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Surfing the Next Wave: Design and Implementation Challenges of Ubiquitous Computing

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SURFING THE NEXT WAVE: DESIGN AND IMPLEMENTATION CHALLENGES OF UBIQUITOUS COMPUTING ENVIRONMENTS

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ABSTRACT

As computing becomes more mobile and pervasive, designing and implementing ubiquitous computing environments emerge as key challenges for information systems research and practice. The four short papers in this article report the highlights of the second Ubiquitous Computing Workshop at Case Western Reserve University in October 2003. The objectives of the papers are to set up a research agenda in this emerging interdisciplinary field, to share current levels of understanding of leading edge research topics, and to create cumulative research streams in this field.

Keywords: ubiquitous computing, design, implementation

Editor's Note: This paper consists of an overview of the second Ubiquitous Computing Workshop by its organizers, Kalle Lyytinen and Youngjin Yoo, followed by four papers summarizing its four major working groups. The four papers were prepared and can be read independently. They are not integrated.

I. INTRODUCTION

Computing is becoming both mobile and pervasive [Lyytinen and Yoo 2002a]. A knowledge worker's use of computing and communication services is no longer limited to solitary moments at an office desk. Instead, it extends to all aspects of social life, transcending the traditional boundary of work and leisure. Increasingly, organizational work processes and tasks are mediated through computing devices that are embedded in the physical spaces or move with workers. Unlike traditional computing devices that perform dedicated tasks, ubiquitous devices perform diverse services using heterogeneous resources. Consequently, the experience of managing and organizing in the future will involve multifaceted engagements with an "intelligent" computing environment through a rich array of computing utilities including desktop devices, mobile communicators, digital assistants, wrist watches, game consoles, clothing, consumer electronics (e.g., TVs, radios, refrigerators), cars, Radio Frequency Identification Tags (RFIDs) and motes, just to name a few. These engagements will accelerate digitization of all type of information leading to new forms of services, organization, and strategy based on anytime, any place computing.

Designing and implementing ubiquitous computing environments will be radically different from traditional desktop computing environments. Novel technical, social, and organizational challenges will need to be addressed at all levels – individuals, teams, organizations, and society – and many old problems need to be revisited in light of the ubiquity of computing in our lives. We argued previously that implementing ubiquitous computing requires implementing and managing two layers of computing capability: infrastructure and services [Lyytinen and Yoo 2002b]. Both present new social and technical challenges.

New forms of digital services will be invented for existing business processes and, at the same time, new forms of organizational processes and practices will emerge as a result of experimenting with ubiquitous computing. As we already witness in the mobile phone industry, the availability and provision of ubiquitous computing services will destroy old industries and create new ones that transcend traditional industry boundaries.

The provisioning of digital service will require a large-scale infrastructure. Such an infrastructure poses complex technical challenges for scalability, reliability, availability, and security and creates new social and economic challenges of governance, ownership, privacy, and economic value. The emergence of ubiquitous computing services and the evolution of infrastructure will likely be reciprocally dependent and dynamic, covering both social and technical domains.

We organized the second Ubiquitous Computing Workshop at Case Western Reserve University between October 24 and 26, 2003 to discuss these issues[1]. Approximately 50 researchers from academia and industry were invited. The group included researchers with an interest either in the technical or the social issues surrounding this emerging field. The goal of the workshop was to discuss the dawning social and technical challenges of designing and implementing ubiquitous computing services and infrastructure. The participants were grouped in four smaller working groups. Each group focused on one of the four sub-topics:

- platform of ubiquitous computing,
- design of ubiquitous applications and services,
- impacts of ubiquitous computing, and
- social issues around ubiquitous computing.

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[1] The first Ubiquitous Computing Workshop, Exploring within the Next Wave: The Design and Exploration of Ubiquitous Computing Environments was held from October 26 to 28, 2001 (http://weatherhead.cwru.edu/pervasive/2001). The reports from the first workshop were published in the December 2002 issue of the *Communication of ACM*.

Each working group heard presentations by their members and carried out focused discussions around emerging new topics in the area[2]. The four short papers in this article report the highlights of these rich explorations. They are presented here to describe the further research agenda in this emerging important field, to share current levels of understanding of leading edge research topics, and to create cumulative research streams in this new research arena.

The first paper, by Varshney (Section II), summarizes the results of the working group that explored new technical platforms of ubiquitous computing necessary to build sound infrastructure. The paper identifies six emerging issues that need to be tackled when implementing ubiquitous computing infrastructures. The second paper, by Ackerman (Section III), summarizes the discussions of the working group that deal with the design of ubiquitous computing applications and services. The three key issues summarized by the group show that the key challenges in designing ubiquitous computing not only include technical issues related to the infrastructure, but also social and organizational issues. The third paper, by Davis (Section IV), is the summary of the findings of the working group on individual and organizational impacts of ubiquitous computing. The group identified four high impact areas of ubiquitous computing in business and management. Finally, the paper by Avital, et al. (Section V) is a summary of the working group on societal and organizational issues in ubiquitous computing. The group identified seven broad socio-technical issues that are important for furthering ubiquitous computing research.

We conclude our report with four key themes that emerged from these reports (Section VI).

REFERENCES FOR SECTION I

Lyytinen, K. and Yoo, Y. (2002a) "Issues and Challenges in Ubiquitous Computing," *Communications of the ACM* (45)12, pp. 63-65.

Lyytinen, K. and Yoo, Y. (2002b) "The Next Wave of Nomadic Computing," *Information Systems Research* (13)4, pp. 377-388.

