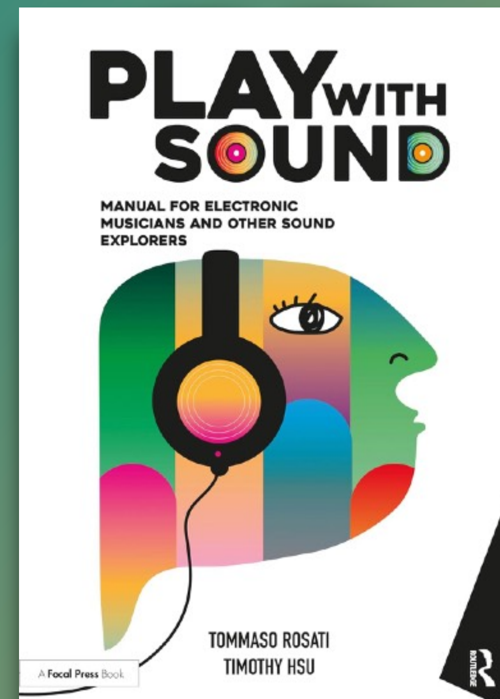
ADDITIVE
SUBTRACTIVE
RM-AM
FM
PHASE DISTORTION
WAVESHAPING
PHYSICAL MODELING
GRANULAR
SAMPLING
WAVETABLE

SOUND SYNTHESIS



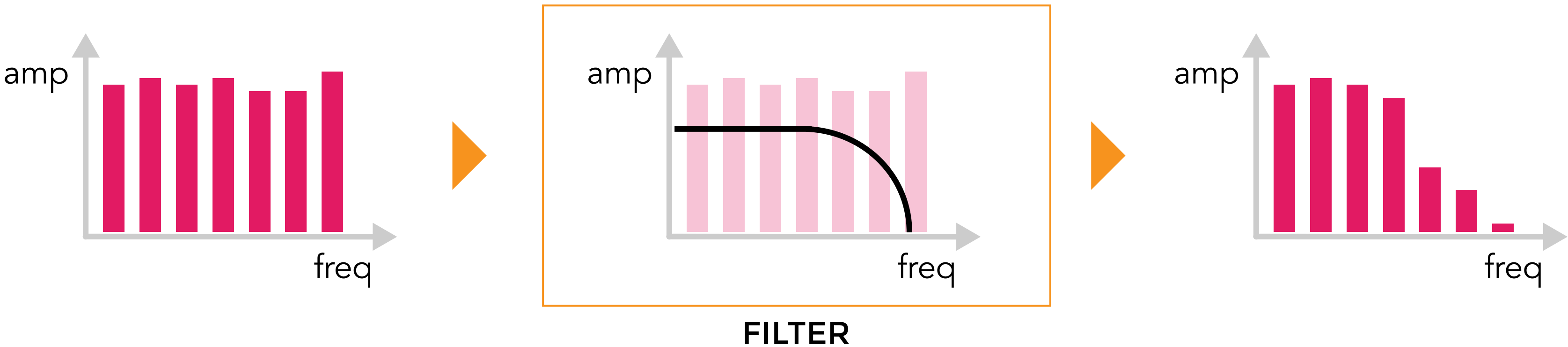
THE BOOK IS NOW AVAILABLE!

TOMMASO ROSATI
SOUND ART

Introductory concepts

FILTERS

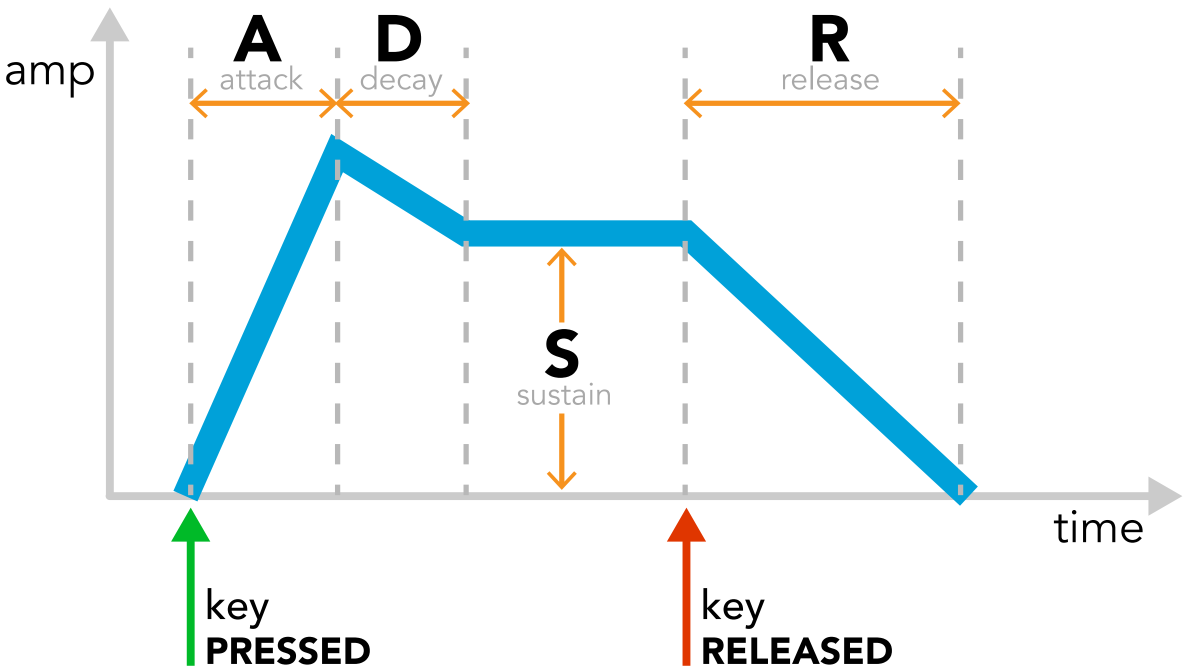
A **filter** is a device that attenuates (sometimes emphasizes) the amplitude and alters the phase of certain frequencies in a sound.
Filters can help us refine or sculpt the sound to meet our sound synthesis goals.



Introductory concepts

ENVELOPE

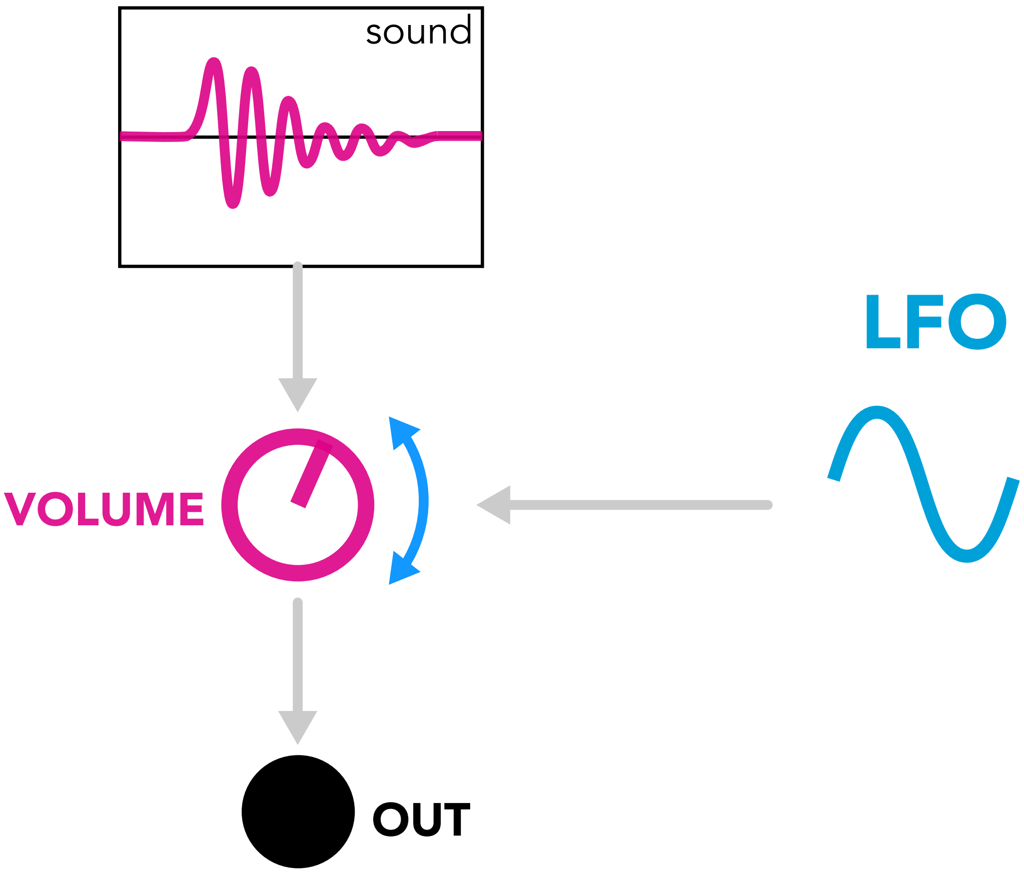
The **envelope** is the time-based trajectory of an instrument's amplitude (or sometimes other parameters) from the moment a note is excited to when the note fades away to nothing.



Introductory concepts

LFO (Low Frequency Oscillator)

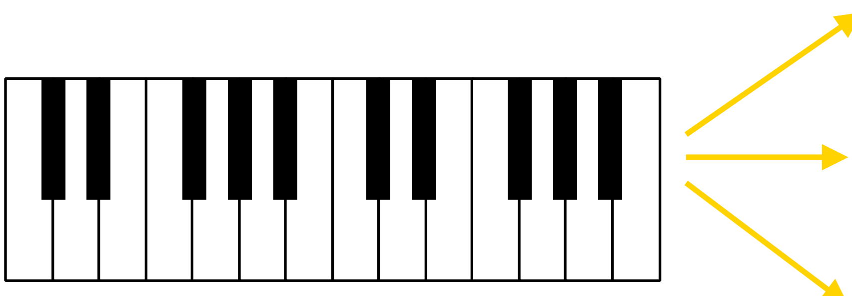
LFO (Low-Frequency Oscillator) is an oscillator that is not used to generate sound but to move certain parameters of the synthesis algorithm.



Introductory concepts

CV (Control Voltage)

Control Voltage is the system by which the output voltage of analog synths are used to control various parametersof another synthesizer or algorithm that ultimately generates the sound.



VCO [voltage control oscillator]
control the pitch of the oscillators

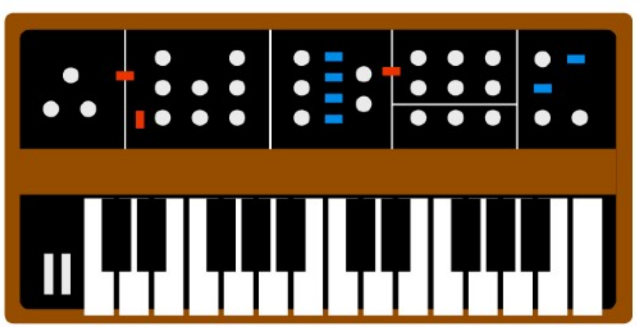
VCF [voltage control filter]
control the filter stage

VCA [voltage control amplitude]
control a dynamic envelope

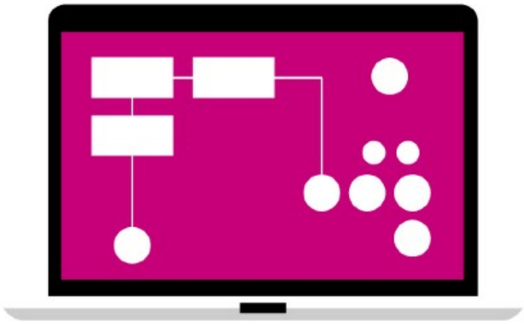
Hardware or Software

Sound synthesis algorithms can be implemented by **hardware** systems, or **software** programs executed on a computer.

HARDWARE



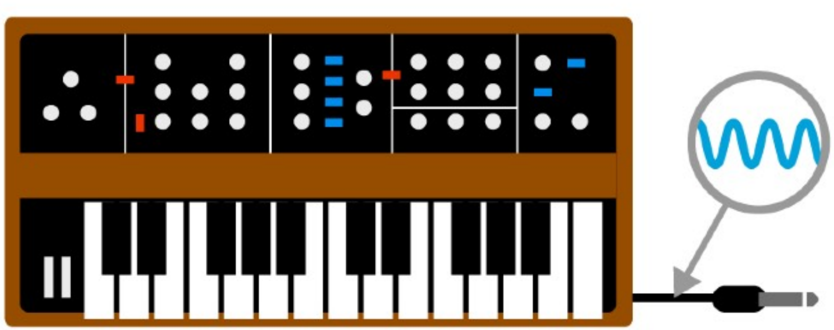
SOFTWARE



Analog or Digital

In the case of software, the synthesis will be **digital**. Historically, hardware synthesizers only had **analog** circuits, but modern hardware synths can take a hybrid approach with analog and digital circuitry.

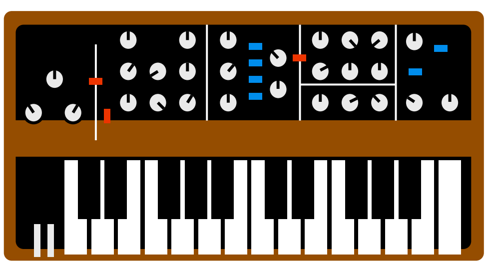
ANALOG



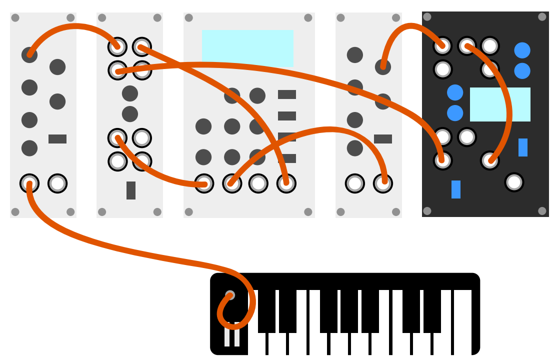
DIGITAL

Hardware or Software, Analog or Digital, Standalone, Modular or Semi-Modular

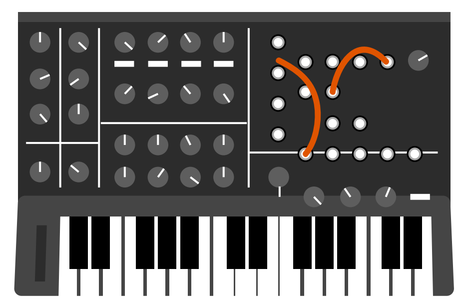
Synthesizers can be classified into 3 categories.
Standalone synthesizers have fixed internal circuitry. **Modular** synthesizers have customizable module connections. **Semi-modular** synthesizers blend standalone operability with modular flexibility.



standalone



modular



semi-modular

LINEAR techniques

They are based on adding and subtracting processes. Consequently, the degree of the algorithm's complexity is directly linked to the spectral complexity of the sound produced.

NONLINEAR techniques

Here, the sonic result does not vary in proportion to the signals' complexity. We can generate signals with many harmonic or inharmonic components from just a few initial elements.

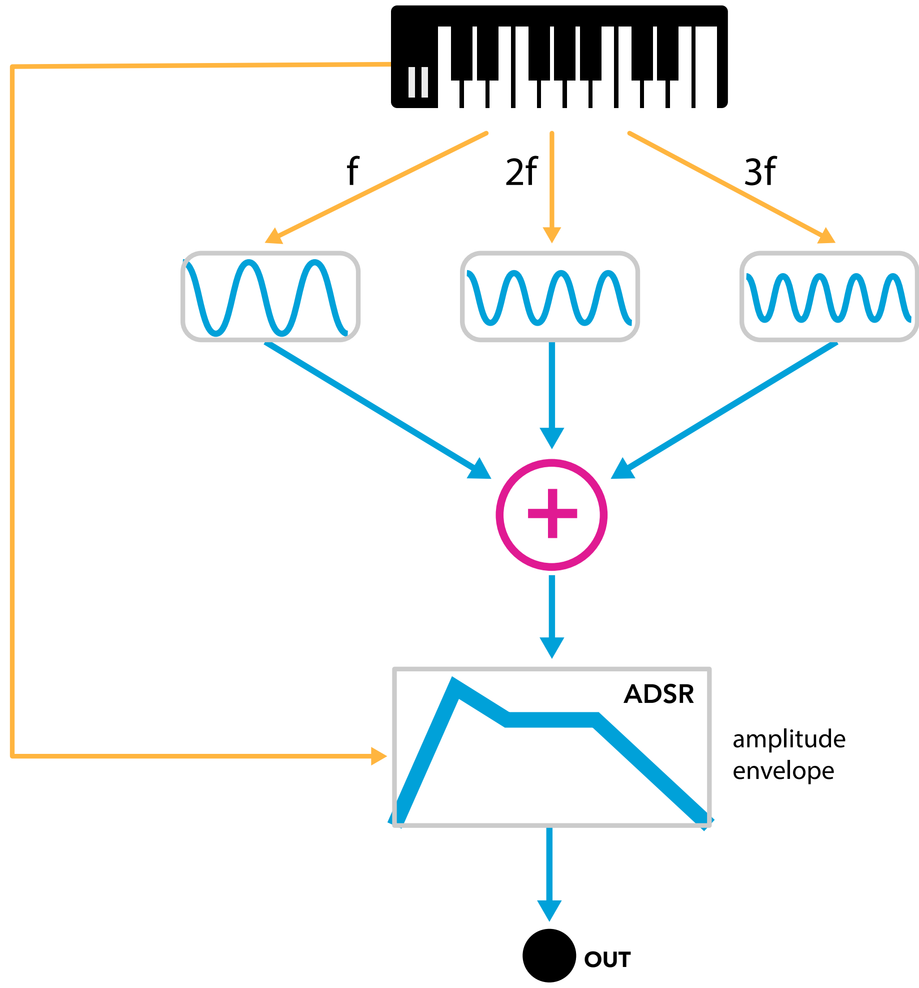
ADDITIVEm SUBTRACTIVE, GRANULAR

AM, RM, FM, WAVESHAPING

ADDITIVE SYNTHESIS

A linear sound synthesis technique, additive synthesis operates on the summation of properly tuned sine waves.

Theoretically, with additive synthesis, it is possible to reconstruct any timbre and create complex new ones, but it is very computationally expensive.

