In this special issue, we turn our attention to the complex relationship between pervasive computing and environmental sustainability. We could begin this introduction by observing that it is urgently important to ensure environmental sustainability, but at this point, that would be almost trite. Due to widespread media coverage, word of mouth, and other means, concerns about issues such as global warming, natural resource depletion, and environmental toxins have permeated the public consciousness. The academic community has attended closely to these issues as well, and research relating to sustainability has ramped up in many areas. Pervasive computing is no
exception. The Ubicomp and Pervasive conferences have both recently held workshops on sustainability, and related fields such as human-computer interaction (HCI) are also forming communities around this topic (see the “Additional Resources” sidebar).2,3

Core Challenges
Pervasive computing naturally lends itself to many of environmental sustainability’s core challenges. Environmental sustainability involves efforts such as monitoring the state of the physical world; managing the direct and indirect impacts of large-scale human enterprises such as agriculture, transport, and manufacturing; and informing individuals’ personal choices in consumption and behavior. These needs are well-aligned with pervasive computing’s vision, which promises to deliver computational intelligence embedded in the physical world, human enterprises, and people’s lives.

Climate science, for example, depends on computational advances to progress. Traditionally, this has involved the creation of machines and algorithms capable of modeling complex climate features; sensor networks and other pervasive technologies provide critical data for these models. Pervasive devices can also push forward citizen science—as argued by Sasank Reddy and his coauthors at the recent UrbanSense Workshop (http://sensorlab.cs.dartmouth.edu/urbansensing/papers/reddy_urbansense08.pdf)—and heralded by Al Gore as a key part of the solution to the climate crisis in *Earth in the Balance: Forging a New Common Purpose* (Earthscan Publications, 1992). Further, the Climate Group argues that technology can facilitate worldwide reductions in global energy consumption of up to 15 percent by 2020 if applied to critical problem areas (www.smart2020.org). Pervasive computing can play a key role in these reductions by identifying and addressing inefficiencies in major infrastructural and industrial systems, as well as by influencing and increasing understanding of individual behavior.4,5

Conversely, pervasive computing also poses threats to ecological sustainability.6 Computational energy consumption reached 2 percent of world emissions in 2007 (www.smart2020.org), and as pervasive devices proliferate, concerns mount regarding the impact of their energy use. Energy consumption has of course long been a central research issue in pervasive computing for practical considerations: small, portable devices must conserve power to be useful. Some current areas of research include energy-efficient sensor networks,7 human-driven techniques for increasing battery life,8 and “scavenging” energy from human movement, sunlight, ambient heat, and other sources.9 An additional concern is electronic waste, which reflects the additive impact of billions of retired or soon-to-be retired devices. Eli Blevis and his coauthors challenge us to reduce this potential waste, discussing solutions such as designing devices that are likely to become heirlooms rather than being disposed of after only brief use.2

In this Issue
The articles in this special issue reflect the dichotomous potential of pervasive computing. The first three explore ways in which pervasive computing can positively influence the environmental impact of the perishable goods supply chain, agricultural enterprise, and user-driven domestic energy use; the fourth article sheds light on the factors influencing the negative impact that mobile phones have on the environment.

“Using Sensor Information to Reduce the Carbon Footprint of Perishable Goods,” by Alexander Ilic and coauthors, explores how sensor technologies can be used to improve the management of perishable goods such as fruits, fresh produce, and meat. Such goods are often produced, shipped, and then unfortunately thrown away because they’ve become unusable after improper storage, transport, and handling; this is a serious issue because perishable goods account for a significant percentage of greenhouse gas emissions. Pervasive technologies have great potential to improve the efficiency of this food supply chain. For example, the use of a sensor-based first-expire-first-out (FEFO) issuing policy can increase efficiency tremendously, in contrast to the conventional first-in-first-out (FIFO) issuing policy. However, the application of such sensor-based technology incurs

Additional Resources
Sustainability is gaining momentum in academic communities, as reflected by gatherings at several recent workshops. For more information, see the following workshops’ Web sites:

