Nicolas Collins
Improvising with Architecture -- *Pea Soup* and Related Work with Audio Feedback
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Background

Microphone + speaker = feedback. I can't believe there are more than a handful of people on our planet who haven't heard this primal electronic squeal. But then I am of the feedback generation: from John Lennon's disruptive skid into "I Feel Fine" in 1964 to Jimi Hendrix's performances in the films of the Monterey Pop Festival and Woodstock, feedback was as essential a voice in the music of my youth as guitars and drums. Experiments in high school with a second-hand Tandberg reel-to-reel tape recorder made extensive use of feedback because I couldn't afford much else. When I arrived in Middletown, CT, as a freshman at Wesleyan University in 1972 and fell under the twin influences of John Cage and Alvin Lucier, feedback re-asserted itself as a fortuitous gift.

Cage's admonition that "any sound can be a musical sound" induced a kind of sonic paralysis in me. I spent hours in front of the studio's synthesizer only to realize, at the end of the night, that I had no preference for one configuration of patchcords over another. But plug in a microphone, turn up the speaker, and feedback's Zen-like infinite amplification of silence produced sounds with minimal interference on my part. Feedback served as a sort of electronic *I Ching*: I moved the mike instead of tossing yarrow sticks, notes emerged, but I never knew which pitch would pop out next. The results were more a question of acoustics, however, than of pure chance -- the overtone series became my hexagrams -- and here's where my other role model, Lucier, exerted his influence.

I grew up in a rather unmusical family[1], with architectural historians for parents. At age 18 my interests were all over the place. Without a "serious" musical background to draw on, I found Lucier's embrace of fundamental acoustics in compositions such as *Chambers*, *Vespers* and "*I am sitting in a room"* familiar and reassuring. Physical acoustics – and the notion that a room or a teapot could be a musical instrument and an echolocating bat a musician – became the conceptual glue with which I sought to unify my disparate interests into a meaningful, personal musical style.

The Wesleyan studio had a Sony 152SD portable stereo cassette recorder, slightly smaller than an attaché case. I could trick it into serving as a microphone preamplifier by poking the tip of my pinkie against the erase-protect tongue at the rear of the cassette well while pressing down the "record" button. In addition to line outputs the Sony had a robust internal speaker that transformed the recorder into a self-contained, portable feedback instrument. Moreover, its built-in limiter did a wonderful job of taming feedback's shriek, reducing it to a mellow sine wave.

Figure 1: Sony TC152 cassette recorder (1974)

For the next three years I ran feedback through as many variations as I could. I carried the Sony outdoors and used feedback to "play" culverts under roadways as if they were huge trombones. Lucier owned a set of Shure industrial contact microphones (intended for analyzing noises in machinery) with which I could similarly cycle feedback though solid objects such as tables, walls, floors and tree trunks[2]. I resonated the air columns of wind and brass instruments by embedding tiny lavaliere microphones inside mouthpieces and feeding them back with speakers; performers used fingering or slide position, as well as movement of the instrument in space, to nudge the feedback to break to different overtones. Later I substituted small speakers for some of the mouthpiece-mounted microphones, transforming trombones and tubas into "speaker-instruments", and I manipulated feedback between pairs of instruments without the need for an external PA[3].

The Countryman Phase Shifter

When the Electronic Music Studios opened in the new Wesleyan Arts Center in 1973, Lucier disconnected the keyboards that arrived with the two Arp 2600 synthesizers and locked them in a closet. This was done primarily to pre-empt endless rock riffs by students, but our placid acceptance of this musical amputation was indicative of the "proto-digital" direction that synthesis was taking by that time. Rather than playing the Arp directly in the manner of an elaborate electric organ, we interconnected the various voltage-controlled modules (oscillators, filters, amplifiers, etc.) to create self-governing networks that, left to their own devices, created complex, cyclical patterns. By the end of the decade we were programming similar work on primitive, pre-Apple microcomputers like the Kim-1, but plugging patchcords and twiddling knobs introduced us to algorithmic thinking[4].

It was in this context that I began building synthesizer patches to control feedback. My goal was to emulate electronically the physical movement of the microphone through space, and thus create some kind of automatic feedback variation machine. I cobbled together numerous arrangements of filters and amplifiers, modulated by low frequency

Figure 2: Countryman 968 Phase Shifter (1974)

oscillators (think virtual *Pendulum Music*[5]) before stumbling upon the Countryman Type 968 Phase Shifter[6].

