

FEEDBACK INSTRUMENTS: GENERATING MUSICAL SOUNDS, GESTURES, AND TEXTURES IN REAL TIME WITH COMPLEX FEEDBACK SYSTEMS

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ABSTRACT

After an introductory survey of how feedback appears in common musical processes and situations, interactive compositions by the author are described, which have later been incorporated in complex feedback systems. In such systems, software is able to take on a voice of its own and become responsive more like an instrument than a composition. This highlights aspects of the changing roles of the composer and computer in musical creation and performance. A general model of feedback instruments is drawn from observations made in developing and performing these works in the past two years.

1. INTRODUCTION

Elektrodynamik and *Motet* are improvisational software compositions, and Gamepad Sampler is an instrument for live sampling in improvisations. All three were created by the author and have been explored in performance and studio recordings since 2005. They each began with the intention of sampling and restructuring the sound of a live performer, but each produces profoundly different results when able to take in and process its own output, whether this feedback occurs within the software or between speakers and microphones. Especially in the cases of *Elektrodynamik* and *Motet*, in which constant streams of feedback can be established, software can quickly take on its own voice emerging from the chaotic aspects of the feedback path and computation.

Basically, any time-domain effect is based on a delay process, and many effects also incorporate feedback. A wide variety of effects can be produced using delays with feedback, including echo effects, reverberation, resonant filters, chorus and flange effects, comb filters, and physical models of strings (Karplus and Strong, 1983). These processes use *electronic feedback*, in which the output of the system is connected to its input while it is still an electrical signal (Meyers, 2002). These techniques were explored in the mid-twentieth century by Les Paul (Bode, 1984) and Pierre Henry (Chadabe, 1997, 31), and are now common techniques music production.

Electroacoustic feedback describes the kind of feedback more commonly known to audiences, in which

the output of a speaker is picked up by a microphone that is connected to that speaker through an amplifier. Electroacoustic feedback can yield more complex results than electronic feedback, because the acoustical system of the room is more complex than the simple systems described above. Simple sinusoidal electroacoustic feedback has been explored by David Tudor (Pritchett, 2004) and Alvin Lucier (2002), and more recently by Nicolas Collins (2002), a student of Lucier, and Roger Dannenberg (2006). In simple electroacoustic feedback, the only delay is the inherent latency of the whole system, which is primarily a function of the distance travelled by the sound between the speaker and the microphone.

More complex sounds can result from a feedback system whose properties are in flux. Collins used phase shifters to periodically squelch certain resonant modes and allow others to sound in *Pea Soup* (1974–76; 2002). Placed in audible range of a speaker, a microphone used as an input to *Elektrodynamik* or *Motet* can yield very complex results. The shifting delay periods in both works act as macroscopic phase shifters, canceling different resonant modes and supporting others as the delay periods change.

2. Zur Elektrodynamik bewegter Musiker

Zur Elektrodynamik bewegter Musiker was created for cellist Ulrich Maiß, who requested an improvisational work for a solo concert program called ZenMan Improvisations.¹ It was first performed in Brandenburg, Germany, on September 25, 2005 and in Berlin on September 27. The work is dedicated to the centenary of Albert Einstein's special theory of relativity (1905), and the title is derived from the title of Einstein's paper presenting the theory.

Elektrodynamik was designed to be an autonomous partner in improvisation with a human soloist, changing settings and its mode of interactivity automatically. However, controls created for use in the development stage have proven valuable for the performer to use if he or she chooses. The program builds up textures and gestures from the performer's live input using delays, Doppler

¹ <http://www.zenman.org>, accessed July 5, 2007.

shifts, and changing sample rates. The user is given little control over details but instead acts more like a conductor: starting, stopping, or triggering change, and adjusting loudness levels. In this way, the user has the ability to directly trigger an event at a given time, but the details concerning which event is triggered are determined by the program.

The composition is a study in imitation as a technique to build musical textures and gestures, inspired by the implications of special relativity, in particular, those related to Einstein's musing about traveling at the speed of light while looking in a mirror. In the composition, delay lines and samples recorded during performance are the sonic mirrors, reflecting the sound of the soloist. These are applied in three different ways in three musical voices called *Player*, *Beat*, and *FX*. All sounds played by the program in a performance originate from sounds played by the performer during the same performance.

