Today’s computing technology is radically different from that of 10 years ago. This is partly due to the inevitable year-by-year increase in speed and computing power. However, something even bigger has occurred; a threshold has been crossed because today’s general public holds in their hands (via smartphones, tablets, and increasingly wearable devices) portable multi-media workstations whose usage is embedded into everyday life. The effect of this is transformative because people now rely on their devices all day long. No longer is a computer something in another room that takes minutes to boot up and is thus relegated to solitary, serious data entry work. Instead computers have become always-on devices used for communication with work colleagues and family; information stations; entertainment pods for audio, video and games; and financial managers and payment solutions. These devices are found wherever we are. In other words, the era of pervasive computing predicted by Mark Weiser¹ is here.

Researchers and developers can take advantage of this new era by knowing that the public has personal access to highly interactive multi-media devices. Interfaces involving sound are already in the hands of millions of people. For information display, sound promises an alternative to squeezing information onto small screens that then force us to attend to them, thus making us lose awareness of our immediate environment. This special issue looks at some of the upcoming research on how such interaction with sound can be used in a variety of areas and applications.

**Background to Sonification**

Auditory displays are systems that transform data into sound in a systematic way and present this information to human users using an interface that allows them to interact with the sound synthesis process. This transformation of data into sound is called **sonification**, which can be defined as the data-dependent generation of sound in a way that reflects objective properties of the input data.²

Sonification and auditory display research takes place in a community that builds upon a range of disciplines, including physics, acoustics, psychoacoustics, signal processing, statistics, computer science, and musicology. Application examples range from auditory displays in assistive technology for visually impaired people to data exploration and industrial process monitoring. Since 1994, the main forum for discussing and disseminating such ideas has been the International Community for Auditory Display (ICAD, www.icad.org).

The aim of auditory displays and sonification is to exploit, among other capabilities, the ability of our powerful auditory sense to interpret sounds using multiple layers of understanding, perceive multiple auditory objects within an auditory scene, turn our focus of attention to particular objects, and learn and improve the discrimination of auditory stimuli. Multiple sonification methods exist, including audification, parameter mapping sonification, and model-based sonification, to name a few. A good description of these techniques can be found in *The Sonification Handbook*,³ for which the full text is available online.

Auditory displays typically unfold over time (and often use time as a display axis) because sound is inherently a temporal phenomenon. Interaction thus becomes an integral part of the process in order to select, manipulate, excite, or control the display, and this has implications for the interface between humans and computers. In recent years, it has become clear that there is an important need for research to address the interaction with auditory displays more explicitly.

**Interactive Sonification**

*Interactive sonification* is the specialized research topic concerned with the use of sound to
portray data, where a human being is at the heart of an interactive control loop. The International Workshop on Interactive Sonification (ISon, www.interactive-sonification.org) was introduced in 2004 to focus on auditory displays that sonify data with such human-controlled feedback. A selection of papers from the first ISon (2004) and third ISon (2010) was published in a special issue of the IEEE Multimedia and a special issue of the Springer Journal on Multimodal User Interfaces, respectively.

The Fourth Interactive Sonification Workshop at Fraunhofer IIS, Germany, in December 2013 invited papers from around the world to focus on the dynamic interaction between humans, computers, and auditory interfaces, with a special focus on how the rapidly changing world of computer interfaces and pervasive computing is providing new widely available platforms for real-time multimedia processing and applications, including sonification. The workshop also focused on the problem of reproducible research in interactive sonification to allow for the formal evaluation and comparison of systems and the establishment of sonification standards. Authors participating in ISon 2013 were invited to submit their contributions to this special issue and, in addition, a general call for papers was made to sonification and audio researchers. Twenty-seven submissions were submitted, and five contributions plus two short contributions were finally selected through a blind peer-review process where researchers from all over the world participated as reviewers.

In This Issue

This special issue covers some of the topics of interest in interactive sonification that will hopefully help to advance this field. Current technological developments allow us to digitally shape the sensory feedback we get from our interaction with real and even virtual devices, changing our perception about the properties and behavior of these systems. These multimodal interfaces can use interactive sonification as an additional mode of interaction and three of the contributions included in this special issue highlight this use.

In “The Effects of Ecological Auditory Feedback on Rhythmic Walking Interaction,” Jystyna Maculewicz, Antti Jylhä, Stefania Serafin, and Cumhur Erkut investigate the effect of auditory feedback on rhythmic walking in the context of closed-loop interactive sonification. Interest in using floor-based interfaces has increased in the last few years in the field of interaction design where walking exercises are emerging, for example, as a tool for rehabilitation on treadmills. In this study, subjects are presented with both natural (ecological) and unnatural (sinusoidal) audio cues to help direct their gait at different target speeds. The authors discuss user experience and performance, as a measure of the error between the performed and target tempo, and show that ecological sounds perform better. In addition, the effect of using audio feedback that adapts to human walking is also analyzed, and the conclusion is that this adaptive condition results in a pace that is more stable and closer to that of natural walking.

