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Composing for Laptop Orchestra

This article is a chronicle of impressions, ideas, methodologies, and challenges relating to the experience of composing for a "laptop orchestra"; specifically, the recently formed Princeton Laptop Orchestra (PLOrk). Here we document some of the compositional issues that have been raised by this unique performing force and the different strategies taken by the composers for control, sound design, spatialization, conductor roles, improvisation, and instrument design. Throughout this document, we will reference a number of specific compositions, all of which are available for listening on the PLOrk Web site, plork.cs.princeton.edu. Appendix A includes a complete listing of pieces written for PLOrk thus far. We are working to document and make available the software used in as many of these pieces as possible, should others be interested in adapting them to their own ensembles—though given their inevitably provisional nature at this early stage, it is likely that most of these pieces will undergo revision in the coming years.

As will become clear, these pieces represent a range of aesthetic approaches. It has been our hope that the ensemble be as transparent as possible, inviting artists from any aesthetic sensibility to imagine how it might come to life. Some of the pieces are naturally indebted to the experimental music tradition, especially in electronic music; the work of the Hub, David Tudor, and John Cage comes to mind. Other pieces are more closely modeled after the traditional Western orchestra, dividing the ensemble into sections and relying on fully composed, notated structures. Yet others look to non-Western musics and ensembles for inspiration: the gamelan, the improvisatory percussion music of Northern India, or the folk music of Scandinavia, for instance. Some pieces do not even treat the ensemble like an ensemble but rather see it as an unusual field for realizing a "soundscape" or a sonically charged context for network gaming. Finally, the technology itself, especially with regards to the possibilities afforded by high-speed networking, has often been a motivating factor, inspiring music that would be impossible to conceive of without such an ensemble. It is, we believe, one of the great strengths of the ensemble that it invites such wide-ranging and provocative aesthetic imaginings, and we hope to maintain this breadth in the years to come.

However, as described elsewhere (Trueman 2007), PLOrk presents significant challenges and constraints: how will the technology involve all the hands, eyes, and ears that are present in the ensemble, in particular? This is not an ensemble for those who are uninterested in human involvement and imperfection. Nor is it an ensemble for those with little tolerance for technological imperfection, as computers and software are always imperfect. So, although we continually push for aesthetic breadth, the nature of the ensemble naturally constrains this push and asserts its own limitations. The pieces described here represent the initial solutions reached by a number of composers with varying intentions and values, and, as such, should offer some sense, however incomplete, of the future possibilities for laptop ensembles.

PLOrk: Motivations and Design

The historical context and motivations for establishing PLOrk, along with a general introduction, are explored in Trueman (2007). The pedagogical

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Figure 1. Overview of a PLOrk meta-instrument.

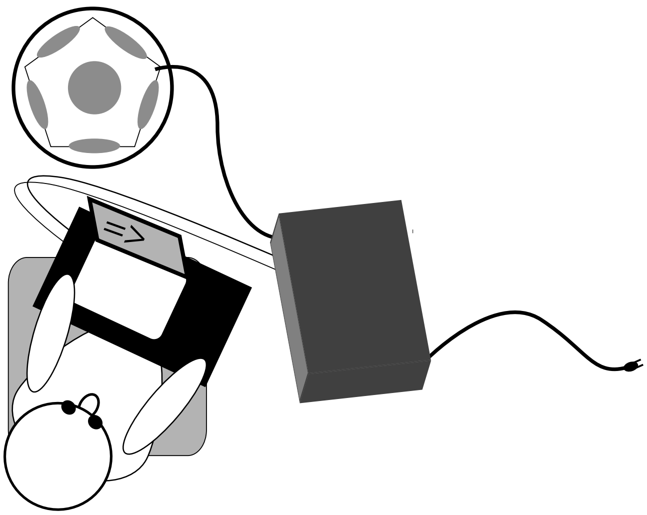


Figure 2. A PLOrk equipment rack.

aspects of PLOrk are discussed in this article's companion (Wang et al. 2008), which appears in this issue of *Computer Music Journal.* Complete technical specifications for PLOrk can be found on the PLOrk Web site, but a summary is provided here. Each of the fifteen meta-instruments in PLOrk consists of laptop computer (currently, Apple 1.5-GHz 12-in. PowerBook G4s and 1.83-GHz 13-in. MacBooks); the software development environments Max/MSP (Puckette 1991), SuperCollider (McCartney 2002), and ChucK (Wang and Cook 2003); a rack of audio equipment consisting of a multi-channel Firewire interface (Edirol FA-101), speaker amplification (Stewart DA-70-2 2-channel amplifier and a Stewart DA-70-4 4-channel amplifier), and a sensor interface (ElectroTap Teabox); and a hemispherical speaker with six individually addressable speakers. Figure 1 shows a visual overview, and Figure 2 shows the face of the rack.

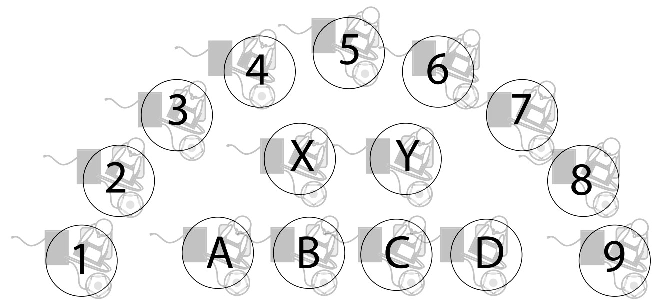
In addition to this, we have a collection of interfacing devices and sensors that can be integrated into any of the meta-instruments to provide physical control of expression. These include off-the-shelf keyboards, percussion pads, and knob/slider controllers, but also custom interfaces using sensors such as accelerometers, pressure pads (using force-sensing-resistors), proximity sensors, light sensors, and so on. We encourage students and composers to conceive of their own ways to interface the players with the computers, and we have provided for the ability to connect a variety of devices—including custom ones—quickly and easily. We also have a variety of microphones (handheld and headset) and pickups that can be used bringing in live sound to each instrument.

Each player sits on a meditation pillow and either holds the laptop literally on the lap (supported and protected by a lap-desk) or places the laptop on the rack to the right and holds instead some interface to the laptop, depending on the requirements of the composition. The speaker sits directly in front of each performer. In this way, each instrument is completely self-contained.

Sound Design and Spatialization

PLOrk is an ensemble of laptop-based instrumentalists with localized sound sources. It produces a sonic space comparable to a large ensemble of instruments that generate sound from various points on a stage, the sound of each player radiating out in all directions. The hemispherical speakers not only project sounds in all directions but can produce different sounds in each of six directions, giving one the possibility of creating a kind of three-dimensional spatial model of an instrument or sound object. This distinction is vital, and the ensemble has a profoundly different sound than that of electro-acoustic music played through a stereo or

Figure 3. Default layout diagram for PLOrk-stations. Lettering/numbering was established to facilitate communication, and also suggests natural sectioning.



surround sound-reinforcement system. At first, it is difficult to imagine what kind of sonic presence of this ensemble has, and composers are usually surprised (either pleasantly or not) when they first hear their music performed by PLOrk.

PLOrk is an orchestra partly because it has a roughly similar sonic and spatial footprint to the conventional orchestra. As composers, it is important to understand that although this orchestra is not "fixed" in terms of specific timbral groupings (first violins on the left, basses on the right, etc.), there are some practical limitations in terms of spatialization, fidelity, volume level, and sonic density. For example, like an orchestra, PLOrk has had to develop a standard seating arrangement out of necessity, owing to the amount of setup time and coordination each rehearsal requires (see Figure 3).

