GUEST EDITOR'S INTRODUCTION

Grand Challenges

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Thirty years ago, Mark Weiser articulated a vision for pervasive computing,[1] while noting some of the challenges that would need to be overcome to make that vision reality. Since then, researchers have set about realizing both some of the specifics mentioned in that article (e.g., Lamming & Flynn's Forget-Me-Not[2]) and the broader vision of computing that is integrated "seamlessly into the world"[1] (e.g., disappearing hardware[3]).

Despite decades of work, however, few pervasive computing researchers would consider Weiser's vision reality. While we should not feel beholden to his original ideas, the idea of *looking back to look forward* (Bardram, in this issue) has considerable value. In this Special Issue, we use the anniversary of Weiser's article as a prompt to reflect on where pervasive computing has been and where it should go. Labs from diverse research fields within pervasive computing identify key areas of challenge that persist today. Together, the accepted articles provide inspiration for the next decades of pervasive computing research.

Our first article: "The Four Phases of Pervasive Computing: From Vision-inspired to Societal-Challenged" charts the changing nature of pervasive computing—from its "calm" beginnings to phases of more deliberately playful and engaging technologies, to the present moment in which innovation and commercialization dominate. From there, Yvonne Rogers articulates a vision for the next decades, in which pervasive computing faces up to its responsibilities and helps to address the societal challenges.

Our second and third articles consider some of the underlying technologies upon which pervasive applications often depend. In "From Sensing to Acting – Can Pervasive Computing Change the World?," Jakob E. Bardram observes that, if we consider the sense-think-act model as the basis of ubicomp, to date we have largely focused on sensing and thinking, with very little acting. Challenge areas for actuation extend to the full stack: the hardware itself, OS and framework support, AI/ML models, and UI/UX. In "Rethinking Language Interaction with Pervasive Applications and Devices," rethink What You See Is What You Get interfaces for audio, with What You Hear Is What You Say. Here, rather than attempt to develop natural-language systems that pass the Turing test, Claudio S. Pinhanez suggests that systems should instead express their understanding using the terms that reflect their comprehension.

Our next three articles explore challenges in some key application areas: education, manufacturing, and mobile health. In "Grand Challenges for Pervasive Technology to Transform Pervasive Education," Judy Kay characterizes aspects and experiences of current and future pervasive education. The article classifies technologies used to realize pervasive education, highlighting the importance but relative neglect of data stores and data management, and articulates 10 grand challenges spanning a range of learner contexts. In "Citizen Manufacturing: Unlocking a New Era of Digital Innovation," Steve Hodges and Mike Fraser envisage a future in which individuals' ideas are readily realized as viable products. Going beyond the current "maker" culture, the authors stress a need to empower individuals to transform their ideas into viable products and spearhead a network of stakeholders to help make their vision a reality.

"Mobile Health with Head-Worn Devices: Challenges and Opportunities" reflects on the growing range of head-worn devices, and their application for health data collection and delivery of clinical inventions. Whether mounted at the eyes, ears, jaw, or other locations, Andrea Ferlini and colleagues suggest a common set of overarching challenges and opportunities that span hardware (e.g., accommodating multiple sensors within a small device footprint), data (e.g., managing uncertainty), communications (e.g., ensuring secure transmission of sensitive data), and usability (e.g., ensuring interactions are socially acceptable).

Finally, in "Safety as a Grand Challenge in Pervasive Computing: Using Feminist Epistemologies to Shift the Paradigm From Security to Safety," Angelika Strohmayer and colleagues address the cross-cutting issue

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of safety. Building on current areas of concern, privacy, and security, the article identifies a need to shift focus to "meaningfully and proactively protect" vulnerable users of pervasive computing—as exemplars, the authors highlight challenges associated with responding to technology-facilitated domestic abuse and algorithmic harm. The authors assert that to design out and combat unintentional harms, developers must acknowledge existing power structures, understand the wider context in which their systems will operate, and move their attention to the process rather than simply concerning themselves with outcomes. Putting this into practice is nontrivial, but this article's articulation of the problem space is complemented with some pragmatic considerations that can shape design.

It seems then, that there is much still to do in pervasive computing. Moreover, while technical challenges abound, our authors are clear that we must not forget the broader societal importance of the technologies we develop, ensuring that they really do "reside in the human word" (in Weiser's work[1]). We must maintain awareness of the role that we play in "ensuring or undoing people's. . . safety" (Strohmayer, in this issue) and in upholding the societies and world in which they must live (Rogers, in this issue).

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