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The Post-PC Era

Early computers processed jobs in batches. This was inconvenient for both programmers and users, but machine time was expensive relative to people's salaries. As technology improved, we moved to time sharing and then personal computers. The PC has had a great run, but some believe its day has passed, and that we are moving on to a post-PC era of ubiquitous computing.

Falling prices have led to a leveling-off of revenue from PC sales, and pundits and manufacturers are gearing up for a wave of intelligent, networked devices. Some of these will be Internet appliances, perhaps next-generation WebTVs and set-top cable boxes. Others will descend from today's personal digital assistants, like the Palm Pilot, which now connects wirelessly to the Internet. Pagers and cell phones will be on the Net as well.

Devices not normally used for messaging and computing will also be networked. Cars will connect wirelessly to the Internet and contain wireless LANs. Home appliances such as refrigerators, clocks, and ovens will be Internet connected, along with vending machines and dog collars. Devices will sense the world in various ways, responding to speech and other sound, movement, acceleration, heat, gesture, touch, and so forth.[1] These devices will know where they are, who and what they are near, and the time of day. Intelligent, networked devices will become so common as to be unremarkable, and eventually they will be taken for granted.

Increasing chip densities will make this possible. Today, a production Web server using low-cost chips fits on a board the size of a matchbox (wearables.stanford.edu), and a more limited one is even smaller (www.ccs.cs.umass.edu/~shri/iPic.html). The next generation will reduce that chip count to one.[2] Consider, for example, Lucent's new phone-on-a-chip—a single chip combining a codec, speech compression, speakerphone echo cancellation, speaker and microphone amplification, Ethernet interface, an Ethernet repeater (so one jack can serve both phone and PC), universal serial bus, infrared link, keypad controller and LCD display driver. Lucent expects this device to bring the cost of the next generation Ethernet telephone down to approximately $150. Future engineers will draw on circuit libraries to produce single-chip systems instead of combining ICs to produce single-board systems. As Eric Benhamou, 3Com chair and CEO, points out, this may lead to a more balanced, less monopolistic industry, as well as better products.

Communication technology and standards are also progressing rapidly. One of the few things outstripping the rate of increase in chip density is the rate of increase in optical communication speed. Furthermore, standards and products for wireless LANs (www.wlana.com, www.iol.unh.edu/training/wireless.html, www.bluetooth.com), phone line LANs (www.homepna.com) and power line LANs (www.cebus.org), are becoming available. Proponents of ubiquitous computing picture a home in which all three media are combined to create a seamless LAN that connects to the Internet over a high-speed link. There is

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[1] For a bullish look at the future of sensors, see [2].

[2] Microsoft estimates the size of an embedded Web server with service discovery as 15-25KB or 64k gates and a companion TCP/IP stack at 25-35KB or 28k gates, marginal cost on tomorrow's mass market chips.

also progress in standards and products for wireless WANs (www.gsmworld.com; www.wapforum.org).

Mark Weiser and his colleagues at Xerox PARC coined the term "ubiquitous computing" and first articulated the vision in the 1980s [5, 6].[3] Weiser also built and deployed prototypes at PARC, adding intelligence—processors, pen input, wireless connectivity and awareness of location in the building—to displays the sizes of whiteboards, writing pads, and post-it notes (called "tabs"). He envisioned a world in which for each person in an office, there would be hundreds of tabs, tens of pads, and one or two boards.

A number of research labs, including the wearable computer groups at Stanford (wearables.stanford.edu) and MIT (www.media.mit.edu/wearables), Project Oxygen (www.scientificamerican.com/1999/0899issue/0899dertouzos.html) at MIT and PARC continue this work, but industry has also jumped on the bandwagon. Capital is rushing in, fueled by market research predictions that the number of Internet devices will exceed the number of computers connected to the Internet in just a few years. Perhaps the two most visible companies are Sun and Microsoft. While their goals appear to be identical, each is offering its own architecture—Jini (www.sun.com/jini) from Sun [4] and Universal Plug and Play (UPnP) from Microsoft (www.microsoft.com/homenet/upnp.htm).