The matrix of 15 speakers and 90 channels is thus fixed spatially (though the hemispheres can be rotated easily as needed). In addition, the speakers themselves have spectral limitations: they are unable to produce frequencies below about 80 Hz. To fill out the lower frequencies, five of the meta-instruments include a subwoofer, usually spaced evenly across the outer ring (near stations 1, 3, 5, 7, and 9—the "outer-odds" as we refer to them). Looking at the diagram, one cannot imagine (or adequately describe) what kind of sound this ensemble might have, but it clearly has a "PLOrk-sound"—a sound that, like a conventional orchestral sound, is both limiting and inspiring.

As would be expected, PLOrk employs a wide range of digital sound techniques. In *Non-Specific Gamelan Taiko Fusion Band,* for instance, Perry Cook and Ge Wang use high-quality samples of a specific set of drums and bells and incorporate the original acoustic instruments into the piece as well. What is remarkable about this is that the samples are virtually indistinguishable from the acoustic instruments owing to their spatial relationships and the dispersion patterns of the speakers. On the other hand, in Dan Trueman's *The PLOrk-Drones,* the entire sound world is synthetic. Inspired by the so-called "Risset Arpeggio" (Risset 1985), the composer created instruments in which each player maintains careful control over a stack of harmonically tuned sine waves. By subtly changing the fundamental (very low, usually around 65 Hz, with a controllable range of variation less than 1 Hz), each player can contribute to a subtly beating texture. Although the natural phasing created by the widely spread multidirectional speakers precludes the emergence of the familiar Risset Arpeggio, the laptop orchestra acoustically and interactively recasts what is by now a classic synthesis technique. In his piece *Idle Swamp,* Brad Garton created a palette of sounds based on a "quasi-retro" LPC digital synthesis technique pioneered by Paul Lansky (1989); in this piece, the sound world sometimes seems synthetic, and other times reveals its source with speech-like utterances. Scott Smallwood's *On the Floor* combines the use of synthetic sounds (emulating electronic slot machine sounds) and field recordings of an Atlantic City casino to create a dialog between an actual physical space and a synthetic recreation of that space. Dan Trueman, in his piece *PLahara,* uses acoustic sounds in his piece in two different ways: in one section of the orchestra, he digitizes the live tabla player (Ustad Zakir Hussain) and routes that live signal to four of the PLOrk players (cast as "soloists"), who rhythmically process and transpose the tabla sound. Meanwhile, the rest of the orchestra uses headset microphones, capturing the acoustic sound of their notated vocal parts to excite tuned comb filters. In all of these cases, the considerations that had to be made for space, density, and balance within the orchestra proved intensely challenging, but they yielded new perspectives to the normal ways of thinking about electro-acoustic music.

Although the standard configuration of PLOrk necessitates a certain way of thinking about the sonic canvas, there have been and will continue to be ways of altering this standard through special kinds of concerts and installation scenarios. In one case, we organized a special concert of pieces "in the round," because we were able to make use of a special performance space (the Chancellor Green Rotunda at Princeton University) that allowed us to set up in a circle, above and surrounding the audience. This invited us to develop works that were different in their approach to space. For example, the piece *ChucK ChucK Rocket,* a collaborative work by Scott Smallwood and Ge Wang, utilizes a game scenario in which sounds are passed around the circle of players, creating a unique surround experience that would not have been possible in the standard concert configuration. There is also the possibility of writing for smaller or larger forces. Paul Lansky opted to write for a more intimate group: a quintet. His multi-movement piece *A Guy Walked into a Modal Bar* utilizes instruments he created in SuperCollider based primarily on physical modeling. Though a chamber work, the approach to sound in this piece is clearly framed by the nature of PLOrk, and the composer developed it through weekly rehearsals with the students directly on their meta-instruments. On the other hand, Brad Garton (in *Idle Swamp*) augments the standard group with five additional players spread throughout the hall in an effort to create a more immersive, ambient "soundscape." Finally, Perry Cook and Ge Wang often invite additional drummers to join the group in *Non-Specific Gamelan Taiko Fusion Band,* in which case the network-synched laptops act as a kind of mediator for a drum circle that can approach thirty players (PLOrk included).

Interfacing and Control

PLOrk uses laptops as instruments, and in the ensemble they are the most immediate interfaces to the world of sound. It is important to realize the ways in which the laptop has become an extension of the human body for many people in our culture. Although it is true that the human body is not well suited to sit hours at a time, typing and pointing and clicking while staring into an illuminated screen (Sommerich et al. 2002), it is also true that, regardless, many humans have become quite accustomed to doing just that. Composers working on pieces for a laptop orchestra have the choice to embrace the given laptop interface as an instrument, or to find ways of providing more suitable control mechanisms for making sound, depending on the kind of instrument they are designing.

Many of the pieces composed in PLOrk's first year relied exclusively on the laptop interface for control. One of the first instruments we developed allows each player to quickly record a pool of samples of themselves speaking the name of each QWERTY key ("A," "B," "C," "return," "spacebar," etc.) and then associate that pool with the appropriate key; pressing a particular key randomly chooses one of the samples from the corresponding pool for playback. The QWERTY keyboard then becomes a kind of personalized percussion instrument. Although the keys are obviously not pressure-sensitive, the playback time is controlled by how long the keys are held, allowing the performer to either touch the keys quickly and get only an unrecognizable percussive attack, or hold the keys down longer to hear the complete utterance. In general, we found the latency of the QWERTY keyboard acceptable for most rhythmic playing, and the ability to leverage already established typing skills is empowering; it seems likely that there is much that can be done along these lines.

In an entirely different approach, Pauline Oliveros, Seth Cluett, and Scott Smallwood developed instruments for *Sound Scatter* that require only occasional control and rely exclusively on the laptop keyboard and trackpad. In this piece, Ms. Oliveros improvises on accordion, and her sound is cast into the orchestra via a wired audio network. The PLOrk players mostly just listen and then make occasional small moves with the interface, adjusting volumes, turning various processes on and off. In a sense, the players are more "monitors" than "performers," able to enjoy the slowly changing "soundscape" while subtly pushing and pulling it in various ways.

The laptop as physical interface is, however, decidedly limited. In an effort to invite alternative approaches, we have invested in many off-the-shelf

Figure 4. Tomie Hahn conducting PLOrk in In/Still.

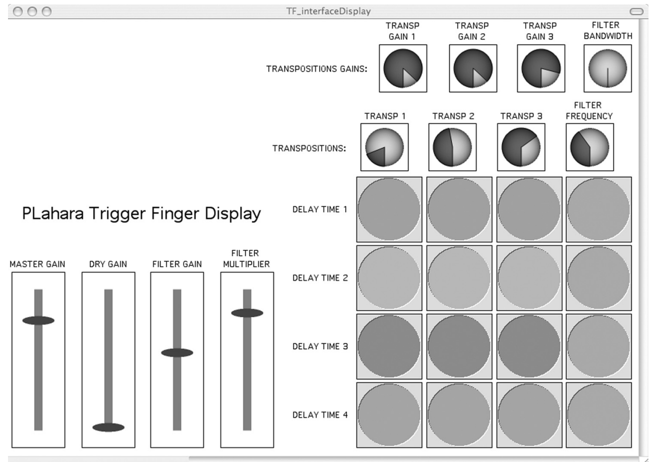


Figure 5

Figure 5. Virtual display of the PLahara *TriggerFinger interface. The on-screen graphics mirror the configuration of a physical set of drum pads, knobs, and sliders. The rightmost column of drum pad can be rhythmically tapped to set the delay time for each row. In practice, these are linked to pre-composed subdivisions.*

