Designing New Musical Instruments

The Artist/Engineer Collaboration

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What was the first musical instrument? We may never know the answer, but we do know that music is much older than recorded history — earliest archeological musical instrument specimens go back 30,000 years or more. Primitive early musical instruments were more discoveries than inventions, but for thousands of years they have evolved to what we now know as modern instruments. Have musical instruments stopped evolving? Highly unlikely — if anything, the pace has increased.

During the course of human history until this century, all music was played acoustically, and thus it was always physically evident how the sound was produced. The player controlled the sound directly by playing (eg, plucking, blowing, striking) the instrument, and the performer's gestures were directly translated by the instrument into sound. This direct physical relationship started to become indirect in recent centuries with keyboard instruments; the piano and the organ both have some kind of mechanism between the player's fingers and the sound.

In the 20th century, the invention of electronic musical instruments has seen a "decoupling" between the performer and the resulting sound. This has led to vast possibilities for entirely new types of "intelligent" musical instruments where the contemporary performing artist uses technology to create innovative new compositions, performances and improvisations. One such new instrument is the radio drum, whose development is being refined through collaborative research among faculty and graduate students of Music and Engineering at the University of Victoria.

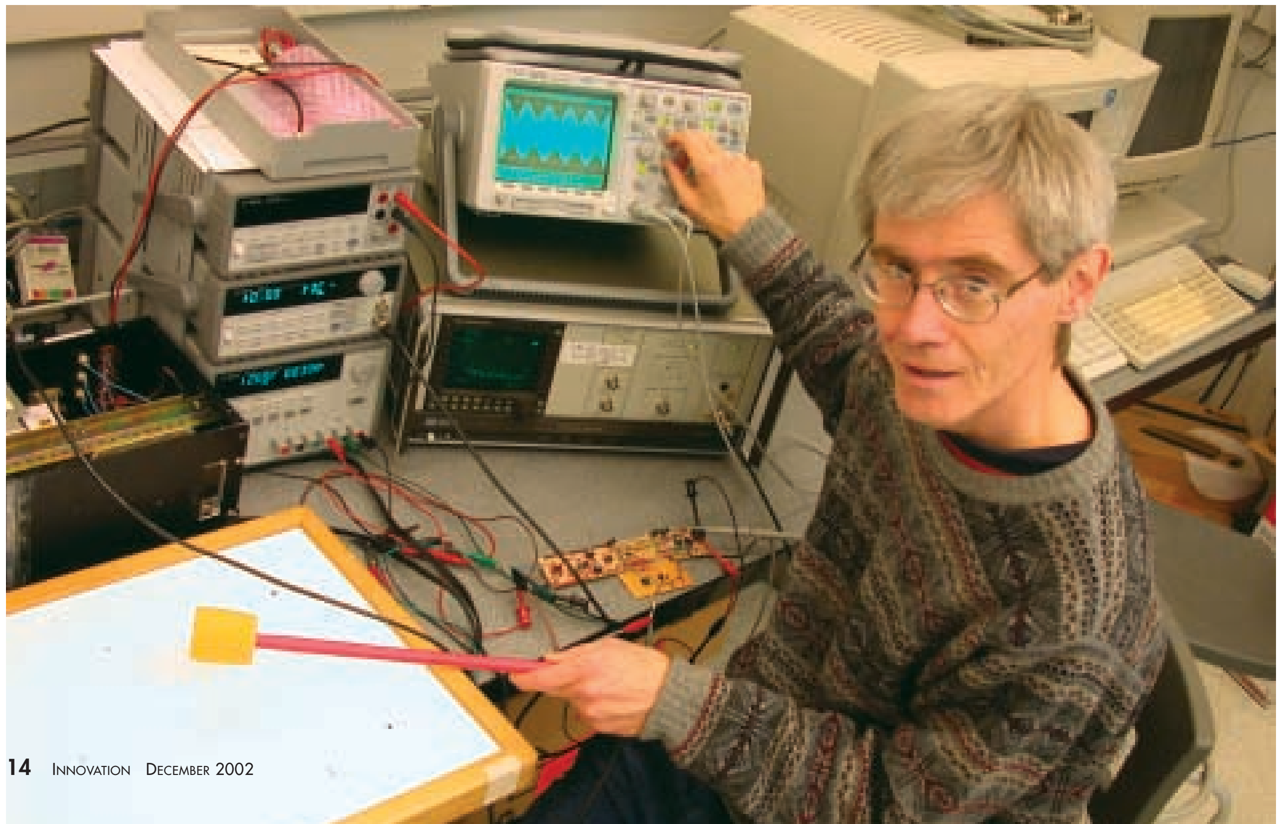
The Radio Drum Explained

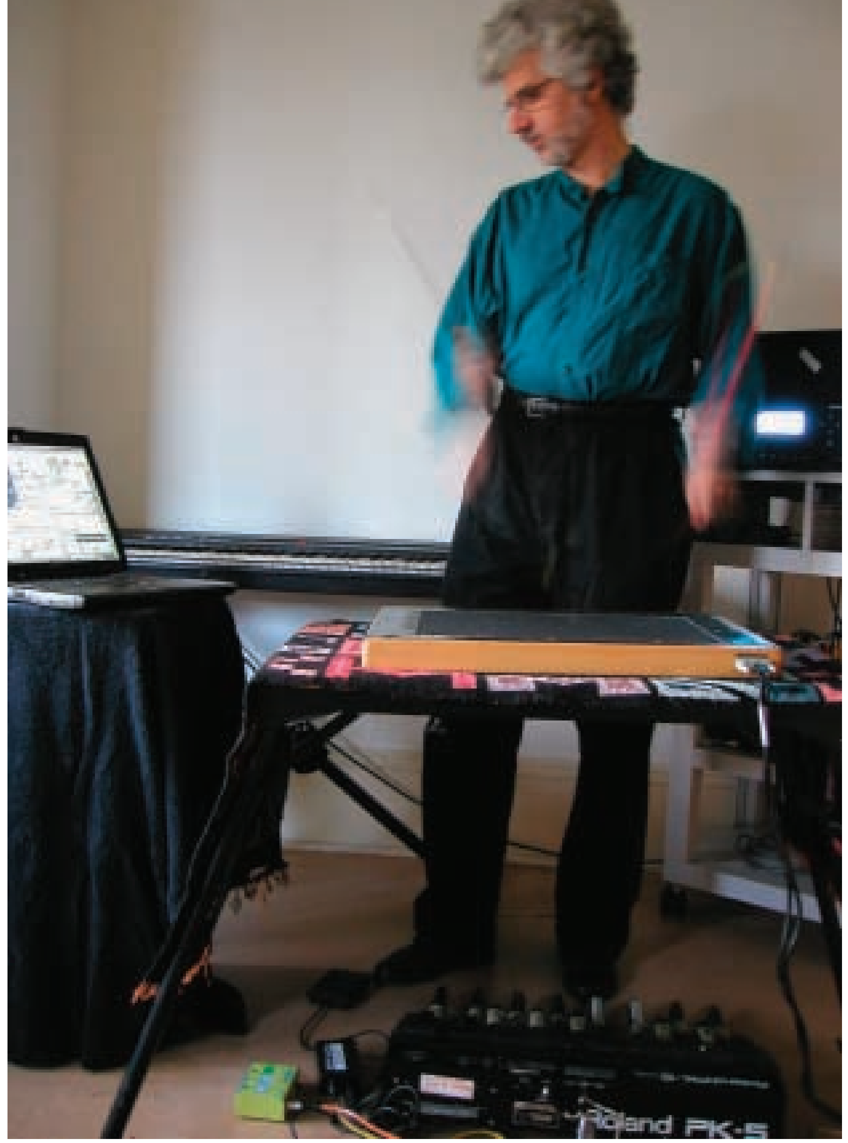
The radio drum was first developed at Bell Laboratories in the mid 1980s as a three-dimensional mouse, which failed as a computer peripheral and instead became a musical instrument. A kind of "virtual instrument," it is a descendant of the theremin, the amazing musical instrument invented in 1917 that generates sound in response to hand movements in free space within an electromagnetic field.