Phase shifters are best known for the characteristic swooshing sound that defined the disco era, but in the time before affordable digital delays these devices were the only practical way to produce variable short time delays on audio signals[7]. Lucier had made some field recordings of the electromagnetic signals produced by meteorites, lightning strikes, the dawn chorus and other atmospheric disturbances. He wanted to pan these sounds around a concert space in emulation of the movement of the signals through the earth's atmosphere, and had read about "Haas Effect Panning", which produces very convincing spatial movement of sound using small time delays, instead of the more typical method of adjusting the balance of loudness amongst the various speakers. A few cheaper guitar-pedal versions of phase shifters were available at the time, but someone knowledgeable (most likely David Tudor) had recommended the Countrymen for its higher audio quality and expanded features. Lucier bought three primarily for his panning experiments, but left them in the studio for general access. In the spring of my sophomore year he delegated me to figure out how to get the phase shifters to pan his recordings amongst the four speakers in the Merce Cunningham Dance Studio (New York City), where he had been invited to provide music for a Cunningham Event. Two Arp 2600s and three Countrymen later I had an absurdly complicated patch that convincingly swept his *Sferics* around the Westbeth ceiling in response to changes in the loudness of the recordings[8].

Back in Middletown, I adapted my patch to the task of using a similar loudness tracking of feedback to "move" a live microphone, instead of panning Lucier's recordings. Over a period of weeks I whittled away modules until I was left with the simplest of configurations: microphone > preamplifier > limiter > phase shifter > amplifier > speaker, with optional equalization (see figure 3)[9]

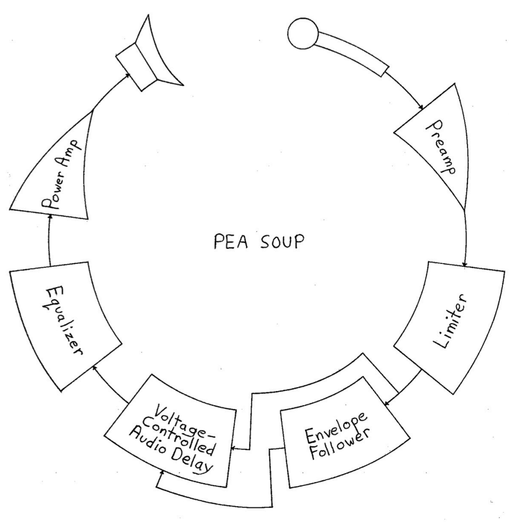

Figure 3: ***Pea Soup*** **original patch diagram (1976)**

I discovered that when I connected a microphone to a speaker through a phase shifter, varying the delay (degrees of phase shift) emulated moving the microphone towards and away from the speaker, in turn causing the feedback to break to different frequencies. Controlling this virtual movement with the loudness of the signal (via an envelope follower circuit conveniently built into the control-voltage input of the Countryman) mimicked a nervous sound engineer jerking a microphone away from the speaker as soon as it starts to feed back.

I inserted the limiters from the Sony TC152 to keep the signal smooth. Whatever equalization was available in the sound system (usually nothing more elaborate than the bass and treble tone controls on the studio's Dynaco amplifiers) could be tweaked to adjust the frequency range of the feedback. By experimenting with the various microphones in the studio I discovered that *omnidirectional* mikes produced a much wider, less shrieky range of pitches than the more common unidirectional cardioid microphones (even the best cardioid mikes have rather irregular off-axis frequency response, which I suspect affects their feedback characteristics.)[10]

Figure 4: Electro-Voice 635a omnidirectional microphone – the perfect feedback mike

A single chain of mike > phase-shifter > speaker tended to seesaw back and forth between two pitches of feedback, as if the mike were bouncing back and forth between two fixed distances from the speaker. But when one or more additional independent chains were added (each with its own mike, phase shifter and speaker), the various channels interacted acoustically to produce more varied and extended melodic patterns[11]. Moreover, these patterns were hypersensitive to the smallest change in acoustic conditions: walking a few steps across the room, making a sound, even opening a door or window could cause a note to be dropped from the melodic phrases or a new one to be added.

