Mega-Utilities Drive Invisible Technologies

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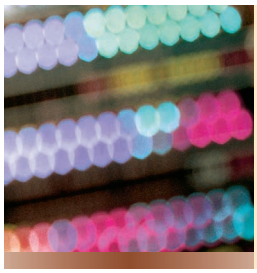
A decade ago, while managing the Computer Science Laboratory at Xerox Palo Alto Research Center, Mark Weiser envisioned a computer "so imbedded, so fitting, so natural, that we use it without even thinking about it" ("Creating the Invisible Interface," *Proc. 7th Ann. ACM Symp. User Interface Software and Technology,* ACM Press, 1994, p. 1). Today, Weiser's vision is coming to pass everywhere: game phones, personal video recorders, digital cameras, sensor networks, automotive telematics, and more.

Despite their apparent simplicity, invisible technologies represent the pinnacle of engineering accomplishments in digital design, networking, user interfaces, and machine learning as well as in the social science disciplines of psychology and anthropology. It takes a lot of science to move technology from the foreground to the background.

This new bimonthly column will focus on leading-edge science that is inspiring the next generation of pervasive computing. Researchers at university and industry labs around the world will explain their work in intelligent user interfaces, interoperability, sensor networks, smart environments, and novel applications. In addition, the column will highlight the emerging area of proactive systems that come from the background to help people at the right time.



As computers fade into the background, emerging technologies bring new challenges as well as benefits.

MEGA-UTILITIES

Computers are becoming pervasive in part because megahertz, megabits per second, and megabytes have become utilities much like water, gas, and electricity.

Megahertz

In 1965, when Gordon Moore articulated his law that chip density would double every 18 months, the notion of a megahertz utility wasn't so obvious. In that year he wrote: "Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today." (www.intel.com/research/silicon/moorespaper.pdf)

Nearly 40 years later, the accuracy of Moore's predictions are evident in the way today's high-speed integrated circuits are transforming everyday objects including wristwatches, phones and pens, into platforms for invisible computing.

For example, Microsoft's Smart Personal Object Technology (SPOT)-enabled wristwatch can receive messages, calendar updates, and customized news, sports, and other data over one-way FM radio signals and display this information on its LCD face. Before long, wristwatch cartoons may be designed, swapped, and downloaded like cell phone ring tones.

Megabits per second

The emerging IEEE 802.11b (Wi-Fi) wireless standard demonstrates another rapidly growing utility: wireless connectivity. For example, because Intel is making 802.11a/b connectivity a basic function of its new Centrino chipset, every laptop shipped in the near future will have built-in wireless communications capability.

Many Starbucks regulars are aware that in some of its US stores, the chain is serving up wireless connectivity along with gourmet coffee, but this only hints at what's to come. IBM, Intel, and AT&T announced last December that they are jointly establishing a new company, Cometa Networks, that plans to offer a single sign-on, single authentication, and seamless-roaming nationwide network in the 50 largest US cities.

Wi-Fi connectivity facilitates digital interaction with the physical world, especially when combined with location information via the Global Positioning System. Services such as go2online.com and Sweden's Telia let mobile users search for nearby movies, restaurants, and stores. Shared electronic displays such as the Love Board at a busy intersection in Tokyo's trendy Shibuya dis-

