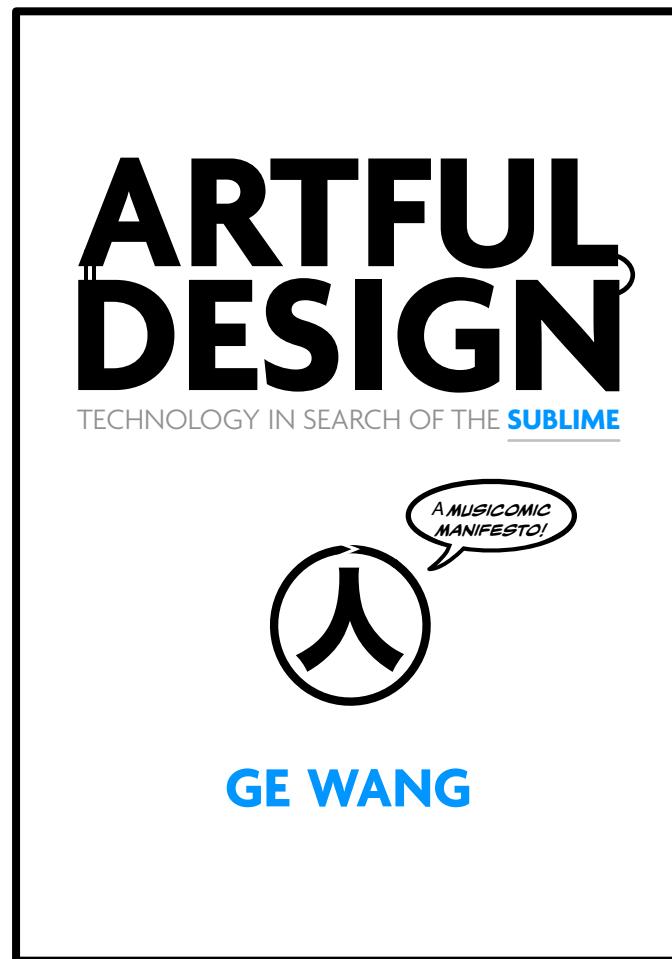


## "Musical Filters"

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.

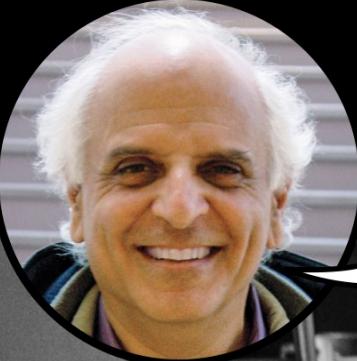
UNTIL RECENTLY, HOWEVER, IT HAS BEEN DIFFICULT TO CAPTURE SOUNDS OF THE NATURAL WORLD AND TAKE THEM INTO OUR COMPOSITION WORKSHOPS. BUT **NOW**, WITH THE CONVERGENCE OF RECORDING AND COMPUTER TECHNOLOGIES, WE HAVE THE ABILITY TO PLAY THESE *INSTRUMENTS* OF THE WORLD AS NEVER BEFORE.

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 *Homebrew*

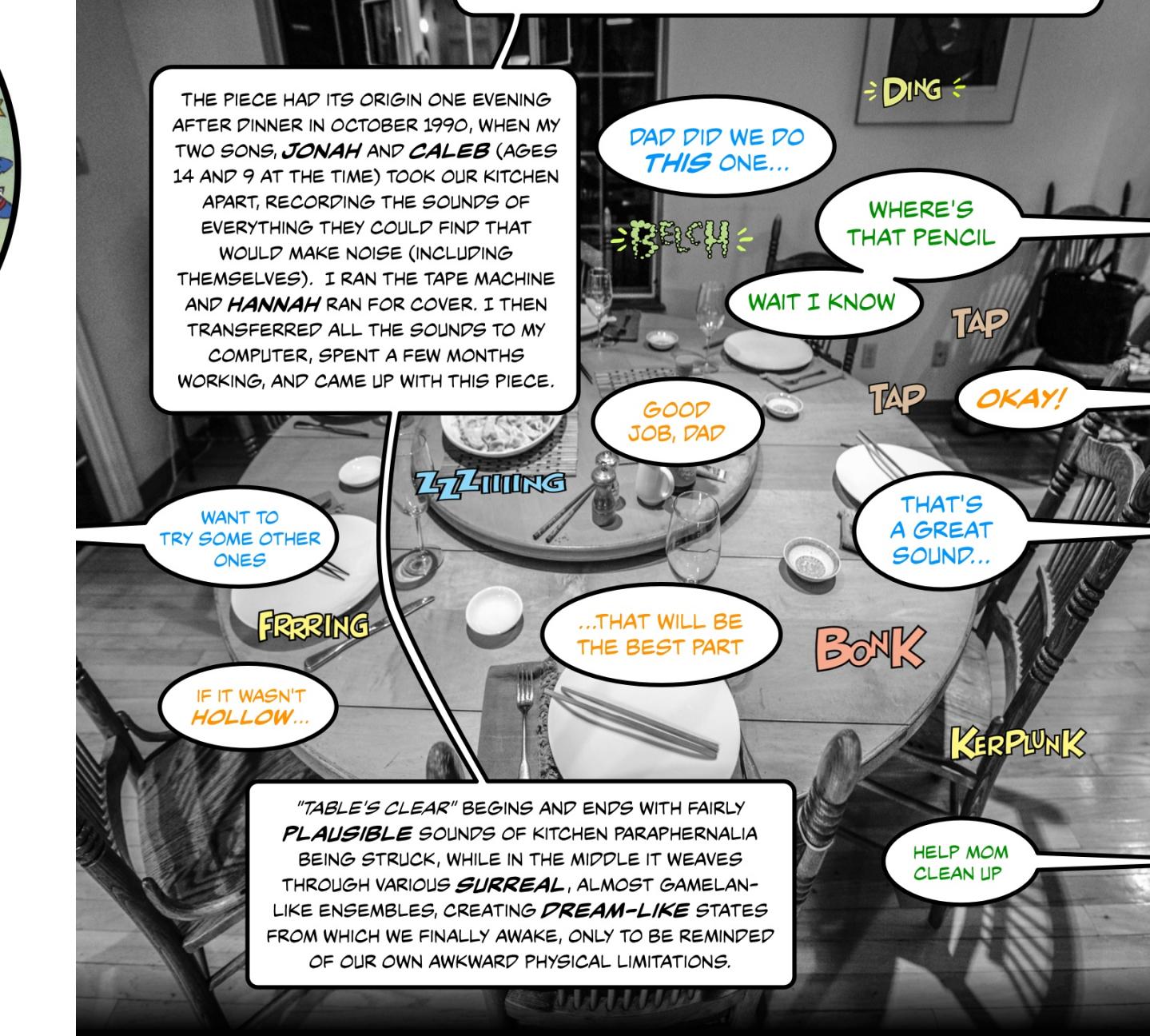
PAUL LANSKY'S 1992 ALBUM *HOMEBREW* USED THE SOUNDS OF KITCHENWARE, TRAFFIC, HANDS CLAPPING, AND A *MALL* IN PRINCETON, NEW JERSEY. IT REIMAGINED THEM WITH THE COMPUTER TO CREATE SOUNDS THAT WERE AT ONCE *FAMILIAR* AND *FANTASTICAL*. WHEN I FIRST HEARD THIS ALBUM YEARS AGO, I WAS *MESMERIZED*. IT SHATTERED 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 DOMAIN -- 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.



