Digital Instrument Building and the Laptop Orchestra

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Musical and technological innovations have long gone hand in hand. Historically, this relationship has evolved slowly, allowing significant time for musicians to live with and explore new possibilities while enabling engineers and instrument builders sufficient time to develop and refine new technologies. These roles—those of musician and instrument builder—have typically been separate; the time and skill required to build an acoustic instrument is typically too great to enable the builder to also master that instrument, and vice versa. Today, the terms of this relationship have changed and the separation of these roles has become blurred as digital technologies allow for rapid development of new instruments. At the same time, social contexts for exploring these new instruments have only developed slowly, and opportunities to make music over long periods of time with these instruments and other musicians have been limited.

The laptop orchestra is a social charged context for making music together with new digital instruments while simultaneously developing those instruments. In fact, music instrument development itself has become part of the performance practice, as the role of the performer and builder have merged and the speed with which instruments can be created and revised has greatly increased. In this paper, I will explore these developments and look at a range of technical challenges and their role in the musical and instrument building process, including: speaker design, human-computer interaction (HCI), digital synthesis, machine learning, and networking.

The Problems of Digital Instrument Building: A Summary

Digital musical instrument building touches on a range of disparate disciplines. In addition to the obvious engineering concerns such as HCI, synthesis, speaker design and so on, fields such as perception, cognition, and both musical and visual aesthetics come into play, making this a highly interdisciplinary venture. The basic feedback loop between player and a generic (acoustic, electronic, or digital) musical instrument is illustrated in Figure 1. In Figure 2, the instrument is exploded to reveal the layers that might make up a digital musical instrument. Traveling along this feedback path, we can see the range of challenges we face, from sensor design and configuration, to haptic feedback systems, through the computational problems with feature extraction, mapping and synthesis, to amplifier and speaker design, not to mention the ergonomic and aesthetic design of the instrument itself.

Building a compelling digital instrument involves addressing all of these problems simultaneously, while taking into account various practical and musical concerns, such as
the size, weight and visual appeal of the instrument, its physicality and its sound quality, its ease of setup (so it might be "giggable"), and its reliability. The most active researchers in this field are typically musicians first, but with significant engineering skills, or engineers with life-long and deeply trained musical abilities.

**Digital Instrument Building in Practice**

My own Bowed-Sensor-Speaker-Array (BoSSA) illustrates one ongoing solution to the digital instrument problem (Trueman et. al., 2000). BoSSA (Figure 3) consists of a spherical speaker array integrated with a number of sensors in a violin-inspired configuration. The sensors, which measure bow position, pressure, left-hand finger position, among other things, provide approximately a dozen streams of control information. Software processes and maps these streams to a variety of synthesis algorithms, which then are amplified and sent out each of the 12 speaker drivers on the speaker surface. This is a fairly low-tech, crude instrument which uses off-the-shelf sensor and speaker components, and is more of a proof of concept than a prototype for future instruments. It's most compelling feature is its integration of sensor and speaker technology into a single localized and intimate instrument.

In recent years, sensor technologies for these sorts of instruments have become much more refined and commercially viable; the k-bow (McMillan, 2008) (Figure 4), for instance, is a wireless sensor-violin bow that hit the markets just this past year. In terms of elegance and engineering, it surpasses earlier sensor bows (including my own), and if it turns out to be commercially viable, gives hope that these kinds of experimental explorations may gain broader traction. Another set of instruments by Jeff Snyder (Snyder, 2010) integrate speaker and sensor technology directly into acoustic resonators so thoroughly that, at first glance, it is not apparent that these are not simply acoustic instruments (Figure 5).

However, none these instruments yet integrate any kind of active haptic feedback. While it remains and open question how important haptic feedback is, I am convinced that it will become more important and valued as digital musical instrument design technologies continue to improve; the physical feedback a violinist gets through the bow and strings is very important to their performance technique and sheer enjoyment of playing, and having the ability to digitally manipulate this interface is intriguing. Some researchers are developing new haptic technologies for music and have demonstrated that they enable new performance techniques. For instance, Edgar Berdahl at Stanford has developed a haptic drum (among other instruments) that enables a one-handed roll that is impossible on an acoustic drum (Berdahl et. al., 2008)(Figure 6).