II. TECHNOLOGY ISSUES IN UBIQUITOUS COMPUTING

Upkar Varshney
Georgia State University

One way to define ubiquitous computing is “any-time” “any-where” access to computing resources. The term “pervasive computing” is similar except that it implies that computing will become part of everything and will be so prevalent that most people would not even notice its presence. Ubiquitous computing becomes possible by many advances in networking, databases, and related areas (Figure 1). In this paper, we look into the following technology-oriented issues in ubiquitous computing:

1. Application Issues
2. Networking and Access Issues
3. Data Issues
4. Security Issues
5. Impact of ubiquitous computing technologies
6. Other related issues

[2] Papers, presentations, and video clips from the workshop are available at http://weatherhead.cwru.edu/pervasive.

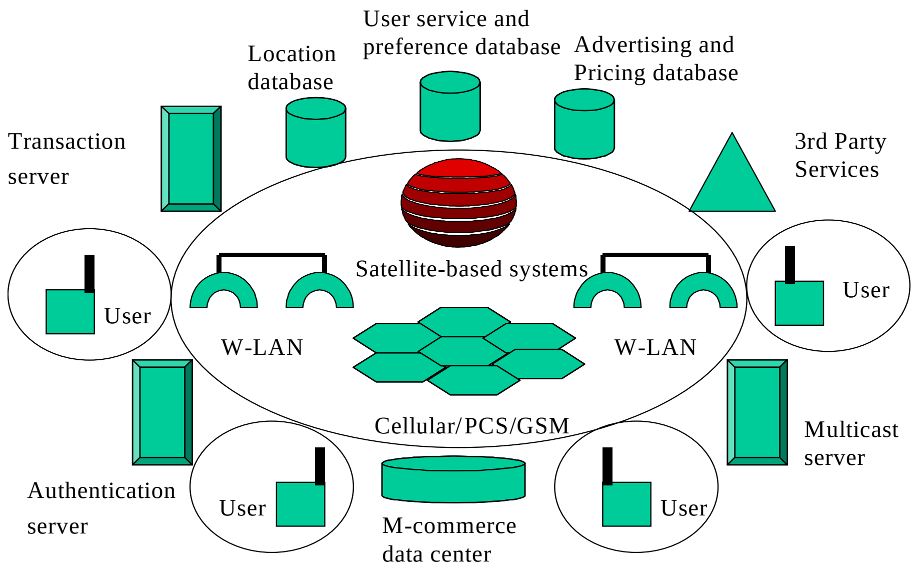

Figure 1. Ubiquitous Computing Environment

APPLICATIONS ISSUES

In the ubiquitous computing environment, the availability and usability of applications become a major issue. Certainly, applications must be designed after considering user, device, networking, and software environments. Ubiquitous computing applications should be both context and location-aware, and offer pro-active and personalized service to users. The user history, intent, and preferences can be considered in how an application acts in such a diverse environment.

The underlying networking environment would present many challenges, such as variable and limited amount of resources and brief and/or intermittent connectivity. The applications designed for a ubiquitous environment must be aware of the limitations of the current network they are operating in and also should be able to adapt as much as possible [5][3].

The applications must be context-aware where different actions could be taken based on the context of user or location. Determination of context is difficult to do because different users could act quite differently even in the same context. Some research is available on context-aware applications [2], where a multi-sensor system is used in determining user context. It is possible to list the states in which a user could be at some time and then combining this information with prior and current actions, context can be derived. Some work is still required to ensure smooth functioning of ubiquitous computing applications and systems without requiring constant actions and attention from users [2].

NETWORKING SUPPORT

The ubiquitous computing environment is likely to rely on a diverse set of networks including

[3] [ ] refers to the specific paper listed at the end of this Section.

- mobile and wireless networks for indoor and outdoor environment,
- local and wide-area networks, and
- networks with varying performance.

It would be a challenge to create seamless ubiquitous computing solutions across multiple wireless and mobile technologies with diverse capabilities. The major issues here are bandwidth, location management, intelligence, level of mobility, coverage, protocols, dependability, quality of service and number of users [1]. From a networking point of view, one challenge would be how to ensure that enough network resources are available to applications any where any time. Traditionally, optimization of resource allocation was a major goal, but in a ubiquitous computing environment, over-provisioning of resources be considered for better quality of service. As the ubiquitous computing environment would enable availability of information any time any where, but such information should be restricted to those that need it and are also authorized to access it.

DATA IN THE UBIQUITOUS COMPUTING ENVIRONMENT

In the ubiquitous computing environment, the amount of data generated and stored is likely to be extremely large because of the number of users, many data-intensive applications, and replication of information necessary to support ubiquitous computing. The major challenges include how to handle a large amount of data and how to allow users to search “effectively” for information in the ubiquitous environment. Because information would need to be replicated, information update and synchronization would become a major issue. An information change in one place would affect several databases, some of which could be mobile themselves. More specific data issues are archiving, indexing, and structure generation; search fusion; knowledge and service discovery; and personalization [3]. To evaluate different solutions, new metrics of evaluation such as improved response time, workload reduction, recall and precision could be used.

SECURITY

The security in ubiquitous computing is a major issue because individuals, groups, and organizations are unlikely to put personal, important, and mission-critical information over an infrastructure that is either not secure or is not perceived to be secure. Certain environments, such as military communications, are likely to require more stringent security [6]. The security weaknesses of wireless and mobile infrastructure stem from both the use of multiple incompatible security schemes and the inherent weaknesses in certain wireless security algorithms (such as wireless LANs). It should be noted that:

- security issues are quite different in wireless networks and
- for a variety of reasons, strong security is not yet implemented in wireless infrastructure.