I had stumbled upon a remarkably simple electronic network that created a site-specific "architectural raga" out of a room's resonant frequencies. The phrasing was a function of the reverberation time – bigger halls yielded slower patterns. Perhaps the most elegant aspect was the responsiveness of the sound itself: one "played" this system not by twiddling knobs or pushing buttons, but by moving or making sounds within field of the feedback[12]. I began to visualize people and objects in a room in terms of their disruption of the flow of sound waves through the space, like blocks placed in the water of the wave-tank used in physics experiments.

The 1970s saw the emergence of the notion of the "circuit as score" – the assumption that a configuration of electronic components was as legitimate an expression of compositional intent as notation on manuscript paper – which I enthusiastically embraced. I had no desire to dictate specific instrumental actions or body movements (these derived from that most ubiquitous of 1970s instructions: "explore…"), but I was quite content to claim this array of modules as my "composition." I dubbed it *Pea Soup*: a reference to the first letters of the core technology (Phase Shifter) and to the expression "as thick as pea soup", which I thought conveyed well the experience of standing within the field of feedback. A silly title but now I'm stuck with it. The first performance took place in a lunchtime concert in the Wesleyan Electronic Music Studios on October 24, 1974.

Pea Soup incorporated four of what I regard (in all modesty) as significant innovations in what was already the well-trodden field of feedback music:

- **Phase delay** changes feedback frequency by emulating physical movement of the microphone.
- A **limiter** transforms feedback's usual shriek into a mellow sine wave.
- **Omnidirectional** microphones (especially dynamic ones) produce more controllable feedback than cardioid mikes, with a more balanced frequency range.
- To the best of my knowledge this is the first composition to use automatic **negative** feedback (the typical "control feedback" studied in cybernetics) to control audible **positive** feedback[13].

Over the remainder of my undergraduate career at Wesleyan I produced several performances and gallery installations of *Pea Soup* on and off campus. With Lucier's encouragement and connections, his small but assertive posse of students arranged concert exchanges with other colleges around New England. I drafted instrumentalists and dancers on site or from amongst my fellow Wesleyan students. I supplemented the electronics with verbal instructions, consisting mostly of admonitions to "do less." The site-specificity of *Pea Soup*'s character made it a satisfyingly portable work, familiar yet surprising wherever it was played. I included an overwrought prose score in my undergraduate Honor's Thesis[14], but had to leave the phase shifters in studio when I graduated in 1976 (I could not afford to buy any on a student budget), and *Pea Soup* was consigned to history.

Reconstruction

Feedback returned to my music with the regularity of a comet over the next few decades, even as my technological palette shifted from homemade circuits to microcomputers to human improvisers to chamber ensembles and back to circuits[15]. In 1997, while living in Berlin as a guest composer of the DAAD Künstlerprogramm, I was asked to revive *Pea Soup* (after a hiatus of more than 20 years) by Kammerensemble Neue Musik Berlin, who wanted to take on some interactive works for electronics and instruments. I reconstructed the original phase shifter circuit with the aid of a schematic generously provided by Carl Countryman himself (who had ceased manufacturing the device sometime in the late-1970s)[16]. Sadly, the Countryman contained one custom-made sub-module that was difficult to replicate; certain characteristics of the original design, and the resulting sonic behavior, remained just beyond my reach.

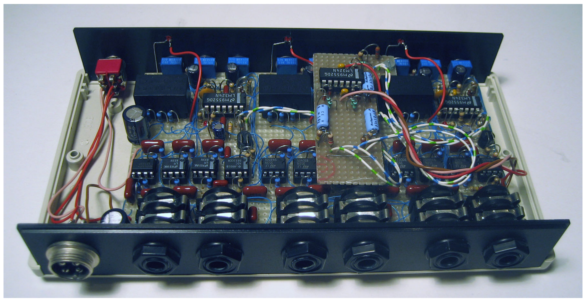

Figure 6: 3-channel Countryman copy, Nicolas Collins (1999)

Figure 5: Modified Moogerfooger M103 Phase Shifter (box on right contains envelope followers), Nicolas Collins (2001)

In 2000 I bought a Moogerfooger M103 Phaser which I modified (with the assistance of documentation directly from the hand of Robert Moog) to mimic the behavior of the original Countryman as best I could; Moog's design was beautiful indeed, but still not quite right for this piece. I shelved my circuits after a few more performances and moved on to other projects[17].

