SOUND SYNTHESIS

AIST2010 Lecture 5

OUTLINE

- BACKGROUND
- ADDITIVE SYNTHESIS
- MODULATION SYNTHESIS
- SUBTRACTIVE SYNTHESIS
- SPECTRAL ALTERNATION
- PHYSICAL MODELLING
- SAMPLING

FROM ANALOG SYNTHESIZERS TO VIRTUAL SYNTH

Image from: https://120years.net/the-musical-telegraphelisha-greyusa1876/

***1874**: the **Musical Telegraph** by Elisha Gray*

- Audio was the first time generated using oscillations created by electromagnets

***1920**: the **Theremin** by Léon Theremin*

- Oscillators with frequency and amplitude controlled using capacitance from human hand to antennae
- Still available in market for specialized musicians today, with updated electronics

Read: https://120years.net

Image from: https://www.thomann.de/gb/moog_etherwave_theremin_plus.htm

FROM ANALOG SYNTHESIZERS TO VIRTUAL SYNTH

***1930s-40s**: **electronic** instruments with oscillators, filters, effects, and envelope controllers*

***1957**: the first **programmable** electronic synthesizer by RCA*

- Automatic playback using punch-tape score

***1964**: the Moog **modular synthesizer** by Robert Moog*

- A big legacy, connections between modules made with patch cords

***1974**: the first **digital synthesizer** prototype by Yamaha*

- Microprocessors were used to generate signals, instead of analog circuitry

Image from:
https://modularsynthesis.com/moog/moog1/moog1.htm

Video from: https://youtu.be/n3K_fZDvINs

These analog synths are still in use! See: https://youtu.be/Q5hgQTEf0mg

FROM ANALOG SYNTHESIZERS TO VIRTUAL SYNTH

1983: ***MIDI*** *1.0 was standardized*

1987: *the Roland D-50 pioneered with* ***sample playback*** *heavily fused with digital synthesis*

- Started the era of workstation synthesizers with sufficient computer memory

1996: *Virtual Studio Technology (****VST****) was released by Steinberg*

- VST is the current standard of most software synthesizers
- While some analog/digital synthesizers are still manufactured, software/virtual synthesizers becomes very common

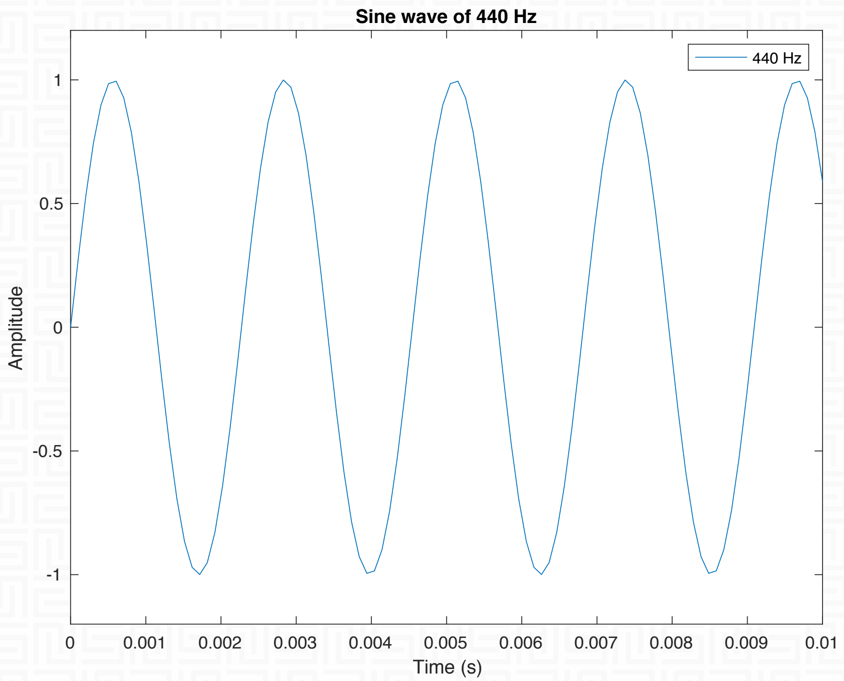
Read: *https://www.juliusdobos.com/the-philosophy-behind/analog-vs-digital-synthesizers-debate*

