"Musical Filters"
excerpt (pp. 182-195) from Artful Design, Chapter 4 "Programability and Sound Design"

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While violins and pianos are sublime vehicles of musical thought, people have often listened with musical ears to the sounds of wine glasses, crickets on a summer night, the wind in the trees, steps on the pavement, bird song, speech, conch shells, church bells, etc., and composers from Monteverdi to Messiaen have tinkered with world noise in their music.

Until recently, however, it has been difficult to capture sounds of the natural world and take them into our composition workshops. But now, with the convergence of recording and computer technologies, we have the ability to play these instruments of the world as never before.

The five pieces on this recording are attempts to view the mundane, everyday noises of daily life through a personal musical filter. There are no other-worldly sounds used here—just the comings and goings which greet our ears as we make it through the day. With the assistance and intervention of computer technology, these pieces modestly try to make the ordinary seem extraordinary, the unmusical, musical. They try to find implicit music in the worldnoise around us!

Paul Lansky's 1992 album Homebrew used the sounds of kitchenware, traffic, hands clapping, and a mall in Princeton, New Jersey. It reimagined them with the computer to create sounds that were at once familiar and fantastical. When I first heard this album years ago, I was mesmerized. It shattered my earlier notion that computerized sounds have to sound cold and mechanical. In Paul's music, I heard a world that was closer to the everyday, and a music that wouldn't be possible without a computer.

The piece had its origin one evening after dinner in October 1990, when my two sons, Jonah and Caleb (ages 14 and 9 at the time) took our kitchen apart, recording the sounds of everything they could find that would make noise (including themselves). I ran the tape machine and Hannah ran for cover. I then transferred all the sounds to my computer, spent a few months working, and came up with this piece.

The first piece on the album was called "Table's Clear." (The idea of a sound kitchen made literal.)

Musicians have always looked at the dinner table with greedy ears (pardon the metaphorical confusion), but it's hard not to treat bottles and glasses as if they were percussion instruments. "Table's Clear" is a digital exploration of this domain—here nothing is breakable, and we can play as fast and hard as we like.

Paul Lansky
Homebrew

"Table's Clear" begins and ends with fairly plausible sounds of kitchen paraphernalia being struck, while in the middle it weaves through various surreal, almost gamelan-like ensembles, creating dream-like states from which we finally awake, only to be reminded of our own awkward physical limitations.

Dad, did we do this one... Where's that pencil... Wait I know... Tap... Okay... Good job, Dad... That's a great sound... Zzzting... Want to try some other ones... Frrrring... If it wasn't hollow......That will be the best part... Bonk... Help mom clean up...
A mixture of pre-determined and dynamically generated musical material creates the expressive rhythms and grooves in "Table's Clear." Many sounds from the kitchen are pitched, pots, pans, lids, plates, glasses all have discernible resonant frequencies, due to their materials and shapes. They are generally not, however, musically tuned. The computer alters this, capable of stretching, tuning sounds, and turning them into building blocks of pitch, harmony, and rhythm.

It's a way to transform reality with computers, taking the familiar everyday and reshaping it through a personal musical filter.

Computers were orders of magnitude slower back in 1997, and programs appeared closer to machine code than human-readable description. But the basic principles were the same. No matter how advanced the technology, it takes human intentionality to use the computer as a tool and a laboratory for new ideas.
I first heard "Table’s Clear" in Scott Lindroth's electronic music course at Duke University (where I did my undergrad). As the everyday sounds of kitchen utensils magically rearranged themselves as if by the wave of a wizard’s wand, I was entranced. Up to that point and in my then limited expertise in computerized sound, I had only heard computer music that was interesting conceptually...

...and here was this piece of music -- visceral, organic, playful -- that I could simply like. Moreover, it was unmistakable that this music was only possible through some artful intervention of the computer.

Paul’s notion of a personal musical filter is a lens through which to hear the implicit music of everyday life, to re-engage with the ordinary sounds that we barely think about with new ears.

I realized if this way of making music is an aesthetic, then aesthetics cannot merely be a passive thing, but an active agent for expression, embracing both the wonders of technology and the human mind that works with it.

It invites us to listen to sounds that naturally exist around us and imagine how we might transform them into something extraordinary, to notice a type of poetry in everyday life.

These ideas inspire us. When the Stanford Laptop Orchestra traveled to Beijing for a residency, we experimented with found sounds. John Grangow and Kitty Shi worked with the sound and interaction of everyday objects like chopsticks, bowls, and fans...

As they explored the unlikely juxtapositions of familiar sounds, a gyroscope sensor (on a phone) tracked the rotation of the table, while the nearby laptop’s sampled and transformed the acoustically mapped sounds!

I thought... I wonder if this awesome fogg will short out the electronics of our laptop orchestra...