Security issues in the ubiquitous environment include:

- confidentiality,
- authentication,
- integrity,
- authorization,
- non-repudiation, and
- accessibility.

Other issues would include convenience, speed, ease-of-use, and standardization. Depending on the type of data and the cost of possible loss, modification, and stolen data, a security strategy must be devised and implemented. In addition to security and privacy risks, new vulnerabilities arise because of the use of wireless devices. Use of wireless infrastructure may involve multiple wireless networks with different levels of security. These differences could lead to possible change/deletion of information, and denial of service. In addition, many more security issues arise from poor implementation, feature interactions, unplanned growth, and new flaws that are created by prior attacks. End-to-end security issues are important in ubiquitous environment because multiple networks, devices, applications, and software will exist and inter-operate. The security issues can be addressed by mobile middleware.

IMPACT OF UBIQUITOUS COMPUTING TECHNOLOGIES

One major impact of ubiquitous computing is on user privacy. Because location management is part of such an environment, some users may be uncomfortable with the ability of ubiquitous computing system to be able to derive their locations at any time. Although one of the main purposes of ubiquitous computing is user empowerment, the use of multi-network devices and wearable technologies could add to unpredictability, obtrusiveness, and discomfort. More work is needed in evaluating the impact of ubiquitous computing technologies [2]. A number of metrics, such as time saving, minimization of user distraction-number of context switches, and task quality, could be used.

OTHER ISSUES

Other technical issues relate to the devices that will be used to access many applications. These devices must be intelligent, fault-tolerant, and must be easy to use. One major issue would be how to ensure that ubiquitous computing devices are multi-functional, multi-modal, highly intelligent, yet portable [4]. These devices would contain multi-network access, multi-input, and many special features.

CONCLUSIONS AND FURTHER RESEARCH

In this section we presented and discussed many technical issues in ubiquitous computing. The applications in such an environment are likely to revolutionize the computing and information systems, especially if challenges related to network infrastructure, data, and applications design are overcome.

PAPERS PRESENTED

[1] Upkar Varshney, Georgia State University “Network Access and Security Issues in Ubiquitous Computing”,

[2] Daniel Siewiorek, “Pervasive and Context-aware Computing”, Carnegie Mellon University

[3] C. Lee Giles and Sandeep Purao, “The Role of Search in Ubiquitous Computing”, Penn State University

[4] Ora Lassila, “Semantic Gadgets: Device and Information Interoperability”, Nokia Research Center

[5] Vincenzo Liberatore, “Network Adaptive Pervasive Application”, Case Western Reserve University

[6] William Ivancic, “Securing Mobile Networks in an Operational Setting”, NASA Glenn Research Center

Participants

Upkar Varshney, Georgia State University (Chair)

Daniel Siewiorek, Carnegie Mellon University

C. Lee Giles, Penn State University

Ora Lassila, Nokia Research Center

Vincenzo Liberatore, Case Western Reserve University

William Ivancic, NASA Glenn Research Center

Matt Germonprez, Case Western Reserve University

III.DESIGNING APPLICATIONS AND SERVICES IN UBIQUITOUS COMPUTING ENVIRONMENTS

Mark S. Ackerman
The University of Michigan

Our group, Designing Applications and Services in Ubiquitous Computing Environments, concentrated on examining a small number of research questions. We saw the critical issues in designing ubiquitous applications and services not only in the underlying ubiquitous infrastructures, but also in incorporating social and organizational issues appropriately. The group felt to a large extent, determining the proper incorporation of these issues must precede design methodologies and even middleware layers.

The session started off with the presentations listed at the end of this section. In several, the speakers pointed to ubiquitous computing applications that were already present. For example, we discussed Japanese teens using mobile phones with cameras as well as warehouse logistics. Another participant showed that the infrastructure and, to a large extent, the middleware layers for ubiquitous computing applications are already present in mobile phone systems. This led to a discussion about the differences between ubiquitous computing and current mobile computing applications. More than one participant argued that wireless telephone systems provided an infrastructure for further ubiquitous services; that is, mobile computing exists and is the first type of ubiquitous computing environment. A wide-ranging discussion of the types of ubiquitous computing services and their potential adoption patterns was followed with conclusions about the sharp differences between the ultimate vision of ubiquitous computing and the likely adoption realities. This fruitful discussion of adoption patterns and trajectories is described below.

To distill the conversation, we organized the discussion into three high-leverage research themes. These included:

1. Determining a list of contexts and situations that ubiquitous computing should enable. These would be prototypical cases for ubiquitous computing. It was noted that many fields have prototypical test cases for design methodologies and architectural design. The group began to list them in the desire to come up with cases for future design methodologies and system design. The list included home health monitoring, field maintenance, military command and control extending down to the individual soldier, military tactical intelligence (sensor networks), logistics between the warehouse and the retail store, telematics for automobiles, extending product lifecycles to include service, intelligent homes and buildings, and traffic and public safety. Some of these applications would be included in the initial deployment. We agreed that current prototypical cases such as turning on lights, sports and stock quotes, refrigerators that reorder food automatically, and the like are often lame. We felt that creating a set of standard test cases would be beneficial for detailing design methodologies and scoping middleware and infrastructure layers.

2. Incorporating social and organizational requirements into ubiquitous services. These requirements include privacy and other issues that may be critical roadblocks. The group

felt that design of ubiquitous systems would be substantially better if we had representations that more properly and more formally considered the role of information technology in work and in our lives. We need these representations to incorporate these roles and their social effects better within design methodologies for ubiquitous computing. As for the obvious research cycle of theorize, build, and evaluate, several participants spoke in favor of detailed fieldwork studies and more limited field tests to determine how to go about designing appropriately, determining adoption criteria and roadblocks, as well as determining unanticipated consequences. One participant pointed out the difficulty of determining large-scale effects from limited-scale field tests or experiments.

