From the Editor in Chief

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Avoiding Dead Batteries

M. Satyanarayanan

A gripping scene in the movie *Air Force One* depicts the president of the United States getting technical help over a cell phone to dump fuel from his aircraft and thus force its hijackers to land. At a critical moment, when he is about to learn which wire to cut, his cell phone battery dies. Even the president cannot escape the ruthless economics of battery life!

A PERISHABLE RESOURCE

Energy is only one of many resources needed for mobile computing. Other resources include wireless network bandwidth, CPU cycles, main memory, and disk space. However, energy is the only *perishable resource*—once consumed, it cannot be replenished by actions performed within the mobile computing system. Only external actions, such as recharging the battery or replacing it, can replenish the resource. This is in contrast to the other resources I mentioned. You can reclaim both memory and disk space through deletions. With the passage of sufficient time, you can transmit a certain number of bits or execute a certain amount of code, even when bandwidth or CPU cycles are scarce. In general, these scarce resources affect the rate of progress, perceived performance, and user experience in mobile computing. But their scarcity does not have the grim finality of a dead battery.

A good tutorial on the fundamental issues surrounding battery life is the 1997 US National Research Council report, *Energy-Efficient Technologies for the Dismounted Soldier*.[1] The council created the report in response to the energy challenges faced by the Land Warrior system, an early use of wearable computing for military applications.[2] The 2004 report, *Meeting the Energy Needs of Future Warriors*, provides an update on the 1997 report.[3]

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One memorable quote from the first NRC report says, "Using new materials and chemistries, batteries are approaching explosives in terms of energy density." Imagine the battery in your laptop, PDA, or cell phone having the energy content of a stick of dynamite! Fortunately, this energy is released over many hours rather than a few microseconds. But an implication of the quote is that radical improvements in battery technology are unlikely—their energy density is already very high. Incremental improvements are likely, but some of those improvements will be eaten up by the energy demands of increased functionality in mobile devices. It is therefore essential to explore alternative approaches to extending battery life.

EXPLORING ALTERNATIVES

One approach is to improve hardware power efficiency, a key concern of every designer of mobile hardware. Another is to make software energy-aware, thereby reducing its energy demands on hardware.[4] A third approach is to perform *cyber foraging* by offloading work to nearby servers,[5] and a fourth approach is to trigger external actions that replenish a battery's energy. All are viable options, and we will likely use different combinations of them in different circumstances.

Given the vital role of energy in mobile and pervasive computing, this issue focuses on this topic. The guest editors are all researchers who have made important contributions to this area. Roy Want leads the Personal Server project at Intel Research; Chandra Narayanaswami leads the group at IBM Research that created the first Linux wristwatch computer; Keith Farkas contributed to many aspects of energy efficiency in the Itsy pocket computer at Compaq Research. Their

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Guest Editors' Introduction discusses the energy-related topics we explore in this issue.

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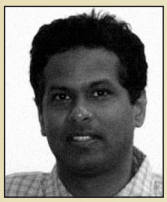
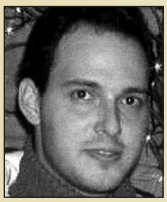


Chandra Narayanaswami manages the Wearable Computing group at the IBM T.J. Watson Research Center. His group is investigating challenging issues in device form factors, infrastructure support and exploitation, symbiotic computing, new applications and user interfaces, and power management for pervasive computing. His research interests are mobile and pervasive computing, including wearable computing, the use of pervasive devices in business processes, middleware for interdevice interaction among ubiquitous devices, novel applications, and power management. He received his BTech in electrical engineering from the Indian Institute of Technology, Bombay, and his MS and PhD in computer and systems engineering from Rensselaer Polytechnic Institute. He is a senior member of the IEEE and a member of the ACM. Contact him at chandras@us.ibm.com; www.research.ibm.com/people/c/chandras.



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