```

/* 22c soft pop*/770956,
/* 23c softpop 2*/778982,
/* 24c soft pop 3*/788816,
/* 25c soft pop 4*/702270
PAUL'S ORIGINAL CODE WAS WRITTEN IN CMIX,
A PROGRAMMING LANGUAGE HE CREATED.
/* 26c water gurgle*/809146,
/* 27c
INDIVIDUAL SOUNDS ARE
ISOLATED FROM THE RECORDING,
EDITED, AND TRANSFORMED
INTO USABLE MUSICAL ATOMS!
/* 28c
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.
/* 29c
it's a great sound */
/* 30c
will be the best part */
/* 31c
clean up */
IT'S A WAY TO TRANSFORM
REALITY WITH COMPUTERS,
TAKING THE FAMILIAR EVERYDAY
AND RESHAPING IT THROUGH
A PERSONAL MUSICAL FILTER!
/* 32c
COMPUTERS WERE ORDERS OF
MAGNITUDE SLOWER BACK IN
1992, 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.
z=3
/* 33c
softpop*
/* 34c
soft fry1
/* 35c
harder fry
clap1 */
/* 36c
clap2 */
/* 37c
end */
A MIXTURE OF PREDETERMINED AND
DYNAMICALLY GENERATED
MUSICAL MATERIAL CREATES THE
EXPRESSIVE RHYTHMS AND
GROOVES IN "TABLE'S CLEAR."
oldpch = clearglass=29
inskip = get_array(0,clearglass)/SR
endnote = get_array(0,clearglass+1)/SR
newpitches = load_array(1,7.10,8.07)
time=0
olddur = endnote-inskip
for(i=0; i<newpitches; i=i+1) {
    newpch = get_array(1,i)
    transposition = (octpch(newpch)
    octpch(oldpch)) * 12
    chaotic(newpch,oldpch+transpositi
    float SR SR=44100
phrases = load_array(0,
/* 0 big belch 1 */
/* 1 big belch 2 */
okay */
/* 2 where that pencil */
/* 3 wait I know */
/* 4 put all these things down */
/* 5 if it wasnt hollow */
/* 6 want to try some other ones */
/* 7 dad.wait dad */
/* 8
0, 670:
111572, 132:
210:
278:
406:
630:
681:
712:
759:
810:
761:
027:
972:
lls *
4151,
122:
134:
995*SF
2,0 ,1
2373.3
1239.2