Both Sun and Microsoft seek zero-administration networking with devices automatically joining and leaving networks at any time. They provide devices with a means of joining a network, advertising the service they offer, and finding services that are currently available. A camera might join the network and look for display and image editing services or a printer might announce its availability when switched on. A smartcard could join the network in a taxicab when a passenger first enters and disconnect when the passenger leaves. Two people could exchange business cards with a push of a button. There is only one catch: Jini devices communicate by transferring appropriate Java code to the client while UPnP devices share descriptions of their capabilities, not code. When a UPnP service joins a network, it advertises its characteristics and control mechanisms in an XML document and assumes that its protocol is known by clients.

Bumps in the Road

I look forward to ubiquitous computing, but fear that the journey toward it may be longer and bumpier than the enthusiasts predict. My vision is clouded by a number of issues.

Interoperability. Will I need a sign that says "Jini-equipped" on the front door of my house? Will I need to carry both Jini and UPnP smartcards to pay for cab rides and restaurant meals? The battle between Jini and UPnP may make Beta vs. VHS look like small potatoes.

Both Microsoft and Sun are making major investments. Microsoft featured UPnP at their Spring Windows Hardware Engineering Conference (www.microsoft.com/winhec). They had an interoperability island in the exhibit area with UPnP devices from 21 companies, and featured UPnP in many technical sessions. The UPnP forum (www.upnp.org) lists 56 supporting organizations at present, and UPnP will be added to the entire Windows product line. For its part, Sun hopes to capture a large, creative developer community with the Sun Community Source Code License (www.sun.com/jini/licensing). Source code will be open, but it will allow proprietary modifications and extension, and will perform product testing to ensure compatibility. There will be no charge to research and education users or for limited internal deployment within any organization. Compatibility with the Home Audio-Visual Interoperability specification of eight large consumer electronic companies (www.havi.org) is being considered.

I raised the question of interoperability in a very limited two-person survey. An engineer at Sun stated that the UPnP approach to low-level networking (assigning IP addresses) is fine since Jini does not address that layer. He believes devices could implement both the UPnP and Jini discovery mechanisms because there is not much code involved in either, but once services are located, he suggests using the Jini's programming model (transferring Java code) for interaction. A Microsoft engineer suggested that Sun join the UPnP Forum and implement protocols in Java.

[3] Weiser continued this work until his untimely death at age 46 this year. See www.ubiquitous.com/hypertext/weiser/UbiHome.html.

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Privacy. In a fully networked world filled with ubiquitous, sensor-equipped devices, one worries about privacy. Some applications require the explicit forfeiture of privacy. For example, a system for locating colleagues at work would require their locations to be public. Social norms, laws, company policies, and so forth can be posited to give one control over such information, but cheating and hacking will always be possible.

Regulation and Oligopoly. The ultimate vision is that our homes and offices will all have LANs, and connect to the Internet over an always-on, high-bandwidth link. It will be in the interest of the provider of that high bandwidth link to exploit it. Today's CATV operators restrict content, offering relatively few bundles of material, often produced by companies they own, and seek to tie users to their own ISPs. Local telephone companies place roadblocks in the way of access to their facilities by competing local exchange carriers, and their capital equipment rollouts are geared to profit, not optimal technology. I don't blame them; I would probably do the same in their position. I cannot predict what will occur, but the interaction between regulators in all nations and the pursuit of self interest by large, oligopolistic carriers and content providers like Telefonica, Time Warner, News Corp., and Microsoft will help shape our ubiquitous computing world.[4]

Repackaging Software. Breaking an application does not reduce the need for those parts. For example, today we use a PC running a program like Photoshop for digital photography. We can physically and logically separate the storage, display and printing devices from each other (printers are already often remote), but we still need the image processing service. Will that execute on the household hub, in the camera, in a remote server somewhere on the Internet (where our storage may already be)? Regardless of where it executes, the service has to run somewhere, and someone has to write the program for it. We will need new software and new business practices to regulate these functions.

Reliability. Household or office hubs acting as routers, local stores, directory and application servers, and so forth are a single point of failure. The hub may not be as mechanically complex as a PC, or be running as many lines of code, but it will be central to much of the function of our offices and homes. In general, if something is ubiquitous, we will miss it sorely when it does not work.