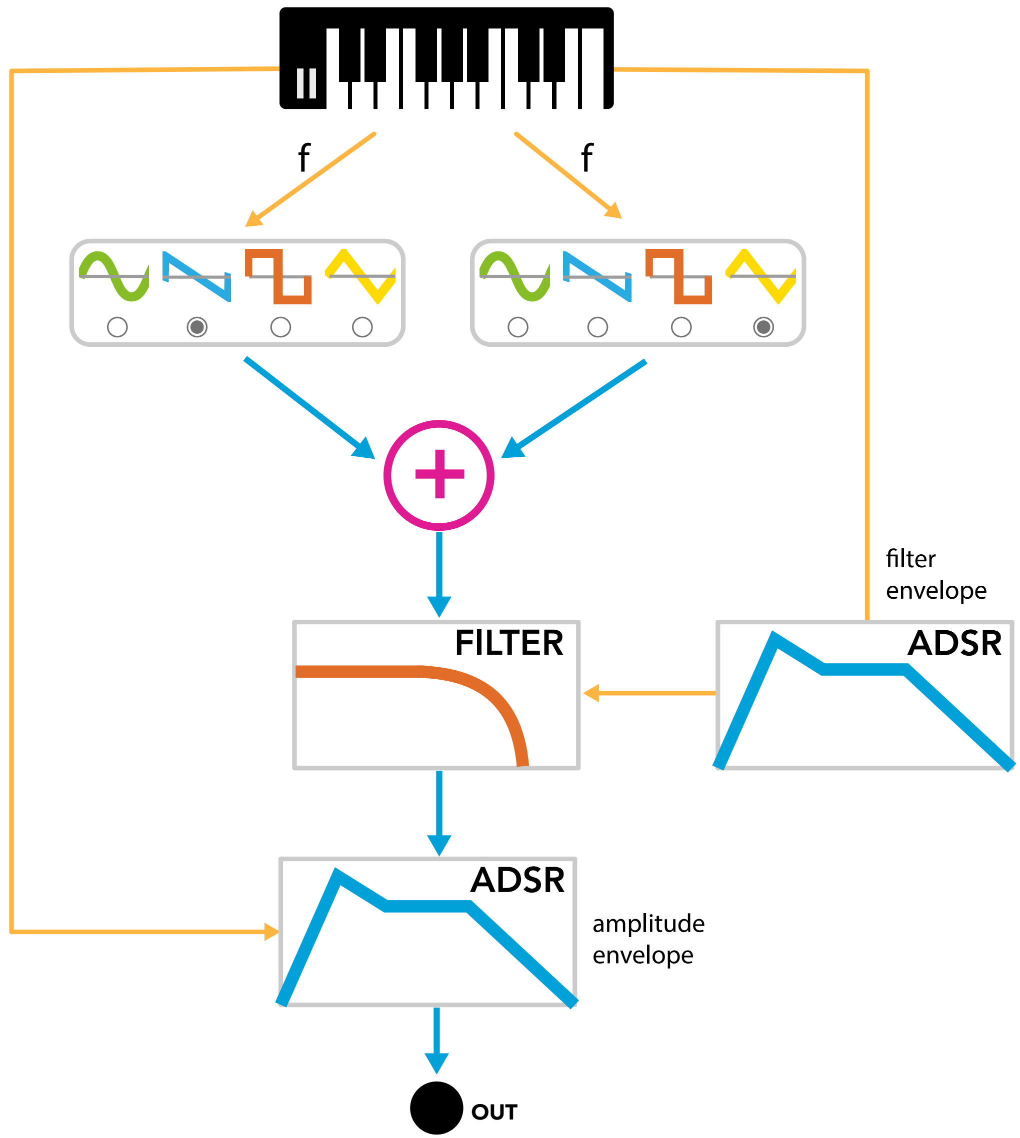


ADDITIVE SYNTHESIS

Hammond Organ B3 (Model A from 1935)

SUBTRACTIVE SYNTHESIS

Subtractive synthesis, widely favored for its simplicity and applicability in both analog and digital formats, shapes sound by filtering out frequencies from an initial complex sound. This is akin to a sculptor chiseling away marble to reveal a defined form.



SUBTRACTIVE SYNTHESIS

Minimoog Model D (1971)

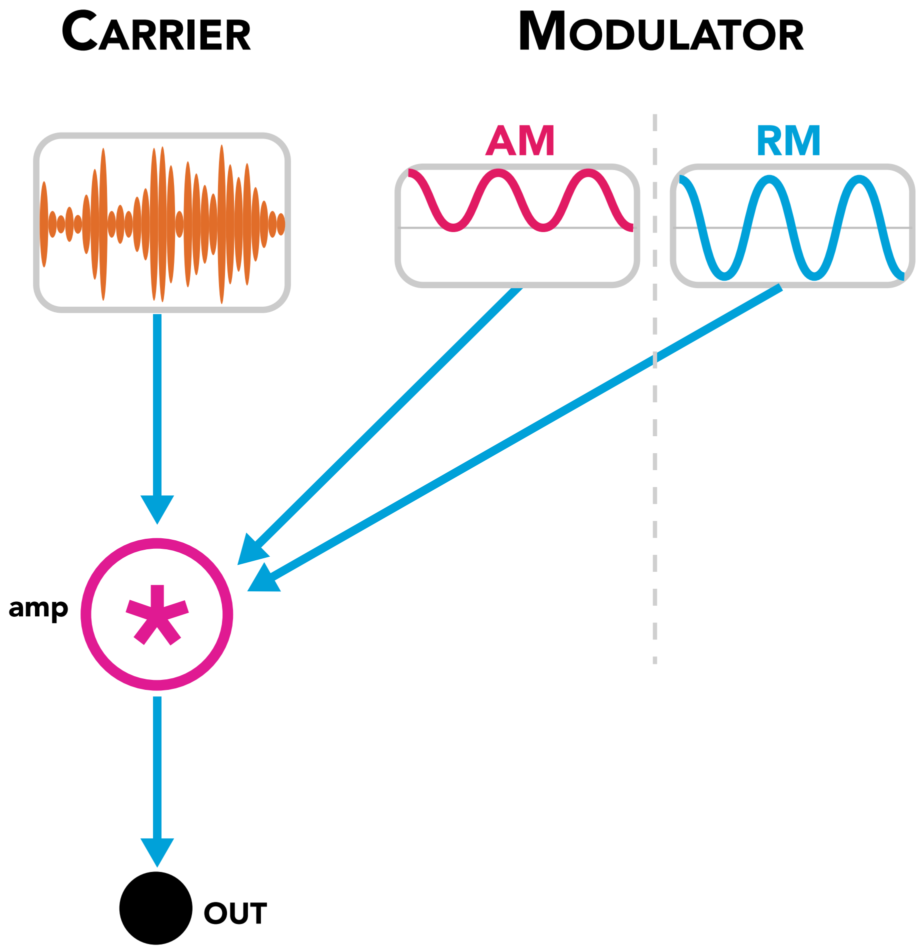
SUBTRACTIVE SYNTHESIS

ANALOG in Ableton Live

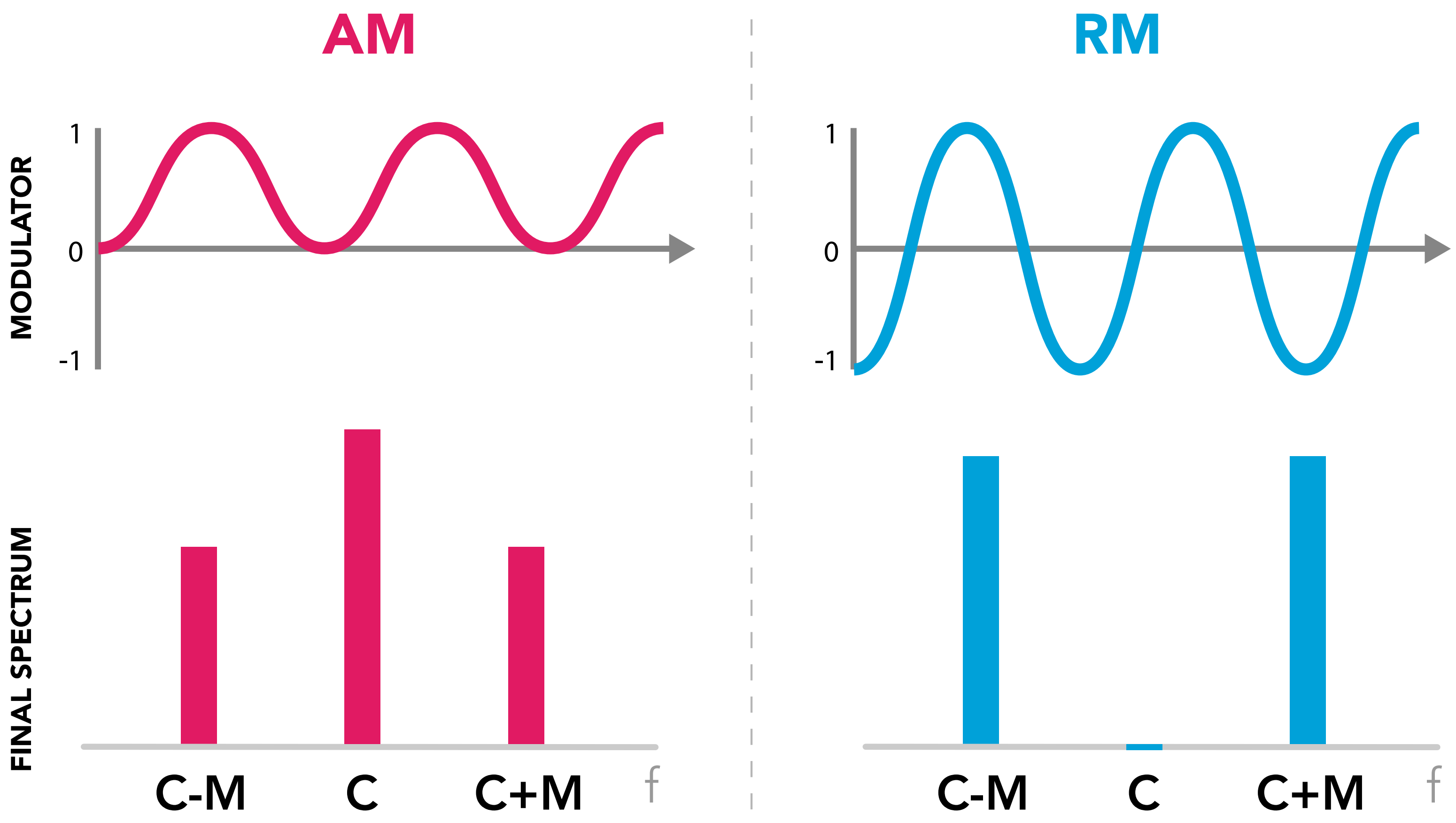
AM (AMPLITUDE MODULATION) - RM (RING MODULATION)

We can use a sine wave (of greater than 15 Hz) to control the amplitude of another sound wave, resulting in an output that is a richer in timbre.

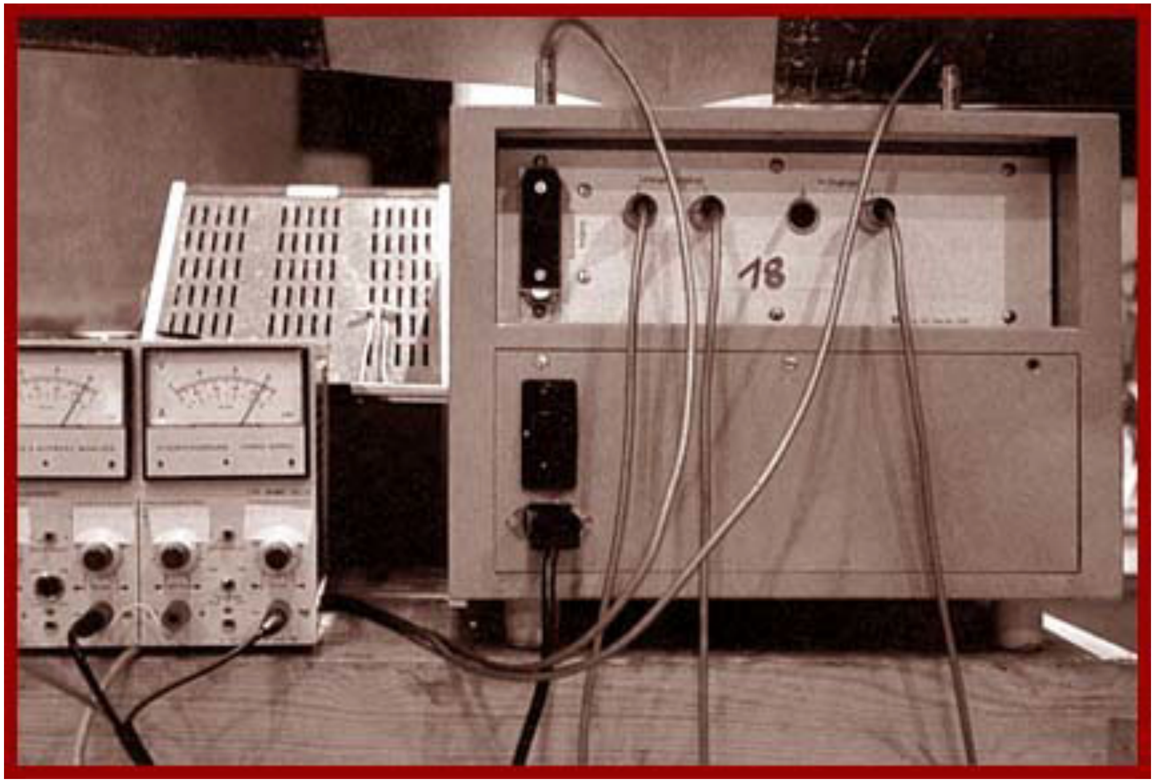
The key difference between AM and RM is that AM uses a unipolar wave (amplitude 0 to 1) for modulation, while RM employs a bipolar wave (amplitude -1 to 1).



AM (amplitude modulation) - RM (ring modulation)

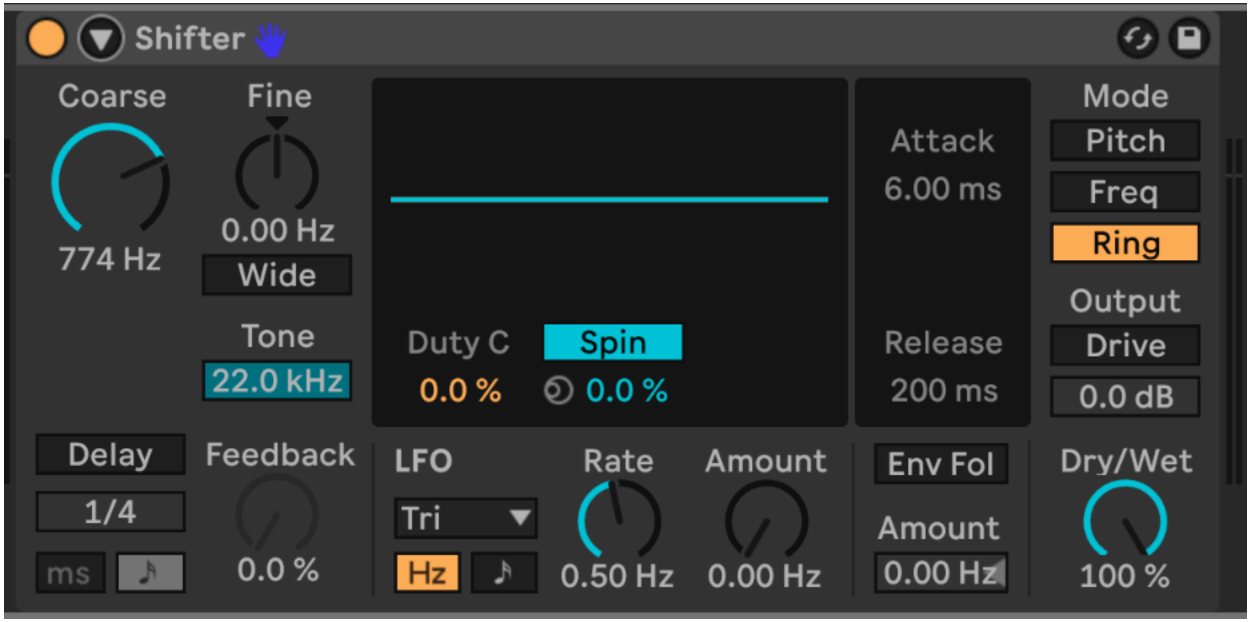


AM (amplitude modulation) - RM (ring modulation)



Ring Modulator, Studio for Electronic Music of the West German Radio in Cologne (1955)

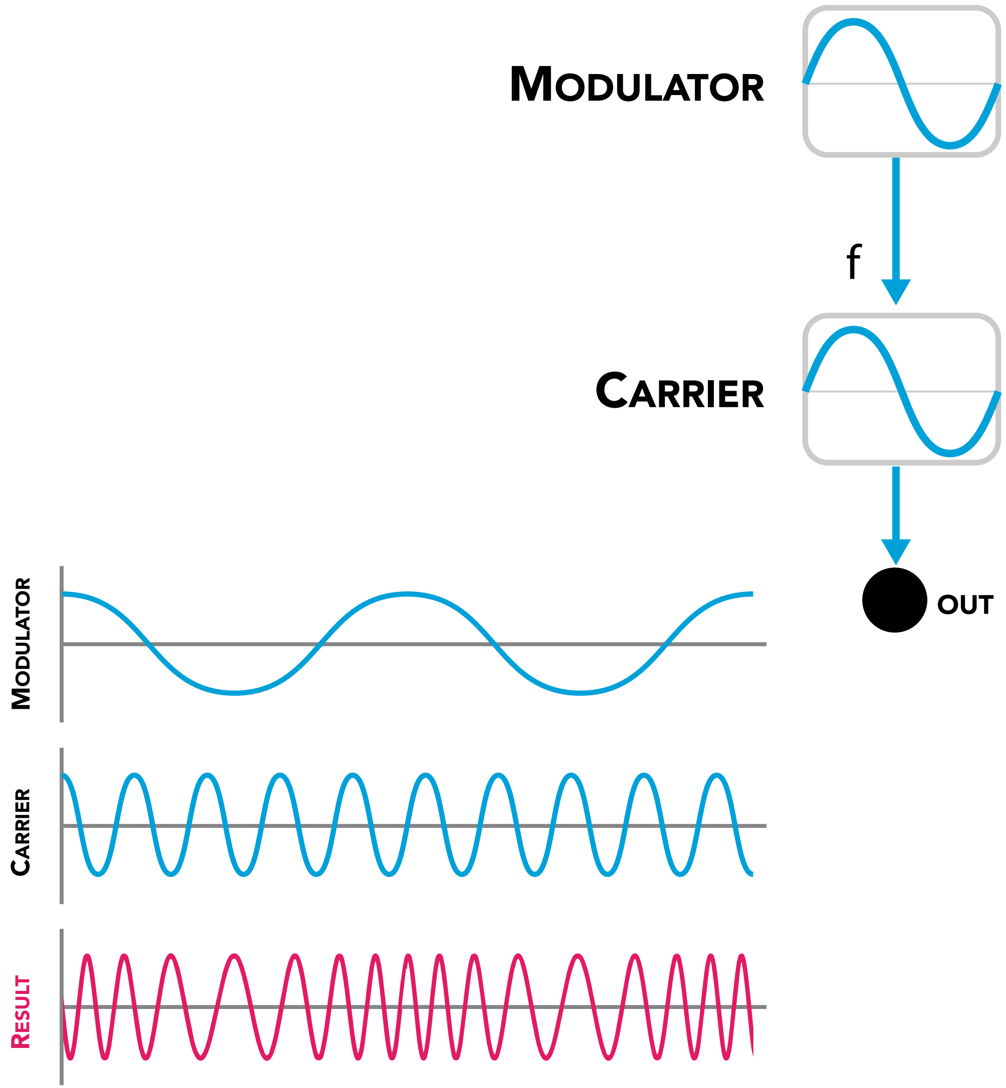
AM (amplitude modulation) - RM (ring modulation)