3. Evolution of usable ubiquitous computing systems. The group spent a considerable amount of time on this research question. The discussion inevitably led to a discussion of how all the necessary infrastructure is to be built. A difficulty in specifying architectures, service substrates, and even design methodologies is the current uncertainty about likely adoption patterns, because high quality forecasts of adoption are required for successful funding, deployment, and use. Some of the issues involved were relatively obvious: the role of standards, funding, and business models. Some were less obvious: The rhetoric of ubiquitous computing often is revolutionary, but if deployment and adoption is actually evolutionary, different design methodologies, architectural layering, and staging are required. (This difference motivated much of our discussion.) Indeed, the question of revolution versus evolution can be further broken down into all-at-once, islands of ubiquitous computing, and layers of ubiquitous computing. If deployment and adoption are not all-at-once (an unlikely event), then the proper determination of network effects becomes critical, because network externalities will often govern where further adoption will take place. One participant went so far as to suggest a pervasive commons, an infrastructure constructed by a consortium or government, from which ubiquitous services and applications could be more easily constructed and adopted. This commons would be one way to achieve potentially necessary bandwagon effects.

It was pointed out in plenary discussion that each of the applications provided in the first research question (e.g., logistics) potentially includes many layers of services. These ubiquitous computing services would necessarily include service discovery and perhaps location discovery.

PAPERS PRESENTED

[1] Mark Ackerman, “Privacy - A Socio-Technical Obstruction for Pervasive Environments,” The University of Michigan

[2] Jan Damsgaard, “Mobiconomy - Location-, Situation- And Time-Sensitive m-Services,” Copenhagen Business School

[3] Mark Medovich, “Pervasive Computing and Pervasive Economies in the 21st Century,” Sun Microsystems

[4] Andrew Fano, “Giving Eyesight to Call Centers,” Accenture Technology Labs

[5] Sandeep Purao, “The Role of Search in Ubiquitous Computing,” Penn State University

[6] John Krogstie, “Mobile Process Support Systems - Myths and Misconceptions,” SINTEF and NTNU

PARTICIPANTS

Mark Ackerman, The University of Michigan (Chair)

Jan Damsgaard, Copenhagen Business School

Mark Medovich, Sun Microsystems

Andrew Fano, Accenture Technology Labs

Sandeep Purao, Penn State University

John Krogstie, SINTEF and NTNU

IV. IMPACT OF UBIQUITOUS COMPUTING

Gordon Davis
University of Minnesota

SUMMARY OF WORK GROUP DISCUSSIONS

The work group discussed five papers (listed at the end of this section) on issues related to the impact of ubiquitous computing. These papers included effects on knowledge management, affordances of ubiquitous computing and productivity, effects of passive (RFID) and active sensors (motes), measuring the consequences of ubiquitous computing, and a case example of police patrol mobility with technology. The group identified effects on the technology platform, individual workers, teams and units, and organizational processes. Both intended and unintended consequences were explored. The group summarized their discussions by looking at the impacts at the level of the business and on management and a few business functions.

A FRAMEWORK FOR THE GROUP'S DISCUSSION ON IMPACTS OF UBIQUITOUS COMPUTING

The group discussions and the papers presented ranged from the impacts of the computing environmental context, the individual, and units and teams. The papers addressed selected parts of the potential impact diagram below: platform (the artifact) to organizational processes and performance with recognition of the environmental context, the individual, and units and teams. The papers addressed selected parts of the potential impact diagram shown in Figure 2.

SUMMARY OF DISCUSSION ON EFFECTS ON BUSINESS IN GENERAL

- The platform strategy is important because businesses innovate from existing platform capabilities. Therefore infrastructure is critical in thinking about organizational processes. An example is innovation in the use of camera phones based on a platform that supports cell phones in maintenance work.
- Ubiquitous computing allows new interesting affordances[4]. The way these affordances are presented to users must be compatible with their perceptions. They must perceive the affordances when the technology is presented to them (at the level of individual).
- Ubiquitous computing is more than portable deviceds such as PDAs and multi-function cell phones; it is a computing environment that covers all layers of organizational impact and a configuration of both social and technical components.

DISCUSSION OF POSSIBLE IMPACTS ON BUSINESS FUNCTIONS

How does a business organization make the business case for ubiquitous computing? The business case is more effective when it is made by business functions. The business functions must be convinced that the expenditures for implementing and maintaining ubiquitous computing will be worth it. A ubiquitous computing environment will probably not have the same or equal impact on all business functions.

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[4] Affordance is a term from cognitive psychology that refers to what an object suggests to us [http://en.wikipedia.org/wiki/Affordance]

