"Musical Filters"

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

https://artful.design/
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 WORLDNOISE 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 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 ROMAN -- HERE NOTHING IS BREAKABLE, AND WE CAN PLAY AS FAST AND HARD AS WE LIKE.

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.

DAD DID WE DO THIS ONE... WHERE’S THAT PENCIL WAIT I KNOW TAP OKAY!

GOOD JOB, DAD THAT’S A GREAT SOUND...

WANT TO TRY SOME OTHER ONES... FRERRING...THAT WILL BE THE BEST PART

IF IT WASN’T HOLLOW... Bonk

HELP MOM CLEAN UP

“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 AKWARD PHYSICAL LIMITATIONS.
INPUT("BACK"
OUTPUT(1)
C"PITCHED & PERCUSSIVE"
RINGING SOUNDS AND UNPITCHED PERCUSSIVE ELEMENTS MAKE FOR A PENULTIMATE EXPLORATION OF THE SOURCE MATERIAL. IT'S OUR RETURN TRIP BACK TO EVERYDAY REALITY...

A NEW DIRECTION FOR THE INTEGRATION OF MUSIC AND ART.

THE MAGIC OF THIS PIECE IS THAT THE EVERYDAY KITCHEN QUASITLIES ALIVE AND ASSEMBLES ITSELF INTO COHESIVE MUSIC Pitches AND SHIFTING RHETORICAL PATTERNS. THIS SECTION TRANSFORMS AND DEFAMILiARIZES THE ORDINARY INTO THE EXTRAORDINARY.

"THE ORDINARY"
STARTS OUT ORDINARY, JUST sounds THAT KITCHENWARE BEINGS STRIKES HARMONIously, CHAOTICALLY...

"PERCUSSIVE THROWDOWN"
SOUNDS ARE REVISITED IN AN UNPITCHED PERCUSSION HOUSING YET ANOTHER RECONCEPTUALIZATION OF THE MATERIAL!

"SELF-ORGANIZATION"
THE MAGIC OF THIS PIECE IS THAT THE EVERYDAY KITCHEN QUASITLIES ALIVE AND ASSEMBLES ITSELF INTO COHESIVE MUSIC Pitches AND SHIFTING RHETORICAL PATTERNS. THIS SECTION TRANSFORMS AND DEFAMILiARIZES THE ORDINARY INTO THE EXTRAORDINARY.

"ASCENSION"
ETHEREAL ASCENDING VOICES PROVIDE A SENSATION OF WEIGHTLESSNESS CONTRASTED WITH MORE URGENT ENERGY OF RAPIDLY STRUCK SOUNDS OF PRIOR SECTIONS. THE FANTASTICAL TRANSFORMATION REACHES A CLIMAX.

"BACK TO START"
ENTS WHERE WE STARTED AS IF WAKING FROM A DREAM...

THIS SPECTROGRAM BELOW VISUALIZES THE FREQUENCY CONTENT THROUGHOUT THE 15 MINUTES OF "TABLE IS CLEAR," AND REVEALS ITS STRUCUTURAL FORM. TIME PROCEEDS FROM LEFT TO RIGHT. LOWER FREQUENCIES APPEAR AT THE BOTTOM, COLOR-CODED FOR INTENSITY.

LAYER BY LAYER AND WITH INCREASING COMPLEXITY, AN IMPROBABLY RHYTHM BEGINS TO EMERGE... AS IF THE SOUNDS CANNOT HELP BUT MUSICALLY FALL INTO RHYTHM WITH ONE ANOTHER.

VERTICAL LINES VISUALIZE BROAD-SPECTRUM SIGNALS LIKE THE SOUND OF A POT BEING STRICKED.

THE FIRST HARMONIC SHIFT / CHORD CHANGE IS A PROMINENT MOMENT, UP TO NOW EVERYTHING HAS BEEN IN RHYTHMIC DEVELOPMENT. THE INTRODUCTION OF NEW HARMONIC LANGUAGES ADDS ANOTHER DIMENSION.

WE CAN SEE THE ASCENDING VOICES IN THE UPWARD SLOPING REP LINES.

A MUSICAL SCORE, INDIVIDUAL SOUNDS CAN BE PRECISELY SEQUENCED THROUGH ALGORITHMS THAT TELL THE COMPUTER WHAT TO PLAY WHEN, AND HOW. THIS ALGORITHMIC PROCESS CAN EXPRESS A MIXTURE OF DELIBERATE ORDER AND CONTROLLED CHANCE. FOR EXAMPLE, USES A LOT OF RANDOM-WITHOUT-REPLACEMENT ALGORITHMS, WHICH DISALLOW DUPLICATES WHILE RANDOMLY CHOOSING FROM A SET OF POSSIBLE SOUNDS.

A MIXTURE OF PREDETERMINED AND DYNAMICALLY GENERATED MUSICAL MATERIAL, CREATES THE EXPRESIVE RHETORIC AND SOUNDS IN "TABLE IS CLEAR."

A PROGRAMMABLE LANGUAGE HE CREATED.

TRANSLATION INTO USABLE MUSICAL ATOMS!

MANY SOUNDS FROM THE KITCHEN ARE PITCHED. POTS, PANS, LIDS, PLATES, GLASSES ALL HAVE DISCERNABLE 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 TURNS THEM INTO BUILDING BLOCKS OF PITCH, HARMONY, AND RHYTHM.