SHIFTER audio effect in Ableton Live

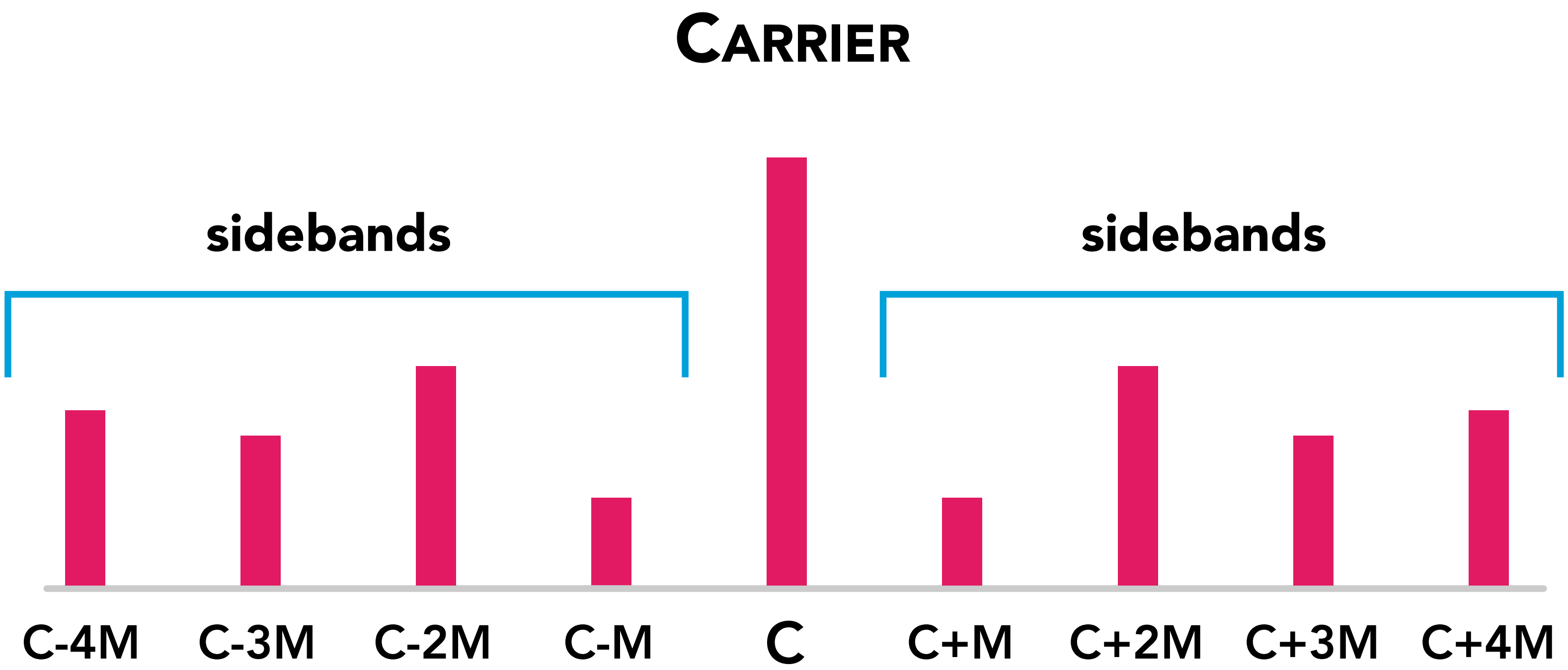
FM (FREQUENCY MODULATION)

Frequency Modulation synthesis is based on an oscillator wave, called a Modulator, that varies the frequency of another oscillator called the Carrier. This process is nonlinear because it can create a complex spectra with many frequencies, all while using just a few elements.



FM (frequency modulation)

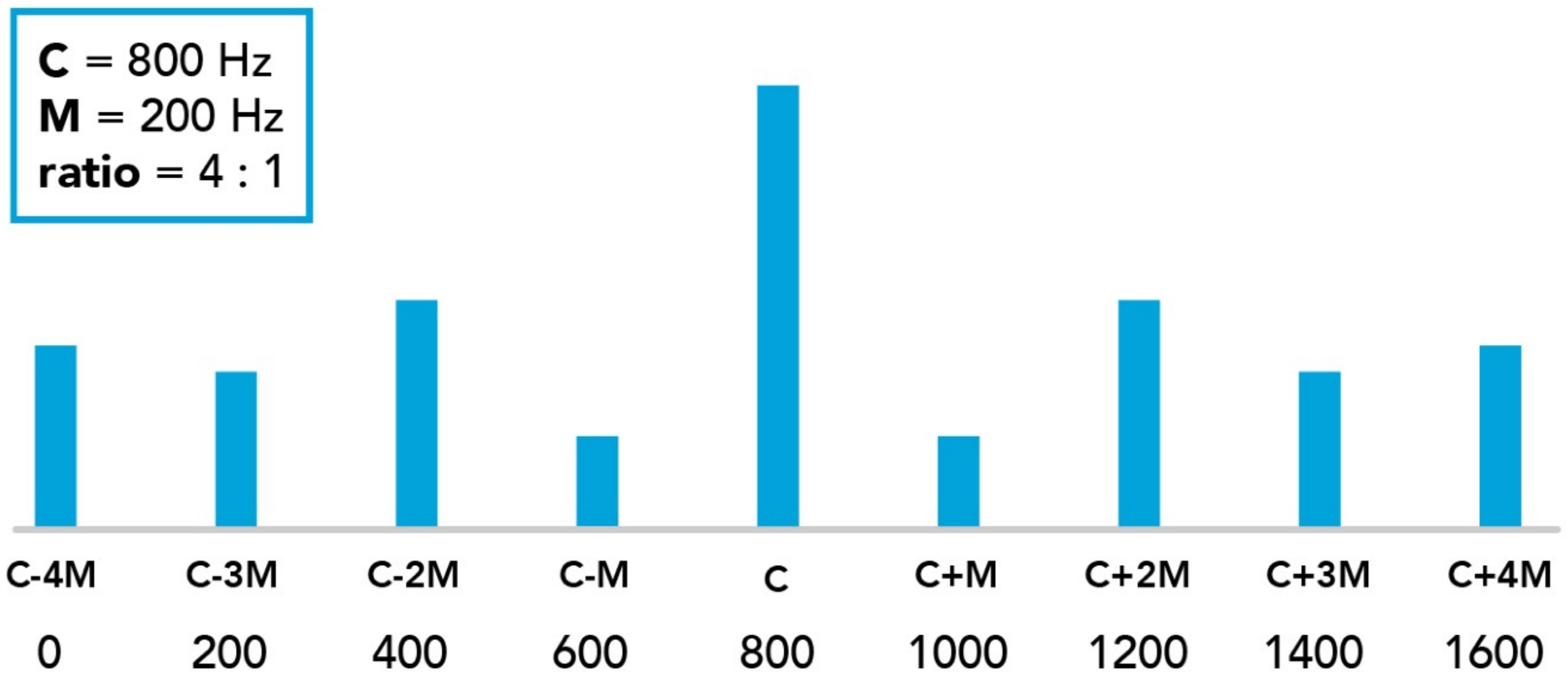
FM synthesis results in a timbre with a series of sidebands centered around the carrier frequency.



FM

POSITION OF THE BANDS

The resultant frequency of the sidebands depends on the ratio between Carrier and Modulator, or the **C:M ratio**. The FM generates a harmonic spectrum when the C:M ratio can be reduced to an integer (e.g., 4:1).

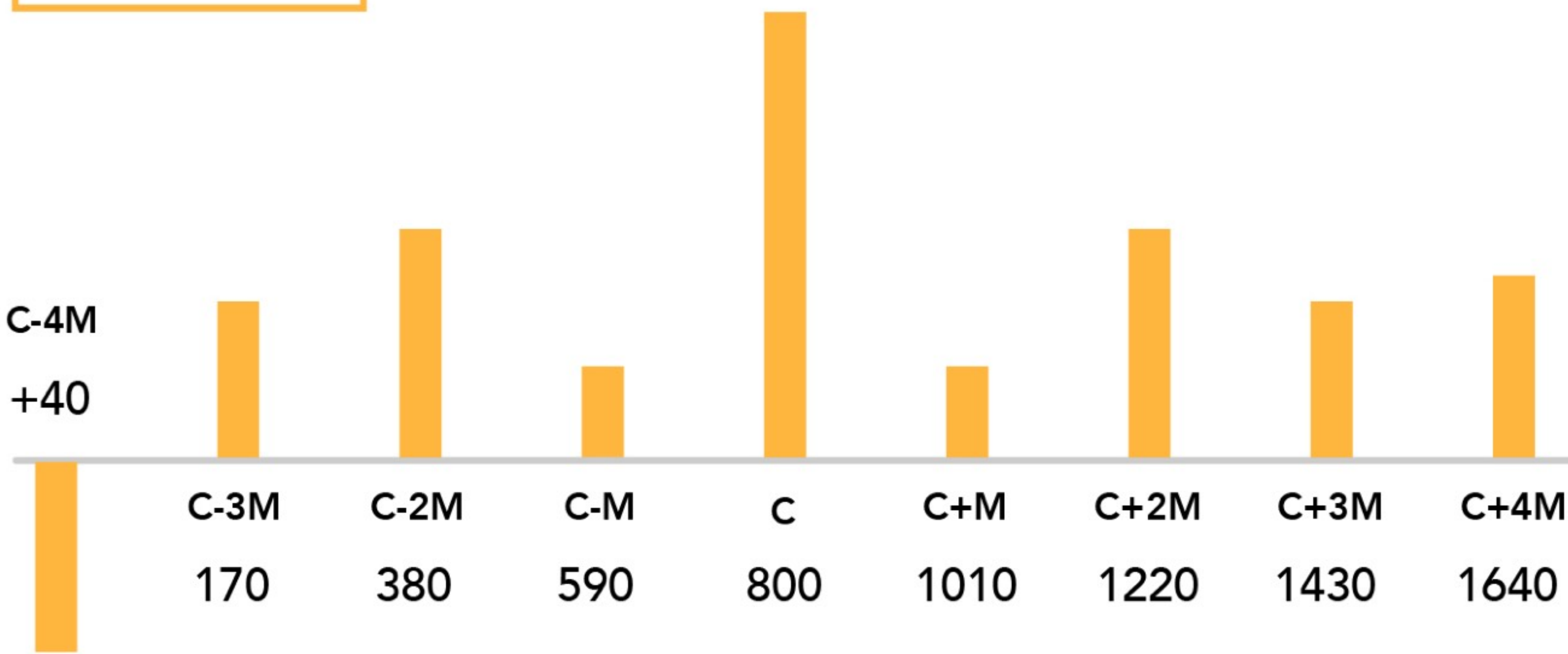


FM

POSITION OF THE BANDS

If the **C:M ratio**, on the other hand, is not an integer (e.g., 8:2.1), the resultant sound has an inharmonic spectrum.

C = 800 Hz
M = 210 Hz
ratio = 4 : 1,1



FM

QUANTITY OF BANDS

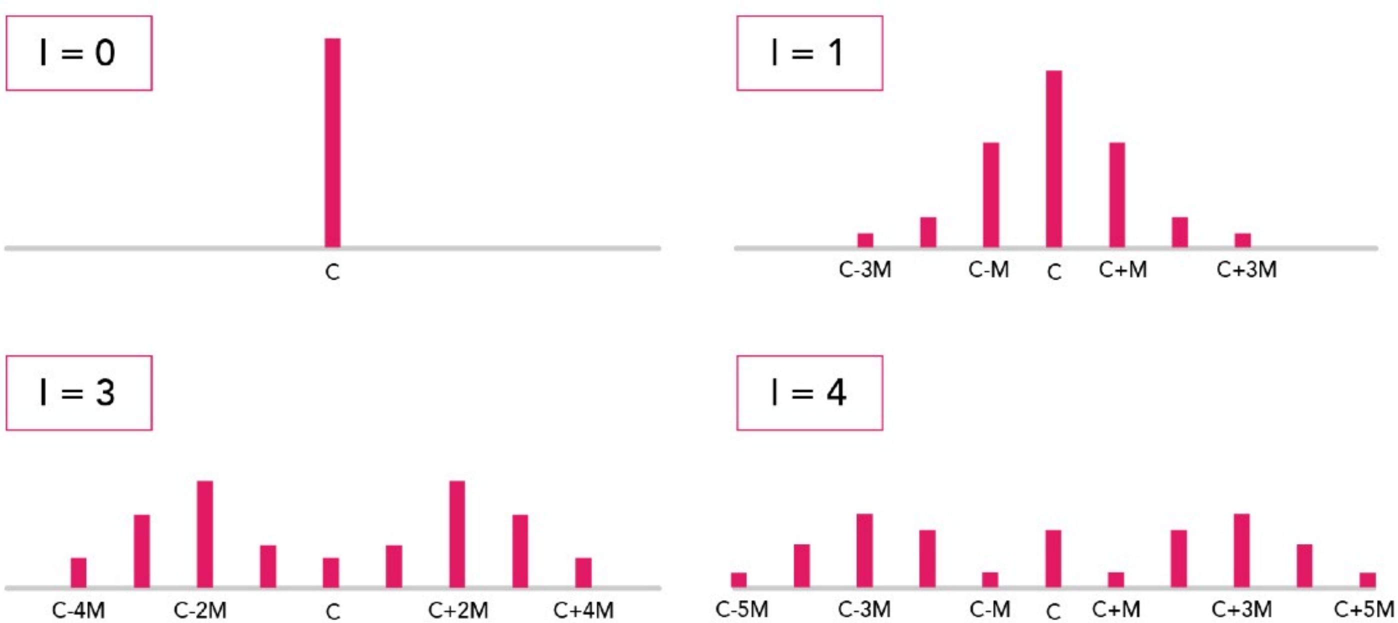
As the **modulation index** increases, the timbre becomes more complicated with an increasing number of sidebands.

$$I = \frac{D}{M}$$

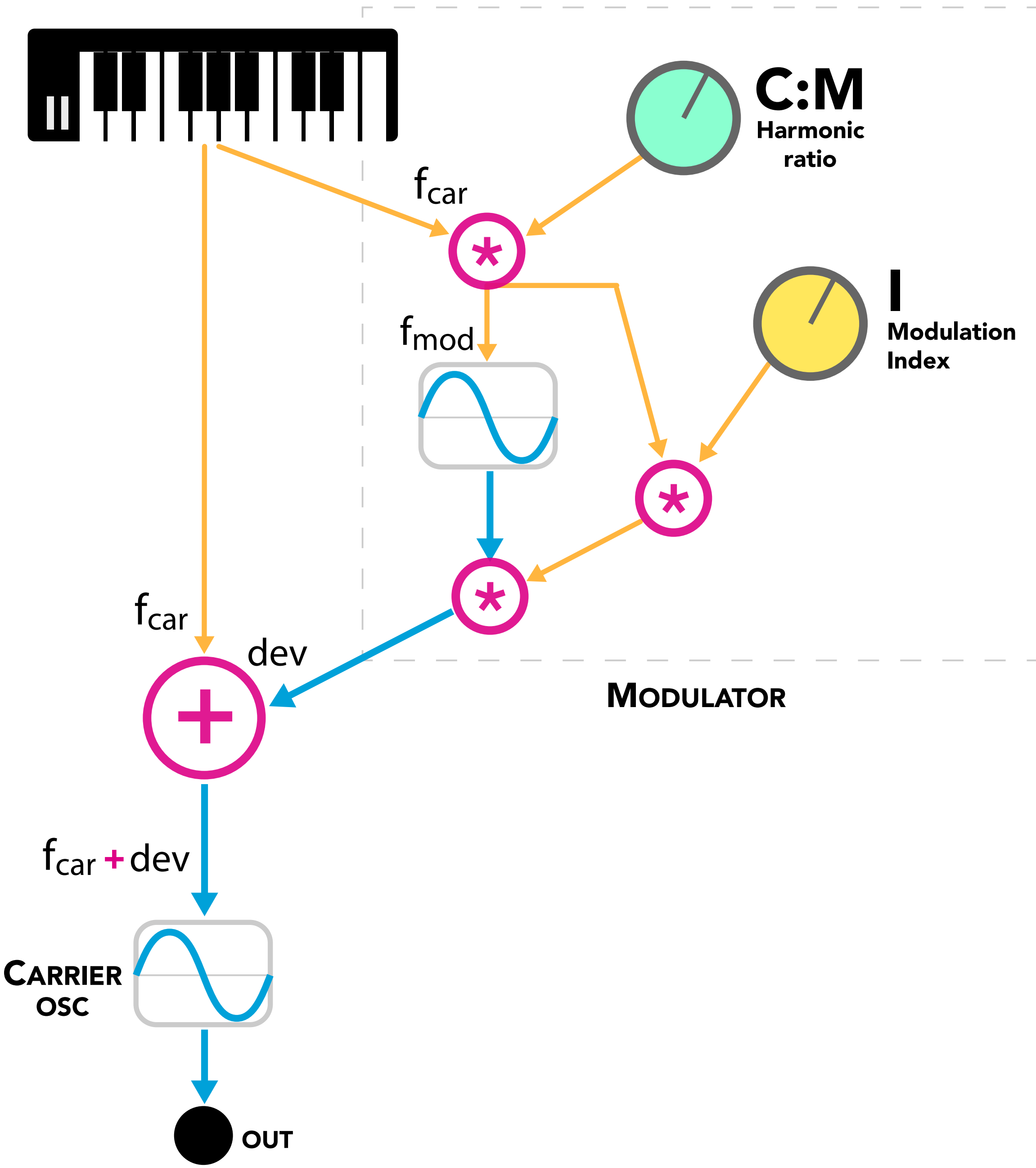
D: Deviation between C and M

M: M frequency

→ $I \times M = D$

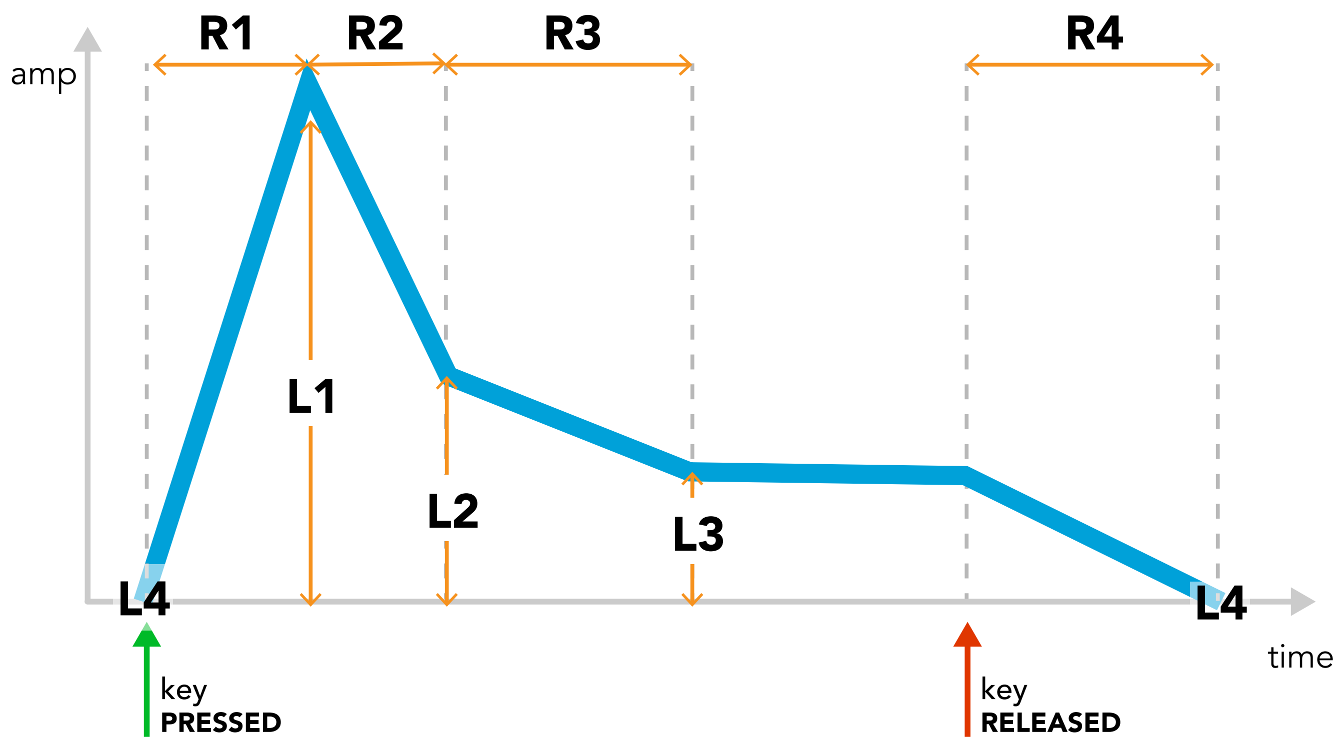


FM


C:M
Harmonic ratio
I
Modulation Index
f_{car}
f_{mod}
f_{car}
dev
MODULATOR
f_{car} + dev
CARRIER OSC
OUT