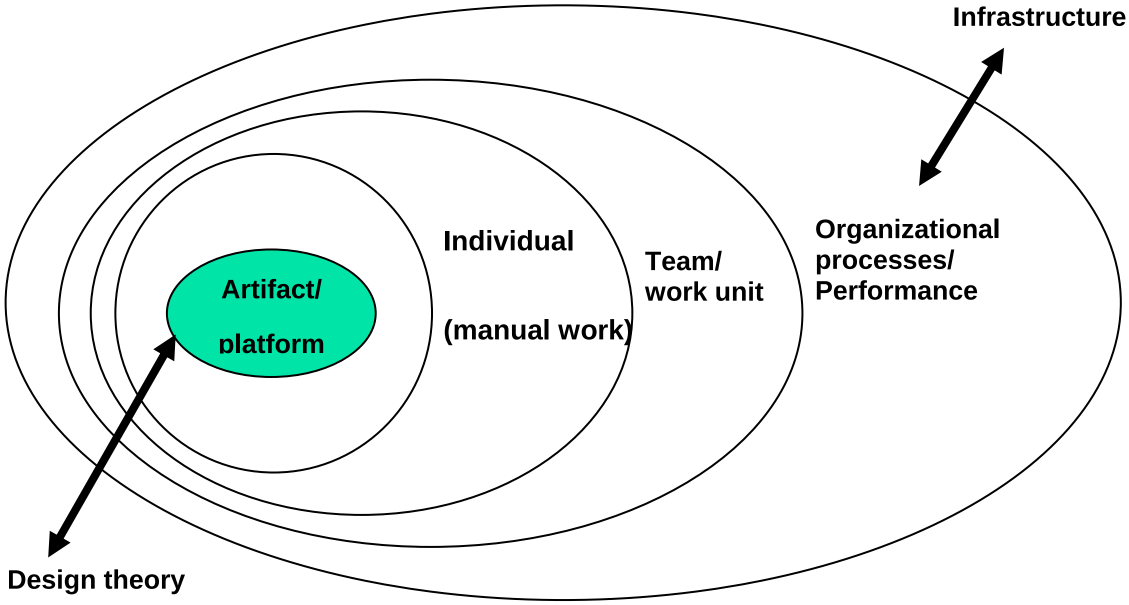

Figure 2. A Model of Ubiquitous Computing Impact

The group brainstormed to identify possible impacts of ubiquitous computing on management personnel and on the business functions of logistics and operations management, marketing, and human resources management.

- Management. The effect on management personnel is likely to come from both improved communications and improved decision making. The improved communications result from the personnel tracking, finding, and connecting affordances of ubiquitous computing. Locating and connecting to the right person when communication is needed for management processes is likely to improve availability of information from a variety of sources and improve quality of discussion and feedback. Decision making may be improved by improving access to simulations, semantic level data searches, and artificial intelligence. The ubiquitous computing environment allows management to connect to simulations from many locations and in many different settings. Simulations that are now available only in narrow, functional contexts because of the computing support required may become available at higher levels of management and to other functional areas. Data storage technology is making very large databases of internal and external data feasible. The management problem is to formulate sets of queries to find data useful for decision making. The combination of storage technology and ubiquitous computing may allow management personnel to formulate requests in terms of natural semantics rather than requiring specification of search procedures or processes. Artificial intelligence (AI) may be revived for business use by the combination of the ubiquitous computing environment and large databases. For managers to track data in real time is not generally feasible with traditional computing environments, both because of the systems are not designed for online monitoring of transactions by management and because managers do not have the human information processing ability to monitor them. With ubiquitous computing, AI applications may monitor the flow of transaction and other internal and external data available to the system and alert management when human analysis is suggested or decisions need to be made.

- Logistics and operations management. This function manages resources that are being acquired, moved in, stored, and moved out (for in-company processes or to customers). These activities require information about such quantitites as the status, location, and movement of materials, personnel, work-in-process, and finished products. Use of both active and passive sensors on machines, products, parts, personnel identification tags, will introduce new data for scheduling and operations management. For example, RFIDs on parts and packets and identification badges provide the logistics function with existence and movement data. The ubiquitous computing environment supports the use of these sensors. Dynamic scheduling and crisis projections and monitoring become more feasible.

- Marketing. This function depends on data about customers and their behavior relative to company products and services. Analysis of this data is needed both for making short term changes in marketing efforts such as promotions and for longer term changes in strategy. Ubiquitous computing and the availability of sensors on products suggest there will be much more data available about products and, in some cases, behavior of retail customers when picking products from shelves. The result will be more and better business intelligence data. Of course, sensors used to track and record customer behavior may result in customer concerns about privacy.

- Human resources. Ubiquitous computing will result in changes, some of them unintended. The human resources affordances of ubiquitous computing include searching in real time for an employee with needed skills and experience, personnel location tracking, and finding and connecting to a person on demand. The intended changes are faster identification of persons with needed skills and abilities and faster location and connection to employees. An unintended consequence may be increases in stress (because of more monitoring and more interruptions) and the weakening of boundaries between work life and personal life. The ubiquitous computing environment is likely to cause changes in aculturization (more technology interfaces changing person-to-person interchanges), new skills, new supervision issues, and need for situated learning involving both the office and the field.

PAPERS PRESENTED

[1] Bongsug Chae, "Ubiquitous Computing for Mundane Knowledge Management: Hopes Challenges, and Questions," Kansas State University

[2] Gordon Davis, "Affordances of Ubiquitous Computing and Productivity in Knowledge Work," University of Minnesota

[3] John Henderson "Platform Strategy: a Mote Overview," Boston University

[4] Kalle Lyytinen,"Measuring the Consequences of Ubiquitous Computing in Networked Organizations," Case Western Reserve University

[5] Urban Nulden, "Police Patrol Mobility," Viktoria Institute, Gothenburg, Sweden

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Bongsug Chae, Kansas State University

John Henderson, Boston University

Kalle Lyytinen, Case Western Reserve University

Urban Nulden, Victoria Institute, Gothenburg, Sweden

Anatole Gershman, Accenture Technology Labs

V. SOCIAL AND ORGANIZATIONAL ISSUES IN UBIQUITOUS COMPUTING

Michel Avital
Case Western Reserve University
Daniel Robey
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Steve Sawyer
Pennsylvania State University
Carsten Sorensen
London School of Economics

INTRODUCTION

In this section we articulate themes of ubiquitous computing in terms of social and organizational influences and effects. The themes both build on and extend the lively discussions conducted in the October, 2003 workshop on this topic.