The performer is given sliders to control the level of each musical voice and a minimal set of key commands to change the current scene, change presets in the *FX* voice, change interaction modes for all voices, start or stop the *Beat* voice, and start or stop automated mixing. A momentary mute button is also provided, in order to prevent unwanted sounds from being sampled, to break up wanted feedback loops, or to impose rhythmic rests on the material as it is sampled.

Whereas the score of a traditionally notated composition contains instructions or values (in pitch, duration, loudness, etc.) to be realized by performers during performance, the *Scenes* module in *Elektrodynamik* sets parameters and modes of the other modules in the program. This score consists of ten scenes selected through a "drunk walk" randomized process, allowing it to move to adjacent scenes. Many scenes do not set values for all parameters, instead inheriting settings from the last scene to set a given parameter, in order to allow for coherence across sections and variety each time a scene is called.

The *Player* voice records the live input and plays randomly selected passages from it according to the parameters of the current scene. The pitch shift and time distortion resulting from changing playback speeds facilitates development of previously played material and the creation of new or more distinct musical gestures.

The first noticeable sound from the program in performance is the *FX* voice. It is simply a delay line with feedback and carefully chosen preset values. As described above a delay can be used to create many diverse effects, including not only echo and reverberation, but also chorus and flange effects, comb filters, and speed change with transposition. Unlike presets in most special effect units, the presets used here include delay period and feedback values that change over time. Where static preset values would each yield a single static textural effect, the presets as defined in this module define textures that evolve over time, or form gestures or motivic material. The *FX* voice is the first to be heard from the program, because the other voices take more time to capture enough material

from the performer in order to begin sounding. It is often the most active, responsive, or distinct voice in the performance because it processes the streaming input from the performer instead of relying on larger buffers. This makes it the most effective for synthesizing tones when used in a feedback system.

The *Beat* voice fills a five-second delay buffer with about ninety percent feedback from the live input signal to act as a *reservoir*, a slowly evolving collection of sounds from the live input folded upon itself in time to build a somewhat homogenous sound source to fuel a rhythmic amplitude envelope. The reservoir sound is divided into high, middle, and low frequency bands and articulated in metric patterns as described in Morris (2004), which acts like a *shutter*.

A similar technique was employed by the author in the live audio processing of *Platonic 5*, a three-day long sculpture-performance by Paolo Piscitelli, a resident artist of the Texas A&M University College of Architecture, September 26–28, 2006 at the Texas A&M University Riverside campus. Two pressure zone microphones (PZM, or boundary microphones) were placed in the small performance area along with seven small loudspeakers and a subwoofer. Each of the seven main speakers played a delay loop passing through a resonant bandpass filter fed by one of the two microphones. Short delay periods or high resonance settings would allow the system to be dominated by feedback resonance, but these values were periodically changed for different textural effects. To keep the sound under control in these moments, and also to prevent the processed sound from dominating the performance, an amplitude envelope was imposed on the input signals, acting like a camera shutter. Different opening and closing speeds allowed more textural control by creating the effect of having input sounds with independently controlled attacks and releases. In moments when other parameters might let unruly resonances appear, the overall duration of the envelope, like a shutter speed, was shortened, successfully keeping the results under control while allowing the system to resonate.

Each of the three voice modules in *Elektrodynamik* is passed through an individual *Transit* module that builds a stereophonic texture by simulating effects of motion at great distances and speeds, inspired by the effects of special relativity that become apparent while approaching the speed of light. This is not a straightforward panorama process that merely makes a sound louder in one channel than in the other, giving the illusion that the sound originates from a point between the left and right extremes but closer to the louder sounding channel. The *Transit* module is instead a textural device exploring the effects of motion among multiple reference frames, like two mirrors aimed at the virtual sound source and reflecting different views of a single source toward the observer. The left and right reference frames are not at the ends of the line segment, but are halfway between the center and an end of the line segment. The loudness of the input is scaled so that it is loudest when it is at the position of a given

reference frame and it is silent at the position of the opposite reference frame. If the imaginary position of the input is between the two reference frames, it will be heard to some extent in each channel. If it is between one reference frame and the nearest end of the line segment, however, it will only be heard in one channel.