Figure 6

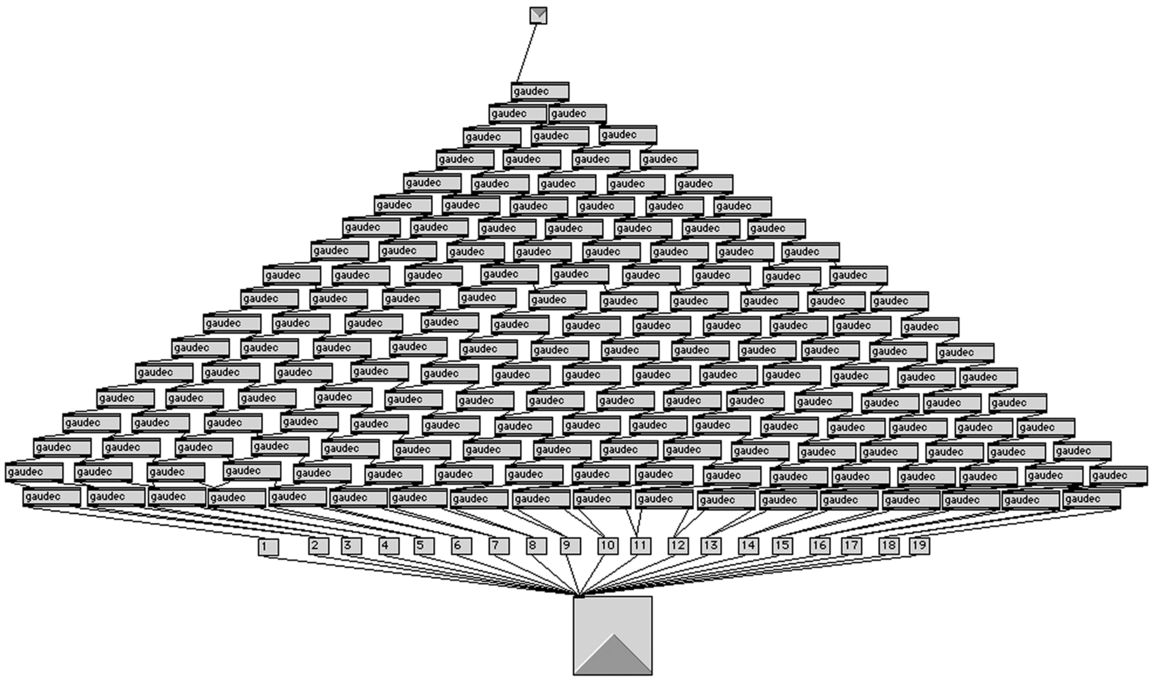
Figure 6. Lawson White of So Percussion processing Zakir Hussain in PLahara.

devices, including pressure-pad "finger drum" interfaces, MIDI keyboards, slider and knob boxes, and graphics tablets. Each station also has a Teabox sensor interface (available from www.electrotap.com), which allows for plug-and-play integration of various kinds of sensors, including force-sensing resistors, accelerometers (for sensing tilt along two axes), light and distance sensors, and floor pressure tablets.

Curtis Bahn and Tomie Hahn, in their piece *In/Still* (see Figure 4), created one of the most compelling approaches to interfacing, both with sensors and the generic laptop interface. Ms. Hahn, who is also a dancer and performer, conducts the players by performing sweeping gestures which the players emulate through movements of the mouse. Players are encouraged to watch her gestures carefully rather than watching their screens, which have very little information on them necessary for performing the piece. Hahn wears an accelerometer on each hand, through which her movements effect both her own sounds and, via the network, the sounds of the orchestra. At one point in the piece, five members of the orchestra, each also wearing accelerometers on their hands, stand and "dance" with Ms. Hahn. Their movements allow them to "scrub" forward and backward through frames of phase-vocoder analyses.

In Dan Trueman's *PLahara,* the four "soloists" who process Ustad Zakir Hussain's tabla perform with TriggerFingers (drum pads for fingers, with additional knobs and sliders; see www.m-audio.com/products/en_us/TriggerFinger-main.html). The grid of 16 pads control varying delay times and transpositions (performed spectrally to avoid tempo changes). The rightmost pad in each row can be struck repeatedly to set the delay time for that row (see the next section for further discussion of how these delay times are set in practice), while a knob above each column can control the transposition of that column. The players can either press continually on particular pads, controlling the volume of that delay and transposition through variable pressure, or strike the pads rhythmically to grab delayed versions of Mr. Hussain's playing. Other knobs and sliders can be used to control bandpass filters and gains (see Figures 5 and 6).

Figure 7. Pauline Oliveros and Zevin Polzin, Murphy abstraction.



Meanwhile, the orchestra uses accelerometers and graphics tablets to control the Risset drones previously described, in *The PLOrk Drones* (while also performing the notated vocalizations into their headset microphones). With the accelerometers, tilting the right hand forward and backward controls volume, and tilting it left and right controls the fundamental frequency. Rotating the left hand moves the drones through various combinations of overtone weightings. Similarly, tilting the pen of the graphics tablet adjusts the fundamental frequency, and pressure controls volume. "Drawing" a circle then moves through the varying overtone weightings. Although the mappings are simple, they are quite performable and require some practice to master. A new version of *The PLOrk Drones* relies on the Sudden-Motion-Sensor (SMS, a built-in accelerometer) of the Apple laptops for drone control, creating an unfamiliar physical use for the laptop itself as controller (Fiebrink, Wang, and Cook 2007).

Finally, Pauline Oliveros, in her composition *Murphy Mixup: Murphy Intends,* in collaboration with Zevin Polzin, asks the players interface the laptops with their minds alone. Responding to research conducted by Brenda Dunne and Robert Jahn of the PEAR (Princeton Engineering Anomalies Research) laboratory (Dunne and Jahn 2005), the piece simulates in software the Murphy device. This device is an old analog contraption that is built into a large wall of the PEAR lab. A conveyor belt carries 9,000 small balls to the top of the device and dumps them. They fall through a large matrix of pegs until they sort themselves into 19 bins at the bottom of the device. In general, most of the balls tend to fall into the middle bins, but some of the balls make their way across to the edges. The machine tracks the statistics of balls to bins, and plots a curve showing the results. Generally, it produces a bell curve. Jahn and Dunne found, however, that if a person "intends" for the curve to move slightly in one direction or another, even though there is no apparent physical connection between the person and the machine, it can affect the results in a statistically significant way. Ms. Oliveros and Mr. Polzin created a software version of the Murphy device that uses the entire orchestra, with each machine being part of the system. Beforehand, each player created a sound that is part of a bank of 19 sounds, and their job in performance is to "intend" for the system to become biased towards the sound that they created (see Figure 7).

Needless to say, such research has its skeptics, and several researchers have had difficulty replicating the PEAR laboratory results. (See skepdic.com/pear.html/ for a summary of some of these issues, and see Hansen, Utts, and Markwick [1991] for a critique of related work from the lab.) Because of this, some of the more scientifically minded members of PLOrk had difficulty accepting the approach, though they nevertheless attempted to perform the piece in good faith.

Networking and The Conductor

The network can be a powerful conducting tool and also facilitate the design of a kind of macro-instrument with the orchestra. Information that can be passed along the network is quite different from the kind of information traditionally conveyed by a conductor. Thus, possibilities for coordination, message-passing, group control, quantization, tempo, dynamics and so on are on the table for all composers working with PLOrk. Should these tasks be given to a conductor? Should the conductor be human, or should it be a program operating over the network? Or should there be both kinds of conductor?