The Berlin revival of *Pea Soup* was indicative of a wide-spread nostalgia, emerging at the cusp of the millennium, for early electronic music: John Cage's *Cartridge Music* (1960), Takehisa Kosugi's *Micro 1* (1964), Steve Reich's *Pendulum Music* (1968) and David Tudor's *Rainforest IV* (1973) all returned to the concert stage after decades of retirement. This interest in historic works, many of them dependent on obsolete or composer-built technology, coincided with the spread of music programming languages that ran on affordable computers that were finally powerful enough for real-time audio signal processing. The net result was a wave of "porting" of older, hardware-based electronic repertoire into software formats. Sometimes the programming was done by the original composer (David Behrman comes to mind); other times enthusiastic young fans took on the task, adapting older works (often previously limited by homemade circuitry to solo performance by the composer) for the emerging format of laptop ensembles. The quirky look of a table of homemade circuits and cheap effect pedals was replaced by a familiar, rather more stolid, computer, and there often was a subtle change in sound quality. But for performance convenience and ease of distribution this method of reconstruction could not be faulted.

Shortly after moving back to America in 1999 John Corbett asked me to resurrect a circuit-based composition from the mid-1980s, *Devil's Music*. Unable to locate or clone the original hardware, I programmed a workable facsimile in Max/MSP[18]. Around the same time I undertook a similar software adaptation of *Pea Soup*. The impetus for the revival of *Devil's Music* was external: a request for a version that could be played by multiple performers (DJs) in a club context. Limitless duplication and open distribution made software the most appropriate strategy. My motivation for coding *Pea Soup* was more selfish: my interest this composition had been re-kindled by its recent circuit-based performances, and I wanted to bring a practical version of the piece back into my touring repertoire. The final push came from my discovery of a third-party Max object (set of software instructions) that replicated the core mathematical function of a phase shift network and allowed me to delay audio by *degrees of phase* – as in the original analog circuits – rather than absolute time, which is much more common in the digital domain[19]. To my surprise I successfully programmed a convincing software equivalent of the Countryman phase shifter using this function. I coded a basic limiter and some simple equalization, copied and pasted the whole chain to make three discrete channels, and by the summer of 2001 had created a reasonable digital approximation of my 1974-era technology.

Subsequently this new *Pea Soup* has been presented in some 100 performances and installations around the world. The somewhat severe, strictly Minimalist, task-oriented format of the 1970s was replaced by something more akin to “improvising with architecture” – in the hands of a sensitive musician with a good ear and a modest ego the piece is virtually foolproof. The behavior of the technology hasn’t changed significantly (despite its shift from hardware to software), feedback is still feedback, and architectural acoustics are the same now as they were in 1974; but over the past four decades musicians in general have become more skilled at performing open-form compositions that require an instinct for improvisation and a familiarity with electronic sound.

The Software

It’s tempting to “improve” a hardware circuit when emulating it in software: physical sliders and knobs have limits past which they will not move, for example, while numbers in a program can always be made larger or smaller. Sometimes it’s important to retain what are, in software, “artificial” limitations in order to remain faithful to the essential character of the original composition in which the circuit functioned. But other traits in hardware can be the result of economic or technological compromises or shortcomings, and the music might benefit by their removal or modification. My challenge was to preserve the core of the old analog *Pea Soup* while adding a minimum of appropriate innovations made possible by the software environment. (“Authenticity”, in this particular case, was somewhat irrelevant: it’s my piece, I’ll change it as I see fit).