As a sound moves away from a reference point, high frequencies are attenuated by a low-pass filter, reflecting this effect of distance in similar acoustic situations. In the *Transit* module, amplitude is exaggerated so that the effects are audible, much in the same way that thought experiments concerning special relativity assume the ability to see clearly across great distances. More accurately, amplitude is not directly changed at all. Quieter sounds result from extremely low filter cutoff frequencies.

The distance between a sound source and a reference frame also creates a delay between the time a sound is played and the time it is heard. This temporal distortion adds to the overall musical texture. Near the center, the difference in delay is short, and will thicken the texture somewhat. Farther from the center, delays can become long enough to create stereophonic ping-pong echo effects or canons on even larger scales. Large dimensions allow for extreme speeds, which yield significant delays and Doppler shifts as well: upward or downward shifts in pitch and playback rate corresponding to a sound moving toward or away from a reference frame, respectively. The Doppler shifts impose directional gestures on the recorded materials, allowing the software to contribute more actively to the performance.

This approach allows for a variety of effects while avoiding a cluttered spectrum in each channel of the stereophonic texture. It is also possible for voices to end up completely on one side or the other, since the reference frames are away from the left and right ends of the line segment. Panoramic extremes, especially when balanced with similar but different materials on each side, can yield a vivid and intriguing overall texture and clarify complex contrapuntal textures. As a sound source moves in the area between reference frames, the sound will be heard as rising in pitch, speed, and brightness in one channel and falling in the other channel, sometimes creating fascinating contrapuntal moments.

3. *Motet*

Motet is a reflection of more straightforward imitative techniques, based on delays and pitch shifters. It will make minor changes without user interaction, but depends on the user for large-scale form and tightly-coordinated moments. In this environment, the user is able to specify more (but not complete) detail about the delay periods of each of the computerized voices and in this way acts as a live arranger.

The performer may focus the computerized voices on various significant times within the performance:

Near Music in the past few seconds (*stretto*).

Early Near the beginning.

Same Around a randomly chosen point.

Wide Each voice at a different randomly chosen point in the performance.

Now Zero delay, acting, for the moment, as a harmonizer.

The voices automatically wander away from the given points some time after being cued, relieving the performer of the responsibility of triggering every change, but this ability allows the performer to plan and cue dramatic textural changes. Each *Voice* module consists of one delay line and pitch shifter. They use a randomized procedure to select transposition level, delay period, and when to change either of these values. All time changes are quantized to a central tempo, which is by default set to 300 milliseconds (200 beats per minute). This tempo may not always be obvious, but it allows for rhythmic patterns to develop between voices, and a degree of textural clarity or a metric feel when material is played in the tempo. The pitch shifter is randomized without any user control. It also implements a spectral gate for noise reduction in the input signal. With higher values, it also causes the electronic voices to audibly deteriorate as they are copied from the soloist. When feedback is used (in any form), this degradation effect can continue progressively for distinct effects.

A slider is provided to fade in feedback from the output of the voices to the input of the delay line. Since this happens in the digital realm or in the domain of data, this might be called *digital* or *data feedback*, as opposed to *electronic* and *electroacoustic feedback*. The feedback amount can be controlled directly, or clicking a toggle switch can trigger a gradual rise in the feedback level, quickly returning to zero when clicked again. This feedback multiplies the number of voices and the textural and registral effects of their delay and pitch shifter settings. It can be effective for building to climaxes, or if left at a constant, moderate level, it can help thicken sparse textures.