The ability to tightly synchronize the ensemble via the network is remarkable, though not flawless. It is practical and easy to have a single "conducting" computer send a sequence of pulses (e.g., Max `bang` messages or similar) over the network to control rhythmically timed events, and in our experience, the timing is more than tight enough for very small pulse-widths (on the order of 40 msec or so). In most situations, we found the wireless network capable of maintaining a constant, "hiccup-free" pulse without difficulty, though in some situations this was not the case (perhaps owing to heavy local wireless traffic from other networks), and we are exploring ways to make our network more robust and immune to interference (including working with a wired network). Even in good situations, however, packets are occasionally dropped, and composers need to build a certain amount of protection into their programs if this is likely to cause problems. For instance, if it is important for all the machines to be on the same beat in, say, a 16-beat cycle, the conducting machine should send the beat number over the network and not simply a pulse; this will ensure that if a packet is dropped to a par ticular machine, it will not get out of phase because it is locally counting pulses. Also, if particular messages are crucial, it is essential to have them paired with subsequent messages that ask for message receipt confirmation. We are hopeful that the need for such strategies will be minimized in future versions of our network.

Figure 8. Ge Wang conducting CliX.

Ge Wang's *CliX* (see Figure 8) makes use of two different kinds of conductors. A conductor laptop sends rapid pulses over the network; these pulses effectively quantize the events generated on each machine. The players type, generating pitched clicks (the pitches are dependent on the key struck; for instance, it is possible to play a chromatic scale by typing the alphabet), and their clicks are then

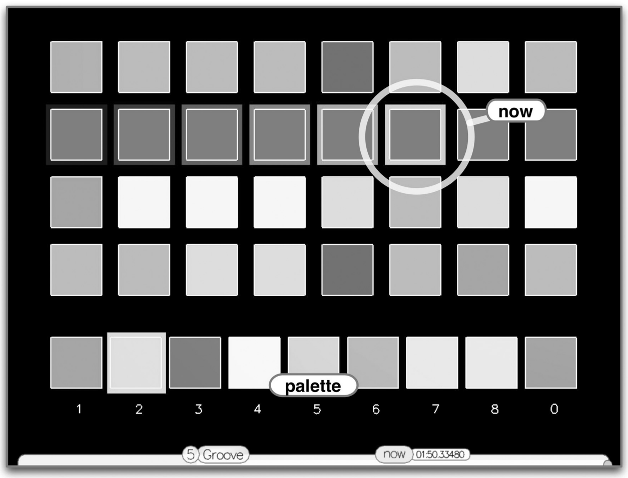


Figure 9. Onscreen interface for Non-Specific Gamelan Taiko Fusion Band. *Different colors indicate sound types. The players choose a color from the bottom palette. The network pulse can be seen racing from left to right, and then top to bottom, through all 32 beats.*

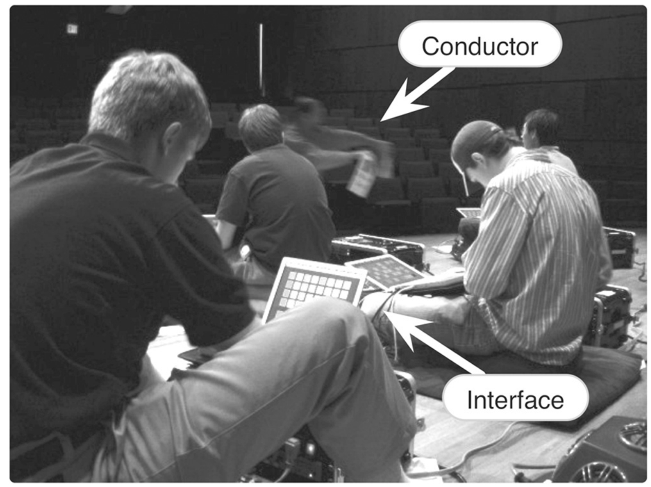


Figure 10. Non-Specific Gamelan Taiko Fusion Band *in performance.*

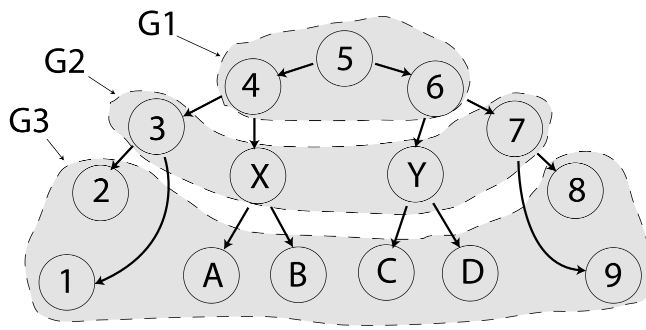


Figure 11. Binary tree structure for Dan Trueman's The PLOrk Tree. *The "conductor" is at station 5, and the different layers of the tree are indicated by G1, G2, and G3.*

quantized to the network pulse (synchronization pulses are sent over the network every 0.09287 seconds), keeping all the machines tightly in "sync." Mr. Wang conducts the ensemble by visually indicating which section of the ensemble should be active and whether their typing should generate high or low pitches. In any particular performance, the composer-conductor can elicit a variety of gestures, including sudden stops and starts, slow rises and falls, and what we call "the PLOrk spiral," where the players type in sequence, stations 1–9, then D–A, and finally X–Y.

In Perry Cook and Ge Wang's *Non-Specific Gamelan Taiko Fusion Band,* the ensemble is once again synchronized by a network pulse. Here, the pulse is visible via a set of onscreen colored boxes (see Figure 9). The players can choose which sound they would like to hear in each box, though the program assigns a event probability for each box, so even if the players placed an event in a particular box, they are not guaranteed a sound will actually be triggered.

When Mr. Cook conducts, he prints instructions from an onstage printer and displays these to the players, either in sections or to the ensemble as a whole (see Figure 10). (The printer was added as a theatrical component. Its sound on stage does not interfere with the piece, as the printer is relatively quiet, and the piece is relatively loud.) These instructions might include requests for high or low densities, or for particular colors or spacings.

In Mr. Trueman's *The PLOrk Tree,* the conductor plays a minimal role, but the network is crucial. This piece is a quasi-improvisation based on a network binary tree (see Figure 11). The conductor sits at the "bottom" of the tree (station 5) and sends a network pulse to synchronize the ensemble. All the players (including the conductor) have the same instrument (a step-sequencer with controls for pitch and amplitude; see Figure 12) and the state of their instrument can be seen by their two network neighbors "up" the tree. Similarly, all the players (save the conductor) can see the state of their "lower" neighbor.

The piece begins when the conductor at station 5 starts manipulating his interface. Players 4 and 6 can then copy what they see the conductor doing