Perhaps the most compelling aspect of these instruments lies in the mapping layer. Here, relationships between body and sound can be created that would otherwise be impossible, and they can be changed instantaneously; in fact, the mapping layer itself can be dynamic, changing as the instrument is played. However, as described earlier, creating these mappings by manually connecting features to synthesis parameters is challenging, sometimes practically impossible. One particularly exciting development has been the application of machine learning techniques to the mapping layer. Rebecca Fiebrink has
created the Wekinator (Fiebrink et. al., 2009)(Fiebrink, 2010) which gives the musician a way to rapidly and dynamically apply techniques from the Weka machine learning libraries (Witten et. al., 2005) to create new mappings. For instance, a musician might create a handful of example correspondences (gesture G with the controller should yield sound S, as set by particular parameter values), creating a data set from the sensor features that can be used by machine learning algorithms of various sorts to create mapping models that can then be performed with. The player can then explore these new models, see how they sound and feel, add new data to the training set, and retrain, or simply start over until finding something that is satisfying to perform with. This is an unusual application of ML in that the end result is usually unknown at the outset; rather, the solutions that ML provides feed back into a creative process, finally yielding an instrument that would be impossible to fully imagine beforehand. Ultimately, then, ML and the Wekinator play a major role in facilitating a creative process.

**Playing Well with Others**

From a musical perspective, computers are great at multiplying; from a little (or nothing at all), they can make a lot. As a result, much laptop music is solo; one player, making a lot of sound, sometimes with little or no effort. One of the main aims of the Princeton Laptop Orchestra (PLOrk) (Trueman, 2007)(Figure 7) is to create a musically and socially charged environment which can act as a counterweight to the tendency of laptop musicians to effortlessly overwhelm. By putting many such musicians in a room and inviting them to make music together, we force instrument builders and players (often one and the same person) to focus on responsive, subtle instruments, instruments that require constant effort and attention, that can turn on a dime in response to what others do and force their players to break a sweat. The laptop orchestra is, in a sense, a specific and constrained environment within which digital musical instruments can evolve; those that engage us as musicians and enable us to play well with others survive.

While a laptop orchestra is, like an orchestra, a collection of localized musical instruments manned by individual players, the possibility of leveraging local wireless networks for musical purposes is irresistible and novel. For instance, a “conductor” might be a virtual entity that sends pulsed information over the network. Or, musicians might set the course of an improvisation on the fly via some sort of musically coded text-messaging system (Freeman, 2010). Controllers themselves might be network enabled, sharing their control data (Weinberg, 2005). However, humans are highly sensitive to timing variability, and wireless networks are often not up to the challenge. For instance, when sending pulses over the network every 200ms, humans will hear jitter if the arrival times vary by more than 6ms (the just-noticeable-difference), and some researchers have concluded that expressive variability occurs even within that window (Iyer, 1998). Some preliminary research has been done on the musical usability of wireless routers (Cerqueira et. al., 2010), but the perfect wireless router for musical purposes has yet to be found.

**Closing Thoughts**
Musical instruments are subjective technologies. They are not optimal solutions to well-defined problems; rather, they reflect individual and cultural values, and are ongoing ad hoc manifestations of a social activity that challenges our musical and engineering abilities simultaneously. They frame our ability to hear and imagine music, and while they enable human expression and communication, they are themselves expressive and communicative. They require time to evaluate and explore, and they become most meaningful when used in a larger context, with other musicians. Therefore, it is essential to view instrument building as a fluid, ongoing process, without “correct” solutions, a process that requires a larger context within which these instruments can inspire and be explored.

References


Figure 1: Basic Player/Instrument Feedback Loop
Figure 2: Player/Digital-Instrument Feedback Loop
Figure 3: the Bowed Sensor Speaker Array
Figure 4: The K-bow

Figure 5: the Snyder Contravielles
The word haptic comes from Greek and pertains to the sense of touch. The haptic drum harnesses the power of force-feedback to assist drummers in playing parts that would otherwise be difficult or impossible. This patent-pending device consists of a drum pad, a DSP, an amplifier, and a woofer. Whenever a drumstick impacts the drum pad, the woofer gives a small push in the upward direction, adding energy to the bouncing drumstick.

The haptic drum:
- makes it easy to play a one-handed drum roll, freeing up the other hand
- can sustain drum rolls for arbitrarily long periods of time
- allows drum rolls to be played at very fast rates (e.g. up to 60 impacts/second)
- makes it possible to play exotic new drumming rudiments
- is compatible with the standard drum set
- fits inside of a 10” snare drum shell

Quote: “Now electric guitarists won’t be the only ones having all the fun with their electronic effects!”

Video demonstration at: http://ccrma.stanford.edu/~eberdahl/Projects/HapticDrum

Come see what all the fuss is about!

Contact Edgar Berdahl for a demo.
Figure 7: The Princeton Laptop Orchestra