998,32767/2310.7998
98,32767/627564.25,
,-1.215011,32767/6
,-1.916995,32767/6
01,-1.228997,32767
01,-1.193988,32767
89,-2.55,32767/677
88,-3.801974,32767
0,-1.967999,32767/4
988,-1.463991,32767
989,-2.196,32767/33
99,-1.429999,32767/4
2767/1
2767/1
2767/1
32767/
2767/8
32767/
767/31
32767/
767/48
32767/
32767/

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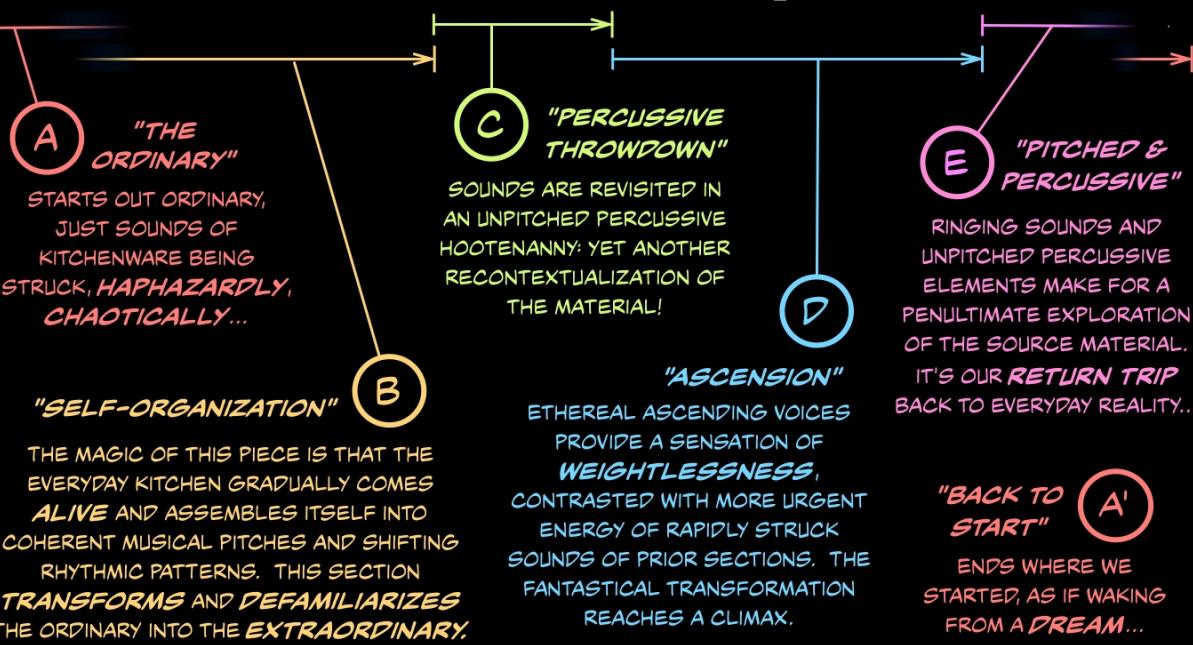
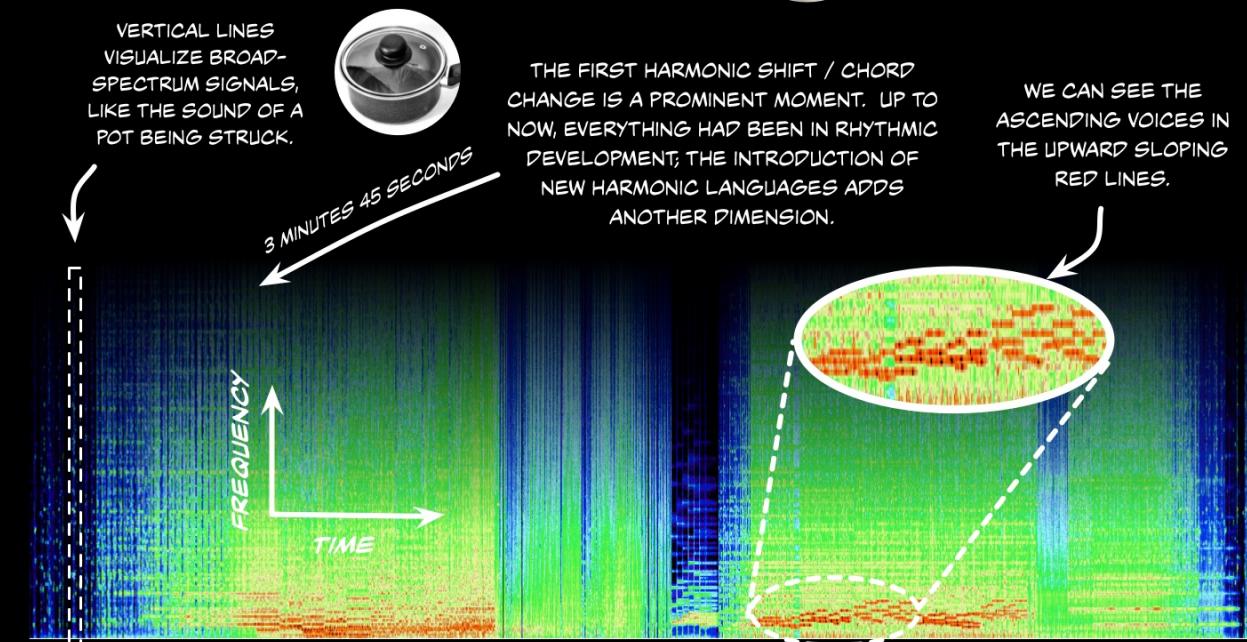
THIS SPECTROGRAM BELOW VISUALIZES THE FREQUENCY CONTENT THROUGHOUT THE 18 MINUTES OF "TABLE'S CLEAR," AND REVEALS ITS STRUCTURAL FORM. TIME PROCEEDS FROM LEFT TO RIGHT. LOWER FREQUENCIES APPEAR TOWARD THE BOTTOM, COLOR-CODED FOR INTENSITY.



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



IMPROBABLE GIVES WAY TO FANTASTICAL, AS THE SOUNDS OF THE KITCHEN COME TOGETHER IN A FULL-ON SYMPHONIC DANCE.



**A'**

ENDS WHERE WE STARTED, AS IF WAKING FROM A DREAM...

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 MAGICKALLY 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 **FOUND SOUNDS**. **JOHN GRANZOW** AND **KITTY SHI** WORKED WITH THE SOUND AND INTERACTION OF EVERYDAY OBJECTS LIKE CHOPSTICKS, BOWLS, AND FANS...

JOHN  
UMM... I WONDER IF THIS AWESOME FOG WILL SHORT OUT THE ELECTRONICS OF OUR LAPTOP ORCHESTRA...

ROMAIN

KITTY

ROTARY FAN

CERAMIC JARS

METAL BOWLS

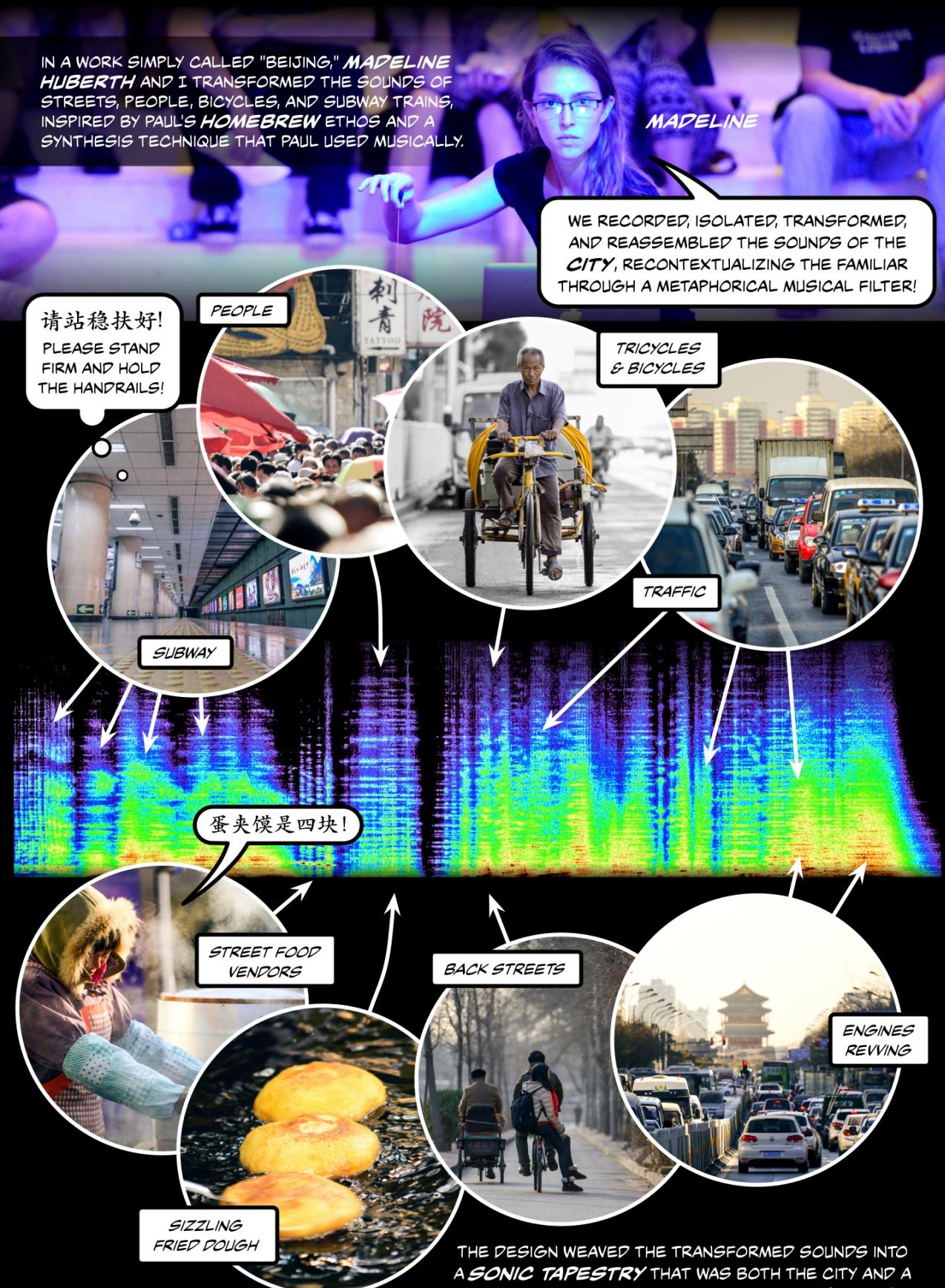
CHOPSTICKS ERHU BOW

LAZY SUSAN (ROTATING SERVING TABLE)

IN A WORK SIMPLY CALLED "BEIJING," **MADELINE HUBERTH** AND I TRANSFORMED THE SOUNDS OF STREETS, PEOPLE, BICYCLES, AND SUBWAY TRAINS, INSPIRED BY PAUL'S **HOMEBREW** ETHOS AND A SYNTHESIS TECHNIQUE THAT PAUL USED MUSICALLY.