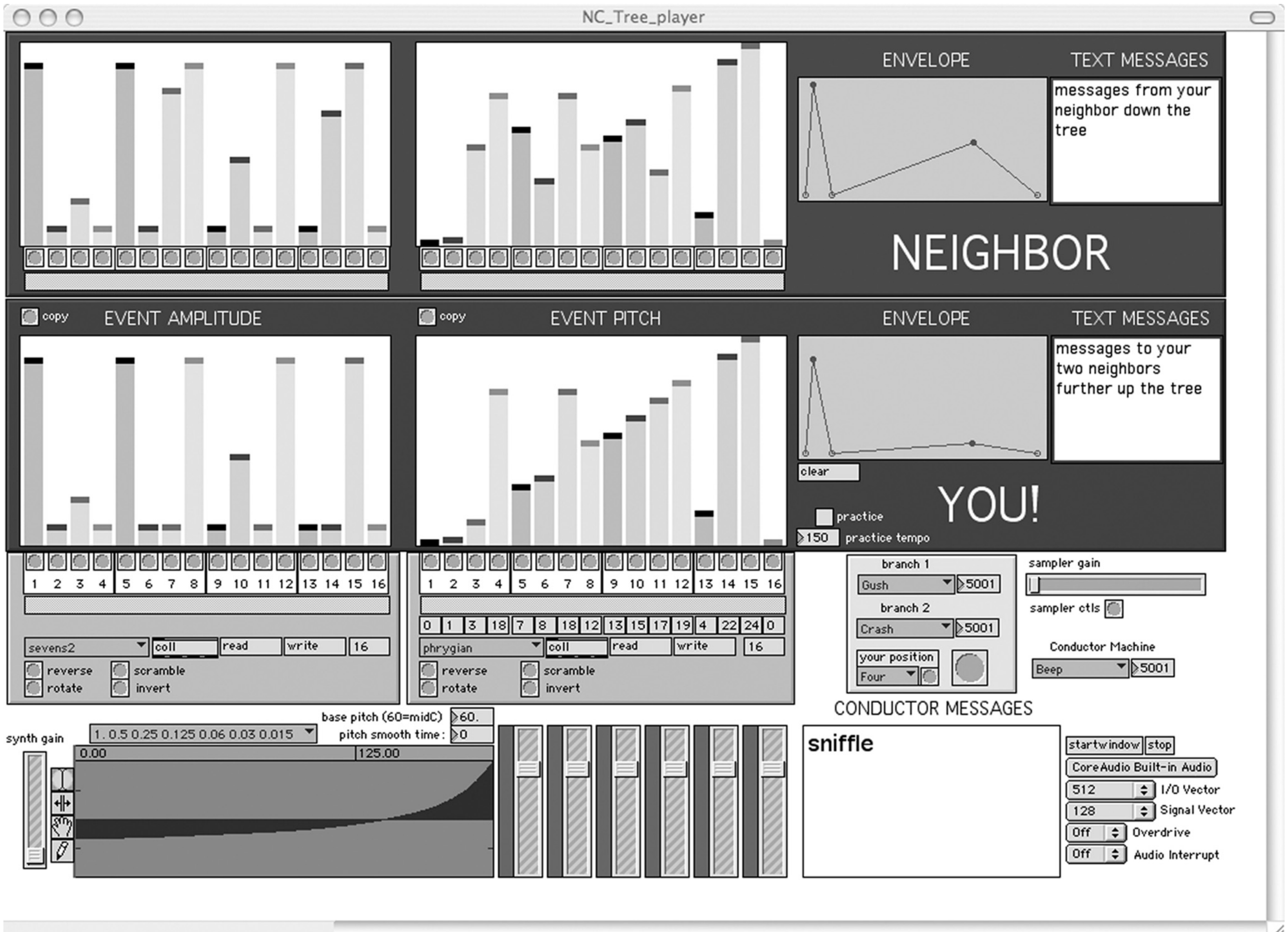
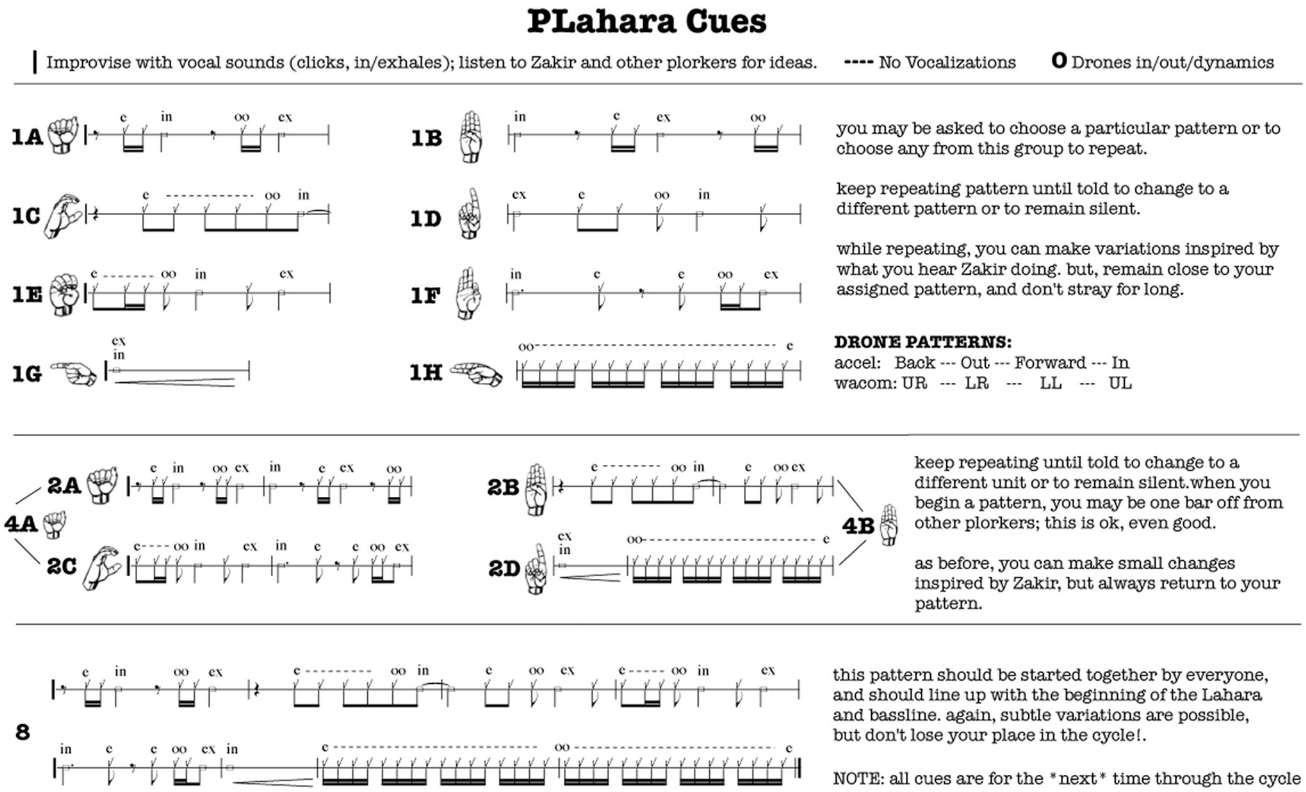


Figure 12. Dan Trueman's The PLOrk Tree *player interface. The top row is the state of their network neighbor's interface, which can be copied with a single click and then modified. Sounds include simple wavetable synthesis (the wave is visible and "drawable" at the bottom left) and samples. Conductor text-messages are visible at bottom, while neighbor text-messages can be seen at top right and then sent to the middle right.*

and modify it (or do something else entirely), and this then propagates further down the tree. Players can also send text messages through the tree structure, and the conductor can send text messages to the group as a whole or to the different layers (G1, G2, G3) of the tree. Finally, the conductor sees the state of all the interfaces at the end of the tree (G3), and can choose to copy and modify what is visible, thereby feeding information back into the network. In practice, this piece can result in an exciting sense of anarchy, with individual players wreaking havoc and creating localized structures.