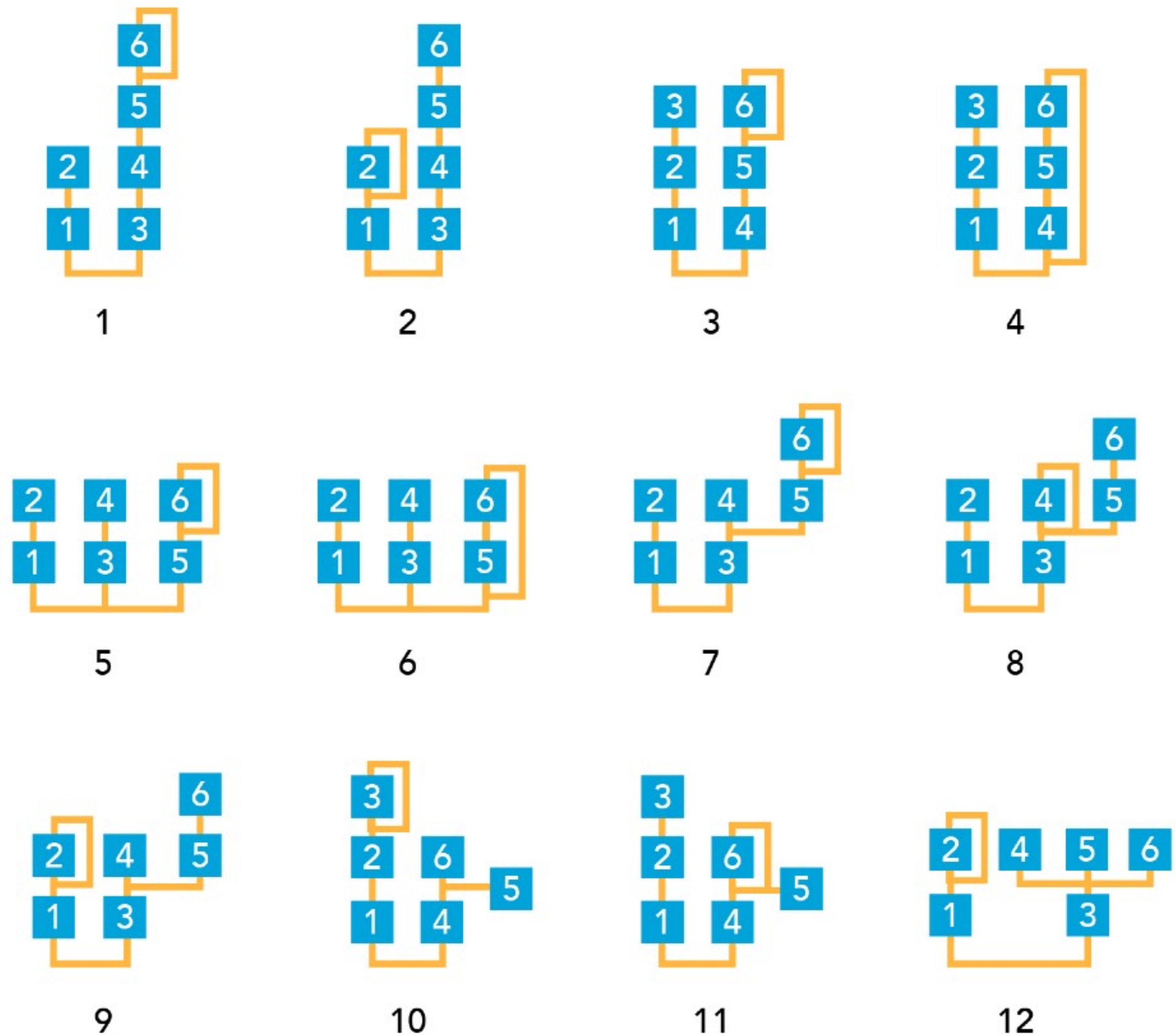
FM (frequency modulation)

In FM synthesis, each oscillator usually has its own envelope, which adjusts the amplitude, creating movement within the timbre that is less static. The **EG (envelope generator)** makes these movements possible and is composed of four amplitude levels and four rates that control the slope (and consequentially the time) of the envelope segments.

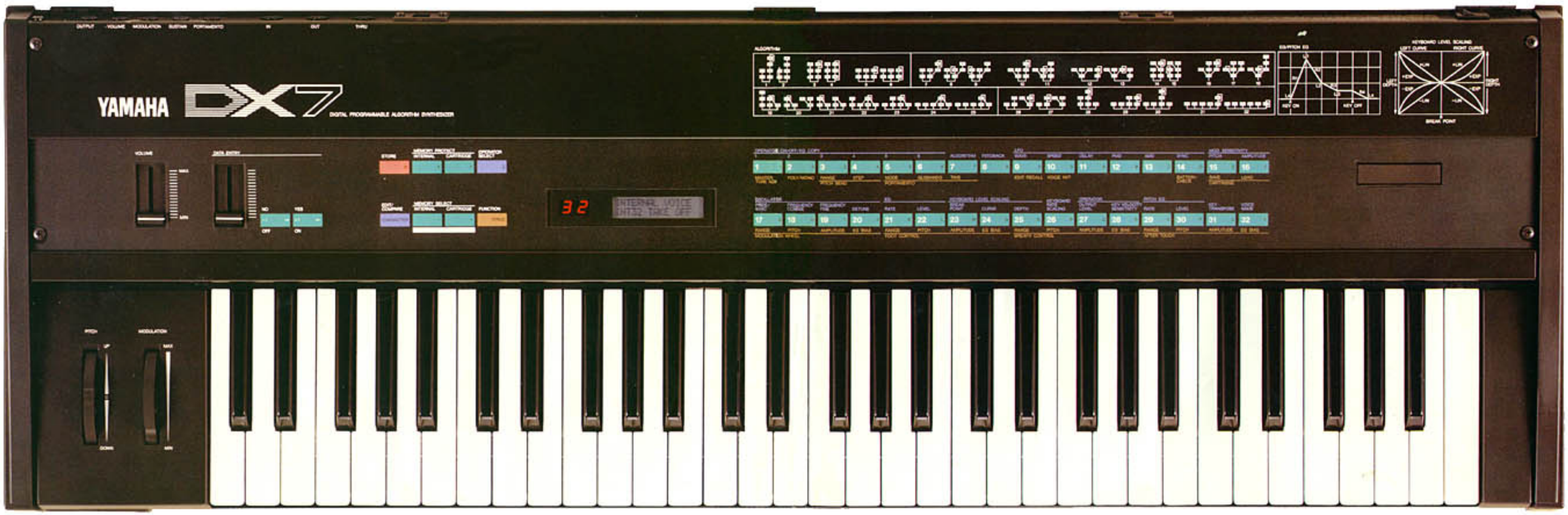


FM (frequency modulation)

In the classic FM synthesis model, oscillators are called **operators** and an **algorithm** is defined by how we combine, organize, and configure multiple operators together.



FM (frequency modulation)

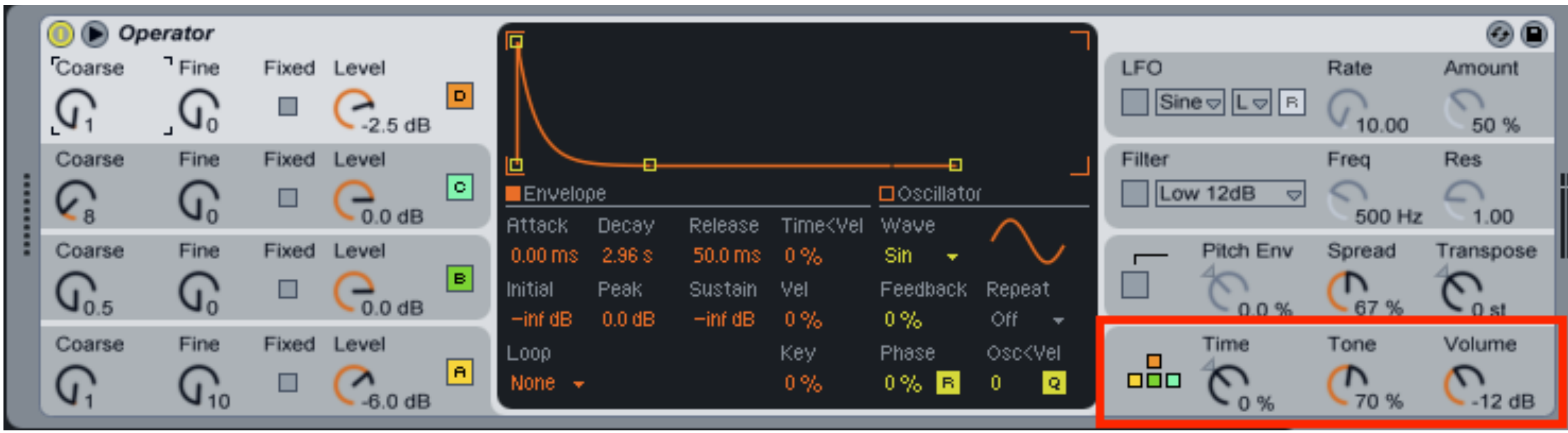


YAMAHA DX7 (1982)

FM (frequency modulation)

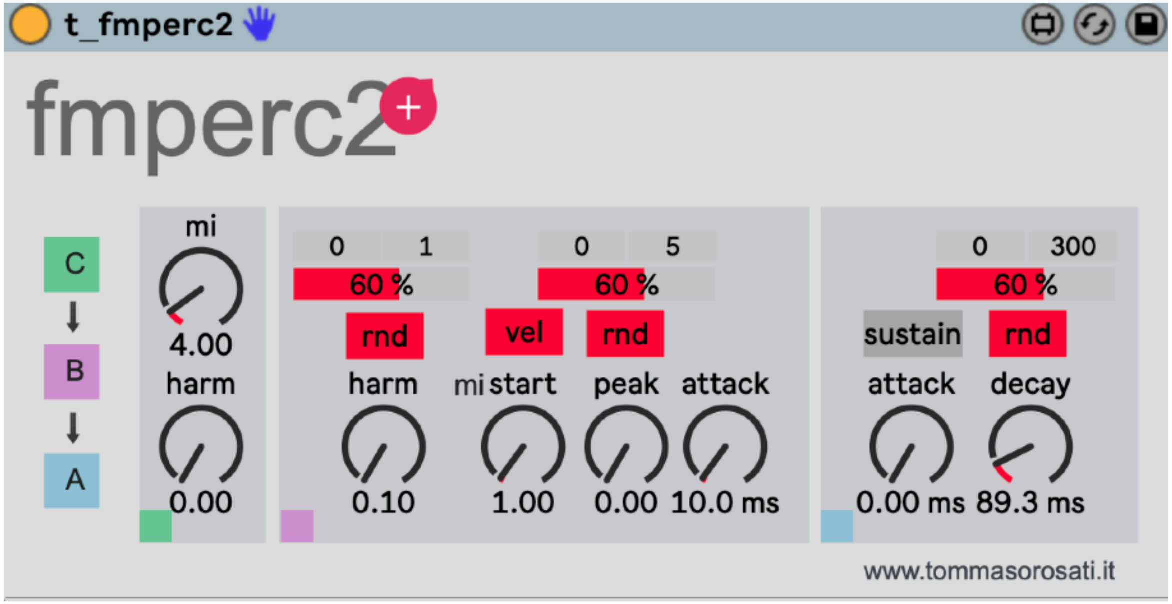
FM8 VST by Native Instruments

FM (frequency modulation)



Operator in Ableton Live

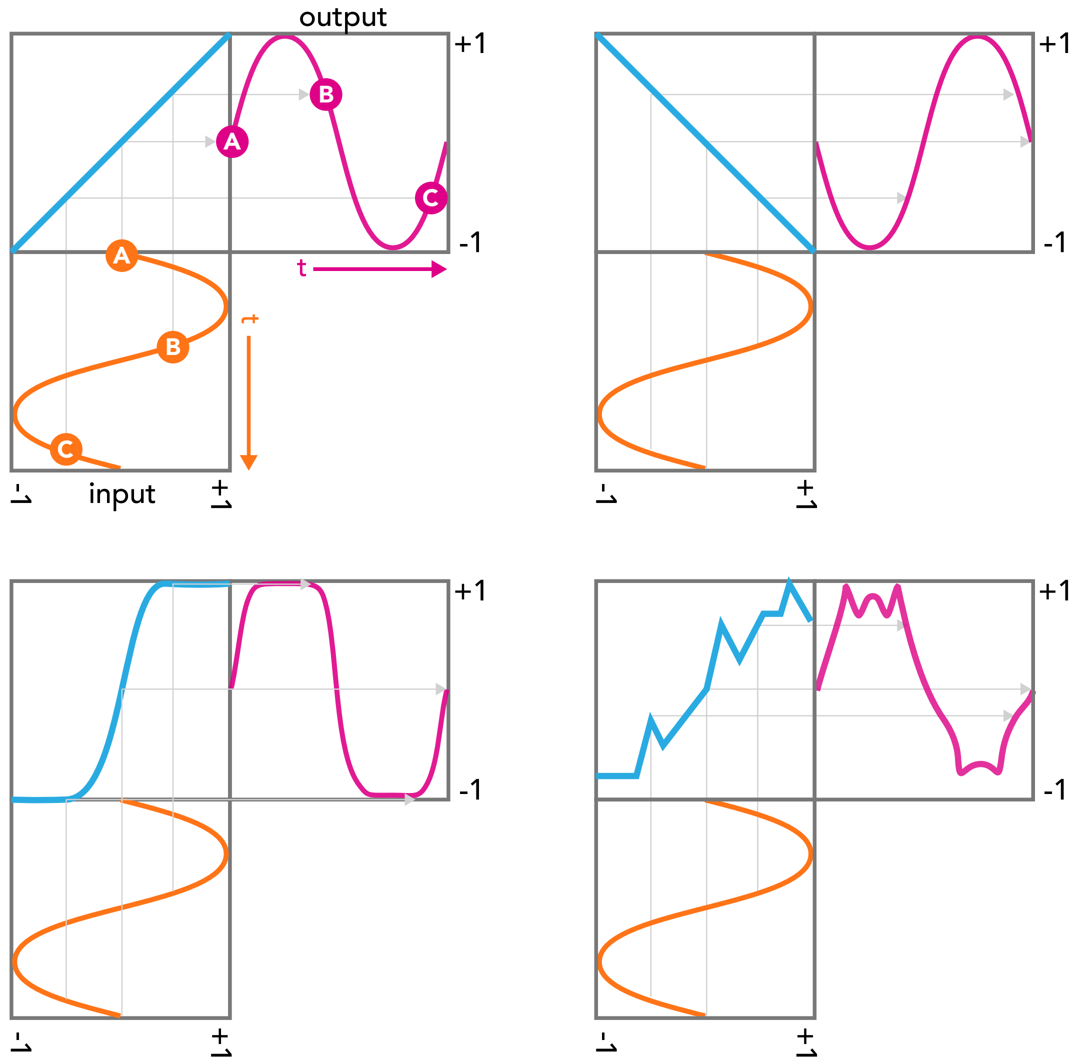
FM



fmperc2 by piumaxforlive

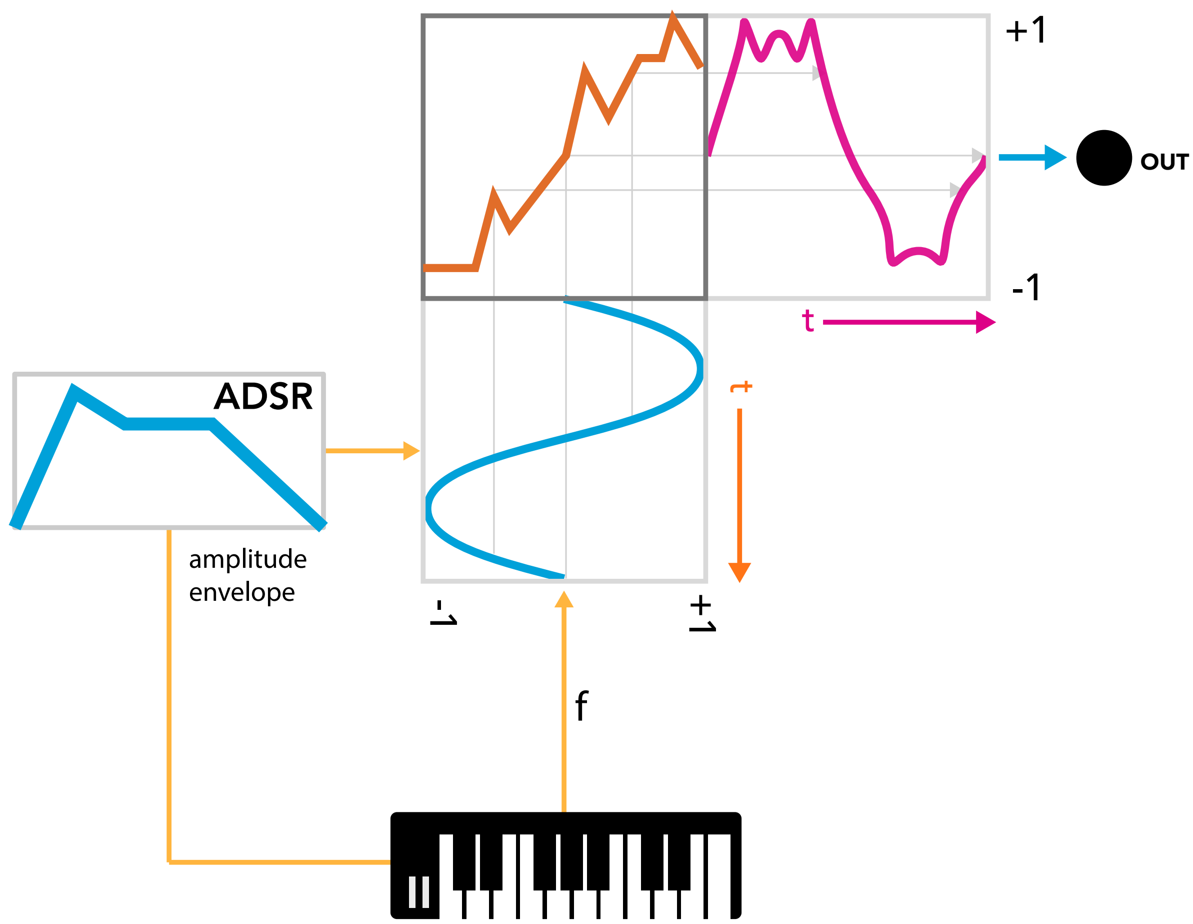
WAVESHAPING

This algorithm is based on passing one period of an input wave, such as a sine wave, through a transfer function that alters its shape and results in one period of an output wave.