MADELINE

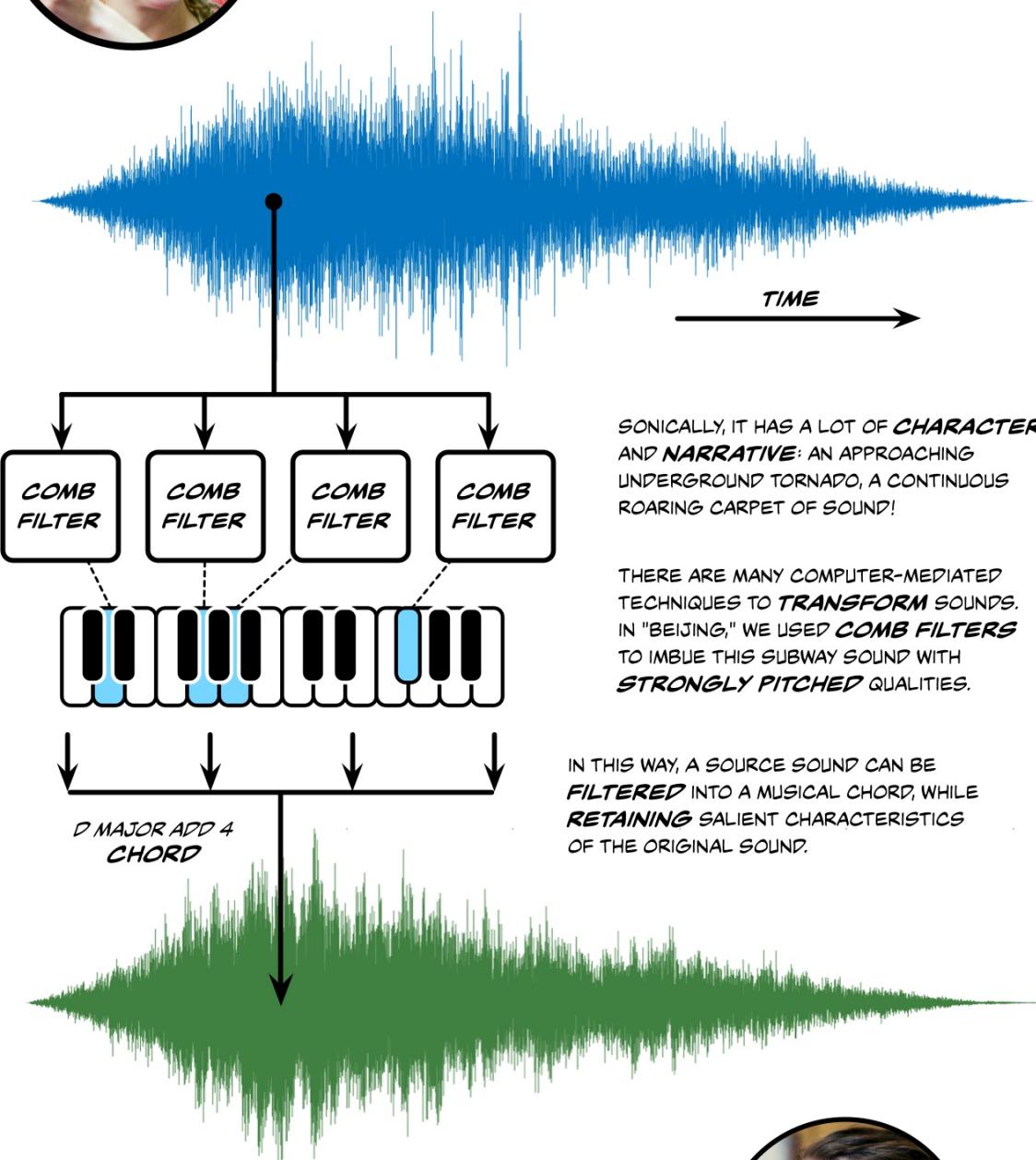
WE RECORDED, ISOLATED, TRANSFORMED, AND REASSEMBLED THE SOUNDS OF THE CITY, RECONTEXTUALIZING THE FAMILIAR THROUGH A METAPHORICAL MUSICAL FILTER!