In Mr. Trueman's *PLahara,* the role of the conductor is distributed among three people. *PLahara* was inspired by the traditional North Indian *lahara* form where a simple tune is repeated over and over again, providing a structure within which percussionists (typically) can improvise. In *PLahara,* this tune is played by the composer on the Hardanger fiddle (a Norwegian folk fiddle) and doubled on a MIDI keyboard by one of the conductors. This "lahara-conductor" adds a pre-composed bass line to the tune, and this pitch information is sent over the network to all the players. As described earlier, the orchestra is articulating a variety of vocal sounds through microphones to excite tuned comb filters; the tuning of these filters is set by the lahara-conductor's playing. Also, the fundamental for the Risset drones that the players are controlling is set by this lahara-conductor. In this way, pitch (which is typically one

Figure 13. Part for PLahara *vocalizers. Sign language is used to cue particular riffs.*



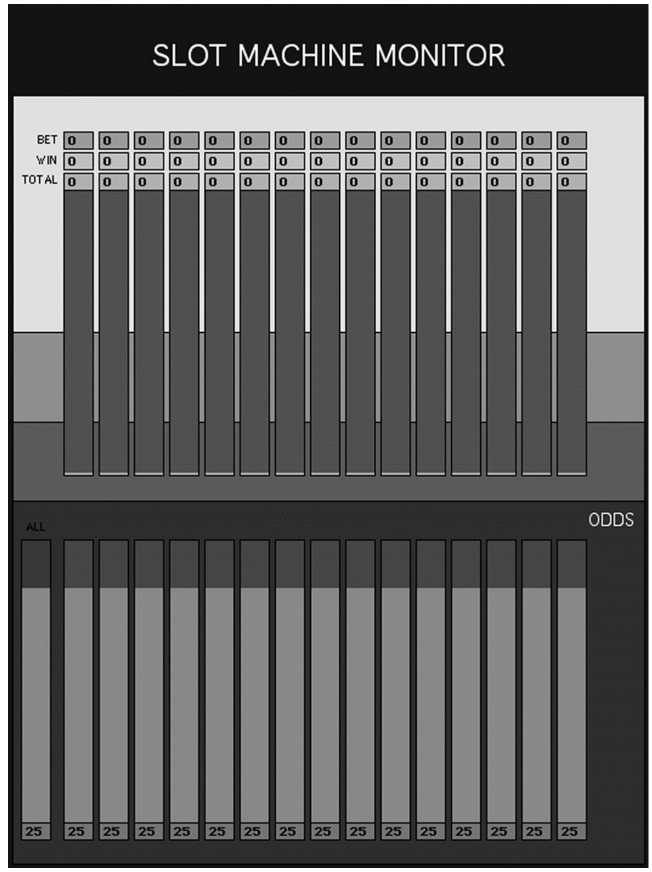
of the main parameters controlled by the players in a conventional orchestra) is controlled by a single person, leaving the orchestral players free to focus their attention on other performance issues. Finally, the lahara-conductor's laptop has a tempo follower, which constantly updates the delay times (via the network) on the signal-processing soloist's Trigger-Finger delay-line interfaces. This allows the ensemble to stay in "sync" without locking to a network pulse or arbitrary delay-time; changing tempos, crucial to Indian percussion improvisation, is both possible and smooth. A second "conductor" uses sign language to indicate to particular sections of players which pre-composed vocalization riff to perform (see Figures 13 and 14).

Finally, a third conductor uses a knob box to control various parameters of the player's instruments over the network, including volume and a comb-filter feedback coefficient, both crucial to creating a balanced sound and for avoiding excessive feedback. It is important to note that in this piece the laptops are placed off to the side and require no visual attention; all of the players' attention is focused on their parts, the conductors and the work of the soloists.

Scott Smallwood's piece *On the Floor* (see Figures 15 and 16) uses the network conductor in a subtle way. In this piece, players are completely independent, playing a simple slot machine game until they run out of "credits." The sounds created are simply a byproduct of each person's game play. However, each player has the potential to win more credits at any time, determined by the odds programmed into the software machine. The conductor operates surveillance on each player, monitoring the results of their game. If at any time, a player seems to be winning too much, or not enough, the conductor can simply change the player's odds. This way, the con-

Figure 14. The three "conductors" (Oscar Bettison, Seth Cluett, and Scott Smallwood) in a rehearsal of Dan Trueman's PLahara.

Figure 15. Scott Smallwood's conductor interface for On the Floor.



ductor has some control over the length of the piece (as well as the sonic character), because the piece ends when everyone has lost all of their money.

Yet another conducting paradigm is used in Ge Wang's *TBA,* a large-scale group live-coding performance in which players are divided into "squadrons" that follow instructions from a conducting live coder. Directives are issued in the forms of both code fragments (in the ChucK language) and sentence fragments (in the English language). In keeping with the tenets of live coding, these instructions and code segments are projected for the audience to follow along. Players write and edit code "on-the-fly" to sculpt a collective sonic environment over the course of the performance. "Rally points" are preset throughout the code to aid the conductor in directing and coordinating the ensemble. The piece alternates between detailed code changes and sections in which players are encouraged to improvise (see Figure 17).

Game Pieces

Perhaps one of the more obvious areas of investigation in PLOrk are game pieces; it is difficult to resist the idea of playing games with 15 networked computers in the same space! However, what is particularly interesting about this idea is not so much the games themselves but the shared "soundscape." By design, most video games consist of two categories of sounds: sound effects (sounds that provide sonic feedback in the game, including laser blasts, doors opening, jumping or running sounds,

Figure 16. Scott Smallwood's and Ge Wang's player interface screens for On the Floor.

Figure 17. Ge Wang's TBA: orchestral live coding.

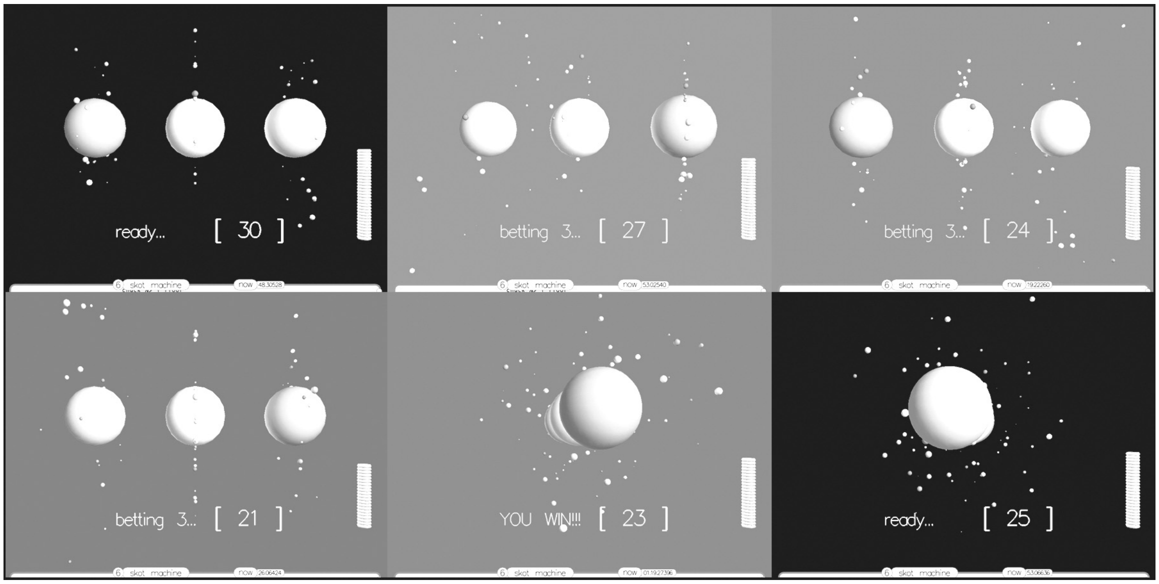


Figure 16

Figure 17

and so forth; and the background "soundscape," which is sometimes designed to create a sense of place (the sound of wind, a distant storm, insects chirping in the forest, mechanical drones, etc.) and at other times is simply some kind of composed music, such as a melodic or rhythmic loop, a song, or even an orchestrated soundtrack. Several game pieces have been created for PLOrk that investigate the musical and performative possibilities within this framework.