Auditory displays can play an important role in improving the usability of hand-gesture interfaces where haptic feedback is not possible or difficult to implement. In this context, Yongki Park, Jaehoon Kim, and Kyogu Lee show the benefits of using interactive sonification in hand-gesture interfaces for the task of selecting menu items. In their article “Effects of Auditory Feedback on Menu Selection in Hand-Gesture Interfaces,” the authors describe new audio feedback methods and compare these with traditional visual and audio approaches, showing significant improvements in selection efficiency and effectiveness.

“Sonification of Surface Tapping Changes Behavior, Surface Perception, and Emotion” presented by Ana Tajadura-Jiménez, Nadia Bianchi-Berthouze, Enrico Furfaro, and Frédéric Bevilacqua describes a sonic interactive surface that digitally modifies the audio-feedback resulting from tactile interactions in real time. Users tap on a real or virtual surface, and this tapping sound is modified to simulate different strengths of tapping. Results show that the altered tapping sounds affect the users’ emotional responses. The article shows that interactive sonification can be used as a powerful tool for shaping tactile interactions, aiming to change movement behavior, emotional state, and perception of material properties.

Designing a meaningful interactive auditory display is a complex task, and two of the works included in this issue deal with this topic.

Nina Schaffert and Klaus Mattes describe the use of interactive sonification technology to create coherence between action and reaction in sports in their article “Interactive Sonification in Rowing: Acoustic Feedback for
Interactive sonification offers scientists and researchers the potential to understand a range of fast-moving and high-dimensional data.

On-Water Training.” This study describes the experiences of using sonification in on-water rowing with elite athletes, explaining the audio-movement relationship to understand expertise and skill acquisition. In addition, this work provides criteria and recommendations for the development of an auditory display to be used in the context of motion and rehabilitation, a topic which is of great interest in the field of auditory display design.

Visda Goudarzi's article “Designing an Interactive Audio Interface for Climate Science” presents a user-centered design of an auditory display for data analysis in the area of climate science. The author describes the systematic approach followed in order to create an appropriate soundscape that best portrays the specific parameters used by these scientists. Interviews with scientists were used to assess the data analysis process and the specific language used by the scientists. Later, participants were asked to pair sounds with climate parameters.

Finally, two shorter contributions are included. In “Wearable Auditory Biofeedback Device for Blind and Sighted Individuals,” Masaki Matsubara, Takahiro Oba, Hideki Kadone, Hiroko Terasawa, Kenji Suzuki, and Masaki Iguchi emphasize the use of interactive sonification in gait rehabilitation for both blind and sighted individuals. The feasibility of this system is investigated in an ankle-joint motion exercise, suggesting a positive emotional effect of the auditory display on blind users.

In the second short contribution, “Sonic Trampoline: How Audio Feedback Impacts the User’s Experience of Jumping,” Roberto Pugliese and Tapio Takala present the development and evaluation of a system that interactively augments the sound of the act of jumping on an elastic trampoline. This empirical study confirms the hypothesis that interactive sonification affects user experience positively and stimulates changes in the performance of the user, adding an extra dimension in training and body-controlled games.

Conclusion and Future Research Agenda
When designing an auditory display, researchers face the problem of having to select a particular sound generation technique, and the possibilities for mapping data to sound parameters are countless. A formal methodology for the evaluation and comparison of the performance of sonification techniques under different conditions is currently missing from the research literature. This leads to subjective decisions that are difficult to justify in many cases during the design process. To overcome the existing limitations in the evaluation of interactive sonification methods, a reproducible research approach where methods are publicly evaluated in standardized and measurable tasks must be adopted. We envision that the adoption of this open science philosophy will help to establish standard sonification methods that will finally help designers to select the most promising techniques for given standardized use contexts.

Interactive sonification offers scientists and researchers the potential to understand a range of fast-moving and high-dimensional data, in a natural way. The pervasive nature of today’s portable multimedia devices means that the general public now has the capability of accessing such hands-free information displays. In coming years, it will be fascinating to see (and hear) what such a combination of technology, algorithms, and users will allow as we move into a world increasingly full of rich data streams which humans want to perceive.

References
4. T. Hermann and A. Hunt, “An Introduction to Interactive Sonification,” special issue, IEEE MultiMedia,
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