M. Burn and Colin Ash. Managing Knowledge for Strategic Advantages in the Virtual Organization. In Yogesh Malhotra, editor, *Knowledge Management and Virtual Organizations*, pages 144–161. Idea Group Publishing, 2000.

[11] J. A. Byrne. The virtual corporation. *Business Week*, pages 98–102, February 8, 1993.

[12] Carl-Fredrik Sørensen and Alf Inge Wang and Reidar Conradi. Support of Smart Work Processes in Context Rich Environments. To be published.

[13] Harry Chen, Tim Finin, and Anupam Joshi. An Ontology for Context-Aware Pervasive Computing Environments. *Special Issue on Ontologies for Distributed Systems, Knowledge Engineering Review*, 18(3):197–207, May 2004.

[14] The Workflow Management Coalition. Workflow Management Coalition - Terminology & Glossary. Technical report, The Workflow Management Coalition (WfMC), February 1999. Document Number WFMC-TC-1011.

[15] William H. Davidow and Michael S. Malone. *The Virtual Corporation: Structuring and Revitalizing the Corporation for 21st Century.* Harper Business, New York, 1992.

[16] Anind K. Dey and Gregory D. Abowd. Towards a Better Understanding of Context and Context-Awareness. In *Workshop on The What, Who, Where, When, and How of Context-Awareness, as part of the 2000 Conference on Human Factors in Computing Systems (CHI 2000)*, The Hague, The Netherlands, April 2000. ACM Press. Also GVU Technical Report GIT-GVU-99-22.

[17] Adrian Fitzpatrick, Gregory Biegel, Siobhán Clarke, and Vinny Cahill. Towards a Sentient Object Model. In *Workshop on Engineering Context-Aware Object Oriented Systems and Environments (ECOOSE)*, Seattle, WA, USA, November 2002.

[18] George H. Forman and John Zahorjan. The challenges of mobile computing. *Computer*, 27(4):38–47, 1994.

[19] Martin Fowler and Kendall Scott. *UML distilled (2nd ed.): a brief guide to the standard object modeling language.* Addison-Wesley Longman Publishing Co., Inc., 2000.

[20] James J. Gibson. *The senses Considered as Perceptual Systems.* Houghton Mifflin, Boston, 1966.

[21] R.L. Glass, I. Vessey, and V. Ramesh. Research in software engineering: an analysis of the literature. *Information and Software Technology*, 44(8):491–506, 2002.

[22] Frode Hauso and Øivind Røed. Adaptive Mobile Work Processes. Technical report, Department of Computer and Information Science, Norwegian University of Science and Technology, 2004.

[23] Frode Hauso and Øivind Røed. Adaptive Mobile Work Processes. Technical report, Department of Computer and Information Science, Norwegian University of Science and Technology, 2005.

[24] Jason Hill, Mike Horton, Ralph Kling, and Lakshman Krishnamurthy. The Platforms Enabling Wireless Sensor Networks. *Communications of the ACM*, 47(6):41–46, 2004.

[25] David Hollingsworth. The Workflow Management Coalition – The Workflow Reference Model. Technical report, The Workflow Management Coalition (WfMC), January 1995. Document Number WFMC-TC00-1003, version 1.1.

[26] Ian Horrocks. Daml+oil: A reason-able web ontology language. In *EDBT '02: Proceedings of the 8th International Conference on Extending Database Technology*, pages 2–13, London, UK, 2002. Springer-Verlag.

[27] Kristoffer Jacobsen. A Study of Virtual Organizations - in mobile computing environments. Technical report, Department of Computer and Information Science, Norwegian University of Science and Technology, 2004.

[28] Kari Kuutti. Activity theory as a potential framework for human-computer interaction research. In Bonnie A. Nardi, editor, *Context and Consciousness: Activity Theory and Human-Computer Interaction*, pages 17–44. MIT Press, 1995.

[29] Kalle Lyytinen and Youngjin Yoo. Issues and challenges in ubiquitous computing. *Communications of the ACM*, 45(12):62–65, December 2002.

[30] Raymond E. Miles and Charles C. Snow. Organisations: New Concepts for New Forms. *California Management Review*, 28(3):62–73, 1986.

[31] Abbe Mowshowitz. Social dimensions of office automation. *Advances in Computers*, 25:335–404, 1986.

[32] Bonnie A. Nardi. Studying Context: A Comparison of Activity Theory, Situated Action Model, and Distributed Cognition. In Bonnie A. Nardi, editor, *Context and Consciousness: Activity Theory and Human-Computer Interaction*, pages 69–102. MIT Press, 1995.

[33] Jon Ole Nødtvedt and Man Hoang Nguyen. Mobility and context-awareness in workflow systems. Technical report, Department of Computer and Information Science, Norwegian University of Science and Technology, 2004.

[34] Jonathan W. Palmer and Cheri Speier. A typology of virtual organizations: An empirical study. In *Proceedings of the Association for Informations Systems 1997 Americas Conference*, August 15-17, 1997.

[35] Thomas F. La Porta, Krishan K. Sabnani, and Richard D. Gitlin. Challenges for Nomadic Computing: Mobility Management and Wireless Communications. *Mobile Networks and Applications*, 1(1):3–16, 1996.

[36] W. Saabel, T. Werduijn, L. Hagdorn, and K. Kumar. A model of virtual organisation: a structure and process perspective. *eJoV - Electronic Journal of Organizational Virtualness*, 4(1):1–17, 2002.

[37] M. Satyanarayanan. Pervasive Computing: Vision and Challenges. *IEEE Personal Communications*, 8(4):10–17, August 2001.

[38] M. Satyanarayanan. Challenges in Implementing a Context-Aware System. *IEEE Pervasive Computing*, 1(3):2–2, July-September 2002.

[39] M. Satyanarayanan. Of Smart Dust and Brilliant Rocks. *IEEE Pervasive Computing*, 2(4):2–4, October-December 2003.

[40] B. Schilit and M. Theimer. Disseminating Active Map Information to Mobile Hosts. *IEEE Network*, 8(5):22–32, 1994.

[41] Carolyn B. Seaman. Qualitative Methods in Empirical Studies of Software Engineering. *IEEE Transactions on Software Engineering*, 25(4):557–572, July/August 1999.

[42] Charles C. Snow, Raymond E. Miles, and H. J. Coleman. Managing the 21th century network organization. *Ogranizational Dynamics*, 20(3):5–16, 1992.

[43] Alistair Sutcliffe. Scenario-based requirements analysis. *Requirements Engineering*, 3(1):48–65, 1998.

[44] Lev S. Vygotskij. *Mind and Society*. Harvard University Press, Cambridge, MA, USA, 1978.

[45] Mark Weiser. The Computer for the 21st Century. *IEEE Pervasive Computing*, 1(1):18–25, January-March 2002. Reprinted from Scientific American, 1991.

[46] World Wide Web Consortium. OWL Web Ontology Language Overview. http://www.w3.org/TR/owl-features/, 2004.

[47] World Wide Web Consortium. RDF/XML Syntax Specification. http://www.w3.org/TR/rdf-syntax-grammar/, 2004.

[48] Marvin V. Zelkowitz and Dolores R. Wallace. Experimental Models for Validating Technology. *Computer*, 31(5):23–31, May 1998.