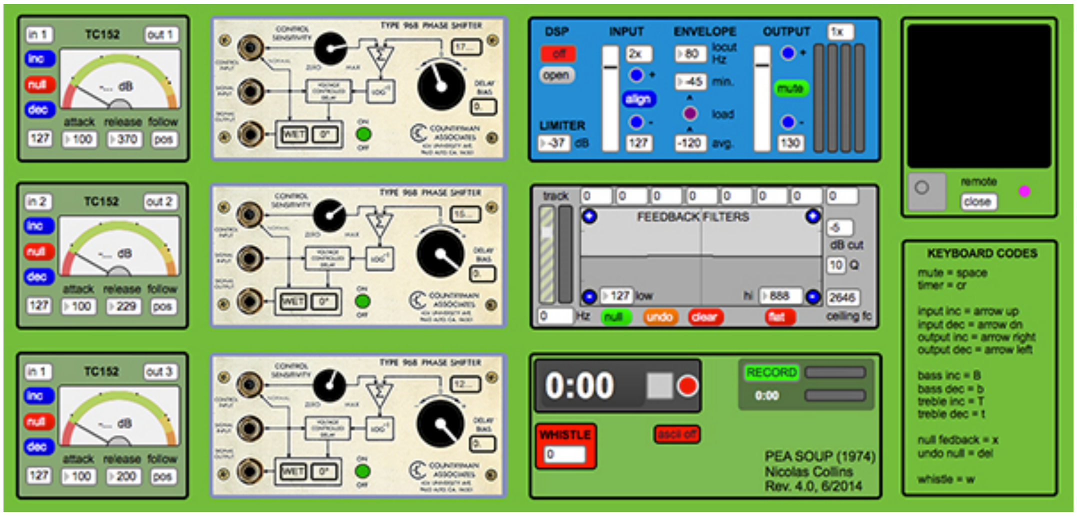

Figure 7: Max/MSP program for software realization of *Pea Soup*

The core functions implemented (in triplicate) in the program are[20]:

- **Countryman Phase Shifter**: an emulation of the Model 968, with a built-in envelope follower to change phase delay in response to loudness.
- **Limiter**: a simple "brick wall" limiter on each channel to prevent distortion, with adjustable threshold (the loudness at which limiting sets in).
- **Equalization**: low frequency and high frequency shelving filters with boost and cut controls, as well as adjustable corner frequencies; to roll off shrieking high frequency feedback, boost the bass response, etc.

These three modules are software equivalents of analog circuits in the original *Pea Soup* patch. To these I have added a few routines that extend the capabilities of the system in ways that would have been very difficult before the advent of digital technology. The critical ones are:

- **Feedback Nulling Filters**: with a tap of the "x" on the computer keyboard a filter locks onto the current pitch of feedback and attenuates that frequency just enough to silence it. This mimics an attentive sound engineer tuning the equalization on the mixer to minimize feedback from mikes on the stage[21]. My module has eight such notch filters: whenever a particular frequency of feedback gets too persistent, a simple "x" will knock it out and allow other pitches to replace it. With each dominant frequency thus eliminated a new feedback pitch usually emerges – judicious use of the Nulling Filters can steer *Pea Soup* through "key changes" as the piece unfolds.
- **Whistler**: playing or singing at the same frequency as the feedback, then de-tuning slightly, produces a beating effect that – if sustained – often forces the feedback to break to a new pitch. The Whistler module plays back a pair of sine waves that can be de-tuned around the feedback to induce beating and pitch breaks.

The best performances of *Pea Soup* result from playing acoustically and moving slowly within the spatial field of the feedback. Manipulations of the software settings are usually done as part of the “tuning” process, and I encourage performers to interfere with the patch as little as possible once the performance is underway. The nulling filters are useful for eliminating strong resonances from the system in the course of the sound check, to increase the variety of feedback pitches; used judiciously, they can also subtly modulate the “key” of the feedback over the course of the performance. The whistler can serve as a substitute for a live musician.

Since 2011 the software has been available on my website for free download by musicians interested in staging performances. I periodically update the code to keep it compatible with upgrade to operating systems.[22]

Pea Soup To Go

Belying its 1970s roots, *Pea Soup* is a classic open-form composition: the score and technology are static, the feedback always presents a similar sonic texture, yet the actual pitch material is site specific, and varies significantly from performance to performance. Every room has its own tuning. Both during its analog days and after shifting over to software I often performed *Pea Soup* as the opening piece on a concert program -- it serves as the *alap* section of an architectural raga, slowly revealing essential musical characteristics of the concert space (characteristics that influence every subsequent piece played in the room, whether the performers or audience are conscious of this acoustic underpinning or not.) I recorded many of these performances, and after I had accumulated several dozen sound files I toyed with the idea of editing them into a long tape composition. I imagined that, properly sequenced, each “room chord” would modulate to the next like a glacially slowed-down progressive rock composition from the 1970s.

