By William O. Plymale

Pervasive Computing Goes to School

In 1991 Mark Weiser introduced the idea of *ubiquitous computing*: a world in which computers and associated technologies become invisible, and thus indistinguishable from everyday life.[1] This invisible computing is accomplished by means of "embodied virtuality," the process of drawing computers into the physical world. Weiser proposed that computing and communication facilities would follow the evolutionary path of the electric motor. Early motors were very large and serviced the needs of many users. Later, in 1918, one could buy a "home motor" from the Sears Roebuck catalog for $8.95 to power several different appliances. Today, a family is surrounded by hundreds of "invisible" motors in the appliances around them. The driver of today's automobile does not need to understand the control and activation of the numerous motors, actuators, and sensors embedded throughout the car in order to efficiently operate it. Likewise, in a pervasive computing educational environment, as students move through an ordinary day at school, they would be constantly assisted by devices and services that require no explicit interaction on their part.

The computing and communication technologies required to achieve Weiser's vision did not exist in 1991. But in 2001, Mahadev Satyanarayanan presented aspects of a pervasive computing environment in which instances of Weiser's ubiquitous computing world could now be explored, given the maturity of computing/communication technologies such as wireless LANs, portable and wearable computers, and sophisticated, embeddable sensors.[2] He also identified several key research areas in pervasive computing: smart spaces, invisibility, localized scalability, and uneven conditioning. Briefly described, a *smart space* is a well-defined area, open or enclosed, that incorporates a collection of embedded systems (computers, sensors, user interfaces, and infrastructure of services). *Invisibility* is the intent that users not be unnecessarily distracted by their interaction with pervasive computing technologies. *Localized scalability* deals with the effective management of information exchange between users and their surroundings—considerations include bandwidth and energy usage, as well as control of user distraction. Finally, *uneven conditioning* refers to the current lack of consistent technologies and services throughout a user's environment; for example, wireless connectivity may be present in one building but not in another.

A number of companies and higher education institutions have begun extensive research projects aimed at investigating the requirements and implementation of pervasive computing environments. They include MIT's Project Oxygen (http://oxygen.lcs.mit.edu/), Georgia Tech's Aware Home (http://www.cc.gatech.edu/fce/ahri/), CMU's Project Aura (http://www2.cs.cmu.edu/~aura/), and UCLA's Smart Kindergarten (http://nesl.ee.ucla.edu/projects/smartkg/). These research activities have identified the following characteristics of a pervasive computing environment:

- Minimal user distraction
- Collaborative interaction
- User mobility
- Context awareness (user/time/location)
- Resource and location discovery
- Ambient information, calm technology
- Event notification
- Adaptive interfaces
- Invisibility—everyday object augmentation
- Anytime/anywhere

Benefits to a University

Given the above characteristics, the possible positive effects that pervasive computing may have on productivity within our lives (at school, work, and home) could be significant:

- Improved capabilities for communications, coordination, collaboration, and knowledge exchange
- Removal of time and space constraints for accessing information
- Enhanced decision-making abilities based on receiving and processing up-to-date organizational and environmental data
- Expanded user awareness of the environment through resource and service discovery[3]

College or university areas that could be positively influenced by a pervasive computing infrastructure include event notification, class/instructor/student collaborative interactions, context-aware applications, new learning spaces, enhanced collaboration and decision-making support for administrators and researchers, and more efficient facilities management. A research project of Gaetano Borriello and others at the University of Washington utilizes event notification as a memory aid.[4] Class/instructor/student interactions are being investigated by researchers such as Deborah Tatar and others at Virginia Tech[5] and by vendors such as Silicon Chalk (http://www.silicon chalk.com/). UCSD's ActiveCampus project (http://activecampus.ucsd.edu/) demonstrates how applications incorporating location awareness could enhance productivity and sociability in an academic setting. Stanford's Interactive Workspaces project (http://iwork.stanford.edu/), which includes iRoom and Meyer TeamSpace, is exploring new ways of supporting informal learning in collaborative learning spaces. Microsoft's Center for Information Work (CIW)(http://www.microsoft.com/presspass/events/ciw/default.asp) is a prototype of a future working environment that demonstrates increased productivity and enhanced decision-making by means of mobility support, sophisticated event-notification handling, and constant connectivity. Lastly, by means of embedded systems and the underlying control infrastructure, new facilities management processes will enable "smart" classrooms and campus buildings: the HESTIA middleware architecture developed by researchers at UIUC provides "smart" building services including "locking and unlocking doors; controlling lights; and configuring heating, ventilation, and air conditioning systems."[6]

Transition

The potential offered by pervasive computing environments warrants continued aggressive investigation. Meanwhile, a college or university can move toward the implementation of a pervasive computing environment by increasing research collaboration, raising administrative awareness, and developing a supportive IT infrastructure.