4. THE COMPOSITIONS USED AS FEEDBACK INSTRUMENTS

When these works are included in feedback loops, the formal structures, textural devices, and signal processing effects become techniques of emergent synthesis; the temporal structures of the works operate at new temporal scales. In performances of *Tappatappatappa* (Morris, 2005a), a 2-inch speaker cone is used as the input to the *Elektrodynamik* program, acting as a dynamic microphone. The speaker used was extracted from a headphone set. Such a low-output speaker cone has a

limited range of motion and will resist introducing direct current (DC) offsets into the signal, which may damage audio equipment. The cone is excited by stroking or tapping with fingers, a pipe brush, and a frayed wire, but it also picks up sounds in the room, allowing the software to sample its own output and also establish feedback resonances. These resonances and the overall sound quality of the recaptured input can be controlled by moving the handheld speaker, pointing it in another direction, covering it, or damping it with a finger, which mutes it, as one would silence a cymbal. The implements used to excite the cone do not need to be rich in timbral possibilities. They provide enough timbral variety to influence the output of the system in a general way and allow precise temporal control to create rhythmic gestures and textures as needed for the system to build upon or to allow soloistic intervention during performance.

The resulting resonances are particular to the orientation of the surfaces, speakers, performer, and audience within the space. This makes performance somewhat of an exploration, and unique to each situation. After performing a while in one environment, the memorized association of each position and angle with a certain resonant response can become like a tactile sensation for the performer. The multiple delays with shifting properties and the beat and auto-mixing features constantly change the system's response, adding to the improvisational aspect of the performance.

Different sounds are produced from *Motet* with feedback because of its use of pitch shifters. With a short delay, or the natural latency of the system without any explicit delay, a sound will be repeated and transposed in a sequence. This sequence will continue upward or downward, depending on the degree and direction of the pitch shifter, and will continue until the output is transposed out of the sensitive frequency range of the equipment. This of course becomes more complex when multiple *Voice* modules are used in the program, each with a different pitch shifter and transposition setting. A single note would be reproduced as a four-note chord, which would be reiterated in sixteen voices, and so on, continuing exponentially. Unless all pitch shifters are set to transpose in the same direction, it is likely that while parts of the output would soon be transposed out of range to be reproduced, some part of the output would be audible to the system for a much longer time. Several generations of transposition sequences may continue to form, and they and the artifacts produced by the system will continue to be processed long after the initial input sound and the first sequence have faded away. Even more complex output results from the automatic shifting of delay times. Sequences will be fragmented and shifted temporally in relation to each other, yielding a texture and pattern that evolves over time.

Complex results can also be achieved with longer delays or manually reiterative processing, as in Lucier's classic composition, *I am Sitting in a Room* (1969), and many of his other works. A similar manual feedback ap-

proach has been used by this author: repeatedly applying a noise reduction process on computer-generated white noise (and consequently the most recent output of that process) in order to "creatively discover"² electronic voice phenomena (Enns, 2005; Morris, 2007 [forthcoming]).

Similarly, Gamepad Sampler allows the performer to recapture the total output of the software into a sample buffer, capturing all buffers and scrubbing gestures playing at the time as a single sound, which can then be further manipulated in performance. In addition to allowing recombinant sampling of materials, this technique also captures the artifacts of the pitch and speed processing, which can allow the sampler's own voice to emerge in the same way as in the other tools with a continuously streaming feedback loop.

When used in feedback systems, *Elektrodynamik*, *Motet*, and Gamepad Sampler can be treated like distinct instruments: *computation instruments*. This echoes a sentiment in Stephen Wolfram's (2002) study of cellular automata, highlighting the beauty of computation not for the purpose of an end result, but for the sake of computation—that is, for the artifacts of the process itself. Before Wolfram, many have mused at the beauty resulting from natural processes like the formation of crystals, erosion of rock, or the growth of plants, and Benoît Mandelbrot (1982) made a connection between these natural processes and simple iterative mathematical processes. Cellular automata as explored by Wolfram exemplify such processes that can yield complex and beautiful results from simple processes. Each automaton is given the same set of rules that determine its state (usually black or white) based on the states of the automata around it. While these can be used to find a particular end result (a solution), the structure of that process can also be appreciated. For Wolfram, this is the value of "computation for the sake of computation," and it is an approach more common to natural structures. For example, it is more common for one to appreciate the overall form of a coastline (or its evolution over time) than to use data to determine the position of one point on a coastline. In nature, process can be appreciated as artistic. In most art, the result of a process is appreciated. In computing, the result is a solution to a problem, and the process is usually neglected, except to see if the result could be reached faster. However, this need not be so.

