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COMPUTER-AUGMENTED ENVIRONMENTS: BACK TO THE REAL WORLD

We live in a complex world, filled with myriad objects, tools, toys, and people. Our lives are spent in diverse interaction with this environment. Yet, for the most part, our computing takes place sitting in front of, and staring at, a single glowing screen attached to an array of buttons and a mouse. Our different tasks are assigned to homogeneous overlapping windows. From the isolation of our workstations we try to interact with our surrounding environment, but the two worlds have little in common. How can we escape from the computer screen and bring these two worlds together?

One view of the future of computing that has captured the popular imagination is *virtual reality*. VR allows us to escape from the computer screen by letting us use our whole bodies and a rich variety of (virtual) objects to interact with the computer. It attempts to replace the physical world with a computer-generated one, using devices such as head-mounted display goggles and data gloves. The result is very useful for purposes such as visualization and simulation, but of course, the artificial world is much simpler than the real world; it has lower resolution, leaves out details, and is limited in its behavior and extent. For certain kinds of entertainment, and for tasks such as learning to land an airplane in a blizzard, the VR approach is invaluable. But for helping us with everyday tasks, VR—even more than the workstation—cuts us off and excludes us from the world in which we live, work and play.

Another view of the future of computing is emerging, taking the opposite approach from VR. Instead of using computers to enclose people in an artificial world, we can use computers to augment objects in the real world. We can make the environment sensitive with infra-red, optical sound, video, heat, motion and light detectors, and we can make the environment react to people's needs by updating displays, activating motors, storing data, driving actuators, controls and valves. With see-through displays and projectors, we can create spaces in which everyday objects gain electronic properties without losing their familiar physical properties. *Computer-augmented environments* merge electronic systems into the physical world instead of attempting to replace them. Our everyday environment is an integral part of these systems; it continues to work as expected, but with new integrated computer functionality.

Computer-augmented environments emerge from the confluence of a number of disciplines. Although we cannot hope to outline the history of this movement here, we can mention the early work in head-mounted displays, interactive performances, dance, art pieces, and the vast range of embedded computer applications in airplanes, cars, telephones, wristwatches and deadly weapons. Recent work has been called names such as *ubiquitous computing* and *augmented reality*. Although the technologies differ, they are united in a common philosophy: the primacy of the physical world and the construction of appropriate tools that enhance our daily activities.

In order to explore the range of possibilities suggested by this philosophy, we can look at a specific everyday environment and imagine how its capabilities could be augmented by using the ideas suggested by the authors in this special issue. Consider your future office, for example, which might be located at home. In Weiser's office, we can imagine an environment that automatically adjusts temperature, music and the information displayed on the whiteboard according to its occupants. Scattered everywhere are small, medium, and large electronic displays of information that work together to help you keep track of projects and keep you in touch with your colleagues.

In Baudel and Beaudouin-Lafon's office you could use free-hand gestures to modify the environment without having to give up your normal use of gestures and hand movements, allowing you to carry on ordinary conversations and manipulate real objects. In the office described by Feiner, MacIntyre and Seligmann, you could wear a see-through head-mounted display that superimposes graphical information on the physical objects around you. These pictures let you see inside your printer, copier, and filing cabinets, dynamically showing you exactly how to service them or how to locate a part or a document. Fitzmaurice's article details a way to retreive and store vast amounts of electronic information everywhere in the room: in the air, on the walls and along the edges of bookshelves.

Despite all this technology, chances are it still will not be a paperless office, so Wellner's article describes an augmented desk that supports computer-based interaction with paper. On this desk, your paper documents gain electronic properties; so your boss can sketch on your papers from her office across town, and you can add up columns of printed numbers. Finally, Resnick's article suggests how children might benefit from this technology. Their toy bricks will communicate, sense, and control their environment, giving them exciting new ways to create, play, and learn.

Computer-augmented environments raise many issues, both technical and social. They may require a complex, distributed infrastructure, precise alignment between the real and electronic worlds, novel input and output devices, and great care for people's privacy. While these articles concentrate mainly on the technical issues, we must not ignore the social issues; much work needs to be done in this area (see sidebar by Spreitzer and Theimer).

We hope this special issue on computer-augmented environments will excite the imagination of the computer science community, who have perhaps too long been content with the current desktop embodiment of the computer. Our aim here is to present a selection of innovative examples of work in this area and to inspire more thinking along these lines. This new field presages a world of great variety, interest and utility. We can imagine a future in which the desktop workstation takes its place next to the telegraph key in the Smithsonian. ■