But, alas, the same Cagean stasis that drove me to feedback in 1972 rendered me incapable of choosing one pretentious chord change over another. So I took refuge in that most ubiquitous mass-market adaptation of Cage’s musical philosophy: “Shuffle Play.” I collaborated with a former graduate student on a web application that plays back my library of *Pea Soup* recordings in pseudo-random order. The start and end points are randomized as well, so that the files don’t always start and finish at the same times. Long cross-fades (15 seconds) make for a seamless mix. The end result, *Pea Soup To Go* (2014) is an encyclopedia of architectural harmonies in the form of an “audio screen saver” that takes over 24 hours to cycle through the 70+ recordings[23].

Figure 8: *Pea Soup To Go* (2014), software for shuffling recordings of *Pea Soup*

Afterword

There is something slightly pathetic about a composer revisiting a student work 30 years on, but taking *Pea Soup* back out on the road re-awakened and expanded my early interest in the musical implications architectural acoustics. The nulling filter routine in the software revealed that the more remote overtones of a room's resonant frequencies tend towards greater dissonance than the pitches that dominate feedback in an un-equalized sound system. I found this intriguing from the standpoint of harmonic theory, and subsequently wrote a computer program that expanded the set of nulling filters to analyze the 24 strongest resonances of a room and display them as conventional staff notation. The resulting composition, *Roomtone Variations* (2013), opens with a brief (less than two minutes) sequence of subdued feedback pitches as the computer analyzes the room acoustics in the presence of the audience; the notation is projected for musicians (and audience) to see as it fills in. The strongest, most resonant pitches appear at the left, the weakest at the far right. After the analysis is complete, and the feedback stops, the players improvise variations on the notes as they are highlighted by a conductor, gradually stepping through this site-specific "architectural tone row" as they make their way into the more obscure regions of the room's overtone series. The audience hears an odd hybrid of Serial and Minimalist music. At the end of the night the notation is printed out and remains as a musical portrait of the concert space.

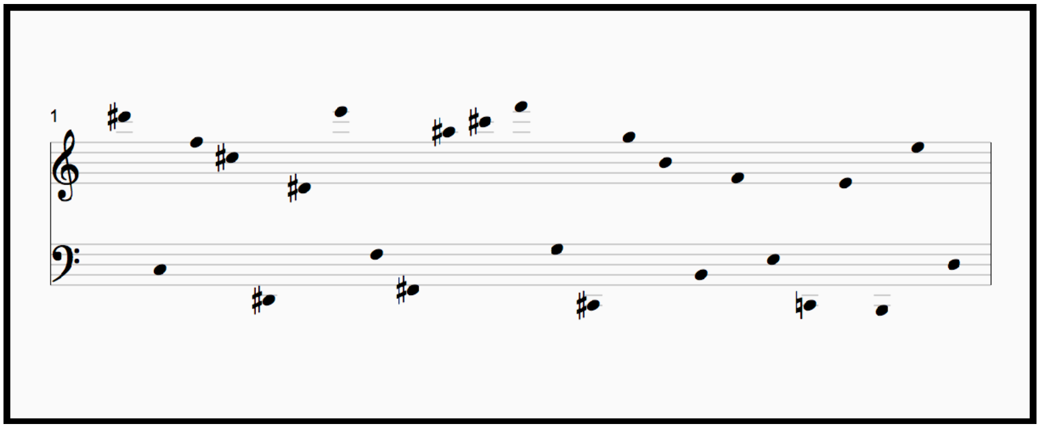

Figure 9: ***Roomtone Variations*** **(2013), initial analysis of room acoustics**

