Introduction to the Special Issue on Virtual Analog Audio Effects and Musical Instruments

DIGITIZATION of electronic, electromechanical, and acoustic systems is an ongoing process in music technology. As analog components and circuits, which resulted from unique design concepts, inevitably age, there is a need to replace the disappearing technology with virtual analog versions of the original systems. This development follows, after a long delay, the development of digital audio recording equipment and digital storage systems, such as the compact disk, which were introduced in the 1970s and 1980s. More than a decade ago, the new fully digital studios and the use of PCs in music production aroused the dream of replacing musical instruments and all other musical devices with software. In addition to achieving a fully digital system, it was desired to reduce the number of connections, error sources, and physical devices, which can be large, expensive, and laborious to maintain. Typical examples of today's virtual music technology are guitar amplifier models, virtual analog synthesizers and filters, and virtual musical instruments, such as digital pianos.

There are methodological similarities between virtual analog modeling and physical modeling of musical instruments. In fact, virtual analog modeling can be seen as a parallel approach to physical modeling, where computational simulations are developed for acoustic systems: in virtual analog modeling, computational simulations of electronic systems are devised. Nonlinear and time-varying systems are often involved in both virtual analog and acoustic models. Some of these systems are particularly challenging for digital simulations.

The research area of virtual analog audio signal processing contains various subtopics. Virtual amplifiers and loudspeaker cabinets simulate the linear and nonlinear response of traditional analog electronics used for example in tube amplifiers, such as those used by electric guitar, bass, and organ players. It is possible to imagine a virtual guitar amplifier in which the user could change the device's component values or circuit connections and hear in real time the resulting change in the amplifier's tone. The paper by De Sanctis and Sarti introduces nonlinear wave digital network approaches to analog modeling, for the purposes of sound synthesis and effects modeling. The paper by Yeh *et al.* presents a nonlinear discrete-time state-space description which allows real-time modeling of nonlinear analog circuits. Pakarinen and Karjalainen describe in their paper a wave digital triode model for real-time tube amplifier emulation.

In virtual analog synthesis, famous electronic music synthesizers of the 1960s or 1970s are simulated with digital signal processing. These virtual instruments usually rely on the same sound generation principle as their analog counterparts, and thus this research topic involves investigation of oscillators and filters used in analog music synthesizers. In his paper, Hélie uses Volterra series to derive a digital simulation of the well-known Moog ladder filter, which has been an essential part of several analog synthesizers. The paper by Fontana and Civolani describes a method for digitizing nonlinear analog circuits as filter networks in a manner that preserves the original circuit structure. The papers by Nam *et al.* and Välimäki *et al.* introduce alternative algorithms for generating approximately bandlimited discrete-time versions of classical waveforms, such as the sawtooth waveform. The resulting signals can be used as oscillators in digital subtractive synthesis of musical tones.

Software implementations of analog effects boxes are yet another popular application area. Some analog effects devices have their own characteristic timbre. The digital implementation must imitate the response of such a device faithfully to reproduce a sufficiently similar timbre. Plate and spring reverberators were once common electromechanical devices that provided spaciousness to dry electronic instrument sounds. They were later replaced with digital reverberation technology. However, there is a constant need to imitate the nostalgic sounds of old recordings, and, for this reason, simulations of electromechanical reverberation devices are now implemented. The contribution by Bilbao and Parker introduces a spring reverberation model which emulates the highly dispersive behavior and coupling between different types of longitudinal and transverse wave propagation that appear in a helical spring.

Another group of papers are related to virtual acoustic musical instruments. String, woodwind, and brass musical instruments are known to be highly expressive and difficult to replace with a computer simulation. The paper by Bank *et al.* describes a computational "modal synthesis" model of the piano (i.e., a parallel second-order resonant filter bank) including both transverse and longitudinal string vibrations, and incorporation of various earlier results. Evangelista and Eckerholm address the problem of modeling plucked and struck (and lightly touched) vibrating strings using a nonlinear scattering junction and "balanced perturbation" in the interior of a digital waveguide string model that propagates sampled displacement waves. The paper by Lee *et al.* suggests a new hybrid model for synthesizing guitar tones by combining the strengths of modal and digital waveguide modeling techniques. Mignot *et al.* describe a computational modeling technique for nonuniform bores, with emphasis on brass instruments such as the trombone; the model consists of a sequence of lossy flared pipe sections derived based on the Webster–Lokshin wave equation, with each section digitized as a state-space model of its s-plane scattering matrix, interconnected as digital waveguide sections (via traveling-wave ports). Maestre *et al.* put the accent on bow control in the violin, and propose a stochastic algorithm for the analysis and synthesis of the temporal contours of bow velocity, pressing force, and distance from the bridge.

Another key challenge in the field is the realistic simulation of percussion instruments, and the next three papers address it

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in different ways. Bilbao's approach is based on a partial-differential-equation description for circular thin shells of spherical geometry, then solved and simulated using time-domain finite-difference schemes. Rabenstein *et al.* model a tubular bell as a rectangular plate with boundary conditions appropriate for a cylindrical shape, and the analytic solution for this model provides the coefficients for modal synthesis using a parallel second-order filter bank. Avanzini and Marogna propose a modular modal synthesis approach to the simulation of drums having a circular membrane, such as rototoms and snare drums.

Regarding future research in this area, one may notice that this special issue lacks contributions on the modeling of analog systems for audio recording, postprocessing, or storage, such as tape recorders and tape-based effects. As with other analog effects, these machines have impressed their acoustic footprints on a large body of analog sound recordings. Their restoration or imitation can be based on modeling the working principles of such devices.

We believe this is the first special issue on virtual analog modeling published in any scientific journal. We hope that the readers will find this issue inspiring. We would like to thank the authors of all submitted papers for their contributions. Also, we want to express our appreciation to the reviewers for their help. Further, we wish to offer our warm thanks to the Editor-in-Chief, Professor Helen Meng, the past Editor-in-Chief, Professor Mari Ostendorf, and the Publications Coordinator, Ms. Kathy Jackson, for their support and assistance during the preparation of this special issue.

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