Ubiquitous Computing and the Concept of Context

Antti Oulasvirta
Helsinki Institute for Information Technology, Finland

Antti Salovaara
Helsinki Institute for Information Technology, Finland

INTRODUCTION

Mark Weiser (1991) envisioned in the beginning of the 1990s that ubiquitous computing, intelligent small-scale technology embedded in the physical environment, would provide useful services in the everyday context of people without disturbing the natural flow of their activities.

From the technological point of view, this vision is based on recent advances in hardware and software technologies. Processors, memories, wireless networking, sensors, actuators, power, packing and integration, optoelectronics, and biomaterials have seen rapid increases in efficiency with simultaneous decreases in size. Moore's law on capacity of microchips doubling every 18 months and growing an order of magnitude every five years has been more or less accurate for the last three decades. Similarly, fixed network transfer capacity grows an order of magnitude every three years, wireless network transfer capacity every 5 to 10 years, and mass storage every 3 years. Significant progress in power consumption is less likely, however. Innovations and breakthroughs in distributed operating environments, ad hoc networking, middleware, and platform technologies recently have begun to add to the ubiquitous computing vision on the software side.

Altogether, these technological advances have a potential to make technology fade into the background, into the woodwork and fabric of everyday life, and incorporate what Weiser (1991) called natural user interfaces. Awareness of situational factors (henceforth, the context) consequently was deemed necessary for this enterprise. This article looks at the history of the concept of context in ubiquitous computing and relates the conceptual advances to advances in envisioning human-computer interaction with ubiquitous computing.

BACKGROUND

Ubiquitous Computing Transforms Human-Computer Interaction

Human-computer interaction currently is shifting its focus from desktop-based interaction to interaction with ubiquitous computing beyond the desktop. Context-aware services and user interface adaptation are the two main application classes for context awareness. Many recent prototypes have demonstrated how context-aware devices could be used in homes, lecture halls, gardens, schools, city streets, cars, buses, trams, shops, malls, and so forth.

With the emergence of so many different ways of making use of situational data, the question of what context is and how it should be acted upon has received a lot of attention from researchers in HCI and computer science. The answer to this question, as will be argued later, has wide ramifications for the design of interaction and innovation of use purposes for ubiquitous computing.

HISTORY

Context as Location

In Weiser's (1991) proposal, ubiquitous computing was realized through small computers distributed throughout the office. Tabs, pads, and boards helped office workers to access virtual information associated to physical places as well as to collaborate over disconnected locations and to share information using interfaces that take locational constraints sensitively into account. Although Weiser (1991) never intended to confine context to mean merely location, the following five years of research mostly focused on location-based adaptation. Want et al. (1992) described the ActiveBadge, a wearable badge for office workers that could be used to find and notify people in an office. Weiser (1993) continued by exploring systems for sharing drawings between disconnected places (the Tivoli system). Schilit et al. (1994) defined context to encompass more than location—to include people and resources as well—but their application examples were still mostly related to location sensing (i.e., proximate selection, location-triggered reconfiguration, location-triggered information, and location-triggered actions). Want, et al. (1995) added physical parameters like time and temperature to the definition. Perhaps the best-known mobile application developed during this location paradigm era was the CyberGuide (Long et al., 1996), an intelligent mobile guide that could be used to search for nearby services in a city. This paradigm was also influential in the research on Smart Spaces, such as intelligent meeting rooms.

The Representational Approach to Context

Although the idea that location equals context was eventually dismissed, many researchers coming from computer science still believed that contexts were something that should be recognized, labeled, and acted upon (Schmidt et al., 1998). Here, context was supposed to be recognized from sensor data, labeled, and given to applications that would use it as a basis for adaptation. Dey et al.'s (1999) five Ws of context—Who, Where, When, What, and Why—extended this approach and demonstrated convincing examples of how a labeled context could be used for presenting, executing, and tagging information. Tennenhouse's (2000) proactive computing paradigm endorsed a similar way of thinking about context, emphasizing the role of computers in doing real-time decisions on behalf of (or pro) the user. A somewhat similar approach that also attempts to delegate decision-making responsibility to intelligent systems is taken by the Ambient Intelligence (AmI) technology program of the European Union (ISTAG). One part of the AmI vision entails intelligent agents that assume some of the control responsibility from the users.

The latest widely referred to definition was given by Dey et al. (2001), who defined context as "any information that characterizes a situation related to the interaction between users, applications, and the surrounding environment" (p. 106). Satyanarayanan's (2001) formulation of pervasive computing also belongs to this line of thinking, but the author has chosen to avoid defining context and merely admits that it is rich and varies.

In his review of context definitions over the years, Dourish (2004) calls this the *representational approach* to context. Recent work within this branch has come close to finding the limits to recognizing and labeling contexts. For example, simple physical activities of a person in a home environment can be recognized with about 80-85% accuracy (Intille et al., 2004), as can be the interruptability of a person working in an office (Fogarty et al., 2004). Some critics have drawn parallels from this enterprise to problems encountered in strong AI (Erickson, 2002).

FUTURE TRENDS

New Directions Inspired by Human and Social Sciences

By the year 1996, other approaches to context were beginning to emerge. Wearable computing (Mann, 1996) looked at personal wearable computers able to help us remember and capture our everyday experiences through video and sound recording of context. Tangible bits (Ishii & Ullmer, 1997), although inspired by ubiquitous computing, looked at context not as something that had to be reacted upon but as surroundings of the user that could be augmented with tangible (i.e., graspable) computers and ambient media that display digital information using distraction-free output channels.

More recently, researchers have started to emphasize the social context and issues in people's practices and everyday conduct. These approaches give special consideration to activities that people engage in and highlight their dynamic nature, different from the labeling-oriented representational ap-

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