The first of such pieces conceived for PLOrk is Scott Smallwood's *On the Floor,* which attempts to recreate the sound environment of an Atlantic City casino. As mentioned previously, this piece consists of 15 virtual slot machines, written in ChucK, with a visual face written in the Audicle (Wang and Cook 2004) by Ge Wang. Each player receives 30 "credits" at the outset and can bet 1–3 credits each turn. If more credits are bet, more credits can be won, but obviously the player can run out of credits faster. The program generates the normal slot-machine sounds each turn, but when the player reaches a certain credit threshold (nine credits left), the sounds change, and instead of hearing a randomized arpeggio, the player hears a looped recording of an actual casino "soundscape," which is randomly chosen from a set of 16 sound files. Each of these sound files reflect a different moment in time and place, extracted from longer recordings made in the same casino on the same evening by the composer. Eventually, everyone loses, and each player is left with a drone, a random member of a C-major triad, so that the piece subsides into an organ-like C-major triad. Thus, the length of this piece is determined by the loss of credits by all 15 members of the ensemble.

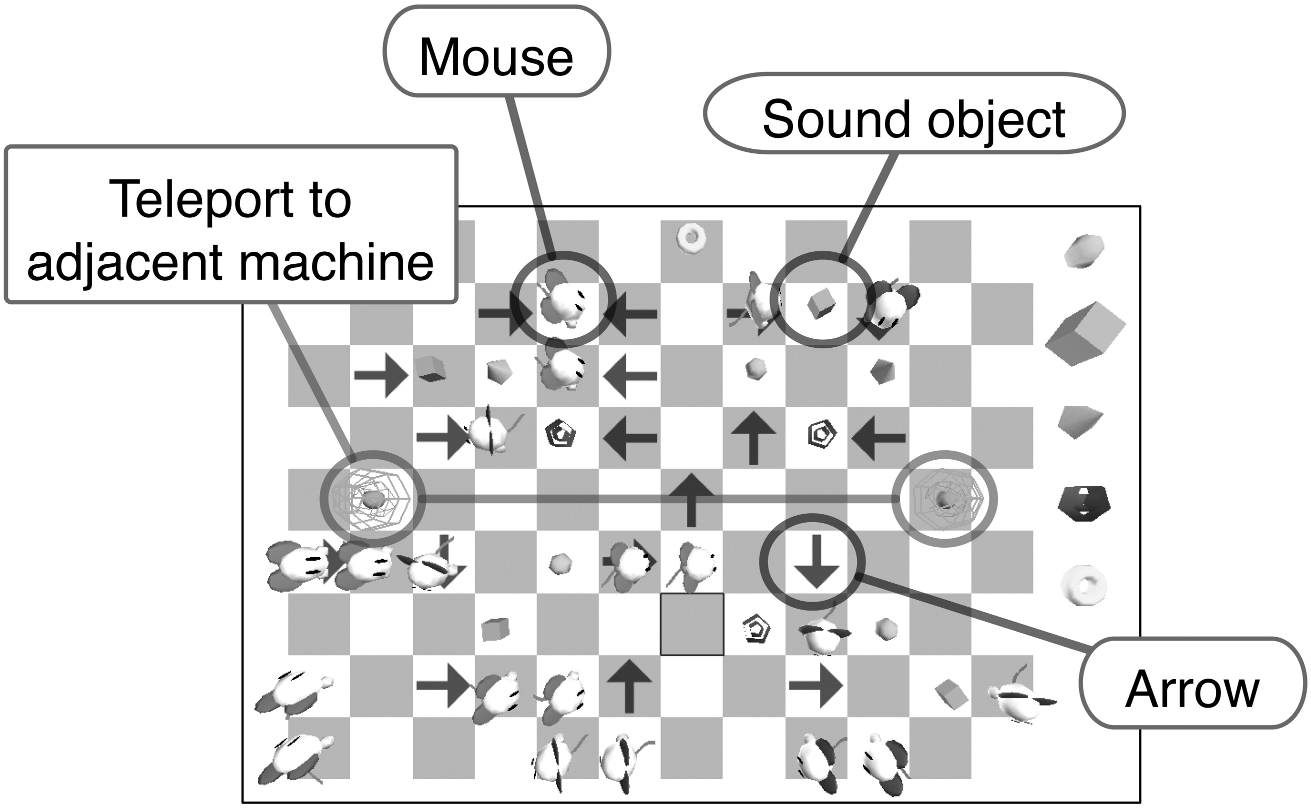
As mentioned earlier, the conductor's role is to monitor the players' winnings, adjusting the odds to ensure that everyone loses and the piece will end. The players' responsibility in this piece, in terms of their actions, is not to be musicians or to reflect any kind of expressivity, but simply to play the game. They are encouraged to show excitement if they win, or frustration if they lose, and each player simply walks off the stage once they have run out of credits. But as a group, we make some decisions together ahead of time about the presentation, the relative volume level of the machines, and how to begin and end. So, this piece is an example of a kind of anti-orchestra piece, because it does not present musicians with an instrument that they must master, nor are the musicians members of an ensemble with which they must blend and interact. Instead, it is a sound composition based on a group of people performing the same individual activities, like a typing pool, or a group of snowmobilers driving through the woods.

Another game piece is Mr. Smallwood's *The Future of Fun (1983)!,* which also features individual game play, but in this case everyone plays a different game. Using Multiple Arcade Machine Emulator (MAME) software, the performers play actual games from the early 1980s arcade-game era. Each player picks a game from a collection, such as *Pac-Man, Defender,* and *Donkey Kong,* and they simply play the game for a specified amount of time. In some ways this is a nostalgic composition: it is a recreation of a lost sound world. Although there was no apparent attempt among video arcade game designers to create sound worlds that were congruent with each other in the way that casino games are, there was nevertheless a very distinct "soundscape" in the early video arcade: in particular, rather than using samples, these games relied on relatively low-resolution synthetic sounds owing to limitations of computing power. The resulting sound world is mostly lost to us today, because it is unlikely that one could find dozens of these vintage game machines in the same room together not also accompanied by the arcade games of today. In fact, most of these games have disappeared entirely except in isolated places. For those who were children at the time, this recreation of a lost sound world tends to bring back a lot of nostalgic joy, excitement, and adrenaline; for those who were parents at the time, this piece is probably annoying, at best!

The final game piece for PLOrk was developed by Ge Wang and Scott Smallwood, called *ChucK ChucK Rocket* (see Figure 18). Based upon Sega's *Chu Chu Rocket!* (see en.wikipedia.org/wiki/ChuChu_Rocket!), the piece is written in ChucK with a visual interface in the Audicle. In the game, mice are released onto a large grid. Each player has a piece of this grid and is able to cause the running mice to change direction by placing arrows in their path; they are also able to place objects in their path that make sound when the mice run over them. Thus, a player can create a kind of instrument with their piece of the grid, trapping groups of mice into loops that contain sound objects of their choosing. They can also send mice to and receive mice from their neighbors through network portals; thus the mice are shared throughout the entire group.

From a composer-conductor standpoint, the central challenge of this piece is to create a shared, improvised composition based upon the individual actions of the players. So, unlike the previous pieces mentioned herein, this piece has more in common with pieces such as John Zorn's *Cobra,* in the sense that the players are interacting with each other through game actions but also are asked to be mindful of their sound and the overall texture of the music. Mr. Wang and Mr. Smallwood developed a sound world that includes both sound effects triggered by mice running over the objects placed in their path, as well as with background sounds that are omnipresent but change based on the density of mice on the screen and the speed that they are trav-

Figure 18. ChucK ChucK Rocket *player interface. The mice move at a pace determined by the "conductor" computer. Arrows redirect the mice. Sounds are generated when the mice move over sound objects. Portals to neighbor machines (both left and right neighbors) allow mice to depart and arrive. (The ensemble is arranged in a doubly linked list.)*



eling throughout the shared virtual space. A conductor machine provides for the ability to change the overall speed of play and the density of mice in the game. More mice can be added to any individual's part of the grid, and any individual can divert his or her mice to their neighbor by directing the mice to run into their network portals.