WAVESHAPING

The input amplitude range determines how much our input "reflects" off the transfer function. If we dynamically control the gain of the input, we can change, in real time, how much of the transfer function is used, thus changing the timbre of distortion of our output.

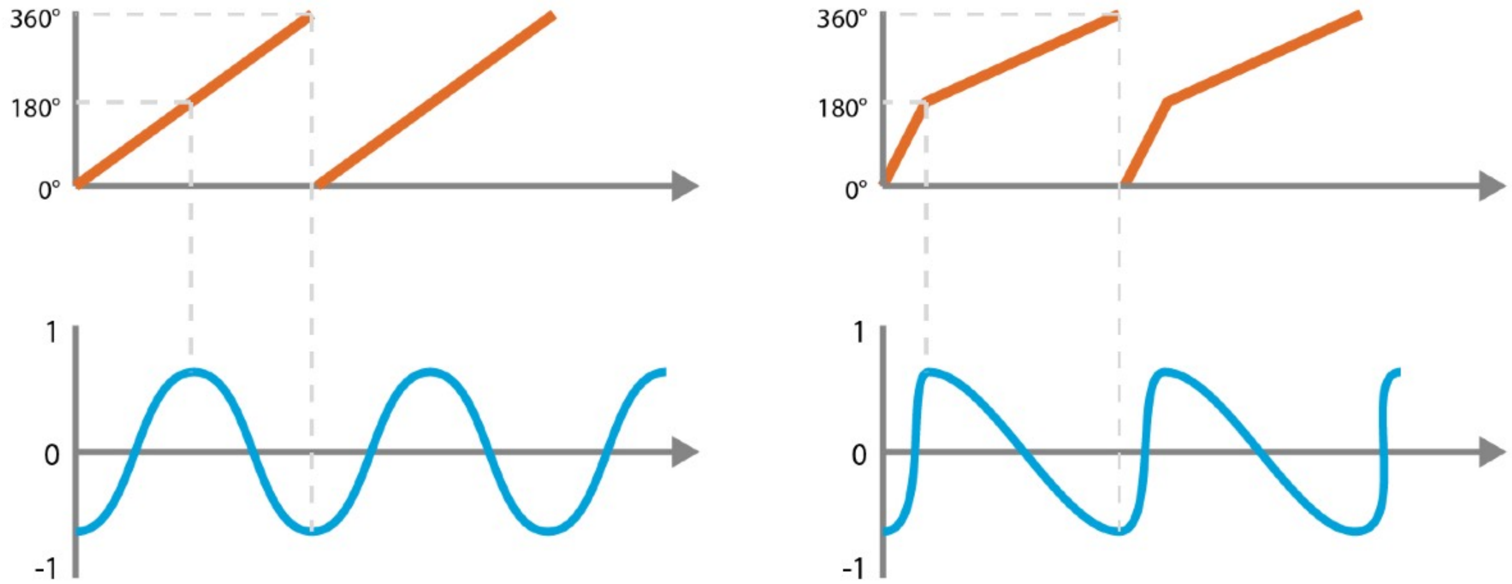


WAVESHAPING

Cakewalk Z3TA+2

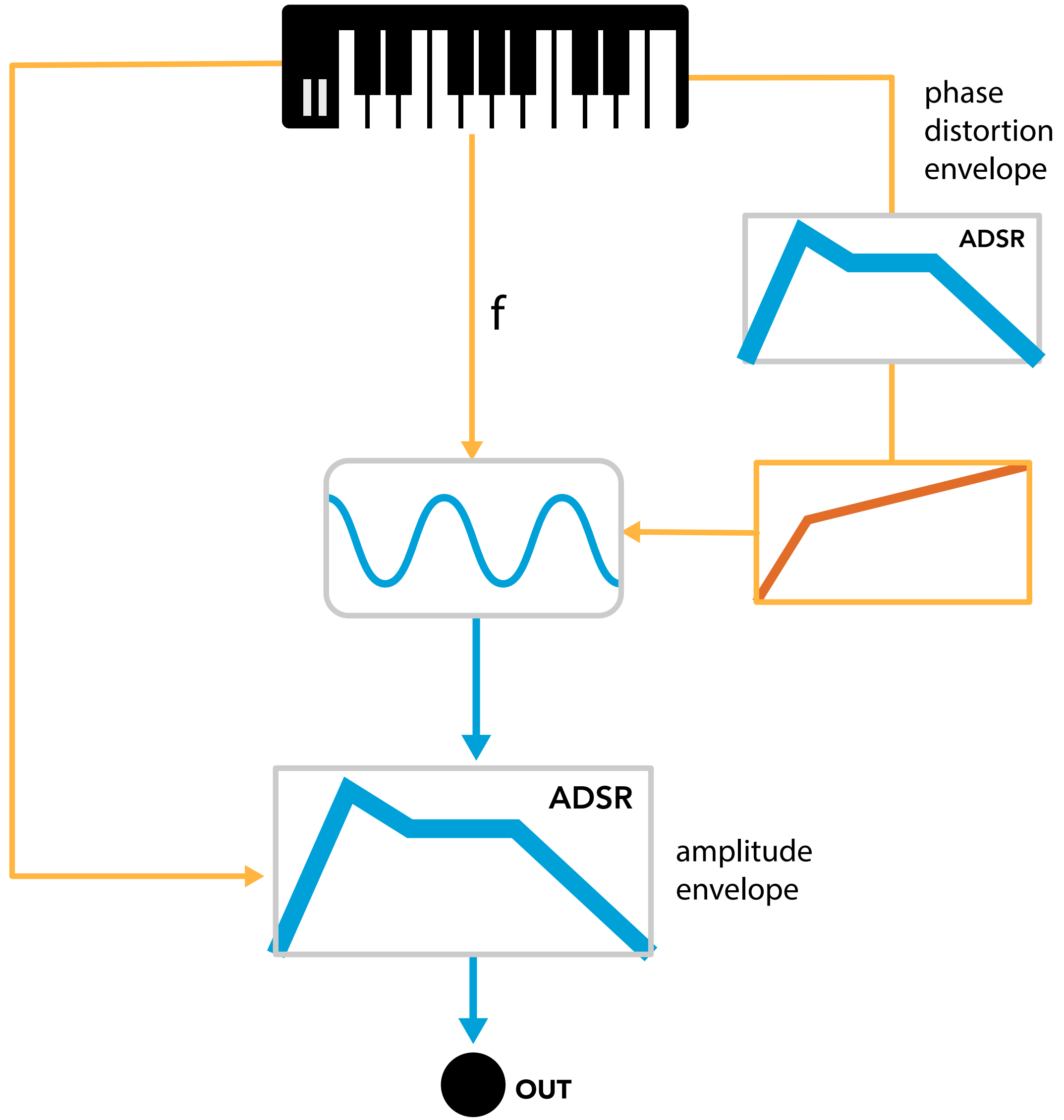
PHASE DISTORTION

Phase distortion is based on reading the values of a sine wave stored in a table at a variable rate. One common phase distortion algorithm reads the wave faster from 0° to 180° (the first half of the full cycle), and then reads slower from 180° to 360° (the second half). The result is that the pitch remains constant on average, but the waveform varies leading to an embellishment of harmonics.



PHASE DISTORTION

Another important feature is the presence of envelopes for both the table lookup speeds and the final amplitude envelope.



PHASE DISTORTION

Casio CZ-101 (1984)

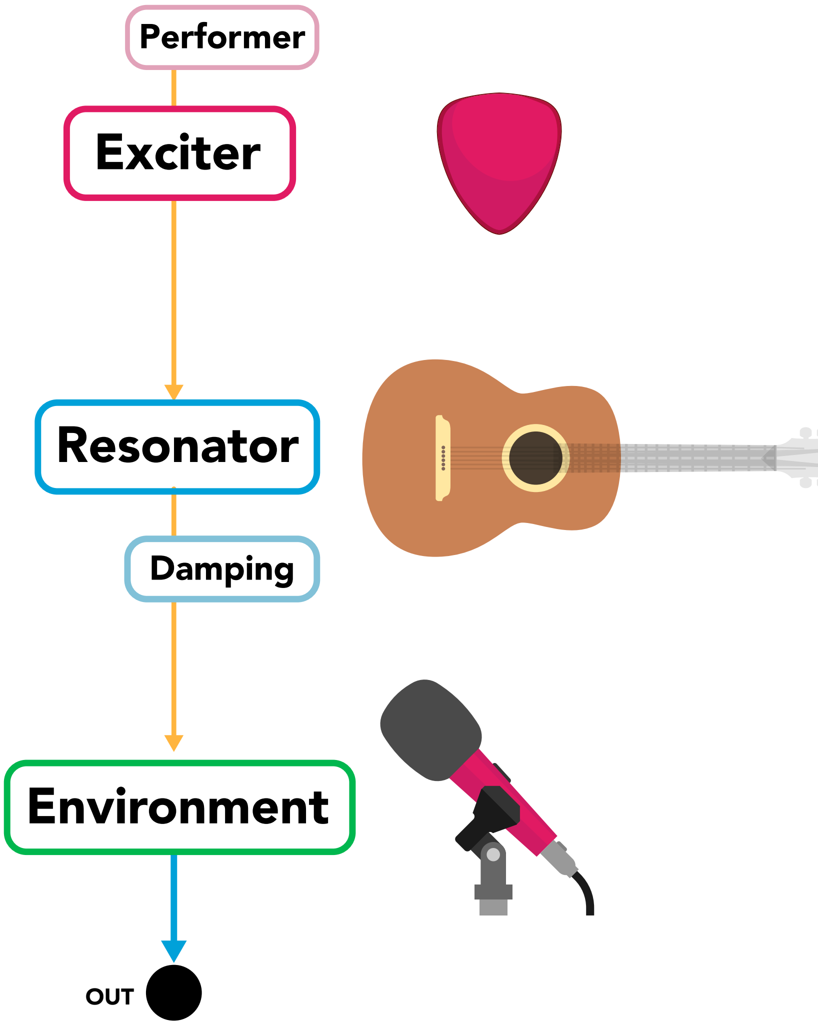
PHASE DISTORTION

VST Digits by Extent of the Jam

PHYSICAL MODELING

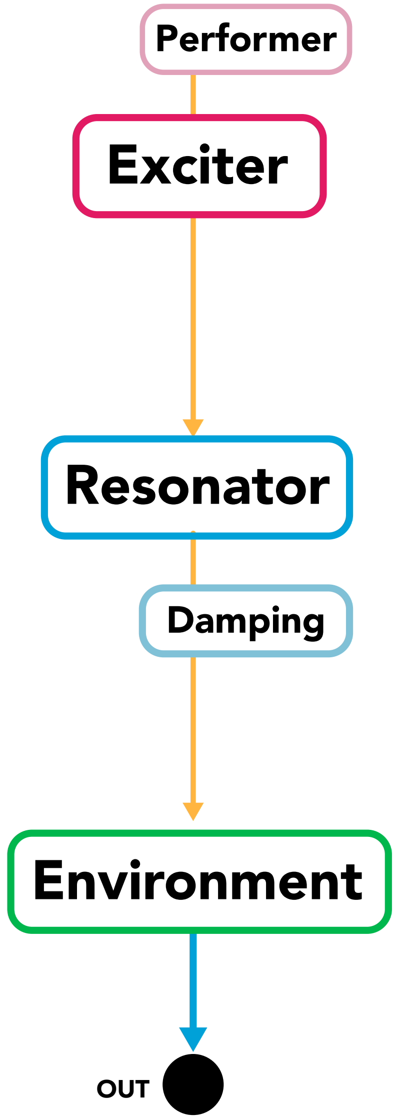
Physical modeling synthesis is not a simply a single algorithm, or single concept, but a family of algorithms or concepts that share the same principle — to observe the physical behavior of real acoustic instruments, mathematically model the physical phenomenon, and mimic the physical behavior virtually to recreate the sound.

This method usually focuses on three stages of sound generation: the **Exciter**, the **Resonator**, and the **Environment**.



PHYSICAL MODELING

All these stages have a unique set of parameters that, when varied, allow us to model the size, material, and shape of each stage into our algorithm, customizing our final sound.



Parameters

Physical characteristics performer: mouth, lips, arm...

Type of exciter: plectrum, pizzicato, reed, air column, drumstick...

Size, shape and material of the resonant body.

Impedance to sound propagation in the resonator given by size, material and shape...

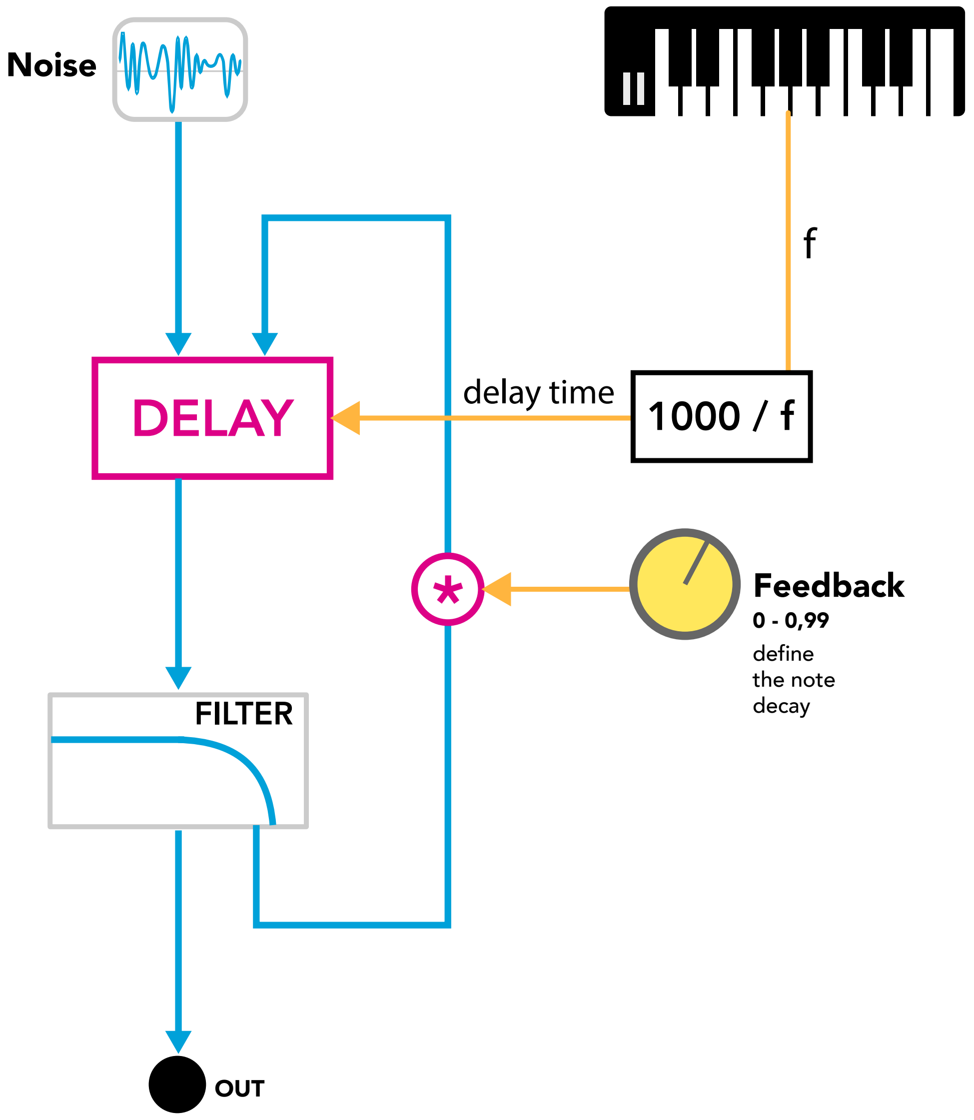
Type of sound pickup system: pickup, microphone... Distance between microphones, between resonant body and microphones...

PHYSICAL MODELING

Karplus - Strong (KS) algorithm

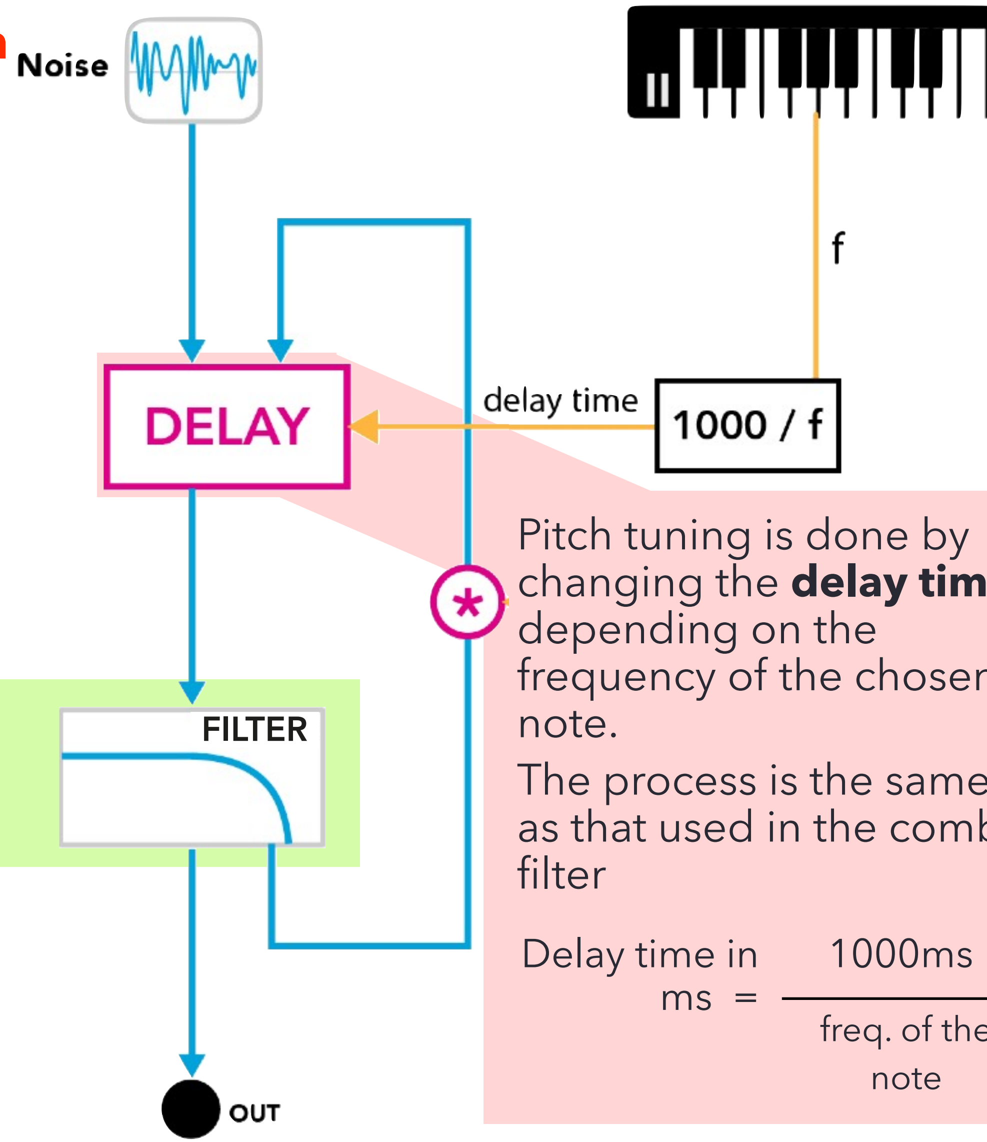
Originally conceptualized in 1983, the KS algorithm reproduces the physical mechanisms of a plucked or struck string

1. White noise is generated
2. This excitation is fed directly into a delay line
3. The output of the delay is input into a filter (usually a first-order low-pass filter)
4. The filtered signal goes to the output and is simultaneously fed back into the delay line, where steps 2-4 are repeated.