Wolfram attempts to explain the artistic value in some natural or computational structures with his principle of computational equivalence:

... almost all processes that are not obviously simple can be viewed as computations of equivalent sophistication. (Wolfram, 2002, 716–17)

He continues to suggest that processes humans perceive as complex or beautiful, ones that in either way make it "easy

² The phrase "creatively discover" is adopted from Dodd (2004, 347), who argues that *composition* is the process in which a musical work is discovered rather than created (i.e., coming into existence at a distinct point in time). It is meant to capture both aspects of the process.

to forget that the rules are really in place.” (Flake, 1998, 11), are perceived that way because the processes are as sophisticated as the humans perceiving them. Perhaps this explains why it is difficult to prescribe processes based on simple steps (like computer programs) that are capable of beautiful results. It can at least be gained from Wolfram’s methodical study of cellular automata that existing fractal or chaotic systems may be instrumental in achieving beauty in computerized processes.

In *Elektrodynamik* and *Motet* with feedback, the chaotic system of room acoustics is explored during performance. While both *Elektrodynamik* and *Motet* involve streaming speaker-to-microphone feedback, the results are distinct, because the programs are distinct. Iterative feedback with Gamepad Sampler employs the randomness in granular sampling techniques and the chance of improvised performance. Feedback not only illuminates the natural resonances of an acoustical system as in Lucier’s works, but also the natural resonances of the software system. The feedback techniques explored with *Elektrodynamik*, *Motet*, and Gamepad Sampler allow the unique voices of the programs to emerge, and the properties of original sonic stimuli disintegrate as they do.

5. COMPONENTS OF A GENERAL MODEL

In reflecting on the properties of these three different approaches to feedback instruments, a model has become apparent that describes a complex feedback system in four elements:

1. The *loop*, in which the output of the system reaches the input of the system in some way. The loop (or distinct segments of it) can be qualified according to the following types. These may be:
 - (a) *electric*, in which only an analog electrical signal connects the output and input,
 - (b) *electroacoustic*, in which the signal passes through the air before reaching the input,
 - (c) *digital*, in which only digital data is passed from the output to the input, within a program or among multiple programs.
2. Some form of *intervention*, which transforms feedback resonance without necessarily stopping it:
 - (a) A gradually changing delay, which simulates a Doppler shift, stretching resonant modes of the loop like moving a trombone slide,
 - (b) A phase shifter, which dampens certain resonant modes and allows others to sound, like overblowing on a trumpet or touching a string to play a natural harmonic, or
 - (c) Filters, which can more generally catalyze or dampen certain frequency bands (by amplification or attenuation, respectively). With narrow bandwidth and high gain, a filter may

also be used to invoke feedback resonance in specific bands.

3. Or some form of *interruption*, which stops feedback resonance in some way:
 - (a) Manual damping, for example, by physically preventing a transducer from vibrating, or by using a momentary mute control, as described above,
 - (b) A *shutter* that only allows a portion of the signal to re-enter the system, according to an amplitude envelope that shapes the incoming signal, or
 - (c) A pitch shifter (acting like changing fingerings on a trumpet), frequency shifter, or other spectral reordering process, which causes a sound entering the system to be output at a different frequency (or set of frequencies).

Note: These modes of interruption may not instantly stop feedback resonances, but will sometimes allow them to “taper off” in some way. For example, the sound that passes through manual damping or a shutter may act as an impulse into a resonant system, which may continue to resonate for a time after the impulse ceases. Also, a pitch shifter or similar approach may “smear” a resonance across the frequency spectrum as the resonance gradually dies away.