The radio drum works on a similar principle: the drum itself does not produce any sound. As a gesture sensor, like the theremin, it detects the performer's movements to trigger and control sound; the performer does not have to physically touch any surface to create a sound.

The radio drum consists of two parts: a rectangular surface (drum) with embedded antennae and two transmitters embedded in conventional sticks that use different radio frequencies. The drum surface is covered with a layer of foam to provide a quiet, elastic playing surface and to avoid striking the circuit board.

The radio tracking technique depends on the electrical capacitance between the radio transmission antenna in the end of each stick and the array of receiving antennas in the drum. The drum generates six separate analog signals that represent the x, y, z position of each stick versus time t. A key attribute of the radio drum is the multidimensional nature of the gestural signal. This is in contrast with unidimensional controllers such as keyboards, which have velocity sensitivity only.





Facing page: **Peter Driessen PEng in his University of Victoria laboratory testing the response characteristics of the radio drum, an electronic musical instrument that detects the performer's movements to control and trigger sound (photo: UVic).** ***Left:*** **Andrew Schloss performs on the radio drum in his home studio using Max/MSP, a language designed for real-time music programming (photo: Irene Mitri).**

Components of New Musical Instruments

In order to consider musical performance with new musical instruments such as the radio drum, three components are required:

- a gesture sensor that detects the performer's movements and responds to them by creating control signals;
- a sound engine that generates sounds according to a sound synthesis model with parameters; and
- control algorithms that map the control signals into the parameters of the sound synthesizer.