PHYSICAL MODELING

Karplus - Strong (KS) algorithm



The **low-pass filter (LPF)** removes higher harmonics and creates a sound similar to traditional instruments. Naturally in traditional instruments, the harmonics in the higher frequencies gradually fade away

Pitch tuning is done by changing the **delay time** depending on the frequency of the chosen note.

The process is the same as that used in the comb filter

$$\text{Delay time in ms} = \frac{1000\text{ms}}{\text{freq. of the note}}$$

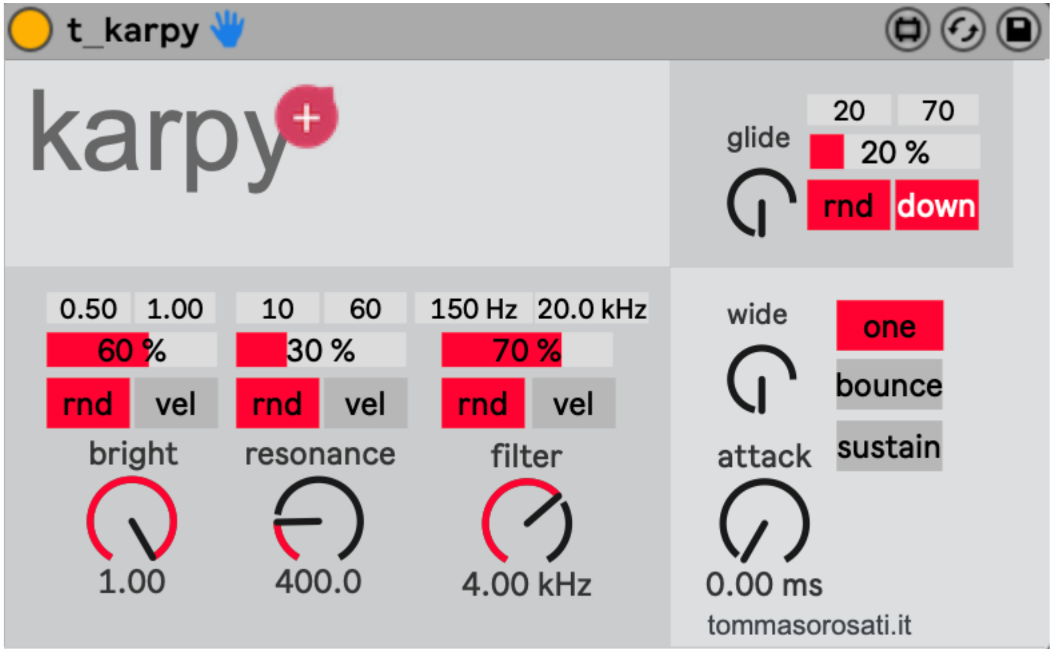
PHYSICAL MODELING

Karplus - Strong (KS) algorithm

Drum Synth Kplus in Ableton Live

PHYSICAL MODELING

Karplus - Strong (KS) algorithm



karpy by piumaxforlive

PHYSICAL MODELING

YAMAHA VL1 (1993) - Waveguide synthesis

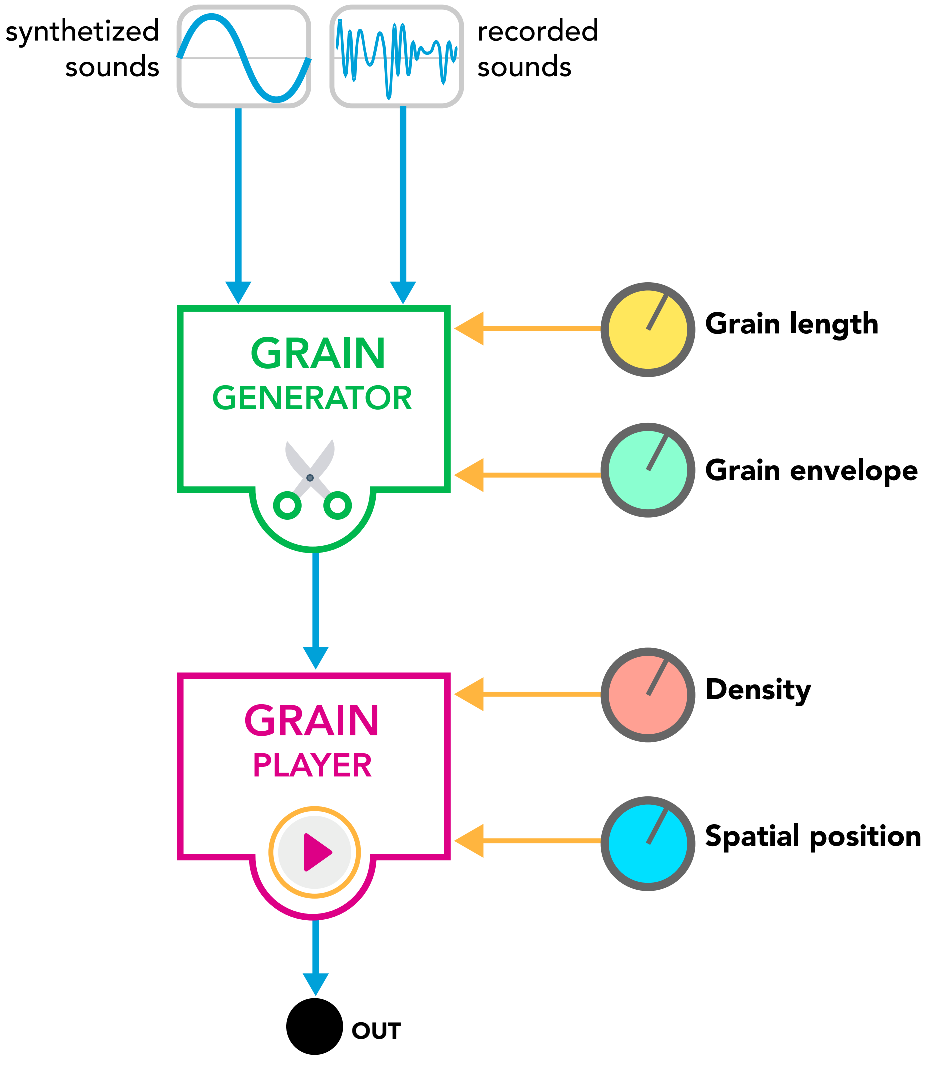
PHYSICAL MODELING

TENSION and COLLISION in Ableton Live

GRANULAR SYNTHESIS

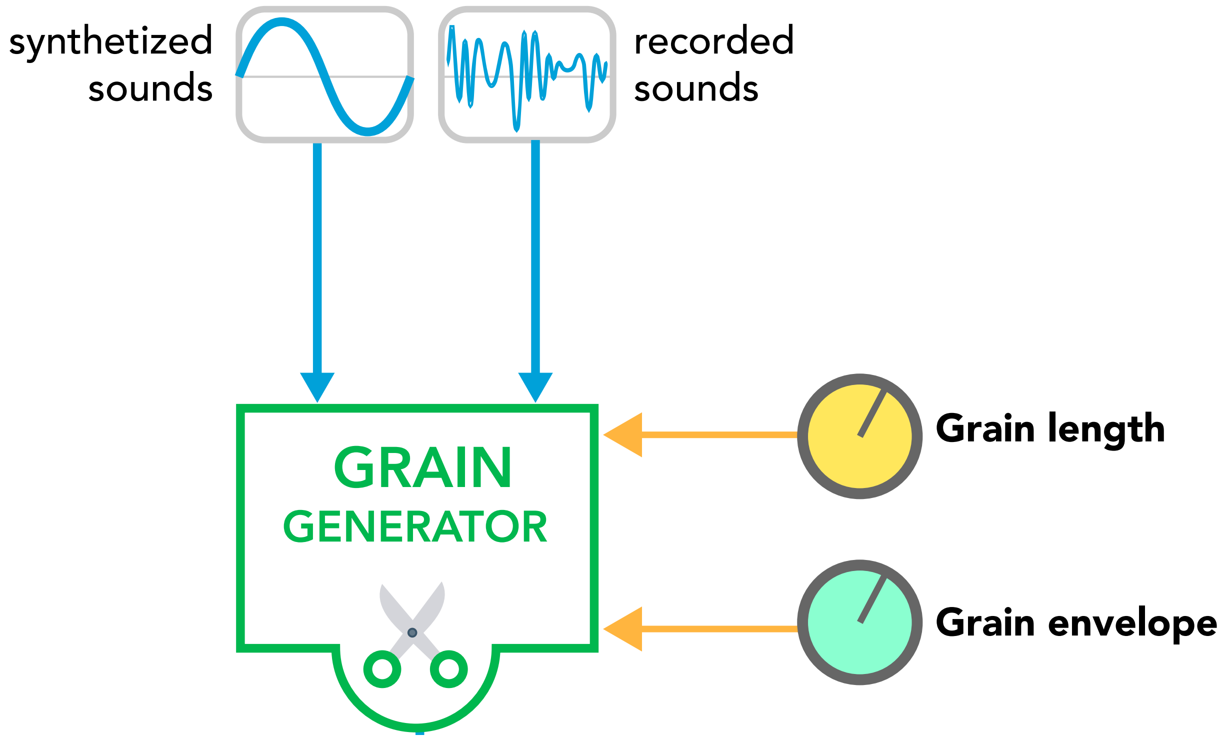
Granular synthesis centers on the idea of creating complex sounds from many simple short sounds called grains.

A **grain** is a very small sound fragment that, when combined and played sequentially and/or superimposed at varying speeds, phases, and volumes, generates a single fused timbre.



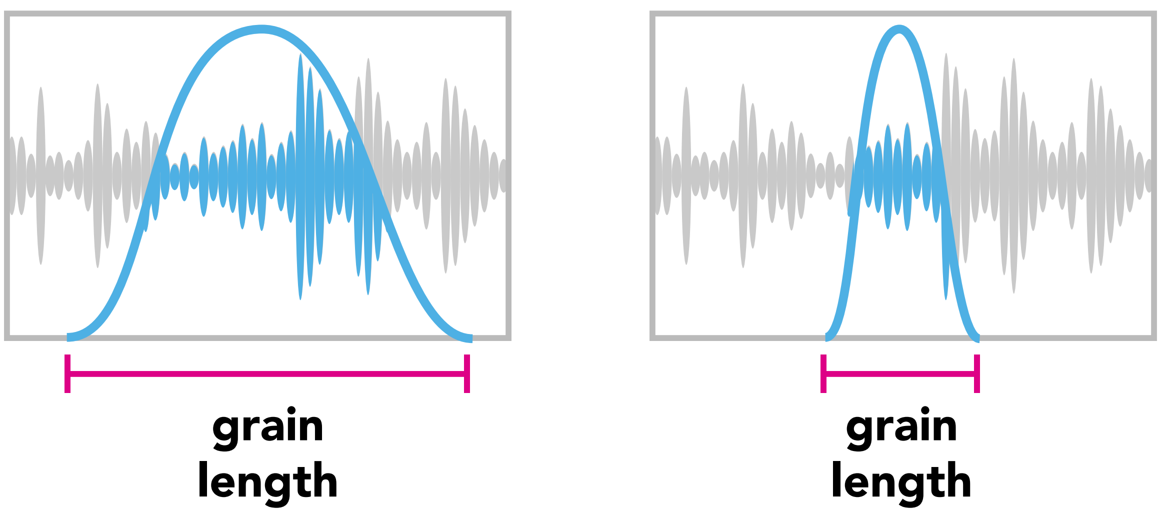
GRANULAR SYNTHESIS

These sounds grains can be derived from various sources, from recorded sounds to other synthesized sounds.



GRANULAR SYNTHESIS

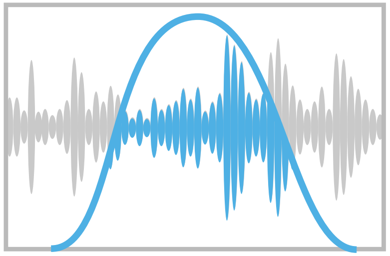
We set the **length** of the grains (generally between 1 and 100 ms)



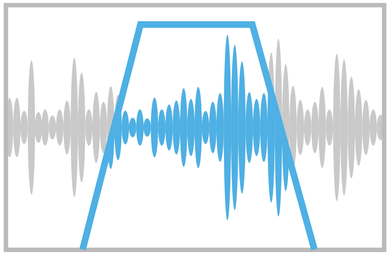
GRANULAR SYNTHESIS

We apply an amplitude **envelope** to each grain.

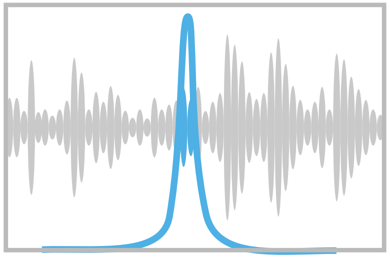
Symmetrical



Gaussian

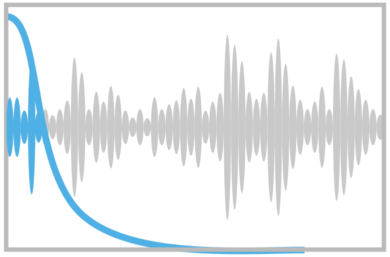


Trapezoidal

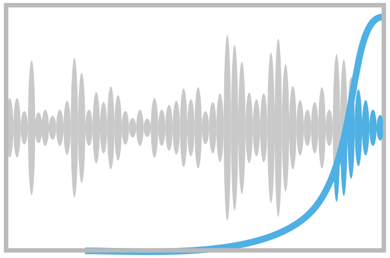


Pulse

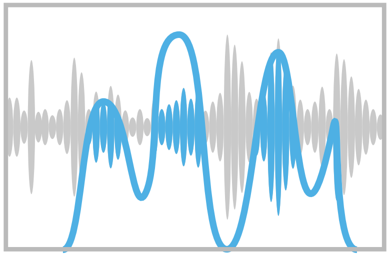
Asymmetrical



Fall



Rise



Noise

GRANULAR SYNTHESIS

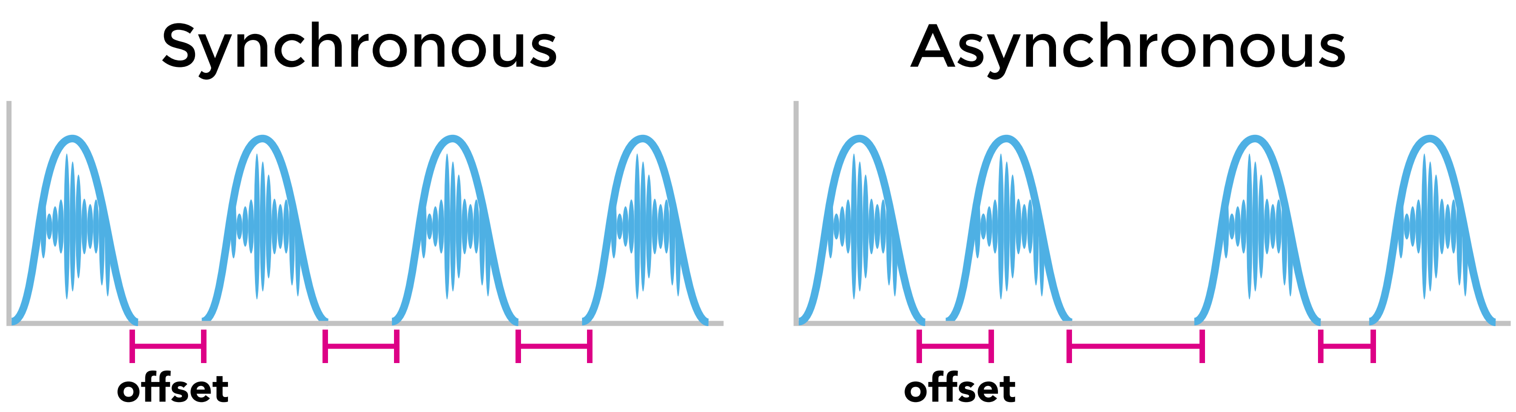
There are four types of grain playback:

Synchronous (Synchronous Granular Synthesis): When playing back a series of grains, the time gap or offset between the grains is constant.

Quasi-synchronous (QSGS): The time gap between the grains is almost, but not exactly, constant.

Asynchronous (ASGS): The time gap between the grains, during playback, is not constant.

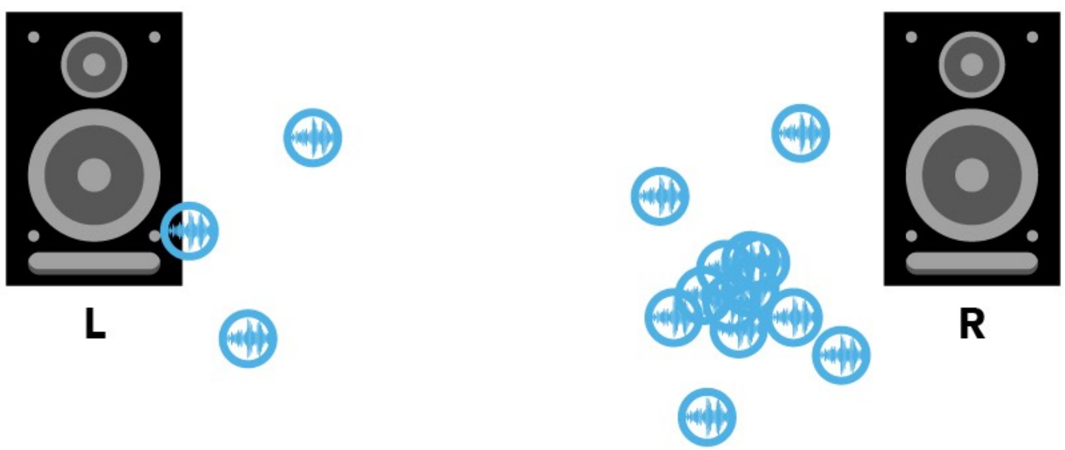
Pitch-synchronous (Pitch-Synchronous Granular Synthesis): The time gap between the grains corresponds to a frequency that is synchronized with the pitch of the grains.