4. Finally, a form of *excitation* is necessary, which is the kernel of sound that sets feedback resonances into motion. The qualities of the excitation can shape the resulting resonance by introducing sounds with certain qualities or frequency ranges, but the excitation can rarely dictate results of the system’s output:
 - (a) *System noise*, including air movement, extraneous sounds in a performance venue, electrical noise such as hiss or hum, or artifacts from digital processing a “silence” that includes acoustic or electrical system noise and may be transformed it into louder artifacts that more readily trigger a feedback system into resonating,
 - (b) *Performed sound*, which is created or electronically triggered by a performer or user for the purpose of fueling the feedback process and perhaps steering it toward a particular general result, or
 - (c) *Looped sound*, such as feedback through a *reservoir* and *shutter* as described above. This process combines real-time feedback with *iterative feedback*.

Feedback instruments require real-time, or “live,” feedback in order to be used as an instrument, creating musical

tones, gestures, or textures. However, feedback processes can be implemented out of real-time and may be called *iterative feedback* processes. Iterative feedback includes approaches described above in pieces like *I am Sitting in a Room*, recursive resampling the computer's output with Gamepad Sampler, and cultivation of electronic voice phenomena in *Disturbances*. The use of a long delay loop as in the reservoir technique described above may also be considered iterative feedback.

6. SUMMARY OF MUSICAL APPROACHES

The easiest way to establish musical tones is with a static or slowly changing system state, emphasizing certain frequency ranges with filters or short delays (to act as comb filters). The FX voice in *Elektrodynamik* and the *Near* and *Now* presets in *Motet* are useful for this. A system state often cannot remain constant for long without letting the loop escalate out of control. A slowly changing loop, however, can form fascinating musical gestures.

Even though delays longer than the period of audible frequencies or sample recording and playback will not usually produce feedback resonances, they could be useful to establish musical tones in a sufficiently rich feedback system. Any system that samples its own output will progressively emphasize the resonant frequencies of the system. When sampled material is played again, it is tailor-made to excite the same resonant modes again.

These tones can be manipulated into broader gestures with a shifting delay or phase shifter to change the state of the system within a controlled range. As with the changing playback speed in the *Player* voices and the gradually changing delay settings in FX presets in *Elektrodynamik*, simple ascending, descending, or alternating forms would be most salient, especially since resonance may not persist throughout the gesture—this is not necessarily undesirable, as it may add complexity or “dirt” to the musical gesture. Repeated patterns can also be useful in establishing musical motives that may recur or mutate over time. If only parts of the pattern cause resonance, then rhythmic rests become a part of the pattern.

More stable musical textures can be established with longer delays in a relatively constant system state or one that is changing in dramatic, disjunct ways to prevent any single sinusoid resonance from dominating the output. Other effective textural devices include the reservoir and shutter as described above in *Elektrodynamik* and *Platonic 5*, the *Player* voice in *Elektrodynamik*, and the *Early*, *Same*, and *Wide* presets in *Motet*.

In the terms of the general model presented here, *Motet* employs an electroacoustic loop excited by system noise and interrupted by pitch shifters. Its unique properties include the smearing of sounds through reiterative transposition, the temporal “grid” imposed by the quantized delay periods, and the performer's ability to manage the textural changes and recurrences of sampled material through the arranger-like controls.

Tappatappatappa (which uses *Elektrodynamik* as a feedback instrument) employs an electroacoustic loop with performed sound that is interrupted by manual damping and in which gradually changing delay intervenes (via the FX module). It also uses digital loops distorted by gradually changing delays and filters (in the *Player* and *Transit* modules) and others interrupted by shutters (in the *Beat* module). It is unique in the way it builds form by navigating through scenes that describe behavioral and relational characteristics instead of directly referring to specific sound material, in the way it builds textures with a variety of musical voices (*Player*, *Beat*, and *FX* modules), and in the conductor-like controls offered to the performer.