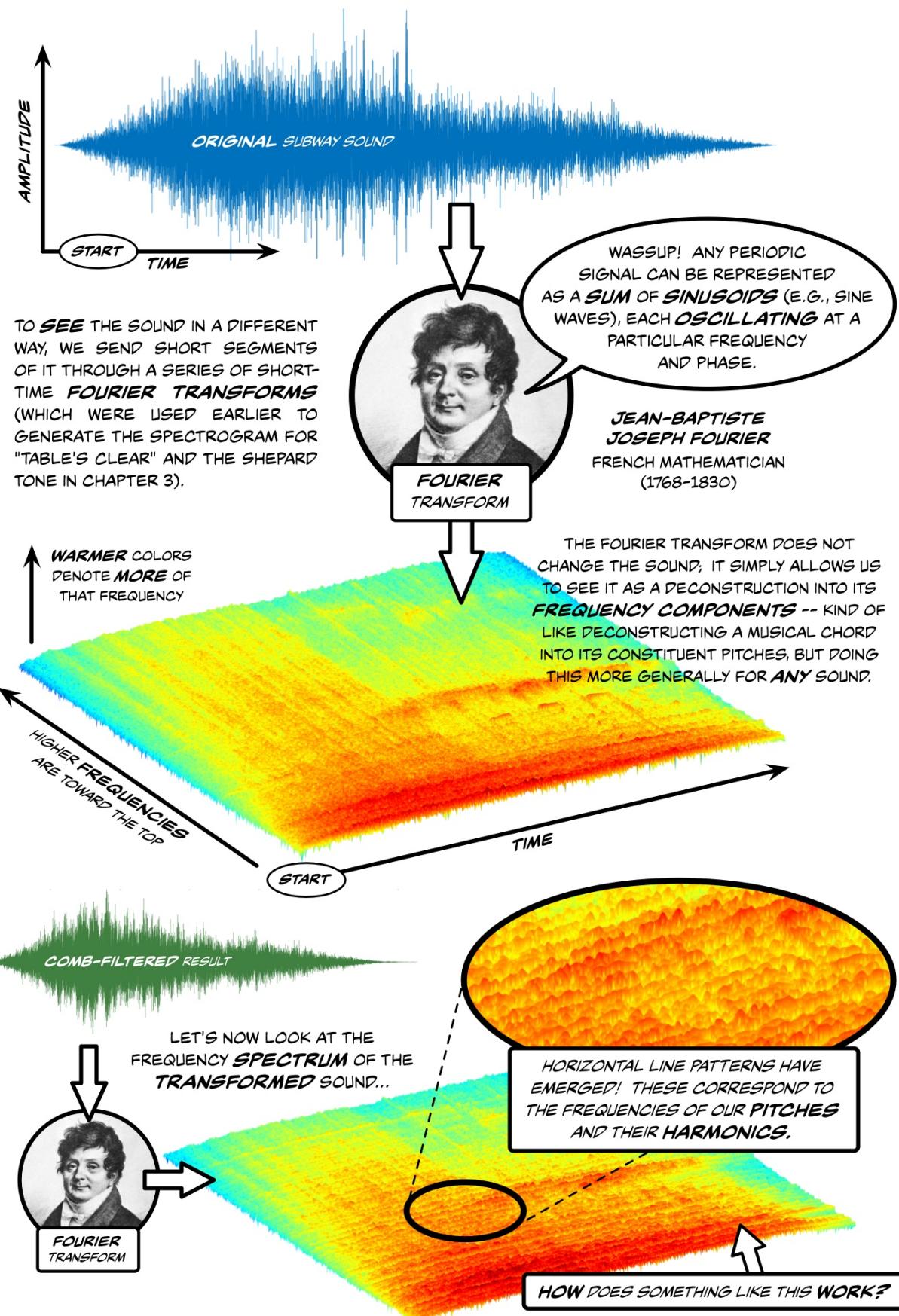
THE DESIGN WEAVED THE TRANSFORMED SOUNDS INTO A SONIC TAPESTRY THAT WAS BOTH THE CITY AND A MORE ABSTRACT VERSION OF IT IN OUR MIND'S EAR...



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.



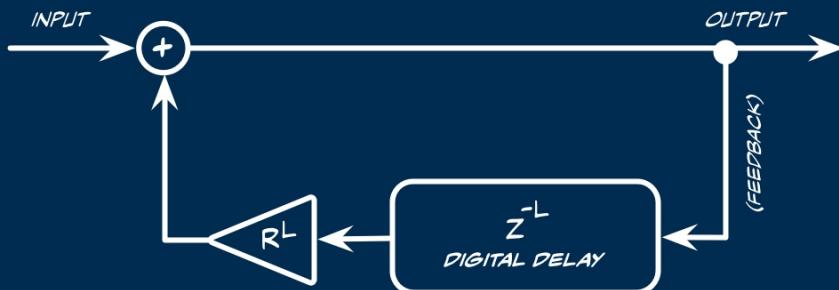
THE RESULTING WAVEFORM MAY NOT **LOOK** DIFFERENT, BUT IT NOW SOUNDS UNMISTAKABLY **PITCHED** AND YET **STILL** LIKE A SUBWAY TRAIN! LET'S TAKE A DIFFERENT LOOK AT THE SOUND...



AN INVERSE COMB FILTER REINFORCES SPECIFIC FREQUENCIES IN AN EXISTING SOUND THROUGH A RECURSIVE FEEDBACK LOOP. AN ELECTRICAL ENGINEER MIGHT REPRESENT IT AS THIS BLOCK DIAGRAM:



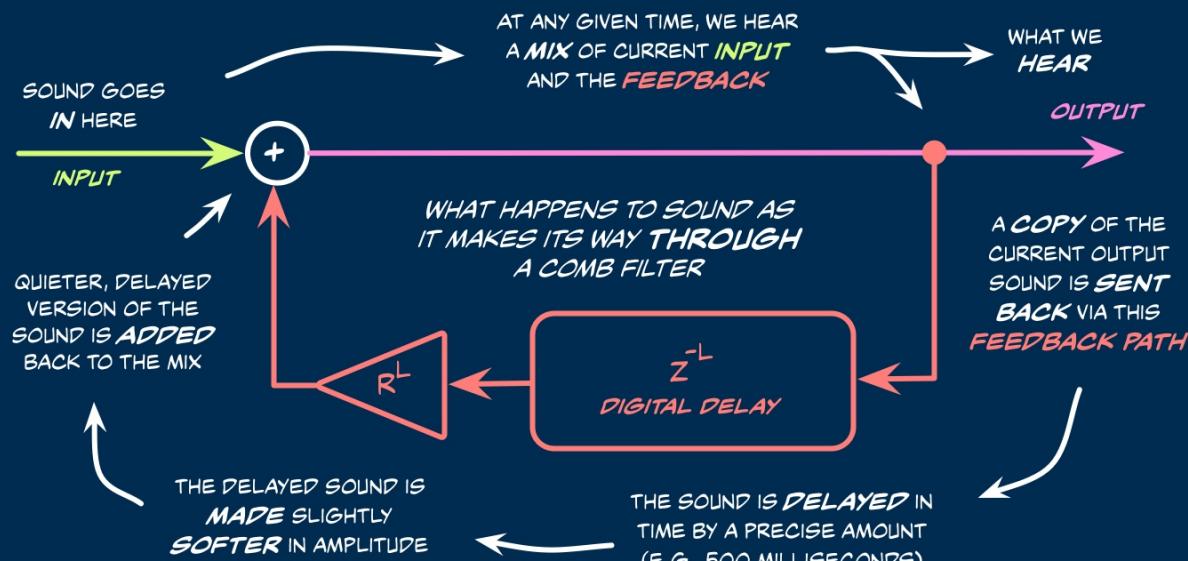
### THE BLUEPRINT OF A COMB FILTER!



```
// feedforward: input to output
adc => Gain node => 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;
```

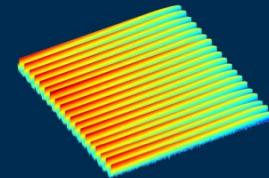
THIS IS THE INTERNAL SCHEMATIC OF A SOUND FILTER! SOUND GOES IN, IT GETS CHANGED SOMEHOW, AND PROCESSED SOUND COMES OUT -- KINDA LIKE AN EFFECT PEDAL FOR AN ELECTRIC GUITAR...



