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Moving Toward a Future of Ubiquitous Computing

Overview: Computing Woven Seamlessly into Everyday Life
A factory technician, hired to bring an old manufacturing facility up to spec, is conducting a site visit. As he walks through the unfamiliar production floor, the screen of his personal digital assistant (PDA) lights up with manuals and notes from previous technicians about the idiosyncrasies of the various machines he passes.

While visiting a dozen key stores across the country, the national sales manager of a major retail chain uses her cell phone to take photos at each location. At the end of her trip, she presses a key on her notebook computer, and the photos appear on a Web page wirelessly transmitted from her cell phone.

A graduate student wanders through a university campus. As he passes the chemistry building, his PDA screen shows that his favorite professor is scheduled to deliver a public presentation in room 405 later that day. He adds the item to his calendar.

The technology to enable these scenarios and more is now being explored at Intel. We are moving toward a future in which computing will be ubiquitous, woven seamlessly into the fabric of everyday life. Intel researchers, in collaboration with leading academic and industry researchers, are engaged in several projects to explore technologies and usage models for everyday uses of computing. In their research, they are addressing fundamental issues that must be resolved in order to enable "anytime, anywhere" computing, such as how to develop a low-cost infrastructure for location-dependent applications, and how to ensure the security and privacy of content as it moves between an increasing array of devices.

Ubiquitous computing research is helping to further Intel's vision of proactive computing. Under this model, computers anticipate what people need and, when appropriate, take proactive steps to meet those needs, with little or no user interaction.

To make ubiquitous computing a reality will require the collaboration of researchers in a broad range of disciplines, within computer science and beyond. Intel's ubiquitous computing research team includes experts in hardware design, systems, networking, signal processing, machine learning, human-computer interface (HCI), and social sciences.

Personal Server: Next-Generation Mobile Computing
The Challenge: What if you could carry all of your personal media with you (including applications, documents, photos, videos and MP3 files) in a convenient pocket form factor, and have wireless access to it when standing in front of a PC, kiosk, or large display, anywhere in the world? That might significantly improve your mobile computing experience.

The Solution: Intel researchers are developing a new class of mobile device that leverages advances in processing, storage, and communications technologies to provide ubiquitous access to personal information and applications through the existing fixed infrastructure. The device, called a personal server, is a small, lightweight computer with high-density data storage capability. It requires no display, so it can be smaller than a typical PDA. A wireless interface enables the user to access content stored in the device through whatever displays are available in the local environment. For example, in the digital home, the personal server could wirelessly stream audio and video stored on the device to a PC or digital home TV.

Personal Server prototype integrated into a Motorola E680* Intel® XScale™/ Linux-based cell

The personal server is primarily a software capability, and it can be integrated into any mobile device. Intel researchers have developed and successfully demonstrated a prototype personal server that is integrated into a Linux*-based cell phone platform, and they continue to refine the technology.

Publicly available infrastructure must be capable of interacting with the personal server. Toward that end, Intel researchers are developing the software infrastructure necessary to support the seamless interaction required to make the personal server an attractive mobile solution.

Potential Impact: The personal server, when integrated into a cell phone (already a "killer application") could make mobile computing far more convenient than a laptop, while ensuring the privacy and accessibility of data. Local wireless connections will also have higher bandwidth and lower latency than metropolitan networks such as GPRS (General Packet Radio Service) and thus will enable large files to be

to work effectively at a remote location using a large, high-quality display. As storage continues to increase in density, this model will become even more attractive, and will provide reassurance to users that they will always have their documents and media available when they're on the go.

Precision Location Technology
The Challenge: Global Positioning System (GPS) technology is widely used for location-dependent applications such as navigating outdoors and providing emergency (E911) services. However, this technology has limitations: GPS receivers do not work indoors or in "urban canyons" where high-rise buildings obstruct the line between the GPS satellite and receiver. In addition, there are a number of applications that require greater accuracy than a typical GPS receiver can provide, but only require this accuracy in a small local region.

The Solution: Intel researchers are developing high-precision location technology that will work indoors as well as outdoors. A key objective is to develop technology that is accurate to within one meter.

Researchers have developed a prototype system that consists of WLAN (wireless local area network) laptop computers and fixed access points (APs). The laptop communicates with each AP to determine its distance from the AP using a Time-Of-Arrival (TOA) method developed by Intel. The laptop also knows the location of every AP. The laptop, knowing its distance from any two APs, and knowing their location, can triangulate its own position. This position can then be utilized at the laptop or transmitted back to the network for infrastructure-based applications.

Potential Impact: When integrated into consumer electronics (CE) devices, high-precision, WLAN-based location technology could be an ideal complement to GPS location capabilities. The technology could be used in a variety of potential applications, such as navigating indoors and tracking equipment in real time (imagine a physician in a hospital who is searching for the nearest defibrillator). The technology maintains privacy; users control who has access to their location information.

Place Lab: Low-Cost Location Technology
The Challenge: For ubiquitous computing to achieve mass adoption, location-enhanced computing must be low cost and must work over a wide area, both indoors and outdoors.