- Workshop at Ubicomp 2007 on Ubiquitous Sustainability: Technologies for Green Values (www.sustainableinteraction.net).
- Workshop at Pervasive 2008 on Pervasive Persuasive Technology and Environmental Sustainability (www.urbaninformatics.net/green).
- Workshop at Ubicomp 2008 on Ubiquitous Sustainability: Citizen Science and Activism (www.urban-atmospheres.net/Ubicomp2008).
financial and environmental costs. The article reports an analysis of the value of deploying sensors in supply-chain settings, taking into account both the financial and environmental impacts. In so doing, it explores an important theme in environmental sustainability—the complex trade-offs involved in deploying a technology in the hopes of improving a given situation. The analysis reported in this article clearly has direct implications for improving supply-chain management. More broadly, it promotes reflective analysis of the overall impacts of proposed solutions to environmental challenges to ensure that a solution’s costs (environmental and financial) don’t outweigh its benefits.

Sensor networks—large networks of low-cost, embedded devices containing microcomputers, radios, and sensors—have long been explored as a mechanism for measuring and monitoring conditions in the natural world. In “Sensor and Actuator Networks: Protecting Environmentally Sensitive Areas,” Tim Wark and his fellow researchers extend this focus by exploring how sensor networks can incorporate technologies that actively influence environmental conditions. Agricultural activities such as cattle grazing can damage environmentally sensitive regions, such as river banks or riparian zones. To protect such regions, the authors explore improvements to virtual fencing—the use of real-time wireless sensor and actuator networks to enable spatial control of large cattle herds. This work provokes reflection on the logistically and ethically complex issue of using pervasive technologies to promote the protection of natural resources while supporting a large-scale commercial enterprise.

Domestic energy use has long been studied in fields such as energy management and psychology, and there’s evidence that technology-enabled feedback of domestic energy consumption can promote awareness and lead to energy savings. Recent developments have resulted in a significant upswing in commercially available tools that support homeowners in managing and minimizing their energy use. To date, however, consumers have had little choice of display and there’s been little understanding of the specifics of what makes for a good display design. In “Technology-Enabled Feedback on Domestic Energy Consumption,” Geraldine Fitzpatrick and Greg Smith articulate a set of design issues for home energy management displays based on exploratory user experience and preference studies. Their findings have direct design implications for current and emerging devices such as smart meters, as well as suggesting research agendas for displays based on emerging smart home technologies. In addition, the article illustrates how pervasive technology can be layered on existing technological infrastructure to support or persuade more sustainable behaviors.

Pervasive technologies can be applied in many arenas to assess, demonstrate, or create opportunities for simultaneous economic savings and environmental sustainability.

The previous three articles explore how pervasive technology might help solve sustainability problems created by other enterprises. However, widespread adoption of pervasive technology (and the accompanying manufacturing, distribution, and disposal processes) can itself create sustainability problems such as electronic waste. For example, mobile phones can be considered a pervasive technology, and their proliferation can be considered a sustainability issue, as extensive research has revealed the material dangers and toxic effects of mobile phone disposal. In “Understanding the Situated Sustainability of Mobile Phones: The Influence of Local Constraints and Practices on Transferability,” Elaine Huang and her coauthors explore mobile phone practices, especially end-of-use practices such as reusing, recycling, re-gifting, throwing away, and destroying mobile phones. In particular, the work focuses on how local and community factors affect mobile phone sustainability in several different geographic regions throughout the world. This case study illustrates the environmental challenges associated with a technology’s widespread adoption, and shows how forces such as business models, policy, and cultural context relate to sustainable practice for such technologies.

In the past few years, environmental sustainability has gained great momentum in many sectors. Compelling arguments state that environmental challenges demand immediate action. However, as this issue goes to press, concerns are mounting about the global economy. There is a serious risk that attention to pressing economic issues will overshadow concerns about environmental sustainability. For example, economic constraints might be perceived as limiting the ability of governments, industries, and individuals to pursue environmentally friendly actions or develop environmentally friendly technologies. Although some situations involve complex trade-offs between financial and environmental impacts, pervasive technologies can be applied in many arenas to assess, demonstrate, or create opportunities for simultaneous economic savings and environmental sustainability. Some of these
technologies might not be immediately feasible and might demand a long-term view. As researchers, we often have the privilege of studying long-term issues and selecting the topics on which we work. Recent world events put an even greater burden on our community to preserve the focus on environmental sustainability, and they increase our responsibility to pursue strategic research opportunities that can have significant real-world impact.

REFERENCES


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