7. THE CHANGING ROLE OF THE COMPOSER

In the preceding sections, *Elektrodynamik* and *Motet* are presented both as compositions and as instruments. Could an instrument be considered a composition? Do they lie on a continuum, as Stockhausen (1959) tried to establish with time unifying timbre, tone, rhythm, and form? Are they distinct classes whose definitions can overlap, along with concepts like *performance*, *version*, and *variation*? New definitions are needed. Golo Föllmer, writing about internet-based music, calls for an adjustment of familiar terms:

So we may have to think about a more open way to define the notions of the composer, the performer, the listener. The composer would (still) be a person who sets a scope and lays connections of ideas, concepts and atmospheres in music. The performer would be the person to mediate a primarily auditory event, albeit following different rules than in the past. Finally, the listener would be the one to put it to a final order, to receive it at a final destination and interpret his/her personal version of it. Whatever will happen, the main effect is that the range of roles for each grows. (Föllmer, 2001)

Gary Flake relates the situation of the computer music composer to other artists:

The fact that good programs are logical by necessity does not diminish the beauty at all. In fact, the acts of blending colors, composing a fugue, and chiseling stone are all subject to their own logical rules, but since the result of these actions seems far removed from logic, it is easy to forget that the rules are really in place. Nevertheless, I would like you to consider the computer as a medium of expression just as you would canvas or clay. (Flake, 1998, 11)

Flake says it should not be ruled out that the product of a computer can be beautiful, but it is not license to

assume that any computerized result is good, either. It takes at least as much effort to get good results from a computer program as it does to compose a good fugue or create a good sculpture. Perhaps extra effort is required in computer-based art to overcome the greater distance between the creation of any part of the program and the sensation of the results it can produce. While in traditional composition, any segment may be played on its own and evaluated by the composer from the perspective of an audience, one part of a computer program may require the rest of the program to be in place along with input from a performer before it can be fully evaluated. In interactive musical works like the ones presented here, William Seaman describes the composer's new challenge: "The artist need no longer seek to define a singular artefact, but instead need develop systems that enable a series of sonic artefacts to become operational and polycombinational, thus engendering an emergent relational sonic artefact during exploration" (Seaman, 1999, 234). As the human condition changes, the frontiers of art and the role of the composer are changing.

Instead of viewing the compositional process as one of problem solving, the approach used in these works was to seek elegant paths to new results in order to side-step problems like choosing synthesis methods or prescribing sound material by making them irrelevant—they are natural features of the programs. Alvin Lucier has commented, "Some of art is that you make connections between things that no one else would ever make" (Lucier (1995, 70), quoted in Aufermann (2002)). The creative work described here supports a model of composition as discovery. There is very little in the program code or equipment described above that is truly unique, but connections among these things have yielded distinct musical works.

Perhaps it is becoming more natural or useful to think of creating art as hacking—in a benevolent sense, meaning deconstructing the rules of a system in search of a way to coax from it unintended results. It is more common for programmer-hackers to consider themselves to be artists (Wark, 2004) than for artists to see themselves as hackers, but the analogy seems appropriate. Poets short-circuit syntax in order to achieve greater depth in meaning. Alban Berg manipulated the twelve-tone technique to create tonal structures and embed secret personal allegories (Adorno et al., 1994). Circuit bending, a common musical hacker activity that involves adapting electrical circuits for rich musical results, begins with exploration—playing around in search of intriguing possibilities to pursue (Ghazala, 2005; Collins, 2006). In the explorations leading to the creation of these works, the composer has investigated—played with—the diverse effects achievable from delay lines, the artifacts resulting from dramatically slowed samples, and the self-sustaining sounds emerging from complex feedback systems. This was of course guided by previous experience, research, and intuition. Observations from this process have opened up multiple modes and categories of performance, bringing up

fascinating aesthetic issues including the value of audio feedback systems, the aesthetics of live sampling, stage presence, and the ontology of such works. In the works described above, software compositions have had their inputs hacked. Software itself has been allowed to take on its own musical voice and become something new.

8. SOUND EXAMPLES VIA THE INTERNET

- *Tappatappatappa* (*Elektrodynamik* used in a feedback system) in a studio performance presented as a fixed media work in the SPECTRUM concert series in the Merrill Ellis Intermedia Theater at the University of North Texas on October 10, 2005. <http://www.ourmedia.org/node/240436>
- *Tappatappatappa* performed in the Bellingham Electronic Arts Festival at the American Museum of Radio and Electricity on November 20, 2006. <http://www.ourmedia.org/node/297632>
- *Motet* with feedback in a studio recording in the Texas A&M University Department of Performance Studies on April 27, 2007. <http://www.ourmedia.org/node/313638>

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