The performer therefore controls the sound via gestures, and the range of expression is determined by the complexity available in each of the above three components.

Fully decoupling the gesture from the sound (and putting a computer in between) creates enormous possibilities. The instrument can now do anything as a result of the gesture, which can trigger and control any sound (not only drum sounds). The gesture can also control image and video displays, or any other device that can be controlled via an electronic input signal.

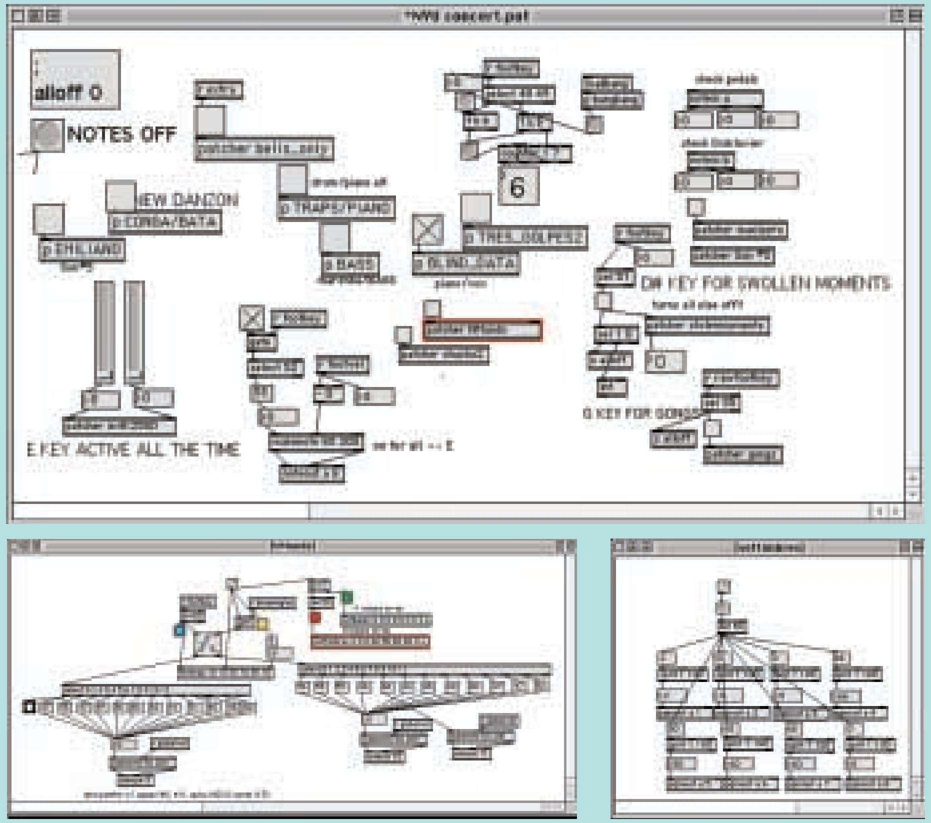
One could say that the mechanism (or "action") in the conventional piano, strings and soundboard have now become electronic circuits, chips and computers. Sound generation is now accomplished via computer chip and nothing vibrates except the loudspeaker at the end of the chain.

This allows the creation of totally new sounds — sounds that would be impossible to replicate physically. Examples are playing 88 notes at once on a piano, dividing the octave into microsteps to create new tonalities, or creating new timbres (character of sounds) with spectra unknown in acoustic music, etc.

These open possibilities are very exhilarating artistically. However, an equally important issue arises: how do you play these new electronic/computer instruments? In other words, even if we can make these wonderful new sounds, how will we control and perform them?

The Performance Question

Early electronic music did not worry so much about performance; early works from the mid 20th century were often



Max/MSP graphical user interface showing top-level concert patch (NYU concert.pat) that the artist sees during the performance (top), along with subpatches that are opened by double-clicking on the parent patch. The NMundo subpatch includes mappings from regions of the drum to different sounds; the settimbres sub-subpatch assigns different timbres to the synthesizer to prepare it for this particular mapping of the drum. Graphical user interfaces are custom made for specific artistic projects; no two are the same. See www.cycling74.com for more information.

recorded in a studio and not performed live. Even so, there was always an interest in live performance and the ability to control the sounds in real time.

Computers have finally become powerful enough to create complex music in real time. Sound synthesis techniques have taken advantage of this computing power and have evolved to include physical modeling of an acoustic instrument, in which the physics of the instrument are implemented in software. Gesture sensing techniques have also improved significantly using new devices such as pressure-sensitive fiber optics.

However, the control algorithms and techniques have not evolved nearly as much. In terms of performance, the problem remains — what kind of control algorithms or mappings make musical sense?