Because it is possible for players to create their own motives and patterns by setting up traps for individual mice (two arrows pointing at each other, causing mice to run back and forth over objects placed in their path, for example), this piece provides for some interesting possibilities. For example, it is possible for the composer-conductor to direct the players to create a certain type of pattern on their screen, such as a four-by-four loop of running mice, by giving a specific cue. Players can also thwart each other's attempts to make structures by sending mice onto each other's screens, disrupting the flow of activity in that part of the space.

Future Directions

In the coming years, we plan to ask many composers to work with PLOrk, both from Princeton and elsewhere. The pieces described here demonstrate a wide range of technical and aesthetic approaches (and we plan to continue performing these pieces for years to come), but it seems that we are just scratching the surface. The technical issues we hope to address include (1) development of a standardized set of interface and networking tools for composers to use in Max/MSP, ChucK, and SuperCollider (some of these resources have recently been made available through the Small Musically Expressive Laptop Toolkit—SMELT—available for download at smelt.cs.princeton.edu and described by Fiebrink, Wang, and Cook 2007); (2) establishment of a more robust, reliable network, with minimal packet drops and no "hiccups"; (3) acquisition of more off-the-shelf interface devices, and development of more idiosyncratic sensor-based interfaces; (4) construction of flight cases for speakers and racks to facilitate travel; (5) development of a yet more portable and easier-to-set-up instrument design; and (6) establishment of a permanent rehearsal and laboratory space, so the ensemble can remain set up at all times for development and rehearsal.

In future pieces, we hope to explore more of the possibilities afforded by networking both data and audio. (We recently designed and had fabricated a set of rack-mount panels for the rear of the PLOrk equipment racks to facilitate access to the audio interface.) Weinberg (2005) has developed a compelling taxonomy of possible network structures that should serve as a good model. We also hope that some future pieces will develop truly unusual and challenging physical interfaces—interfaces that demand practice and force the players to "break a sweat." It is also clear that there are many new game-piece possibilities that are worth pursuing. Finally, we plan to begin carefully integrating video projection into our performance practice as each piece demands. Many of possibilities exist here, depending on budgets and setup complications. For example, multiple machines could deal with projections in separate locations, or they could share computational burdens required by a complicated single-channel projection. We have even discussed using the screens of the laptops themselves as a kind of visual canvas that could be used for pieces that do not require that the screens to give visual cues to the performers.

As with any large ensemble, finding adequate rehearsal time is challenging. Though primarily a student ensemble, these issues remain, and we hope to establish a more standard and generous rehearsal schedule in the future so that we have not only the time to learn the pieces, but also the opportunity to play the pieces enough for them to really come to life. Unlike the conventional orchestra, where the performance practice is largely standardized, we require more time for experimentation to determine how best to proceed for each piece. And though currently a student ensemble, we hope to establish some continuity with our newly developing performance practice so that we do not have to "reinvent the wheel" each year and so we can reach higher levels of skill and familiarity. We also plan to develop smaller pieces (chamber works, but in the PLOrk mold) for professional musicians so we have the opportunity to see and hear how experienced musicians handle and perceive these new instruments and approaches.

This first two years have been focused on the creation of new works and the performances of these works. In the coming years, we plan to more fully document these pieces and all new pieces that are created, and release working versions of the software. (Such documentation is no small undertaking.) The technical design of the ensemble is fully described online, and this description will also be continually be updated, offering a resource for those who wish to begin their own ensembles. Similarly, we hope to have constantly revised versions of PLOrk compositions available online so that others can not only hear the music that has been made, but also see how it has been implemented and take whatever is useful to them. PLOrk will remain whenever possible an "open-source" compositional and technical community.

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Appendix A: Listing of PLOrk Compositions to Date

Composer	Title	Year	Players	Software	Interface(s)
Bahn, Curtis, and Tomie Hahn	*In/Still*	2006	15 + c	max	L, A
Collins, Nicolas	*Waggledance*	2007	15	max	L
Cook, Perry	*Take it for Granite*	2006	12 + c	ck	L
Cook, Perry, and Ge Wang	*(Even) More/Non-Specific Gamelan Taiko Fusion*	2005	15 + c	ck	L, a
Douthitt, Christopher	*Piece for Plucked Strings and Bells*	2006	3	sc	L, K
Elmegreen, Scott, and John Fontein	*PLOrking in the Prairie*	2007	15	ck	L
Elmegreen, Scott, and John Fontein	*PLOrkit!*	2007	15	ck	L, J
Fiebrink, Rebecca, and Ge Wang	*PLOrk Beat Science*	2006–2007	2	ck	L, T, a
Fiebrink, Rebecca, Ge Wang, and Perry Cook	*Joy of Chant*	2006	15 + c	ck	L, J
Garton, Brad	*Idle Swamp*	2006	20 + c	max	L
Hege, Anne	*Gray Spectral*	2006	5	ck	L, v
Hege, Anne	*Maybe the Monolith will just calm down*	2007	1	ck	L, v
Hollander, Laurie	*Fingerplay 12*	2006	12	ck	L
Lansky, Paul	*A Guy Walks into a Modal Bar*	2006	5	sc	L, K
Mazarriello, Andrea	*10:01*	2006	1	ck	L, a
Michel, Nathan	*Mumble*	2006	15 + c	max	L
Oliveros, Pauline, and Zevin Polzin	*Murphy Mixup: Murphy Intends*	2006	15 + c	max	
Oliveros, Pauline, Seth Cluett, and Scott Smallwood	*Sound Scatter*	2006	15 + c	max	L, a
Pluta, Samuel	*Favorite Things or Titre français avec un petit Mondrian*	2007	15 + c	sc	L
Salazar, Spencer	*Cirrus Pattern*	2006	12	ck	L
Smallwood, Scott	*A breeze brings . . .*	2006	15	ck	L
Smallwood, Scott	*Fabrics*	2007	15 + c	ck	L
Smallwood, Scott	*On the Floor*	2005	15 + c	ck/max	L
Smallwood, Scott	*The Future of Fun (1983)!*	2006	15	MAME	L
Tignor, Christopher	*Orbits (5)*	2006	5	java	L, K, W, a
Tormey, Alan	*. . . to shining sea*	2007	15	max	L, A
Trueman, Dan	*Plahara*	2006	17 + 3c	max	L, T, W, H, a
Trueman, Dan	*The PLOrk Chorale*	2006	15 + c	max	L, T, W, H
Trueman, Dan	*The PLOrk Drones*	2006	15	ck	L, T, W
Trueman, Dan	*The PLOrk Tree*	2005–2007	15	max	L
Wang, Ge	*CliX*	2006	15 + c	ck	L
Wang, Ge	*Crystalis*	2006	12 + c	ck	L
Wang, Ge	*TBA*	2007	15 + c	ck	L
Wang, Ge, and Scott Smallwood	*ChucK ChucK Rocket*	2006	15 + c	ck	L
Young, Samson	*Mirror Dance*	2006	5	ck	L

Key

c	conductor	W	Wacom drawing tablet
ck	ChucK	J	Joystick
max	Max/MSP	A	Accelerometers
sc	SuperCollider	H	headset microphone
L	laptop interface (keys, trackpad, mouse, etc)	a	other acoustic instrument
T	Trigger-Finger controller	v	voice
K	MIDI Keyboard controller		