The Solution: To address this challenge, Intel Research Seattle has developed Place Lab, a toolkit that allows commodity devices to estimate their location based on nearby radio sources such as 802.11 access points and GSM cell towers. Place Lab is an open source project and runs on a variety of notebook, PDA and cell phone platforms. The toolkit enables notebooks, PDAs and cell phones to locate themselves by listening for radio beacons such as 802.11 access points, GSM cell phone towers, and fixed Bluetooth* devices that are already installed in large numbers throughout the environment. These beacons all have unique or semi-unique IDs, such as MAC (Media Access Control) addresses. Devices that use Place Lab can determine their locations privately, without having to reveal their location information to a central service.

Potential Impact: By running on commodity devices and utilizing existing infrastructure, Place Lab allows devices to easily and inexpensively estimate their locations. Combined with the open source approach, Place Lab is encouraging the development and deployment of wide-area location-enhanced applications and services. Place Lab is already running campus-wide at both the University of California at San Diego (UCSD) and the Georgia Institute of Technology. These installations aim to provide location-based services for research and educational networks, and to help researchers understand how such systems are used.

Recognizing and Predicting Human Activity
The Challenge: To realize Intel's vision of proactive computing, in which devices embedded throughout the environment anticipate human needs and sometimes offer proactive assistance, the devices must be able to accurately anticipate human activities.

The Solution: Intel Research Seattle, in collaboration with the University of Washington, is developing a system that can automatically infer a wide range of everyday human activities (such as cooking pasta, taking a pill, or washing dishes) and provide proactive assistance, if needed, to complete an activity. The system, called SHARP (System for Human Activity Recognition and Prediction), relies on RFID (radio frequency identification) technology and the latest techniques in data mining and machine learning. Here's how the system works: While a person performs an activity, data is gathered from sensors affixed to every object the person uses. The data is fed into a reasoning engine—a machine learning algorithm that analyzes the data, compares it to a large set of activity models, and infers which model is the best match.

How Machine Learning Systems Work
SHARP is an example of a machine learning system. These systems vary, but all contain three components:

- Sensors that gather data about the physical world—in the case of SHARP, RFID tags gather data about which objects are being used to perform an activity, and additional sensors are used to capture other data, such as motion, temperature or visible light measurements.
- Models—Beliefs or prior knowledge about real-world processes (human activities, in the case of SHARP).
- Reasoning Engine—The machine learning algorithm, which analyzes sensor data, compares it to a large set of models, infers which model is the closest match for the data, improves the models based on observed data, and recommends appropriate actions.

Potential Impact: The main focus of SHARP research is on helping the aging and those with cognitive impairment to perform their daily activities, enabling them to continue living at home for as long as possible. To that end, researchers have developed a proof-of-concept prototype called the Caregiver's Assistant, which uses SHARP technology to automatically detect the activities of an elder without requiring direct observation, freeing the caregiver to focus on the quality of care. Another prototype application, the CareNet Display, is an interactive, digital picture frame that augments a person's photograph with information about her daily life. The Display can be used by family and friends to coordinate an elder's care. There are many other potential applications of SHARP technology, from training medical students in performing procedures to capturing "best known methods" of performing maintenance in a factory.

Looking Ahead
Thus far, Intel's ubiquitous computing research has targeted foundational problems, including how to enable ubiquitous information access (Personal Server), incorporate location capabilities into technology (Precision Location and Place Lab), and automatically infer human activity (SHARP). These research

Developing Technology for the Greater Good
In collaboration with leading academic researchers, Intel's ubiquitous computing researchers are focusing on larger societal problems for which technology could potentially provide solutions. They are exploring how technology can help people to live at home longer as they grow old, how it can support health and wellness, and how technology can address challenges in learning disabilities such as autism.

In collaboration with UC Berkeley and the University of Washington, Intel researchers will explore how technology can be employed in the developing regions of the world, to increase personal income for the disadvantaged, spur economic development, and improve the quality of life. The most basic technology needs in these regions are connectivity in rural areas, intermittent networking, low-cost devices, and user interfaces. Already, Intel technologists and social scientists are at work in the developing regions of Asia, studying how people live, work and play, identifying their computing needs, and testing new technologies.

Researchers have already demonstrated how simple uses of technology can make a big impact in the developing world. For example, today in India, rural farmers can go to a local kiosk where there's an Internet-connected computer and get information about market conditions or deal directly with a grain buyer rather than working through a complicated and archaic system of middlemen. This simple use of technology can often double a farmer's income by helping him to sell his grain quickly and avoid spoilage.

Summary
Today, people's experience of computer technology is, for the most part, time-consuming and frustrating. Intel researchers are looking to address the increasing, sometimes overwhelming, complexity that comes with digital living and will explore ways to measurably simplify the digital experience.

Much research has yet to be done to determine how to simplify technology. The challenge grows as devices become more capable and thus more complex. The complexity increases substantially as users demand that their digital devices work together seamlessly. Intel researchers, in collaboration with their colleagues in leading universities, are starting to leverage machine learning and new networking and data access techniques to address the challenge of making digital living less frustrating and more intuitive.

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- Place Lab
- Personal Server
- Precision Location Technology
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