We recorded, isolated, transformed, and reassembled the sounds of the city, reconceptualizing the familiar through a metaphorical musical filter!
For example, this waveform below is of the sound of a subway train approaching and entering the station. It starts quietly and reaches its loudest point quickly when the train is still at high speed, steadily becoming quieter as the train slows.

Sonically, it has a lot of character and narrative: an approaching underground tornado, a continuous roaring carpet of sound!

There are many computer-mediated techniques to transform sounds. In “Elegia,” we used comb filters to imbue this subway sound with strongly pitched qualities.

In this way, a source sound can be filtered into a musical chord while retaining salient characteristics of the original sound.

The resulting waveform may not look different, but it now sounds unmistakably pitched and yet still like a subway train! Let’s take a different look at the sound...

To see the sound in a different way, we send short segments of it through a series of short-time Fourier transforms (which were used earlier to generate the spectrogram for “Tangle’s Clear and the Shepard Tone in Chapter 3”).

Warmer colors denote more of that frequency.

The Fourier transform does not change the sound, it simply allows us to see it as a deconstruction into its frequency components — kind of like reconstructing a musical chord into its constituent pitches, but does this more generally for any sound.

Jean Baptiste Joseph Fourier, French mathematician (1768–1830)

How does something like this work?

Fourier transform

Comb filtered result

Let’s now look at the frequency spectrum of the transformed sound...

Horizontal line patterns have emerged; these correspond to the frequencies of our pitches and their harmonics.

Wassup! Any periodic signal can be represented as a sum of sinusoids (e.g., sine waves), each oscillating at a particular frequency and phase.
AN INVERSE COMB FILTER REINFORCES SPECIFIC FREQUENCIES IN AN EXISTING SOUND THROUGH A RECURSIVE FEEDBACK LOOP. AN ELECTRICAL ENGINEER MIGHT REPRESENT IT AS THE BLOCK DIAGRAM!

THE FIRST PEAK HOLDS THE FUNDAMENTAL AND IS CLOSELY ASSOCIATED WITH THE PITCH WE HEAR FROM THE OVERALL SOUND.

THE PEAKS OF A COMB FILTER’S FREQUENCY RESPONSE ARE EQUALLY SPACED FREQUENCIES AT INTEGER MULTIPLES, OR HARMONICS, OF THE FIRST FULL PEAK.

THE SHAPES BELOW VISUALIZE WHAT THE COMB FILTER DOES TO DIFFERENT FREQUENCIES IN THE INPUT SOUND — IT REINFORCES FREQUENCIES CORRESPONDING TO THE SHARP TEETH (OR PEAKS), WHILE TAKING OUT FREQUENCIES IN THE “VALLEYS” BETWEEN THEM.

THE CHARACTERSH WAVE SHAPES GIVE THE COMB FILTER ITS NAME.

THE KIND OF FILTER REINFORCES SPECIFIC FREQUENCIES IN AN EXISTING SOUND BY REDUCING ALL OTHER FREQUENCIES IN THE SIGNAL. IT IS A FORM OF SUBTRACTIVE SYNTHESIS.

THE SHAPES BELOW VISUALIZE WHAT THE COMB FILTER DOES TO DIFFERENT FREQUENCIES IN THE INPUT SOUND — IT REINFORCES FREQUENCIES CORRESPONDING TO THE SHARP TEETH (OR PEAKS), WHILE TAKING OUT FREQUENCIES IN THE “VALLEYS” BETWEEN THEM.

HOW TO MUSICALLY CONTROL A COMB FILTER

THE FREQUENCY OF THE FIRST PEAK (AND PITCH WE PERCEIVE) IS ENTIRELY DETERMINED BY THE AMOUNT OF DELAY. SHORTER DELAYS RESULT IN HIGHER FUNDAMENTAL FREQUENCIES (ANALOGOUS TO HOW SHORTER VIBRATING STRINGS PRODUCE HIGHER PITCHES). THE FORMULA BELOW GIVES US A WAY TO TUNE A COMB FILTER TO ISSUE A SPECIFIC PITCH:

\[ \text{Pitch} = \frac{\text{Delay} \times \text{Sample Rate}}{\text{Sample Rate}} \]

AT A TYPICAL AUDIO SAMPLE RATE OF 44.1khz (I.E., SAMPLES PER SECOND, OR HOW MANY VALUES ARE USED TO REPRESENT A SECOND OF AUDIO), THE FOLLOWING MUSICAL CHORD CAN BE CONSTRUCTED USING FOUR COMB FILTERS, WHOSE DELAYS ARE TUNED TO THE FOLLOWING FREQUENCIES:

- 300.3 samples => |COMB FILTER|
- 225.0 samples => |COMB FILTER|
- 200.5 samples => |COMB FILTER|
- 119.2 samples => |COMB FILTER|


EVEN IF WE HAD A CREATIVE DIGITAL ECHOES! BY SETTING THE DELAY AMOUNT (L), WE CAN TUNE THE RATE AT WHICH ECHOES ARE HAPPENING TO THE FREQUENCY THAT WE WANT TO REINFORCE. WE CAN PROGRAM THE ECHOES TO RECUR SO QUICKLY (E.G., HUNDREDS OF TIMES PER SECOND) THAT WE STOP PERCEIVING THEM AS INDIVIDUAL COPIES, BUT INSTEAD AS A PITCH.
Putting a sound through a filter is like pouring a mixture into a sieve; some things fall through, other things remain. With sound, what remains is what you hear. For example...