PCs Win. We hear talk of the demise of the PC and the post-PC era, but if we assume the ubiquitous computing vision is realized, the PC may be the biggest winner. The configuration of directly connected storage and IO devices will be simplified along with those that are located elsewhere on the network. The ability to run remote diagnosis and download bug fixes and software upgrades will apply to PCs as well as to refrigerators. I think my PC has more to gain here than my refrigerator.

Ubiquitous Marketing. One can speak of self-diagnosing appliances and automatic bug fixes and upgrades or one can speak of opportunities to sell maintenance contracts and services. Increasingly sophisticated direct marketing campaigns and techniques are emerging on the Internet and in business plans every day, and one man's link to the Net is another man's distribution channel and marketing opportunity. We may see spam displayed on refrigerator doors instead of Spam stored inside. There will also be market imperfections. My refrigerator may know it is broken, but will it recommend the cheapest parts supplier and repair company, or one which has paid a referral fee?

Infrastructure Vapor. We must deploy vast amounts of communication infrastructure for ubiquitous computing to become a reality. Wireless LANs, two-way satellites, terrestrial wireless data networks, high-speed last mile

[4] One interesting variation on this theme is the Canadian discussion of the feasibility and cost of bringing fiber to every school or every home [3]. What would be the impact on content providers and carriers if the government were to fund an infrastructure project?.

connectivity to homes, and so forth are just beginning to be deployed. We also need standards and techniques to insure guaranteed quality of service across this infrastructure, techniques to seamlessly hand mobile users off as they leave one network and move to another, and we will need the address space of IP V6. But the most difficult "layer" in this communication stack may be working out business relationships and billing and pricing customs. Deploying this infrastructure will take many years.

Complex Standards. In slideware presentations on ubiquitous computing, we hear glib analogies to the development of standards in other industries like power distribution, but ubiquitous computing standards are more complex. We anticipate an open-ended list of devices each with different capabilities and control options, and they will be controlled by people, other devices, or both. This sounds like a tougher nut to crack than settling on the shape of a lamp plug or bulb thread specifications. Debugging and compliance certification will be daunting in such a fluid and diverse environment as ubiquitous computing. Ubiquitous computing will require the cooperation of vendors with substantial installed bases of equipment and protocols.

User Interface. Speech recognition and synthesis, touch and pen input, natural language processing, machine vision, and other input/output methods will be needed. We have invested many years of research and development in these areas, and they remain difficult.

Content will also have to be repurposed. Web sites originally designed for large screens will not work well on small screens or for clients without pointing devices. Some automatic conversion will be possible, but many sites will require redesign and manual preparation of alternative content. On the plus side, more powerful devices will allow improved user interfaces. For example, a Web-based VCR controller on Weiser tab or pad would be a great improvement.

Parochial Applications. Whether from Sun or Microsoft, presentations on hypothetical applications for ubiquitous computing are similar. Imagine that a young business person collaborates with a remote colleague to review a proposal and close the "big deal" while riding in a cab on the way to the airport. Neither paper nor cash are needed in this world, and nothing is ever entered into the system manually, it is all retrieved or copied from somewhere else. At home, dinner is cooked, entertainment is scheduled, and stock portfolios are managed while yard sprinklers, burglar alarms, and temperature sensors quietly do their thing. The vision and presentation styles are similar to that of the advocates of information utilities based on timesharing systems in the 1970s [1], Apple's Knowledge Navigator video from the 1980s, the video on demand presentations of the 1990s, and, one suspects, the hype surrounding the telegraph as well. If many of these applications sound superfluous to me—a professional in the U.S.—how would they sound to a factory worker in Italy or a farmer in Bangladesh?

Lest I sound like too much of a curmudgeon, I do see many possibilities in all this. I already have a home LAN for Internet access and file and print serving, and would welcome reduced administration complexity. I never update PC drivers once something is working, and suffer anxiety every time I install a new piece of hardware or download a service pack. I'd love to be spared that hassle. I constantly jot mnemonic notes on scraps of paper, and they frequently end up in the laundry. That system can surely be improved upon. So I am looking forward to progressing toward ubiquitous computing and networking. I do think we will build it, but I think we will be surprised by what it looks like. I also think the users will come, and we will be surprised by how they use it. C

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