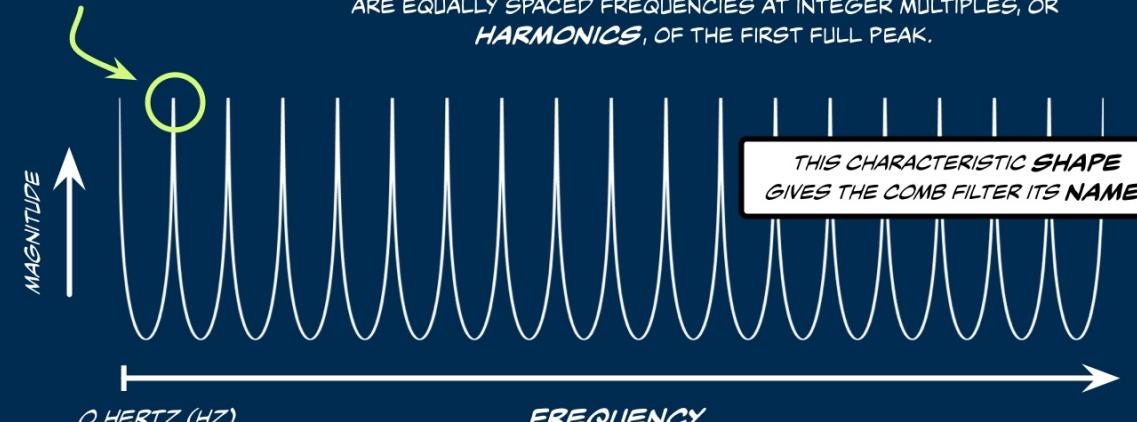
ESSENTIALLY, WE HAVE CREATED DIGITAL ECHOES! BY SETTING THE DELAY AMOUNT ( $L$ ), WE CAN TUNE THE RATE AT WHICH ECHOES ARE HAPPENING TO THE FREQUENCY THAT WE WANT TO REINFORCE. WE CAN PROGRAM THE ECHOES TO RECUR SO QUICKLY (E.G., HUNDREDS OF TIMES PER SECOND) THAT WE STOP PERCEIVING THEM AS INDIVIDUAL COPIES, BUT INSTEAD AS A PITCH.



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

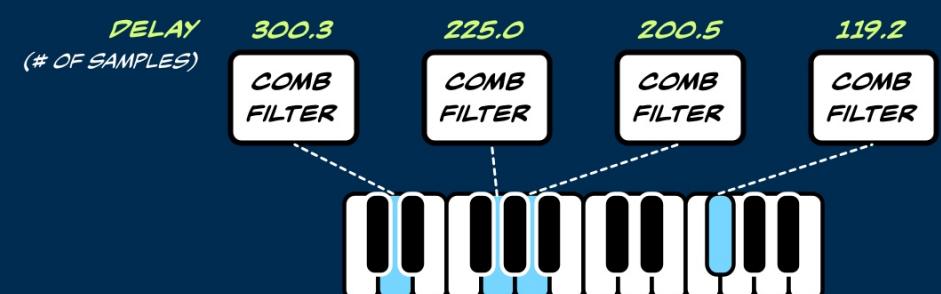


### HOW TO MUSICALLY CONTROL A COMB FILTER

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 IMBUE A SPECIFIC PITCH:

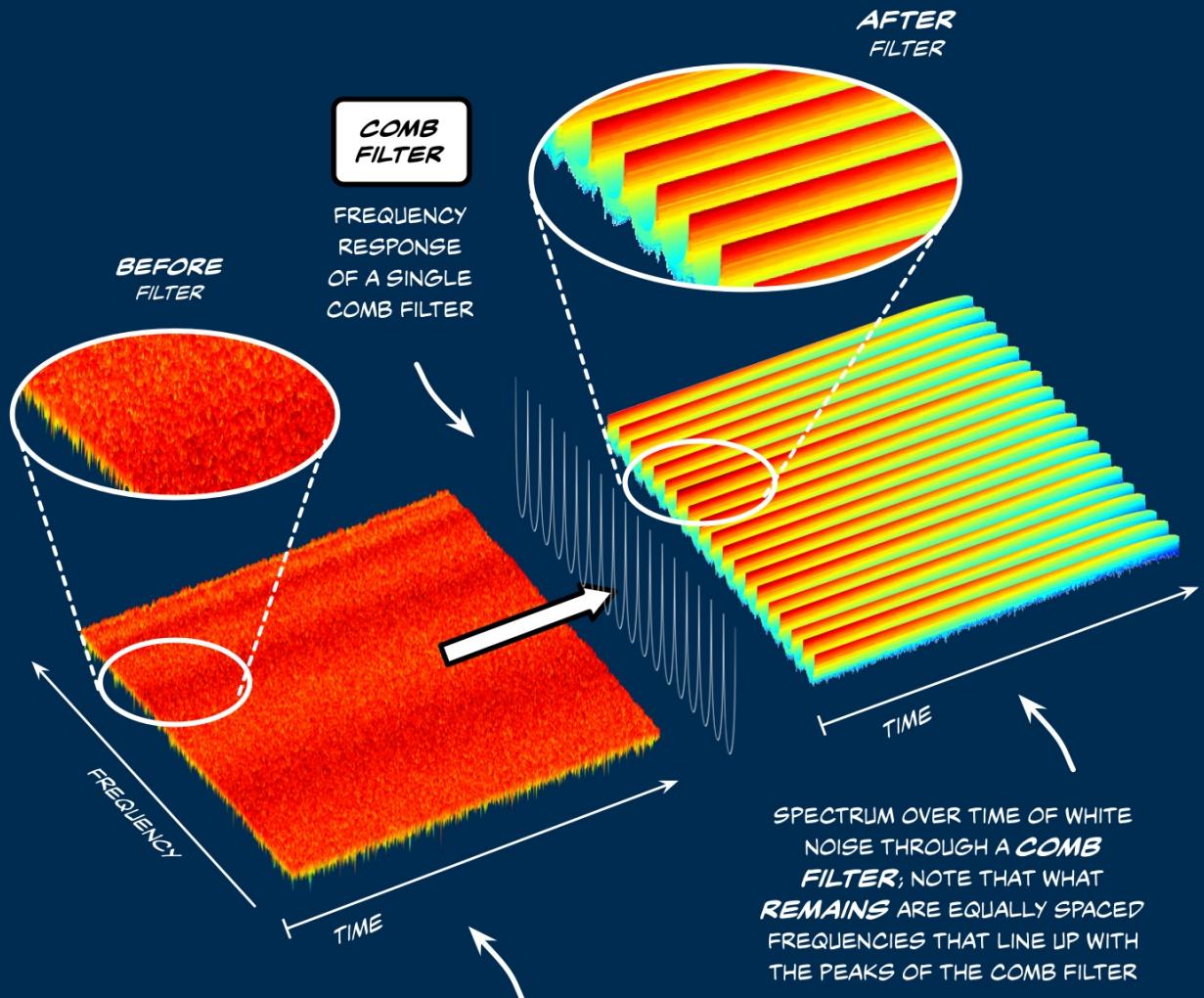
$$\text{DELAY} = \frac{\text{SAMPLE RATE}}{\text{FREQUENCY OF DESIRED PITCH}}$$

AT A TYPICAL AUDIO SAMPLE RATE OF 44100HZ (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:



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.