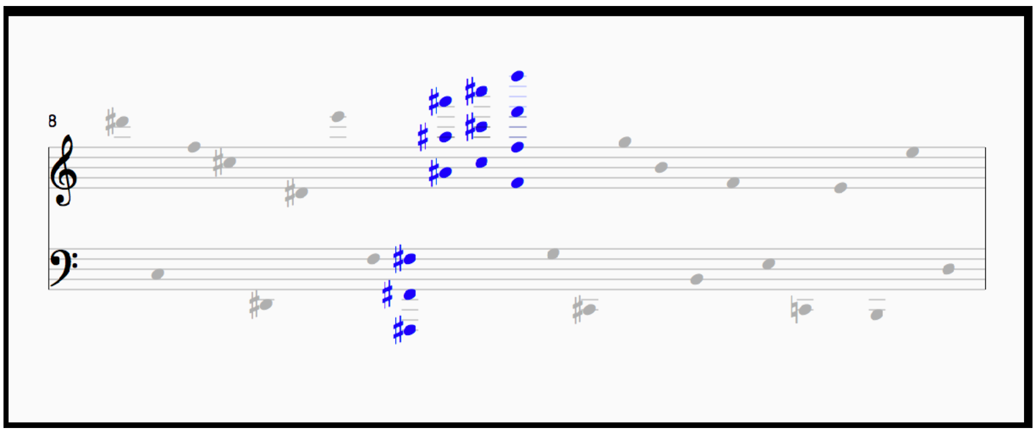

Figure 10: ***Roomtone Variations*** **(2013), score from performance, highlighting pitches to play**

Roomtone Variations begins with a brief electronic preamble, for which a modest sound system is required, and the score is generated by a computer, but the bulk of the composition is performed by unamplified instruments, which stresses the fundamentally "acoustic" character of feedback. The instrumentation is open, and larger groups (more than 15 musicians) generally produce more interesting versions. It is an efficient work to sound check and rehearse, and it well-suited for improvising musicians with only minimal sight-reading skills[24].

Conclusion

The tautological elegance of feedback has a primal charm. Before they could walk, both my children delighted in waving the microphone near the speaker of their My First Sony™, chortling along with the ensuing squeals (really, could I ever ask them to turn it down?). My first experiments with feedback didn't display much more sophistication. The kids have matured, moved on, and left their Sony behind. I, on the other hand, have retained this infantile obsession and nurtured it into a deeper love. My initial infatuation with the beauty of feedback's skin and its risqué behavior grew richer with my appreciation of its inner workings. The balance of responsiveness and independence, of implacable science and seductive invitation, is rife with musical implications. It's a natural phenomenon with social as well as acoustic overtones. And, beyond music, feedback offers us a rare opportunity to adopt the perceptual apparatus of beings who perceive the shape of their world through sound.

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[1] Although my parents were raised some 6000 miles apart (Chile and New England), each was informed as a child that no member of the family had ever been musical, and they should not bother asking for piano lessons, it would be a waste of money. My late-developing (teenage years) interest in composition came as rather a surprise to everyone.

[2] *Nodalings* (1973). See http://www.nicolascollins.com/texts/nodalingsscore.pdf

[3] *Feetback* (1975). See http://www.nicolascollins.com/texts/feetbackscore.pdf
For a more detailed account of my work with feedback see: Nicolas Collins. "All This And Brains Too". Resonance Magazine, Vol. 9 #2 (2002). Available here: http://www.nicolascollins.com/texts/allthisandbrains.pdf

[4] For a description of pre-computer algorithmic music systems see: Joel Chadabe. *Electric Sound – The Past and Promise of Electronic Music*. Prentice Hall, NJ. 1997. Pp. 286-291.

[5] Steve Reich. *Pendulum Music*. 1968.

[6] For a biography of Carl Countryman and an overview of his work as an engineer see https://en.wikipedia.org/wiki/Carl_Countryman (retrieved October 9, 2020).

[7] Some technical background: whereas a digital delay delays all frequencies of an audio signal by the same amount of time, a phase shifter delays the signal by a certain number of *degrees of phase* (typically from 0 to a maximum of 1080 degrees). The absolute delay time varies according to the frequency of the signal: 360° of phase shift on 440hz = 2.2ms, while the same phase shift delays a 1kHz signal by only 1ms. In this way a phase shifter smears the frequency spectrum in time in a somewhat counterintuitive fashion. Not only is the resulting delay very, very short (typically less than 10ms), but this smear changes the sound in ways that cannot be replicated by the digital delays that became commonplace in the following decade.

[8] A CD of his ionospheric recordings, minus my panning system, was later released by Lovely Music: Alvin Lucier. *Sferics*. Lovely Music LP 1988.

[9] Under Lucier's tutelage, in the heyday of American Minimalism, I spent most of my time cutting things out rather than building things up.