There are several variants of a comb filter. The one used in "Beings" is a Karplus-Strong plucked string filter, which has an extra lowpass filter in the feedback loop that attenuates high frequencies over time. This gives it a warmer, less abrasive sound — it also is closer to how sound propagates through air, with higher frequencies dissipating first. Another detail: an all-pass delay can be used to produce fractional (non-integer) sample delay for more precise pitch tuning.

If we preload the delay with a white noise burst and let it recirculate in the filter's feedback loop, we can see the lowpass filter's effect on the resulting signal over time...

And this is how the pitches are imprinted on the subway sounds of "Beings"! As you can see, there is quite a bit of engineering precision involved in this kind of thing, but just as importantly, it's about what we can do with it -- these techniques allow us to transform sound with a computer in ways that would not be possible without!

If our THX sound is synthesis through the addition of 30 voices, then filtering is a type of subtractive synthesis, in which we sculpt a sound by selectively filtering out parts of the original.
**Principle 4.6**

**Use the Computer as Agent of Transformation**

The comb filter is just one of many programmable techniques to transform reality with the computer, to experience the world through a different lens!

It is essential to figure out what to transform. For example, it is unwieldy to transform entire field recordings; instead, we might first isolate individual sounds (e.g., a tap of a frying pan), then transform them (e.g., pitch shift or filter the sound), re-arrange them in time (like Paul Lansky’s kitchenware in a highly rhythmic arrangement), and manipulate each component independently.

**Sound Collection**
- Listen to the world around us
- Found sounds
- Isolation

**Transformation**
- Time modifications can shorten or lengthen a sound to desired musical duration; can also massively stretch sounds to achieve a special effect — e.g., stretching a yell to be 20 times its original length
- Trim individual sounds from recordings
- Identify starting point of each sound (when a sound begins in our perception; especially useful for sounds we intend to use percussively)
- Prepare the sound for reuse: normalize the volume, equalize its frequency content (so it pops the right way), fade in/out the beginning and end (so it won’t sound abrupt when spliced into the mix), etc.

**Assembly**
- Artfully assemble transformed sounds in time (e.g., rhythmic patterns) and layers (how we hear them together)
- The high-level structural plan and overall form of the sonic / musical design

**Structure**
- Sonic gestures
- Musical phrases

**Sequencing and juxtaposition**
- Sound at various timescales: create sonic gestures from compositing individual sounds, or crafting uncanny repetition

**Additive Synthesis**
- Since any periodic sound can be described as a sum of sinusoids (thanks, Fourier), we can, in theory, synthesize any sound by adding specific sine waves together

**Subtractive Synthesis**
- Sculpt sounds through the application of filters (e.g., comb filter)

**Frequency Modulation Synthesis**
- Technique pioneered by John Chowning, whereby oscillators modulate noise oscillators to produce rich timbres efficiently, responsible for “that 80s synth sound” in pop music

**Physical Modeling**
- Use digital signal processing (DSP) to model the physics of how sound moves in various acoustic mediums (e.g., vibrating strings, air columns, etc.)

**Granular Synthesis**
- Break a sound down into short “molecules” and reconstitute them back, like an impressionistic painting of sound particles

**Spatialization**
- Model sound in space: room acoustics, 3D sound, and how our body (head, shoulders, earlobes) affect how we hear. (Direct applications include multi-channel composition, games, virtual reality?)

**Basic Synthesis**
- Generate sounds from basic synthesis elements: oscillators, amplitude envelopes, noise, filters, etc.

**Vocoders**
- A family of techniques to manipulate sound through its frequency bands; these can be used to cross-synthesize signals (e.g., lion’s roar, electric guitar) or phase vocoders operate on signals in the frequency domain for high-quality time and pitch transformations

**Spectral Modeling Synthesis**
- Empirical approach to modeling sound by example: it extracts information from the sound itself (and not the physical mechanics of how it’s generated in contrast to physical modeling)

**Singing / Voice Synthesis**
- The human voice, in its limitless nuance, is special to us. Many techniques have been developed to expressively synthesize speech, singing voice, and even laughter. FM, filter banks, linear predictive coding, articulatory tract modeling, formant wave functions — to name a few