We lay out seven broad-scale issues that serve as both the structure and as a means to engage you, the reader, in pursuing research in this area. We begin by unpacking ubiquitous computing, focusing on terms, concepts, and related issues. We then make explicit that ubiquitous computing is socio-technical and suggest a socio-technical approach to research. In the third section, we explore concepts and issues related to utopia and lived experiences relative to ubiquitous computing. In the fourth section, we highlight how the emerging ubiquity is likely to lead to changing spatial—temporal boundaries. Through section five, we highlight the possibility of (and need to study if) ubiquitous computing is a megatrend. In the sixth section, we suggest possible unintended consequences of ubiquitous computing. Finally, in the last section, we note that there are unresolved and unknown effects, leading to possible alternative paths regarding ubiquity.

UNPACKING "UBIQUITOUS"

Since scholarship is in part about clarity and precision, we need to develop a more common understanding of core aspects of ubiquity in information and communication technologies. At a glance, ubiquitous computing appears to be a hodgepodge of increasingly interconnected computing and telecommunications networks, emerging services, applications, and devices with not much in common. The ubiquitous modifier of computing has been used interchangeably to denote both nomadic and pervasive computing. Whereas nomadic refers to the act of being mobile and to portability of computing, pervasive refers to the broadly accessible and increasingly-seamless embedding of computing into the environment. These two dimensions of ubiquitous computing are different. Yet, they are entangled in our minds as a whole to form interrelated concepts, coherent lexicon, and an array of artifacts associated with the ubiquitous computing domain.

In principle, the information and communications technologies of both instances rely on seamless wireless network infrastructure that is always present and always available.

- Mobile computing technology allows for ubiquity, localization, and personalization of information and services. It enables delivery of the right information to the right person in the right place at the right time. This “anywhere—anytime” connectivity is based on the availability of ubiquitous wireless networks to support it. Human mobility and device portability are possible only within the boundaries of the network infrastructure.

- In the same vein, pervasive computing technology refers to an emerging branch of computing devices that are seamlessly embedded in the background to serve preconfigured purposes. These computing devices are designed to blend into people’s physical surroundings and are engineered to support work practices and routine activities within and across boundaries. This new breed of computing is based on architecture that is not tied to personal devices but instead embedded into the fabric of life.

UBIQUITOUS COMPUTING IS SOCIO-TECHNICAL

In response to an observation that the social discourses and the technical discourses on ubiquitous computing (including the discussions in our workshop) remain remarkably separate, we would like to emphasize its socio-technical nature. Ubiquitous computing is a socio-technical phenomenon in which computers are integrated into people's lives and the world at large. From a technical perspective, ubiquitous computing refers to a coordinated array of task-oriented computing devices that operate semi-independently in net-centric environments enabled by wireless and mobile technologies. From a social perspective, ubiquitous computing enables people potentially to gain control when necessary and to delegate tasks when possible. It provides both a means to stay more connected to others, independent of place and time, and places more pressure on people to do so. The emergence of ubiquitous computing also helps to blur boundaries between work and home and what it means to be with others physically and virtually.

From an organizational perspective, the increasing prevalence of ubiquitous computing is likely to play a significant part in helping to reshape workplace interaction, communication, work practices, work governance, technological infrastructures that organizations must support and other organizational properties. Examining the complexities and interaction effects of ubiquitous computing in organizations requires maintaining a balance between interrelated technological and social considerations. Only then will we be in a position to assess the impacts that the diffusion of these technologies has on our lived experiences, work practices, and social norms.

UTOPIA AND LIVED EXPERIENCE

Academic research is fundamentally based on observations and other empirics underlying or characterizing phenomena. Much of the research on ubiquitous computing is descriptive and retrospective. For example, it examines how police force personnel, people in trucking companies, or engineers in the Navy engaged with ubiquitous computing-enabled devices and applications in an attempt to support their work, transform their work practices, and help their organizations to gain a competitive edge. Whether successful or not, these early attempts provided much insight about ubiquitous computing and its potential outcomes. It may be that we look back on these studies to note their vision into the future, or to highlight how this work turned the focus away from critical issues. Wherever the future points, this work is shaping the current discourse on ubiquity.

Whereas current research focuses mostly on field observations and reflections on lived experience, the domain of ubiquitous computing is amenable for futuristic, visionary research that is prospective and prescriptive in nature. Topics addressed should be prospective rather than retrospective — they should be of concern to our action now and its trajectory to the future. Prospective research provides space for innovation in thinking and an opportunity for pioneering work that addresses topics of significance to the ways we communicate, work, organize, reconstruct reality, define ourselves and live. For example, research may challenge the prevailing understanding of ubiquitous computing and its impact on individuals, organizations, and communities at large; challenge the current assumptions about the nature and role of computing and information systems; offer a new and critical perspective of ubiquitous computing; develop new theories and theoretical approaches; and construct new frameworks for future research and system development.

Naturally, organizations such as the *World Future Society*[5] embrace and incorporate ubiquitous computing technologies into their schemes of the future. However, so far, academics fall short in

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[5] See for example, Snyder, D.P. {2004] "Five Meta-Trends Changing the World." *The Futurist* 38(4) pp 22-27.

the pursuit of futures research, choosing instead a retrospective lens[6]. We encourage an actively forward-looking spirit in research on ubiquitous computing. In research on ubiquitous computing, we should not merely attempt to winnow fiction from reality; rather, we should convert today's visions into tomorrow's reality. As social scientists, we must learn the skills that designers and engineers apply to the creation of new artifacts and apply them to the design of new social structures.