[10] My favorite feedback microphone is still the Electro-Voice 635a dynamic omnidirectional mike, of which we had several in the Wesleyan studio. A popular, modestly-priced reporter's interviewing microphone, it is still in production at the time of writing, more than 50 years after it was introduced.

[11] Three channels turned out to be the magic number: with just two channels (stereo) the patterns never got quite rich enough, but adding a fourth didn't make noticeable improvement. Luckily the studio had three Countrymen, but one developed odd intermittent noise after a year or so. At the suggestion of some sage we discovered that placing the phase shifter in a freezer overnight warded off the noise for 30 minutes or so, but three-channel performances continued to be risky endeavors, even if we only pulled the Countryman from the freezer moments before curtain time.

[12] In later years, especially when I was working at STEIM in Amsterdam in the 1990s, I encountered many instruments and installations that used ultrasound or infrared motion detectors to track and respond to movement, but I've never heard another music system in which the sounds themselves functioned as their own controlling element.

[13] Adam Putz Melbye touches upon this latter point in his paper "Second-order double feedback – A sonic reconsideration of Ashby's model of Double Feedback" (2020). See https://www.researchgate.net/publication/344596144_Second-order_double_feedback_-_A_sonic_reconsideration_of_Ashby's_model_of_Double_Feedback (accessed 10/11/2020)

[14] See http://www.nicolascollins.com/texts/peasoupscore76.pdf

[15] See Collins. "All This And Brains Too".

[16] My day job in the 1980s for a studio design company in New York City frequently brought me to trade shows for the audio industry. By then Carl Countryman had established a reputation for high-quality lavalier microphones and direct boxes. I'd stop by his booth and ask if he'd managed to find any remaining stock of, or spare parts for, his old phase shifters. The answer was always "no." When the Kammerensemble invited me to revive *Pea Soup* I made a last-ditch appeal to Countryman by email, and received the terse reply, "We don't have any more phasers or parts but if you email me your address and promise not to ask for tech support to help you build them, I will send you the circuit." I am one of the few people outside the company to receive any documentation of the design of this historic circuit.

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[17] One performance with my homemade circuit, from the Limbo Festival in Plasy monastery (Czech Republic) in 1999, was released on a label started by an ex-student of mine shortly after he graduated from SAIC: Nicolas Collins. *Pea Soup*. Apestaartje CD (2004).

[18] See: Nicolas Collins. "Some Notes On The History Of *Devil's Music*". Notes to *Devil's Music*. EM Records CD and LP, 2009. Also available at http://www.nicolascollins.com/texts/devilsmusichistory.pdf. The software is available through this page on my website: http://www.nicolascollins.com/software.htm

[19] A Hilbert Transform, to be specific. I am a lousy mathematician and a sloppy programmer, but in the early days of the analog *Pea Soup*, when I was collecting circuit diagrams in pursuit of building my own phase shifters, I had stumbled upon a short article in an electronic engineering magazine that showed a rather unusual implementation of a phase shifter using an analog realization of something called "a Hilbert Transform", a function normally associated with analog frequency shifter such as that made by Harold Bode (*Electronic Design*, March 15, 1969. Pp. 254-256). Some 25 years later the name "Hilbert" caught my eye in a list of Max objects available from IRCAM, the venerable French computer music research center. Once downloaded, that chunk of code became the core of the digital realization of *Pea Soup*.

[20] A more detailed description of the software can be found in the current performance score for *Pea Soup*: http://www.nicolascollins.com/texts/PeaSoup2020.pdf

[21] Or the "Feedback Exterminator", a digital filter produced by Sabine in the late-1990s to notch feedback automatically.

[22] The current version of the program can be downloaded here: http://www.nicolascollins.com/software/peasoupmac.zip

[23] *Pea Soup To Go* went live in October 2014 and can be heard here: http://www.nicolascollins.com/peasouptogo.htm. One can also step through the recordings chronologically here: http://www.nicolascollins.com/collectthemall.htm

[24] An early performance of *Roomtone Variations*, by Fred Frith's improvisation ensemble at Mills College (Oakland, CA), can be seen here (retrieved 10/10/2020): https://www.youtube.com/watch?v=JrqMmY8ikuA