Electronic keyboard instruments — even those with physical modeling sound synthesis — still respond only to note number and velocity gesture inputs. Thus, because of the missing control component, the opportunity to create new musical instruments is largely unexplored.

Mappings for Musical Expression

The subtle and nuanced motions we make while playing a musical instrument relate closely to what and how we intend to play and what sound we intend to make. Thus, good musical instruments are capable of responding to subtle changes in gestures by making subtle changes in sound. An important test for new musical instruments is this: how effective (responsive, subtle, musical) is the instrument in a live performance?

Most of the control software for new musical instruments is written in Max/ MSP, a language designed for real-time music programming that is widely used in the computer music community. It allows very quick prototyping, has a very intuitive graphical interface, and is optimized for both asynchronous event-driven programs and synchronous DSP programs for sound synthesis and analysis. The figure at left shows an example program in Max/MSP that implements algorithms to control the sound via gestures.

In one example, the algorithms control an acoustic piano via gestures on the radio drum. (A special "computer-controlled" acoustic grand piano, the Yamaha Disklavier, has solenoids in every key and is played by sending it note-on, note-off and velocity commands.) The control algorithms, or mappings, are designed to "play" the piano in ways that may be impossible for a human performer while also making musical sense — and, most importantly, retaining the perception of "cause and effect" in the eyes of the audience. The mappings may trigger entire sequences of notes, but always in response to a clearly observable gestural input.

Creating mappings from the gesture sensor to the sound synthesis engine is an unsimulatable process that makes the system musical, satisfying and performable: it is necessary to physically play the instrument when "tuning" the algorithms. There is no other way to calculate, theorize or program this mapping. It has to be done experientially; the performer has to be in the loop at all times.

This experimental approach is an effective way to create something usable and musical, responding in subtle ways to small changes in input and thus fully exploiting the musician's performance skills that were honed over many years.

Mapping Examples

Some examples of mappings already completed with the original radio drum, and possible extensions to be pursued, are as follows:

- Mapping of *x* to pitch, *y* to timbre and *z* to volume or velocity. The *y* axis can be a continuous change of timbre or it can be mapped in horizontal "stripes" that map to discrete timbres; for example, different instruments. Similarly, the *x* dimension can be discrete, as in a chromatic division of the octave (like a piano), or it can be continuous, in which case it can play microtones or glissandi. The important improvement here would be investigating how to map parameters within the "stripes" that will have subtle control over different physical models instead of samples, as is currently done.
- Quantizing *x* and *y* into gridsquares and triggering sounds only when the stick hits the surface at $z = 0$. This "virtual drum kit" maps different kinds of percussion samples to each gridsquare, but within each square there is information that is "thrown away." Here, the obvious improvement would be to allow subtle timbre variation within each gridsquare, mapped to the respective physical model.
- Mapping a gesture dimension to melodic patterns, an example of "macroscopic" or "process" level of control. These interactions can be seen as closer to the conductor paradigm than the musical instrument paradigm, but this is really a continuum. This level of control may or may not map to the synthesis technique, but the innovations here involve a better ability to interpret the gestures of the performer in a more musical way, and applying it to a high-level control of sound.
- Mapping the *y* axis to, for example, the speed of pulses that trigger sonic events, while modifying parameters of these events with gestures in the *x* and *z* axes.

Onstage Results

Schloss has been testing the hardware and software in very demanding concert situations. He has performed on the radio drum with world-class Cuban pianists Chucho Valdés and Hilario Durán in Cuba, Canada and the US, including a live national broadcast on CBC Radio Two. These performances involve jazz improvisation, which is a fairly rigorous test of robustness of musical ideas, mappings, algorithms, response and latency.

He has also recently collaborated with Randy Jones in the creation of UNI, a multimedia work that incorporates the creation of animation in real time, directly driven by the performers. UNI received its premiere in Havana, Cuba and has also been performed in Canada and the United States in several festivals.

Most recently, he has collaborated with San Francisco composer David Jaffe, using the radio drum to control physical models of automobile and jet engines in the context of a new composition by Jaffe entitled "Racing Against Time," which was premiered earlier this year at the Brandon New Music Festival in Manitoba.

Conclusion

It took decades before the saxophone was accepted as a viable musical instrument, and centuries for the piano to develop into its current shape and form. Engineers and artists are in the process of creating new musical instruments of the future that meet the requirements of a virtuoso performer. No one knows which instruments will prevail and which will disappear.

The radio drum has been used successfully in very demanding artistic contexts, but there is still work to be done in generalizing many of its capabilities and evolving towards an instrument that is truly limitless. Interdisciplinary collaboration to create new forms of expression for performing artists continues, and the future possibilities are exciting.

Andrew Schloss performing on the radio drum at the Banff Centre (photo: Banff Centre).

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