Research Collaboration

To prepare for a transition to a pervasive computing environment, the institutional IT organization must begin establishing collaborative alliances with members of the college/university research community. IT services should be mapped to research areas. Logical examples include mapping Learning Technologies with Computer Science, Teaching and Learning, and Architecture to investigate learning spaces, IT Network Services with Computer Engineering to study device and service convergence, and IT Middleware with Computer Engineering to investigate the management of identity and trust relationships. Such collaboration could be further defined by the strategic positioning of research graduate students in respective IT areas. Once formed, these collaborative relationships should instantiate themselves as research incubators—projects geared to moving pervasive computing from theory to prototype, then to acceptance, and finally to practice. These IT alliances could be facilitated and monitored by an IT pervasive computing group or committee.

Administrative Understanding

Pervasive computing marks a paradigm shift in the perception of computers and computing. There needs to be not only an understanding that the user no longer conforms to the computer but also a mindset change regarding systems and services. When designing new learning spaces or renovating old ones, instructional technologists and architects should think about collaborative systems and services instead of audio/video installations and about large interactive displays instead of chalkboards. Pervasive computing researchers should be included in the planning phases of new construction projects and IT initiatives. Efforts should be made to raise the awareness of pervasive computing benefits among the institution's administration, generating a willingness to commit funding, personnel, and other resources to incubator projects.

IT Infrastructure

James Powell, director of Virginia Tech's middleware group, acknowledges that current IT middleware services do not support a pervasive computing environment.[7] The IT infrastructure needs to be developed. Researchers in the Pervasive Computing Group of the Information and Communications University in Korea have identified a common set of services and infrastructure components that address pervasive computing requirements.[8] These components include a Service Discovery mechanism, a Content Sharing component, a Context Management component, an Adaptive Framework, an Adaptive Network component, and Security/Privacy services. Likewise, researchers at Infosys Technologies Limited describe an approach that shows how existing IT technologies "can be used to develop a pervasive IT infrastructure."[9]

Conclusion

Mobility, constant availability, invisibility, privacy, and interface adaptability are characteristics of pervasive computing environments that are intended to free the user from distracting computer interactions. Liberated from current computer and communication usage restrictions, users could effortlessly involve computers in more efficiently accomplishing tasks at hand. Collaborative and instructional systems incorporating pervasive computing services would improve the conveyance, understanding, and retention of knowledge by teachers, students, and researchers. Thus, in pervasive computing—as Weiser foresaw in 1991—the "motors" of computing will have become invisible.

Notes

1. Mark Weiser, "The Computer for the 21st Century," *Scientific American*, vol. 265 (September 1991): 94–104.
2. Mahadev Satyanarayanan, "Pervasive Computing: Vision and Challenges," *IEEE Personal Communications*, vol. 8, no. 4 (August 2001): 10–17.
3. G. B. Davis, "Anytime/Anyplace Computing and the Future of Knowledge Work," *Communications of the ACM*, vol. 45, no. 12 (December 2002): 67–73.
4. Gaetano Borriello, Waylon Brunette, Matthew Hall, Carl Hartung, and Cameron Tangney, "Reminding about Tagged Objects Using Passive RFIDs," presentation at UbiComp 2004, September 8, 2004, Nottingham, England.
5. Deborah Tatar, Jeremy Roschelle, Phil Vahey, and William R. Penuel, "Handhelds Go to School: Lessons Learned," *IEEE Computer*, vol. 36, no. 9 (September 2003): 30–37.
6. Raquel Hill, Jalal Al-Muhtadi, Roy Campbell, Apu Kapadia, Prasad Naldurg, and Anand Ranganathan, "A Middleware Architecture for Securing Ubiquitous Computing Cyber Infrastructures," *IEEE Distributed Systems Online*, vol. 5, no. 9 (2004).
7. James Powell, "Middleware for Pervasive and Proactive Computing," July 2, 2003, <http://www.geocities.com/james_e_powell/internet/internet.html>.
8. D. Lee, S. J. Hyun, Y.-H. Lee, G. Lee, S. Han, S. H. Kang, I. Park, and J. Choi, "A Middleware Infrastructure for Active Surroundings," Information and Communications University, Korea, 2002.
9. Puneet Gupta and Deependra Moitra, "Evolving a Pervasive IT Infrastructure: A Technology Integration Approach," *Personal and Ubiquitous Computing*, vol. 8, no. 1 (February 2004): 31–41.

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