CHANGING SPATIAL—TEMPORAL BOUNDARIES

Mobile and pervasive computing technologies, like many other types of information and communication technologies, alter the spatial-temporal boundaries and change the perceived and enacted meaning of time and place. The nearly universal wireless infrastructure led to the proliferation of new services, applications, and devices that allow people to "re-enact" work practices and organizations to reconsider their basic properties. "Anywhere—anytime" connectivity is instrumental to revising the relationship between virtually mediated work and work that is located in physical place. A range of entirely new options involving both virtual and physical work arise out of the possibilities afforded by ubiquitous computing.

One of the evident advantages of ubiquitous computing relates to mobility and portability of devices and services. Wireless devices are small, light, portable, and easy to embed in the environment. They allow users to extend and vary their capacity for data exchange and acquisition. With mobile phones, notebook computers, and other related gadgetry, users are less constrained by their workstations, offices, or any physical workplace. They can move about the office or travel far away, and still maintain most communication channels. Another variant of remote mobility and micro-mobility is location-based services, which enable tracking and localizing people, vehicles, and practically anything else on the move. They allow increased productivity, cost control, and better security while providing clients with rapid and optimal services.

Ubiquitous computing also relaxes the temporal constraints that govern human action. It facilitates immediate and on-the-fly data and information exchanges, eases coordination, and helps make effective and efficient use of time. For example, field technicians or smart agents can use wireless devices to communicate logistics, machine status, customer information, and billing information. In addition, the technology provides more opportunities for information sharing and interaction, which in turn, facilitates the coordination between coworkers and quick responses to new situations.

The features of ubiquitous computing affect the construction of temporal and spatial perspectives of its users. One such transformation involves the multi-presence phenomenon, which refers to a person's ability to be present virtually in many settings simultaneously. Although one cannot be physically present in multiple locations at the same time, it is relatively simple to appear virtually in multiple places and to exchange information simultaneously. Web-casting, virtual conferencing, and other configurations related to multi-presence are all instances in which the technology enables us to overcome fundamental physical constraints on human activity.

The widespread adoption of wireless applications and devices paved the way for the emergence of new communication and interaction patterns. Ubiquitous computing allows for a new level of flexible and customized communication that transcends physical-temporal boundaries. As wireless devices and services penetrate our personal, organizational and social life, they potentially transform the way we work and live. As they enter the mainstream of modern civilization, their impact on everyday life intensifies while, paradoxically, their effects become less noticeable as part of newly formed routines. New theories and frameworks should be developed

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[6] The bulk of academic research in our field is not about the future. This is not to say that people are not interested or care about the future. But the fact remains, the published work in mostly retrospective and not visionary.

to examine this new ubiquitous computing environment, which is beginning to reconstitute previous notions of spatial mobility and temporal flexibility.

RIDING THE MEGATRENDS

Ubiquitous computing emerged over a decade ago and is often presented as a third wave of computing, a departure from the preceding waves of mainframe and personal computing. Clearly, the technologies under the umbrella of ubiquitous computing are not only new; but they can potentially alter the fundamental properties of organizational life and social order. However, despite its apparent novelty, ubiquitous computing is an evolutionary step in discernible trends influencing the overall development of information technologies. For example, consider the pervasive concept of personal computing, the increased prevalence of mobile phones, the universality of the internet, and the move to an information-based economy.

Consequently, the analytical prism of megatrends provides a dynamic context in which we can understand social phenomena related to the evolution of manmade artifacts. Ubiquitous computing can thus be understood in the context of the socio-technological trends that power the information age.

Examples of trends that provide perspective on ubiquitous computing are:

- the overall convergence of technologies that lead, for instance, to the consolidation of telephone and digital data networks, or media and communication technologies;
- the tailoring and customization of services, applications and devices;
- computing independence that corresponds to the movement of computer technologies from the forefront of our daily activities to the background; and
- computer use becoming technology independent allowing for seamless integration of applications across platform boundaries and a frictionless migration path from current to future versions.

Effortless migration paths make both hardware and software artifacts disposable, like an old pair of sneakers.

The analysis of megatrends can provide a foundation for understanding information systems in general and ubiquitous computing systems in particular. Ubiquitous computing is driven by the new possibilities made available by technology and by attempts to provide new solutions to enduring problems. Whether supply-driven or demand-driven, ubiquitous computing has often been implemented sporadically and opportunistically, with little regard to the larger context of socio-technical realties. The prism of megatrends offers a perspective on designing and implementing ubiquitous computing architectures.

UNINTENDED CONSEQUENCES

The intrinsically personal or even private aspects of ubiquitous computing environments paired with flexible services supporting personalization and improvisation make up a potent cocktail of social experimentation and innovation. Innovative practices adopted by mobile phone users can serve as an appropriate example. Mobile phone users across the world engage in a large-scale social networking experiment where innovative working practices and living habits are facilitated by mobile services, and to a large extent, also shape the general use and design of mobile phone technology and services.

We must, however, be aware of both the striking and subtle, social and organizational, consequences of ubiquitous computing environment, not all of which are necessarily positive. Instant touch offers the technical opportunities to cut through space and time. However, social interaction, mediated or un-mediated, is situated in social contexts where one person's desire to interact can be another person's disturbance. The constant availability of instant connection promotes the reciprocal implicit obligation to render oneself instantly available. This change may have profound implications for how we perceive ourselves and each other, as well as how we organize our interactions. A call to a mobile phone that is not answered can have significant implications for the perception of the person not answering. A call to a video phone that is only answered in voice-mode automatically raises the question: Why will the person not allow me to see him or her? Generally, the technically embedded assumptions of social relations are constantly questioned, accepted, rejected and re-shaped through the use of the ubiquitous computing environment. The technology posits the thesis of instant anytime-anywhere interaction, whereas actual work or leisure contexts dictate specific geographical and temporal configurations.