GRANULAR SYNTHESIS

I can set the following parameters for a grain player:

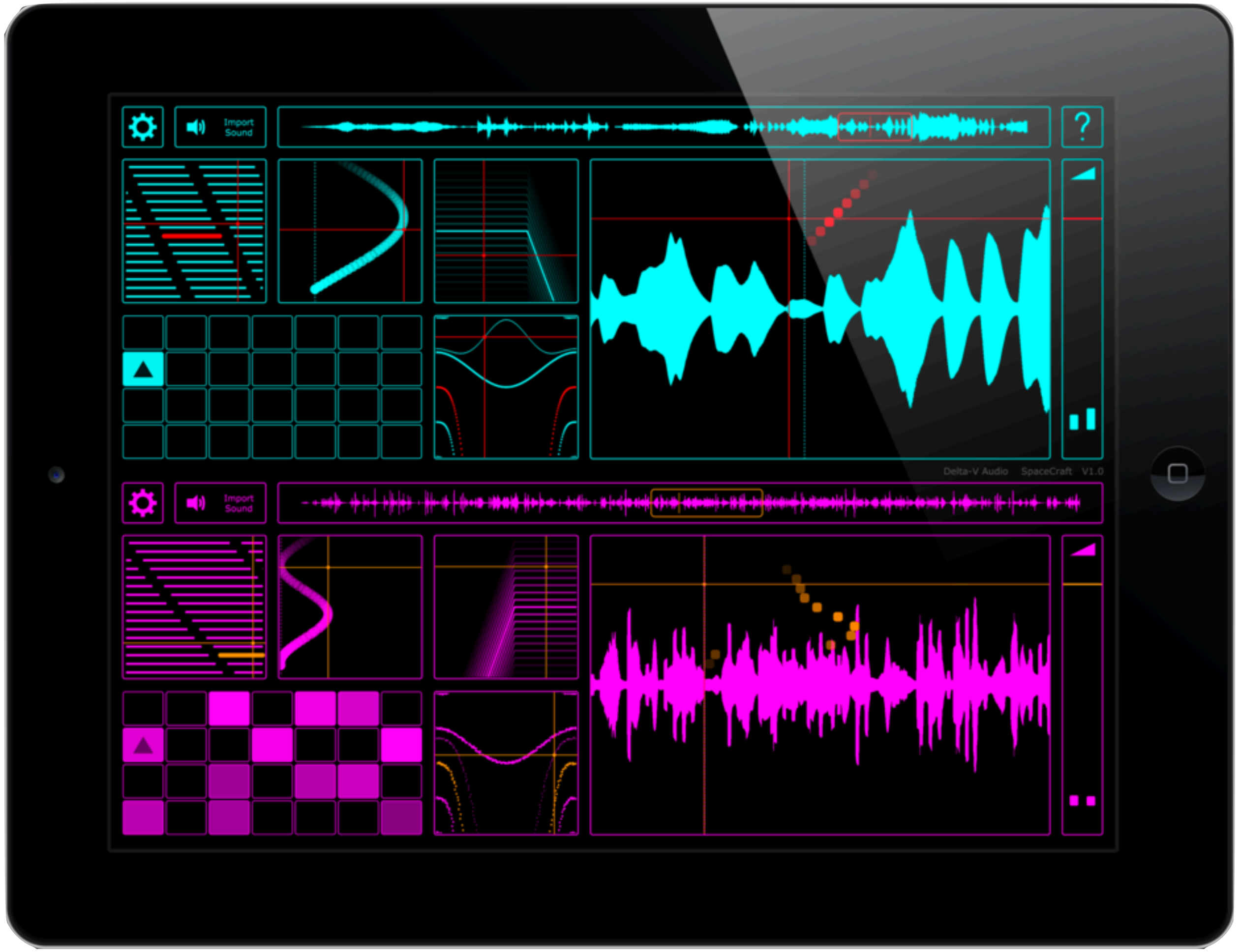
- **Grain density** is the number of grains that the player plays at the same time.
- **Spatial position** determines where to place the grains the players play within the space.



GRANULAR SYNTHESIS

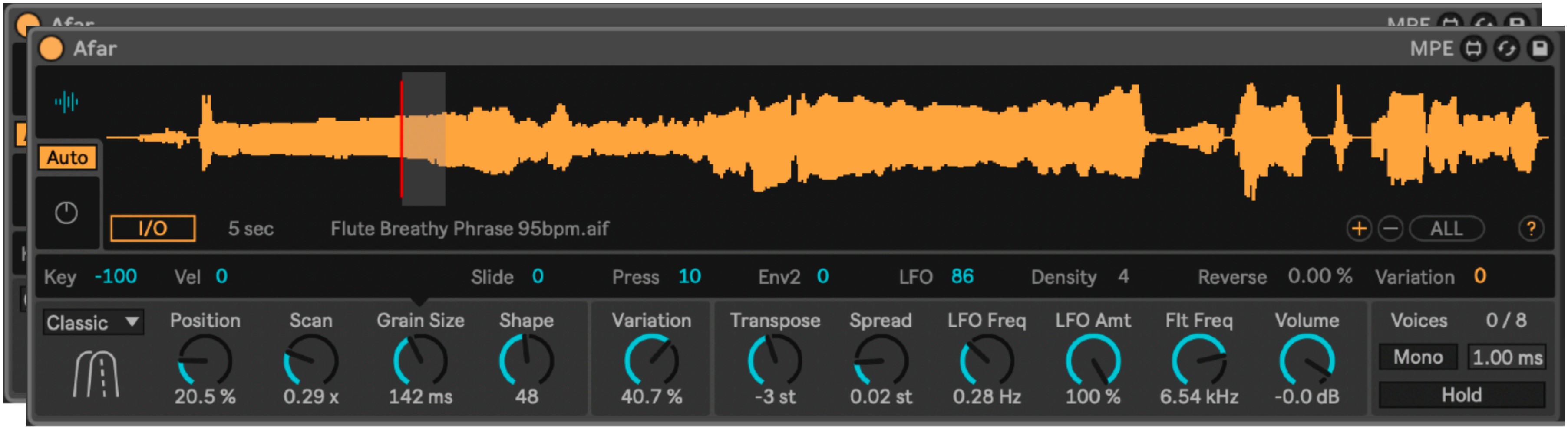
Tasty Chips Electronics GR-1 (2019)

GRANULAR SYNTHESIS



SpaceCraft app (2018)

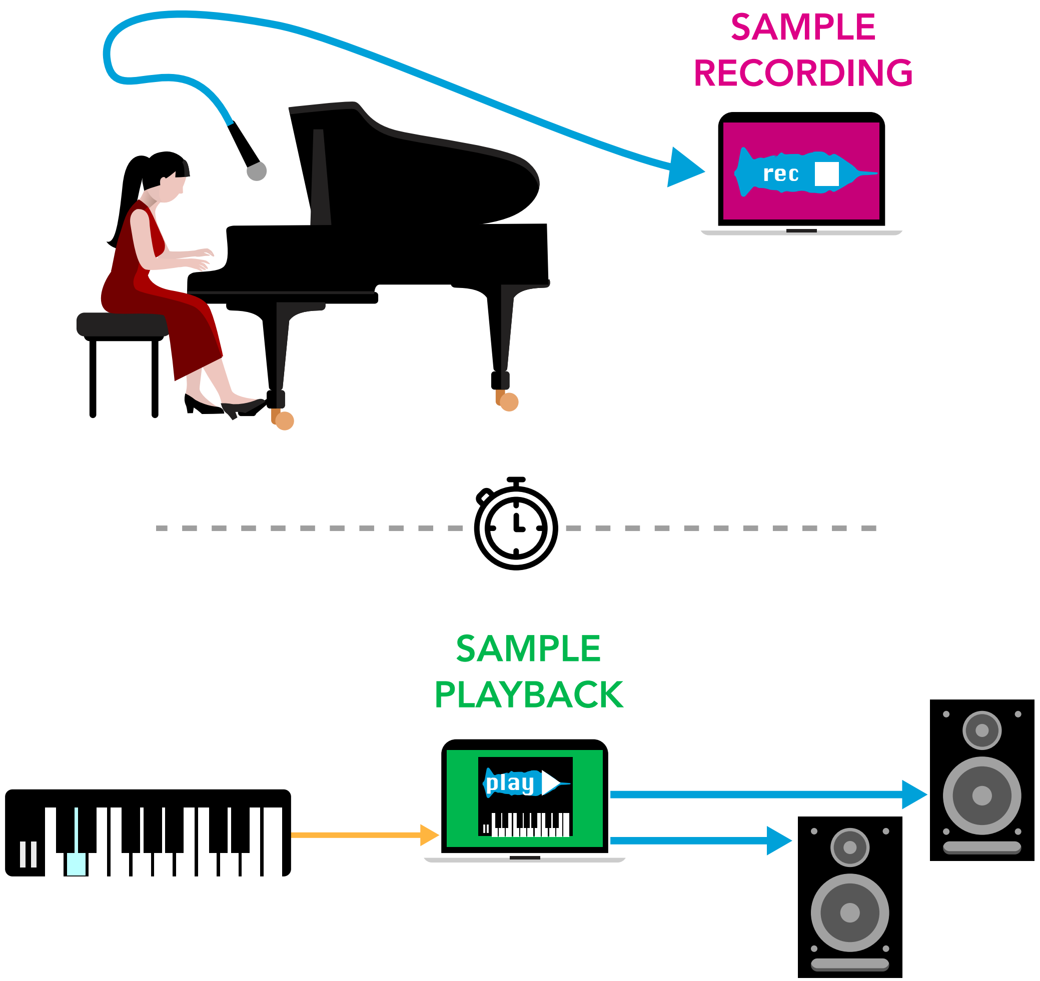
GRANULAR SYNTHESIS



GRANULATOR III in Ableton Live

SAMPLING SYNTHESIS

Sampling synthesis is based on reproducing previously recorded notes upon pressing, for example, keyboard keys.

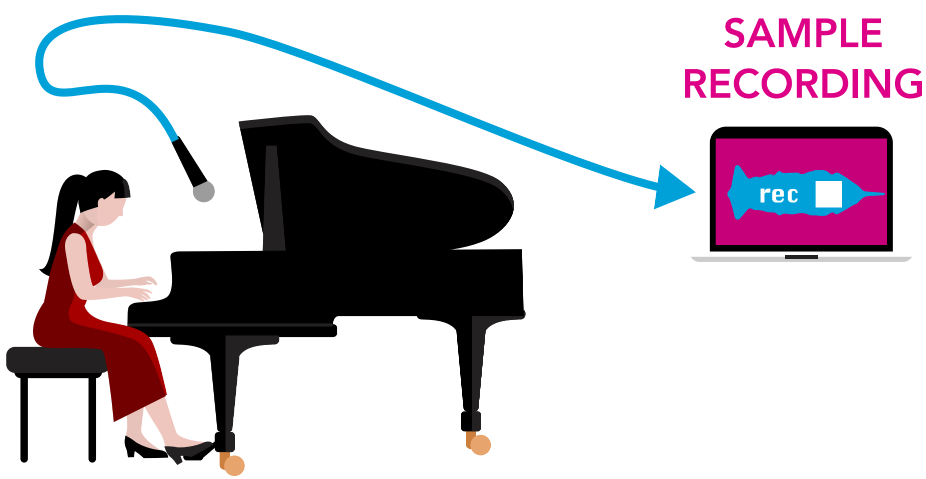


SAMPLING SYNTHESIS

1

Sample recording

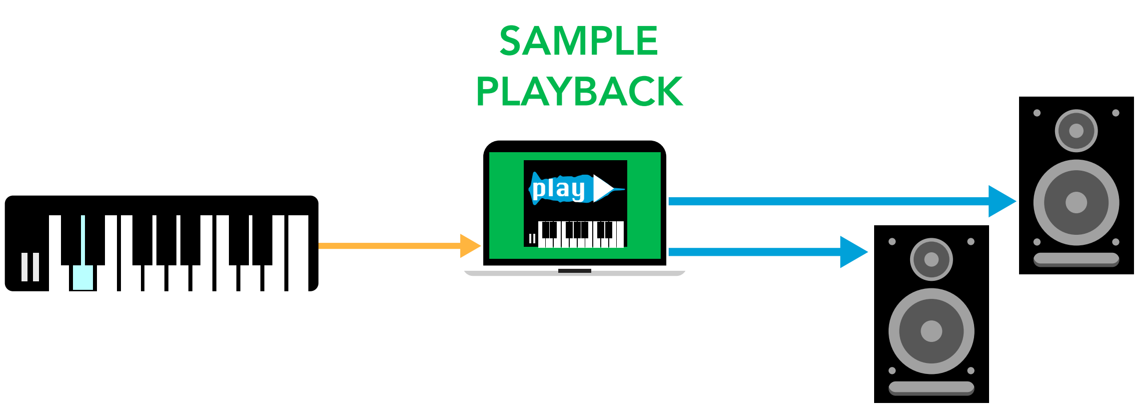
- **Single-sampled**
  one sample is recorded, which will be used, during playback, to generate all the notes of the instrument
- **Multi-sampled**
  a sample is recorded for each note of the instrument
- **Multilayer-sampled**
  not only is every note of an instrument recorded, but each note is also recorded at different dynamics.



SAMPLING SYNTHESIS

2 Sample playback

For single-sampled synthesis, we tell our sampler what note we have recorded as a sample. The software then transposes the note to output pitches for all the other keys that are pressed.

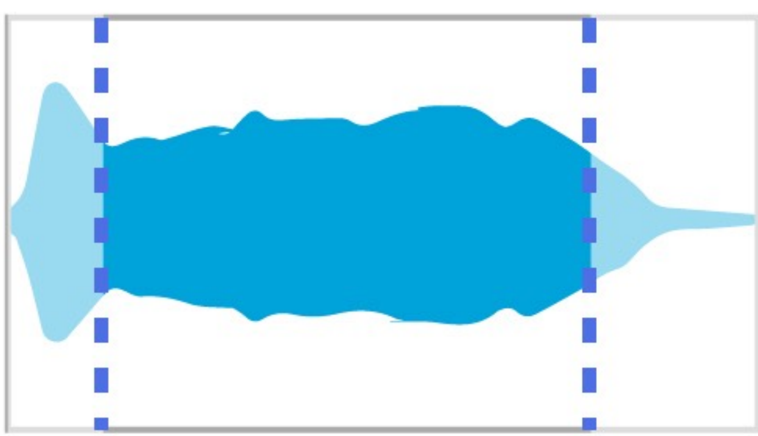


SAMPLING SYNTHESIS

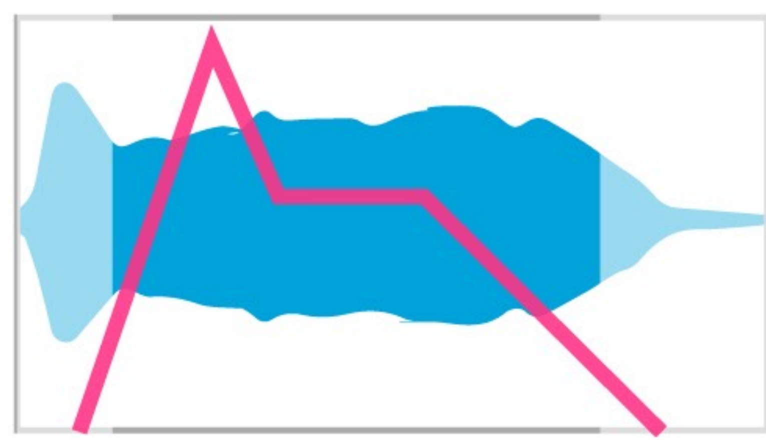
You can choose the start and end point of the sample during playback

You can superimpose an amplitude envelope to each sample

Crop



ADSR

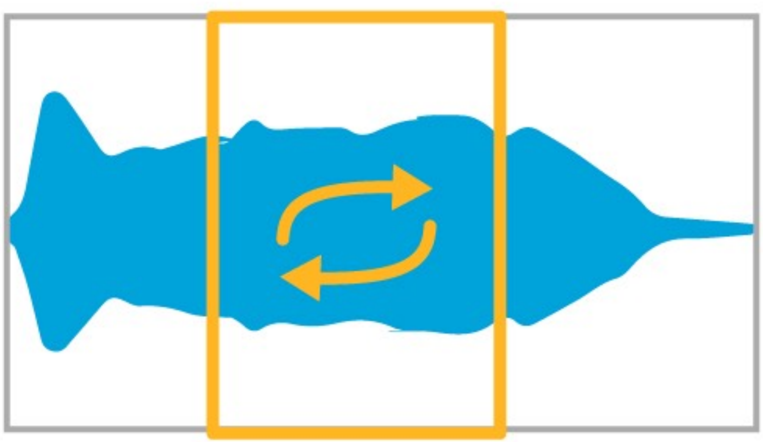


SAMPLING SYNTHESIS

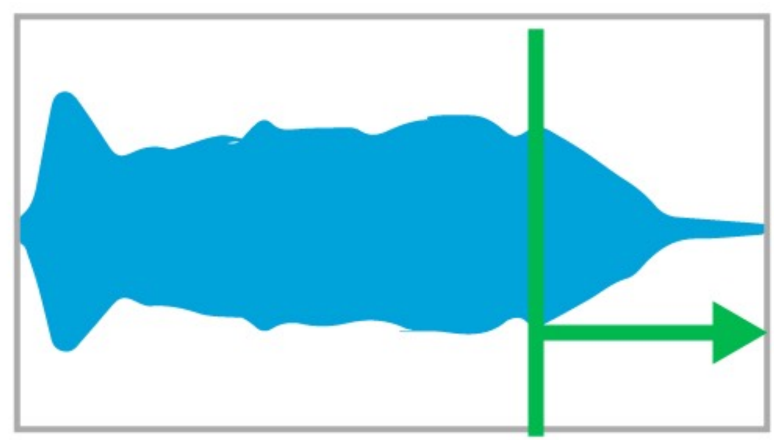
A loop is the portion of the sample that plays back continuously as long as the key is pressed and sustained

The end point is the parameter that marks the time point within the sample that tells the sampler where to go after the key is released

Loop

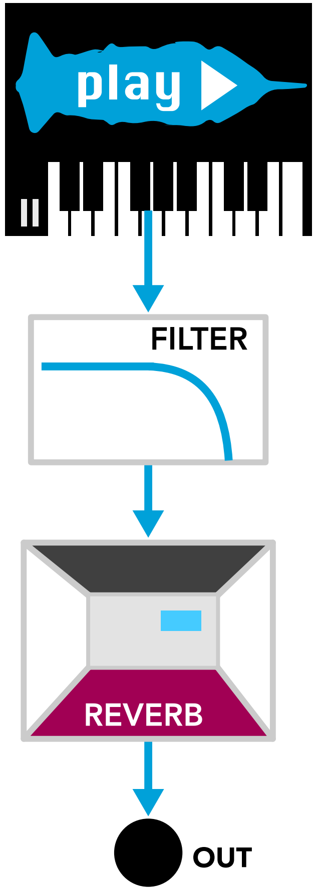


End point

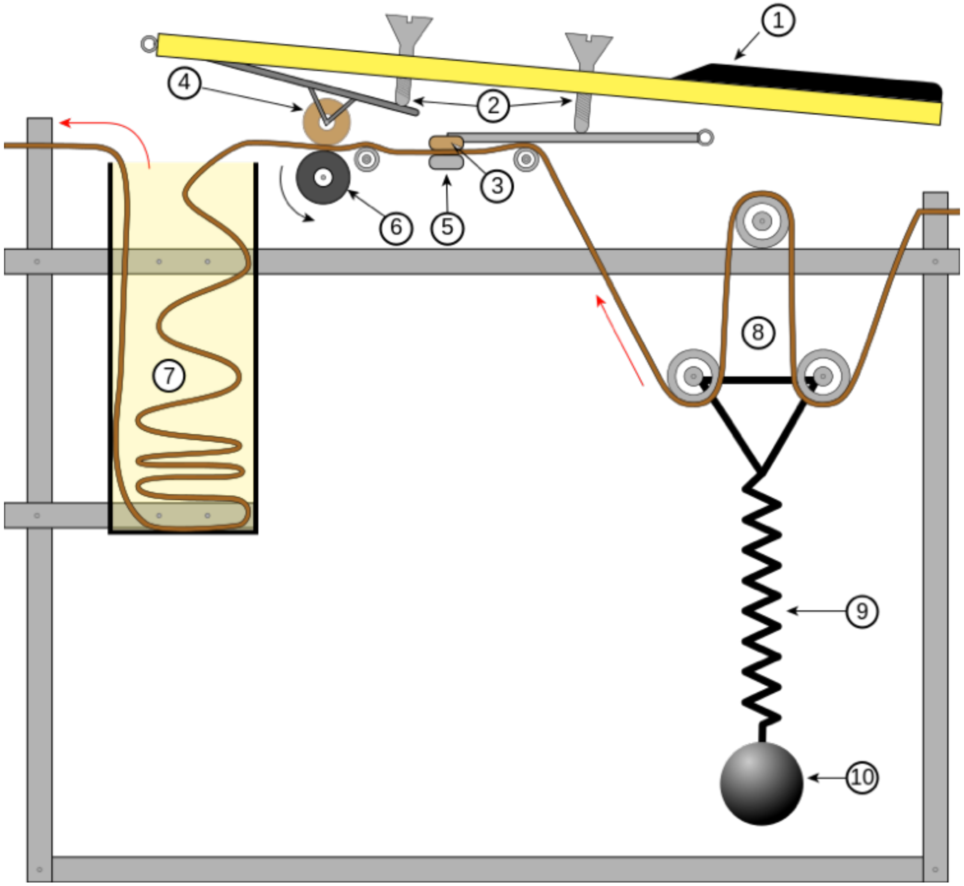


SAMPLING SYNTHESIS

At the end of the sampler's workflow, as with other types of synthesizers, we can find one or more **effects** that helps refines the sound we just created.