IT'S A WAY TO TRANSFORM REALITY WITH COMPUTERS, TAKING THE FAMILIAR EVERYDAY AND REDEFINING IT THROUGH A PERSONAL MUSICAL FILTER.

COMPUTERS WERE ORDERS OF MAGNITUDE SLOWER BACK IN 1992, AND PROGRAMES 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 INTELLIGENCE TO USE THE COMPUTER AS A TOOL AND A LABORATORY FOR NEW IDEAS.

YOU CAN HEAR THE REFLECTION OF THIS TRANSFER IN THE TRANSITION FROM DIRECT TO MUSICAL TO A SUSTAINED AND SUSTAINED SCALES.
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 arranged themselves as if by the wave of a wizard’s wand, I was entranced. Up to that point and in my then limited exposure to 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 sound sounds. John, Gracious, and Kitty Shi worked with the sound and interaction of everyday objects like chopsticks, bowls, and fans...

As they explored the unlikely juxtaposition 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 made sounds!

JAM... I wonder if this awesome fog will short out the electronics of our laptop orchestra...

In a work simply called “Beijing,” Madeline Huberts and I transformed the sounds of streets, people, bowers, and subway trains inspired by Paul’s Homebrew ethos and a synthesis technique that Paul used musically.

We recorded isolated transformer and reassembled the sounds of the city, recontextualizing the familiar through a metaphorical musical filter.

In the city, we fight in the subway, people, traffic, bicycles, tricycles, and street food vendors. The design weaved the transformed sounds into a sonic tapestry that was both the city and a more abstract version of it in our mind’s ear...

蛋夹馍是四块！
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 "BEGINNINGS," WE USED COMB FILTERS TO IMBED 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 "SABLE'S CLEAR" AND THE SHEPARD TONE IN CHAPTER 3).

WARMER COLORS DENOTE MORE OF THAT FREQUENCY

HIGHER FREQUENCIES ARE SHOWN IN THE TOP

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 DECONSTRUCTING A MUSICAL CHORD INTO ITS CONSTITUENT PITCHES, BUT DOES THIS MORE GENERALLY FOR ANY SOUND.

THE FOURIER TRANSFORM REVEALS...
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 BLUEPRINT OF A COMB FILTER!**

- Input
- \( Z^L \) Digital Delay
- Output
- Feedback

**WE CAN PROGRAM A COMB FILTER WITH A FEW LINES OF CHUCK COPE!**

```cpp
// feedforward: input to output
adc => Gain node (G) => dac;
// feedback: from output back to input
node => Delay delay => Gain attenuation => node;
// set amount of delay
500::samp => delay.delay;
// set attenuation
0.8 => attenuation.gain;
```

This is the internal schematic of a sound filter. Sound goes in, gets changed somehow, and processed sound comes out — kind of like an effect pedal for an electric guitar.

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.

\[
\text{Delay} = \frac{\text{Sample Rate}}{\text{Frequency of Desired Pitch}}
\]

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** comb filter
- **225.0** comb filter
- **200.5** comb filter
- **119.2** comb filter

The closer the feedback attenuation is to 1, the sharper the peaks in the response (and more pronounced the audible effect). The closer the attenuation is to 0, the more the filter leaves the signal unchanged.

Essentially, we have created 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...

SPECTRUM OVER TIME OF WHITE NOISE THROUGH A COMB FILTER. NOTE THAT WHAT REMAINS ARE EQUALLY SPACED FREQUENCIES THAT LINE UP WITH THE PEAKS OF THE COMB FILTER

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.

THERE ARE SEVERAL VARIANTS OF A COMB FILTER. THE ONE USED IN "BEINGS" IS A KARPLUS-STRAW 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 ABRASSIVE SOUND -- IT ALSO IS CLOSER TO HOW SOUND PROPAGATES THROUGH AIR, WITH HIGHER FREQUENCIES DISSIPATING FIRST. ANOTHER DETAIL: AN ALLPASS 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!
**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!

Time modifications can shorten or lengthen a sound to desired musical duration. It can also massivly stretch sounds to achieve a special effect — e.g., stretching a yell to be 20 times its original length.

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), rearrange them in time (like Paul Lansky’s kitchenware in a highly rhythmical arrangement), and manipulate each component independently.

**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.

**SUBTRACTION SYNTHESIS**

Sculpt sounds through the application of filters (e.g., comb filter).

**FREQUENCY MODULATION SYNTHESIS**

Technique pioneered by John Chowning, whereby oscillators modulate one another to produce rich timbres efficiently. Responsible for “that 80s synth sound” in pop music.

**PHYSICAL MODELING SYNTHESIS**

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

**BASIC SYNTHESIS**

Generate sounds from basic synthesis elements: oscillators, amplitude envelopes, noise, filters, 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, shoulder, earlobes) affect how we hear. (Direct applications include multi-channel composition, games, virtual reality?)

**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). Phase vocoders operate on signals in the frequency domain for high-quality time and pitch transformations.

**SINGING / VOICE SYNTHESIS**

The human voice, in its infinite expressive 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.

**SPECTRAL MODELING SYNTHESIS**

Empirical approach to modeling sound by example: it extracts information from the sound itself (and not the physical mechanisms of how it’s generated) in contrast to physical modeling.