THESE, OTHER, AND ALTERNATIVE PATHS

Along with the optimism surrounding discourse about ubiquitous computing, one must always reflect upon its unintended side effects. To select just one of these, ubiquitous computing produces an accumulation of enormous repositories of digital traces of our actions, conversations, communications, and intellectual products. Any web search of information about individuals reveals the magnitude of one’s “digital impression,” which expands over time and remains essentially indelible. What will be the impact of these virtual footprints on our future actions and relationships with others? How will it affect organizational memory and boundary spanning? Will it enhance our sense of historicity by allowing us to connect the dots between footprints? One of the most significant challenges we face is the wide-spread availability of instant interaction through technologies that constantly push the boundary for how we represent the social in the technical. For example, the desire of enterprises to render knowledge workers more efficient through the support of a ubiquitous computing environment raises significant social issues of the management of distributed work, control through surveillance, and the consequences of management through data-mining digital footprints.

AN END BUT NOT THE CONCLUSION

As we have developed here, expanding on the discussions begun by our workgroup on Social and Organizational Issues of Ubiquitous Computing, ubiquitous computing is both emerging and poorly understood. The range of social, technical and socio-technical issues that lie unresolved encourage us even as we rush to develop the scientific and conceptual understanding that will help society. In this paper we have highlighted a few issues and pose others as questions that we did not yet engage. Although many of the questions raised reflect classical concerns within our field, distinctly new challenges reflect deeply intimate relationships between social and technical issues. If pursued, such research should provide systems architects and managers with new ways of understanding ubiquitous computing environments and their corollary impacts.

PAPERS PRESENTED

[1] Joe Valacich, “Ubiquitous Trust: Evolving Trust into Ubiquitous Computing Environments,” Washington State University

[2] Michel Avital, “Ubiquitous Computing: Surfing the Trend in a Balanced Act,” Case Western Reserve University

[3] Karlene C. Cousins, “Patterns of Use within Nomadic Computing Environments: An Agency Perspective on Access -- Anytime, Anywhere,” Atlanta, GA: Georgia State University

[4] Carsten Sorensen, “Research Issues in Mobile Informatics: Classical Concerns, Pragmatic Issues and Emerging Discourses,” London,: London School of Economics

[5] Youngjin Yoo, “Diffusion of Broadband Mobile Services in Korea: The Role of Standards and Its Impact on Diffusion of Complex Technology System,” Case Western Reserve University

[6] Jonathan Grudin, “Implication of Technology Use Throughout Organizations,” Microsoft

[7] Steve Sawyer, “Mobility, Work and Governance: A Field Study of Public Safety,” Penn State University

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Jonathan Grudin, Microsoft

Steve Sawyer, Penn State University

VI. CONCLUSION

While each working group focused on specific topics during the workshop, we found four key themes for IS research that emerged from these reports.

1. We need to study the evolution of the infrastructure and the impact of architectural control on the process. Successful diffusion of ubiquitous computing requires erecting and deploying a large-scale infrastructure. Tight and flexible coordination is required among diverse social actors. Furthermore, the infrastructure will involve heterogeneous technological components that are likely controlled by different communities. The actors who invest in the infrastructure will not necessarily be those who will benefit from those investments. Therefore, from a strategy standpoint, it is necessary to understand the implications of architectural control and how alternative patterns of architectural control will affect the diffusion and evolution of ubiquitous computing infrastructure.

2. We need to understand how ubiquitous computing services diffuse and are adopted by the users. In particular, the role of infrastructure and associated network externalities are critical in the adoption process. Given the radically different nature of ubiquitous computing, it is likely that the past models of technology acceptance will not be sufficient in explaining the large-scale adoption of ubiquitous computing services.

3. Design and implementation of ubiquitous computing environments will involve combining of multiple, often conflicting, requirements – both functional and non-functional. As pointed by the papers by Varshney and Ackerman, the challenge of requirements capture is not just how to identify and incorporate technical requirements, but how to foresee and integrate social and organizational requirements with those capabilities. These are often hard to identify before actual deployment of the ubiquitous computing service. In order to successfully design and implement ubiquitous computing, actors who were separated in time and space in the development cycle need to establish much tighter coordination patterns. The development methods and processes for ubiquitous computing environments will need to reflect such new needs.

4. We need to understand better how to develop various forms of experimentation with the technology. Developing and experimenting with large scale use scenarios for ubiquitous computing is important for several reasons. Effective test cases can be used to make the "business case" for the new technology and thereby mobilize necessary social actors for its successful deployment. Effective test cases can be also used to solicit and experiment with large scale user requirements.

These four challenges suggest a proactive and visionary approach to IS research where researchers can play an active role in building experimental use scenarios and participate in the development of a "ubiquitous commons". Such a visionary research approach requires a smooth integration of traditionally separate traditions of design and behavioral research, taking a more proactive role in designing and building the future of technology, rather than examining and evaluating the past. The challenge for the IS academic community will be to respond to such challenges by crafting appropriate research methodologies that embrace such a visionary approach without compromising the integrity and rigor of research. We will be required to develop novel evaluation metrics for our visionary research efforts. We hope that this report on the workshop and the summaries in Sections II through V open the debate further and improve our capability to respond to this important new challenge.

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