SAMPLING SYNTHESIS



MELLOTRON M400 (1970)

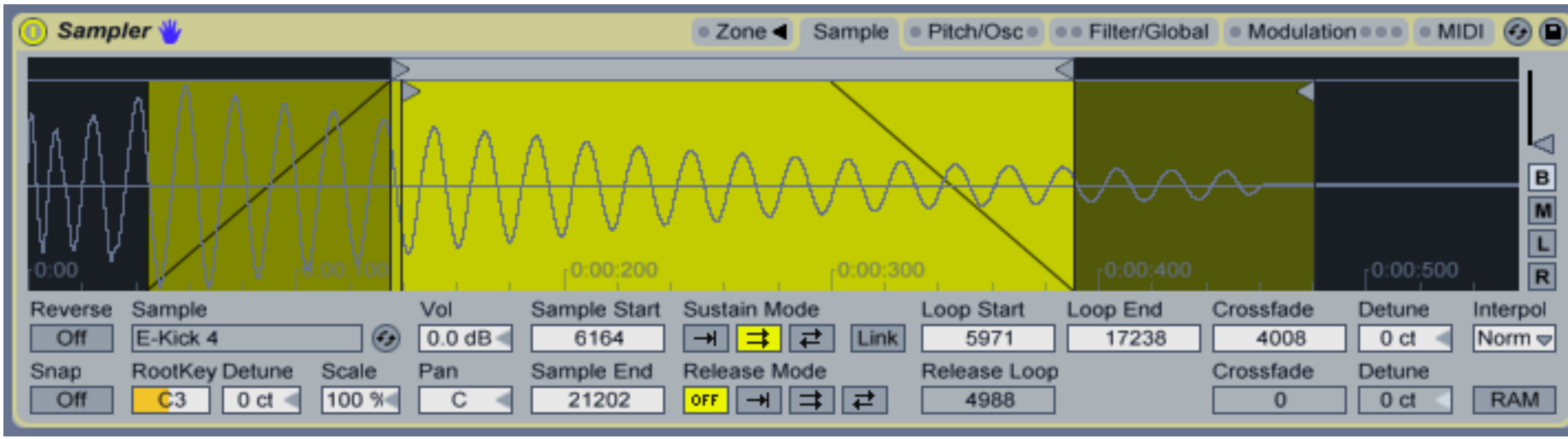
SAMPLING SYNTHESIS

NORD PIANO 4 - Nord (2019)

SAMPLING SYNTHESIS

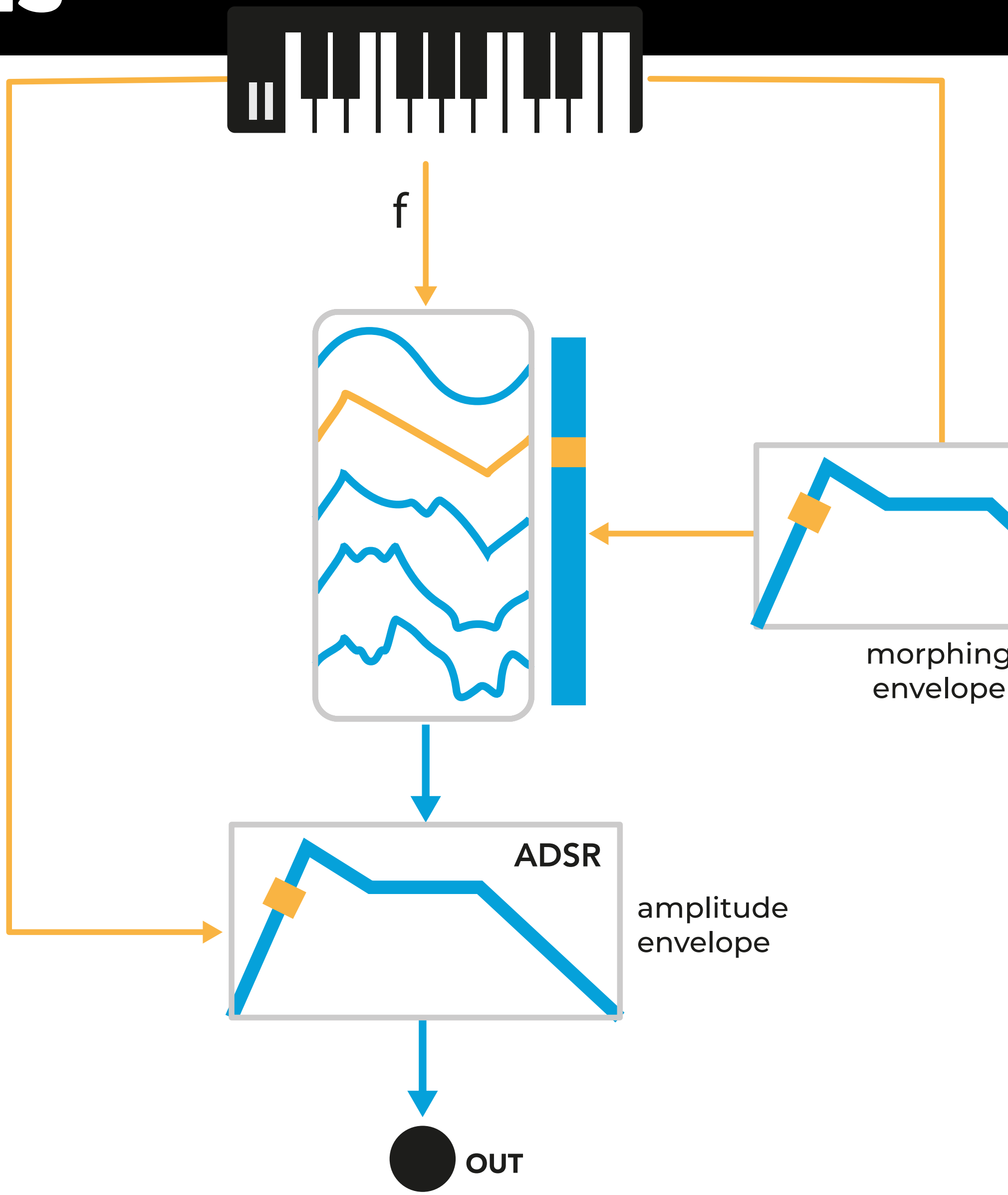
KONTAKTby Native Instruments

SAMPLING SYNTHESIS



SAMPLER in Ableton Live

WAVETABLE SYNTHESIS



Wavetable synthesis generically relies on reading through tables of pre-existing values to create sound. The tables generally store values that represent one period of various waveshapes. By reading through the list of values that denote a particular waveshape at different speeds, this synthesis algorithm is able to generate different pitches while retaining the timbral structure that comes from the waveform itself.

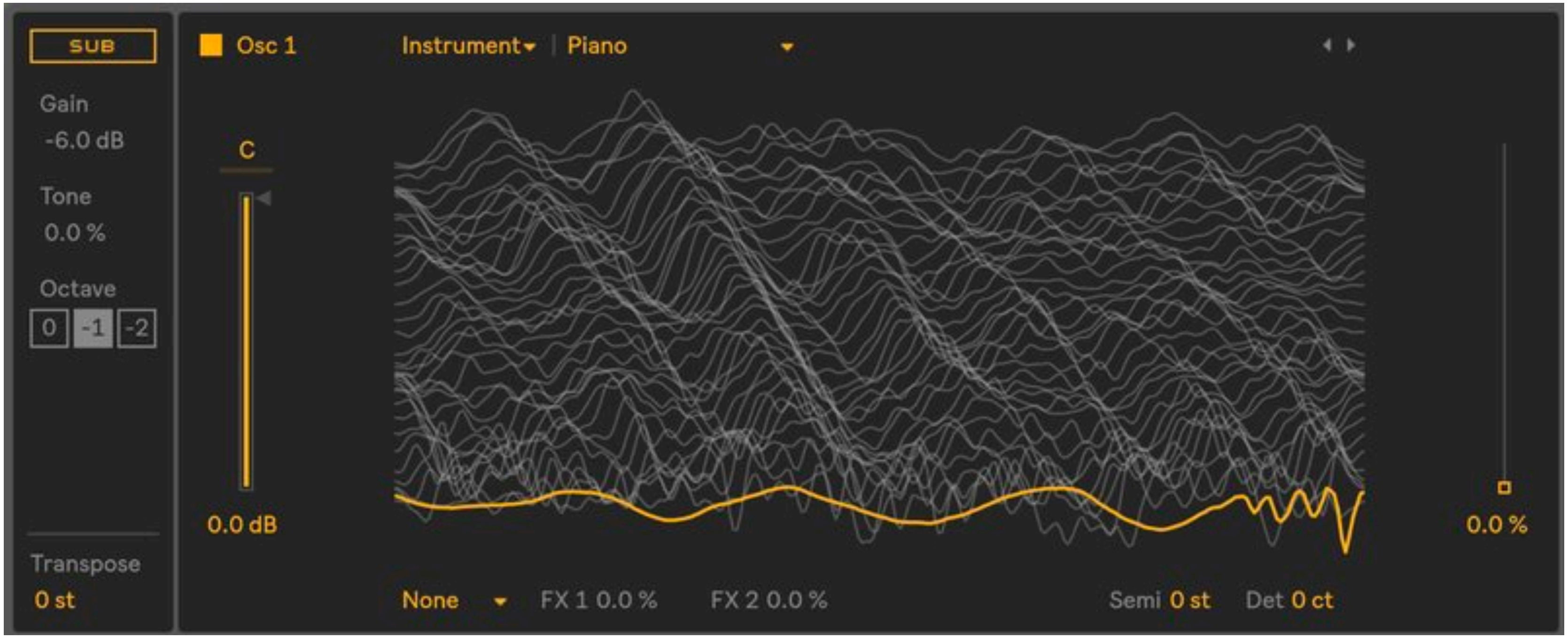
It is also possible, instead of being limited to one waveform or table, to read through several tables containing different waveforms simultaneously. The result creates a timbre that can come “alive,” potentially varying its characteristics as the note is played. To make the sound come alive, a morphing envelope (ADSR, LFO, automated envelopes, manually driven envelopes) is used to move between waveshapes.

Sintesi Wavetable

PPG WAVE 2.2 (1981)

KORG WAVESTATION (1990)

WAVETABLE SYNTHESIS

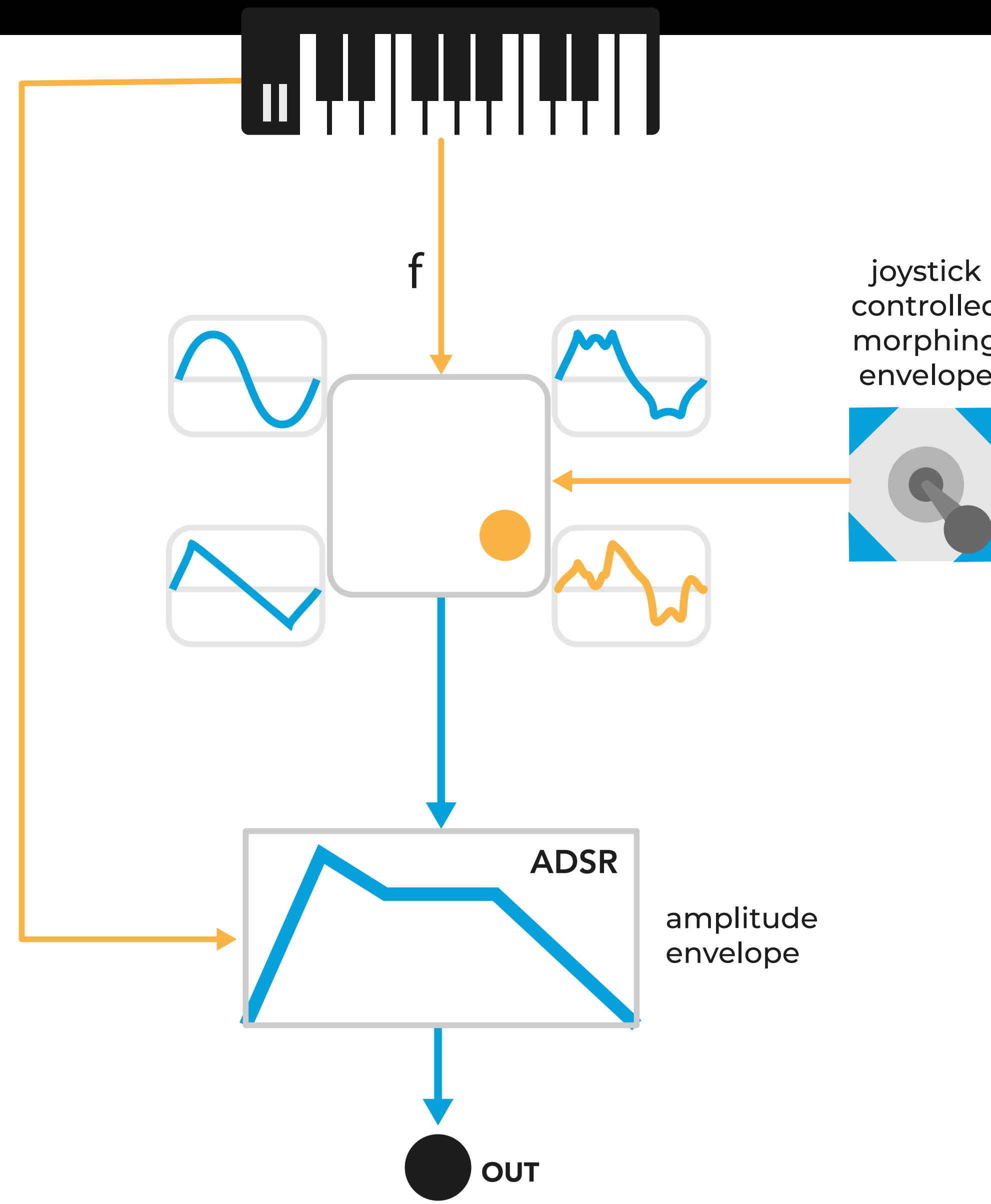


WAVETABLE in Ableton Live

VECTOR SYNTHESIS

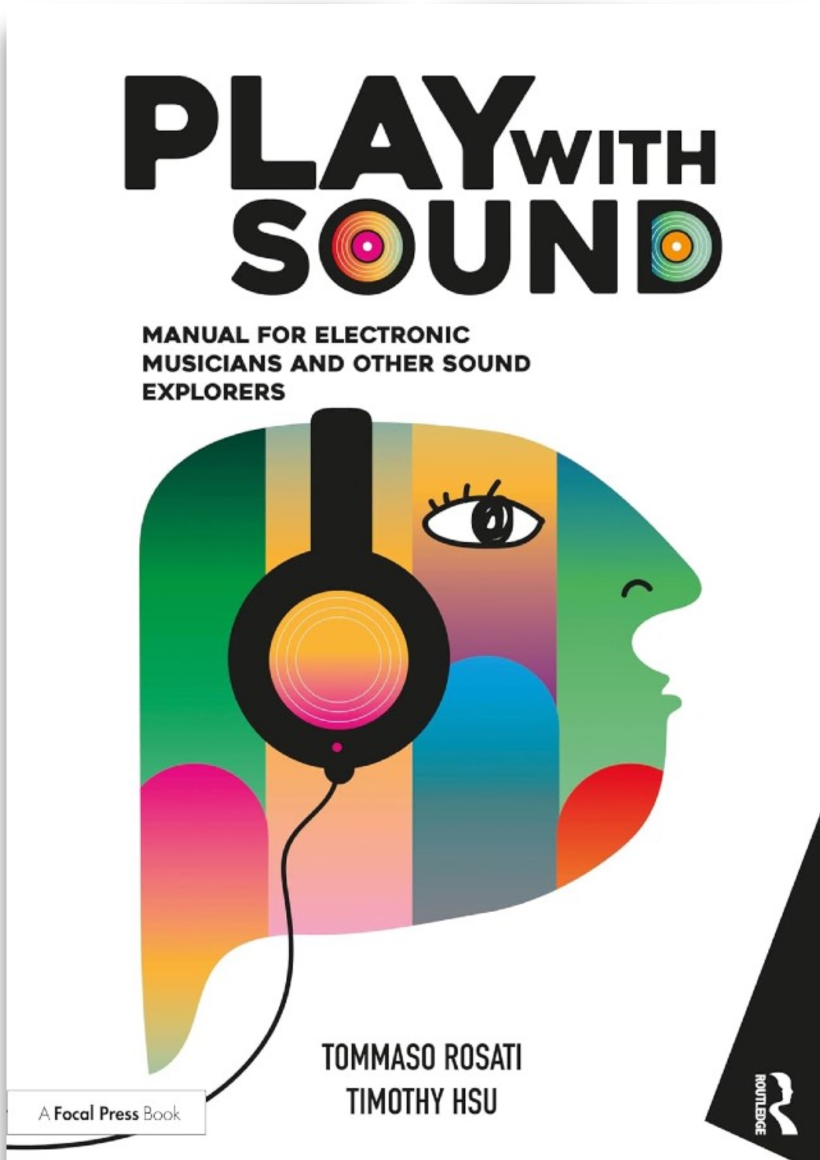
A variation of Wavetable synthesis is **vector synthesis**.

Instead of moving in one dimension through a table, we use a two-dimensional plane with four tables at the corners. A joystick (or similar device) sends X and Y values to morph between the four timbres.



VECTOR SYNTHESIS

Sequential Circuits Prophet-VS (1986-87)



THE BOOK IS NOW AVAILABLE!