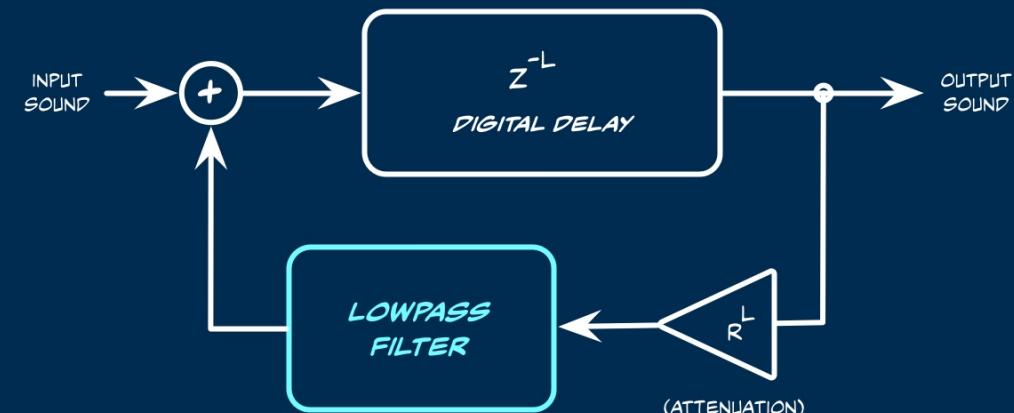
PUTTING A SOUND THROUGH A FILTER IS LIKE POURING A MIXTURE INTO A SIEVE: SOME THINGS FALL THROUGH, OTHER THINGS REMAIN. WITH SOUND, WHAT REMAINS IS WHAT YOU HEAR. FOR EXAMPLE...



SPECTRUM OVER TIME OF 10 SECONDS OF **WHITE NOISE**, WHICH CONTAINS, STATISTICALLY SPEAKING, **ALL** FREQUENCIES IN A DIGITAL SIGNAL (JUST AS THE COLOR **WHITE** CONTAINS **ALL** **COLORS** IN THE VISIBLE SPECTRUM)

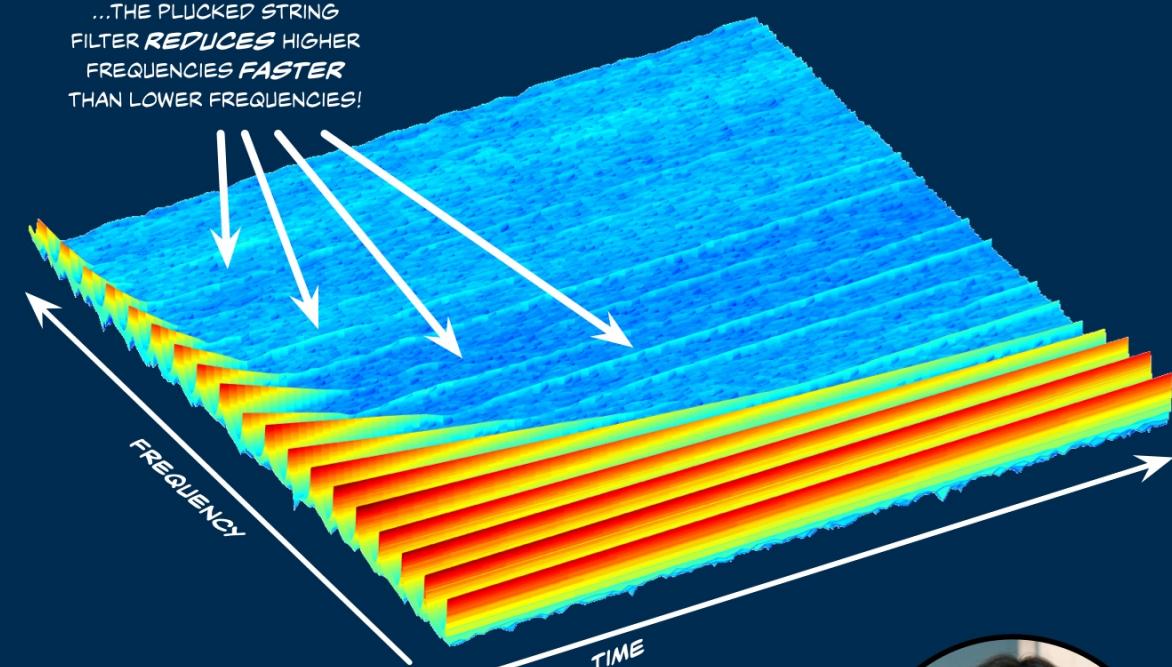
IF OUR THX SOUND IS SYNTHESIS THROUGH THE ADDITION OF 30 VOICES, THEN FILTERING IS A TYPE OF **SUBTRACTIVE SYNTHESIS**, IN WHICH WE SCULPT A SOUND BY SELECTIVELY FILTERING OUT PARTS OF THE ORIGINAL.

THERE ARE SEVERAL VARIANTS OF A COMB FILTER. THE ONE USED IN "BEIJING" 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...

...THE PLUCKED STRING FILTER **REDUCES HIGHER FREQUENCIES FASTER** THAN LOWER FREQUENCIES!



AND **THIS** IS HOW THE PITCHES ARE **IMPRINTED** ON THE SUBWAY SOUNDS OF "BEIJING"! 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!