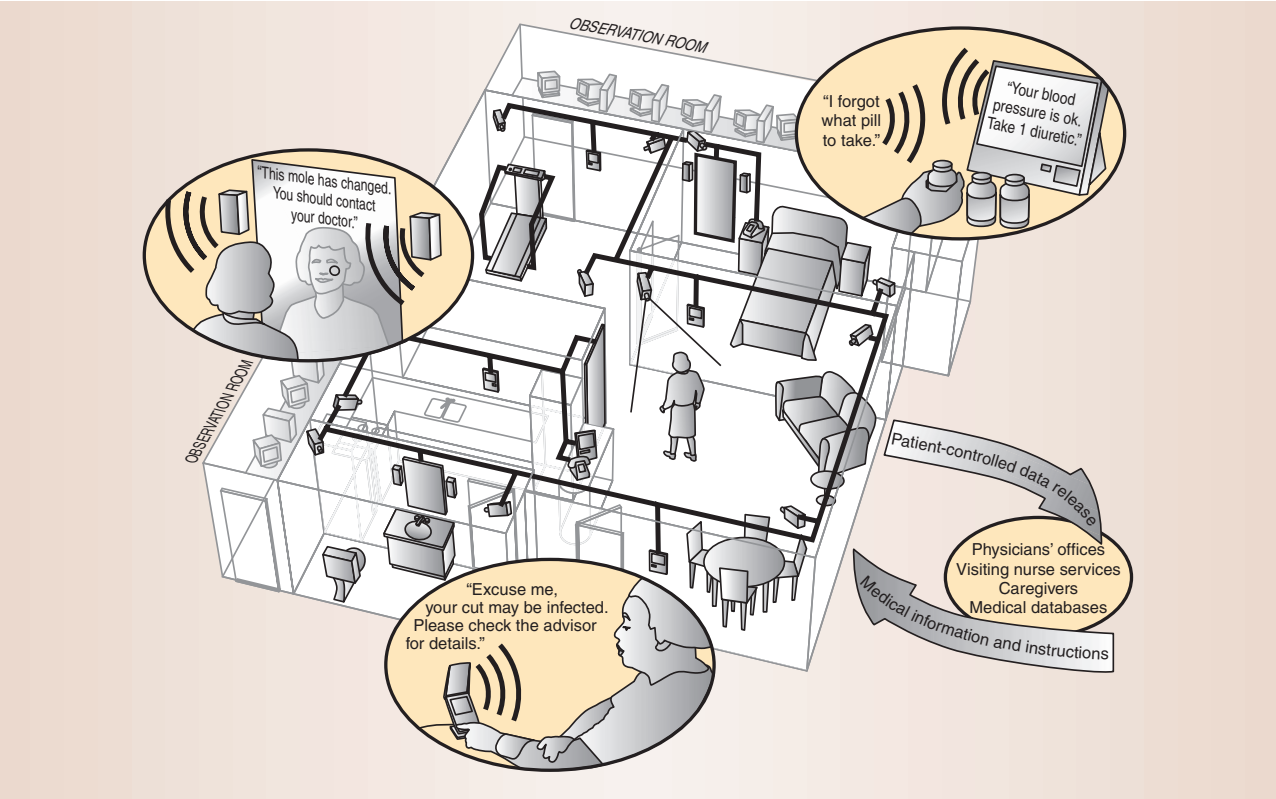


Figure 1. Smart home. The University of Rochester's Center for Future Health is developing invisible and proactive computing elements that let elderly people live independently in smart homes instead of having to move to care facilities.

trict let passersby send photos and text messages from their i-mode phones and PCs to a building-mounted Jumbotron for public viewing.

The potential ubiquity of wireless technology is so great that many believe it should be a public service. The Community Node Wireless Database Project (nodedb.com) lists more than 3,800 public-access Wi-Fi connection points around the world. In what could become a trend, the City of Long Beach, California, is planning to make free wireless Internet access available downtown to help attract visitors.

How far will this integration of the electronic and the real world go? If researchers such as Deborah Estrin at the University of California, Los Angeles, are right, the Earth will soon be covered by a mesh of wireless sensors connected in an ad hoc network, providing the ultimate link between people and their environment.

Megabytes

Mass storage has emerged as yet another mega-utility. In the 1980s, a hard disk for my Macintosh cost US$100 per megabyte; last month, I paid the same amount for 100 gigabytes—100,000 times as much memory—to upgrade my digital video recorder's hard disk. Mass storage has become pervasive in consumer electronics, with digital cameras, USB dongles, PDAs, MP3 players, and some cell phones having megabytes of flash memory.

The megastorage trend is transforming computers from processors of compact, computer-friendly ASCII data to processors of memory-intensive, people-friendly video, image, and audio data. In part, it is the ubiquitous availability of such data that is letting computers blend into the background of day-to-day life.

The rapid increase in storage capacity is prompting researchers to think about how to manage it. For example, Boon Loo of the University of California, Berkeley, and Intel's Anthony LaMarca have developed middleware that lets cameras, PDAs, cell phones, and other portable devices automatically replicate one another's data, creating transparent backups. LaMarca believes that, in the future, small pervasive devices will run the same sort of distributed and replicated storage schemes usually found in back-end server rooms.

INTERACTING WITH THE INVISIBLE

As computer technology fades from view, managing the complexities of human-machine interaction will become increasingly important. At the University of Washington, Oren Etzioni is investigating how to combine *sensed context*—for example, from a home's sensor network—with machine learn-

ing to resolve the ambiguity in natural language processing.

It's not uncommon for a computer equipped with voice recognition software to misinterpret a query such as "Do I have any messages today?" to be "Do I have my massage today?" By using the context of when and where the question is asked, recognition systems can more accurately choose among alternate interpretations.

Enhancing natural language recognition in this and other ways may ultimately let us have reasonably intelligent "conversations" with telephone answering machines as well as home entertainment systems and a multitude of other intricate appliances.

Clearly we don't want to interact, in the conventional sense, with the fabric of the digital world—we can all imagine the terrifying prospect of pop-up dialog boxes and relentlessly dumb digital characters following us wherever we go. Rather, computers should anticipate our needs and sometimes act on our behalf.

Researchers at the Georgia Institute of Technology and the University of Rochester are building smart homes that have the ability to anticipate users' needs. For example, a medicine cabinet in Rochester's smart home, shown in Figure 1, might inform residents that the antacid they are planning to take interacts badly with heart medication they took earlier in the day.

Such proactivity is extremely difficult to achieve, but applying techniques from machine learning—which will improve how systems serve us over time—and data mining—which will provide systems with multiple examples to use for decisions—shows promise.

Invisible computing offers many possible benefits, but without vision and foresight it also has the potential to turn our world into a haunted house filled with digital horrors. The challenge is to make these emerging technologies proactive while leaving users serene and in control.

As we explore technical developments in invisible computing as well as its social implications, I welcome your contributions to this column in future editions of *Computer*. ■

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