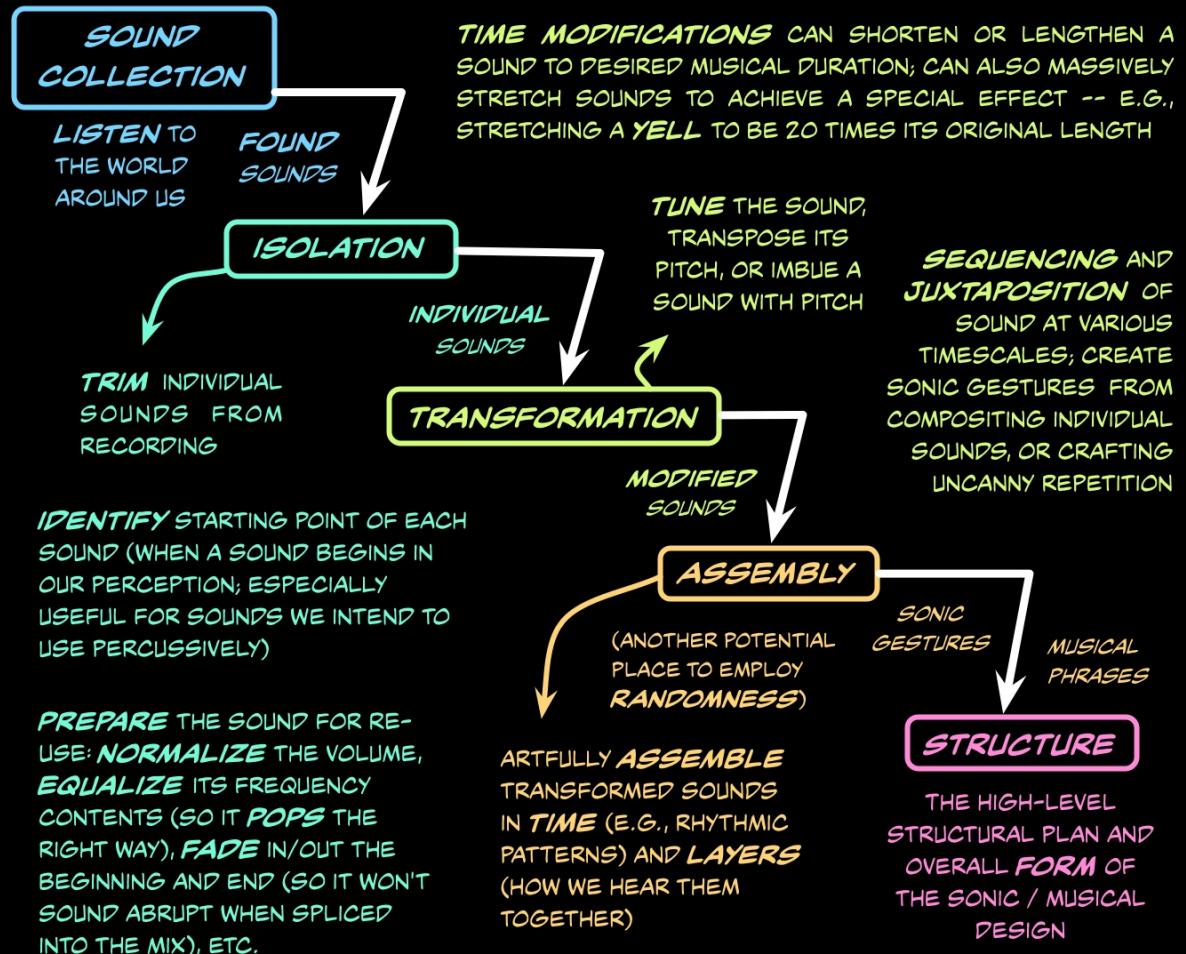
## PRINCIPLE 4.6

### 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!



ONE POSSIBLE BLUEPRINT FOR TRANSFORMATION!



THERE ARE MANY TECHNIQUES TO GENERATE AND TRANSFORM SOUND THROUGH PROGRAMMING.

#### 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)



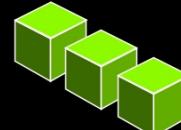
#### FREQUENCY MODULATION SYNTHESIS

TECHNIQUE PIONEERED BY JOHN CHOWNING, WHEREBY OSCILLATORS MODULATE MORE OSCILLATORS TO PRODUCE RICH TIMBRES EFFICIENTLY. RESPONSIBLE FOR "THAT 80S SYNTH SOUND" IN POP MUSIC

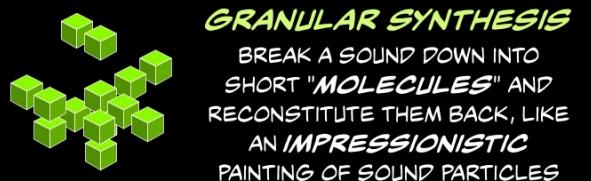


#### BASIC SYNTHESIS

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

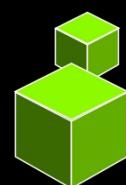


THE MULTITUDES OF TECHNIQUES AND ALGORITHMS ARE THE BUILDING BLOCKS IN A SONIC WORKBENCH! OUR TOOLSHED IS QUITE WELL-STOCKED, AND WE CONTINUE TO DISCOVER NEW TECHNIQUES ALL THE TIME.



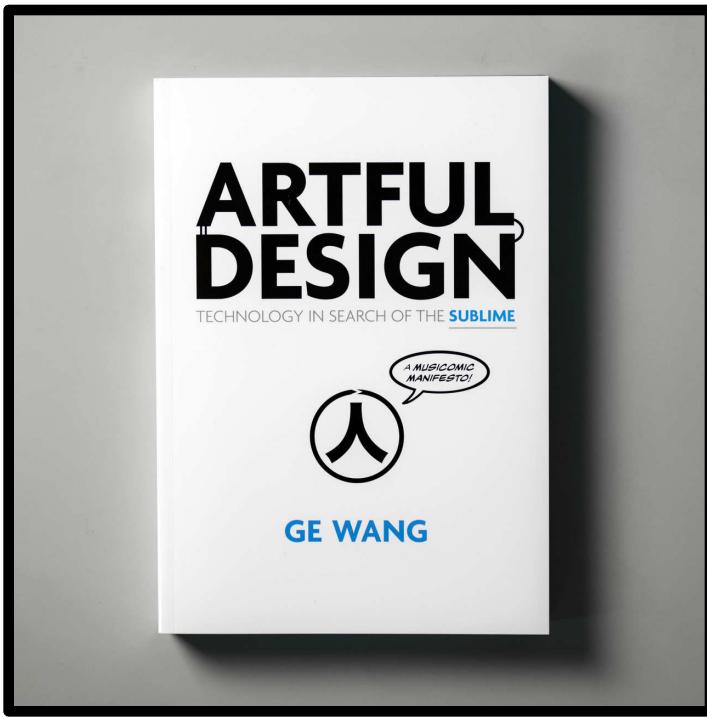
#### SINGING / VOICE SYNTHESIS

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



#### 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)



<https://artful.design/>