A PURE SOUND IN COMPUTER

Inheriting from analog synthesizers, most of the synthesis tools in computer has the base in sinusoids

$$g(t) \coloneqq A \sin(2\pi f t + \varphi)$$

One single sine wave in the audible range is called a pure sound



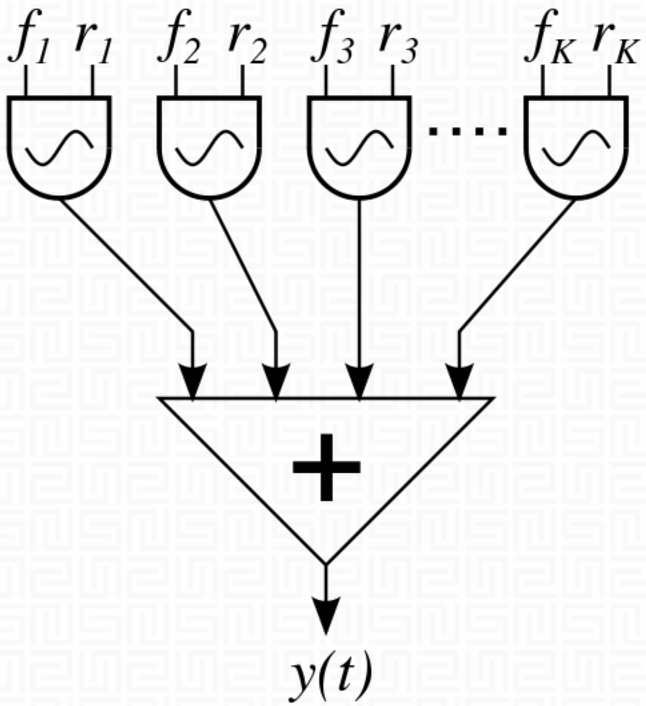
ADDITIVE SYNTHESIS

The most intuitive way to synthesize a sound: sum the sinusoids appropriately

- Different ***amplitude ratios*** for the harmonic sequence affects the timbre

A discrete oscillator is required for each "voice"

- Huge **computation requirements** for real-time synthesis
- Flexible control of envelope of each harmonic

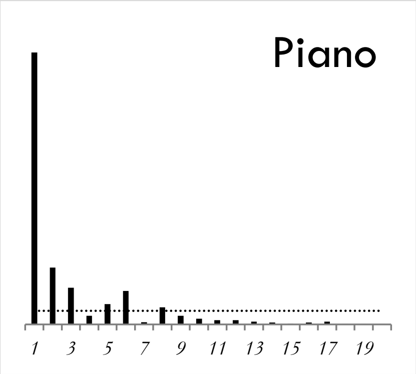


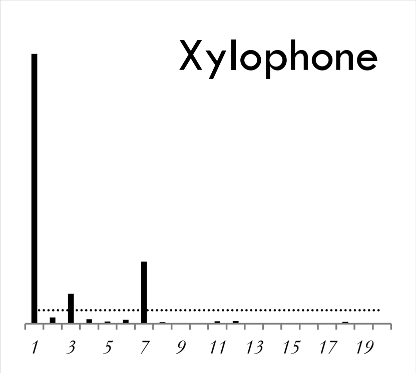
WAVETABLE SYNTHESIS

To generate musical instrument sounds, the frequency ratio of harmonics contributes a lot to the timbre

Wavetable synthesis maintains only lookup tables for (sampled) periodic waveforms or other kind of values

- By specifying the ***relative strength of harmonics***, summation of sine waves can be generated mathematically without using a bunch of oscillators
- Shapes of individual harmonics may not be easily customizable





MODULATION SYNTHESIS

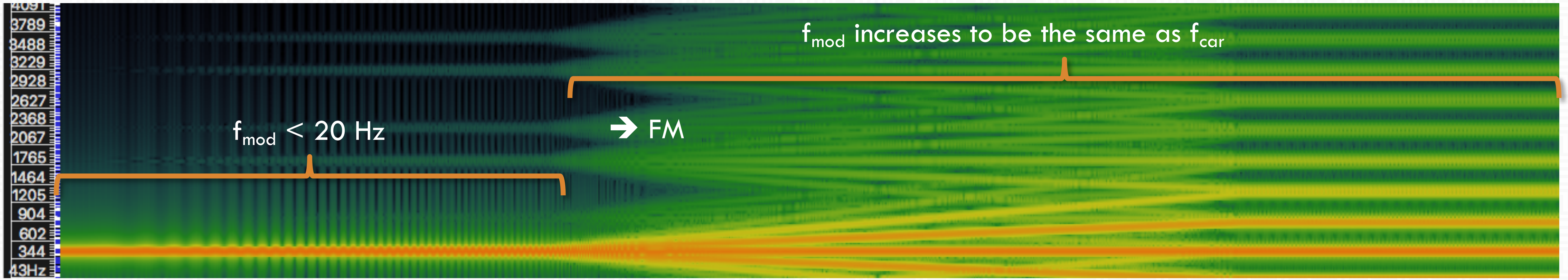
Two musical terms:

- ***Tremolo***: a slight but continuous shake of amplitude
- ***Vibrato***: a slight but continuous shake of frequency

When the vibrato/tremolo rate increases beyond 20 Hz, they go into the audible range and would affect the timbre

Sounds are generated using

- Original "***carrier***" signal at f_{car}
- Changing "***modulating***" signal at f_{mod}



AMPLITUDE MODULATION (AM) VS FREQUENCY MODULATION (FM)

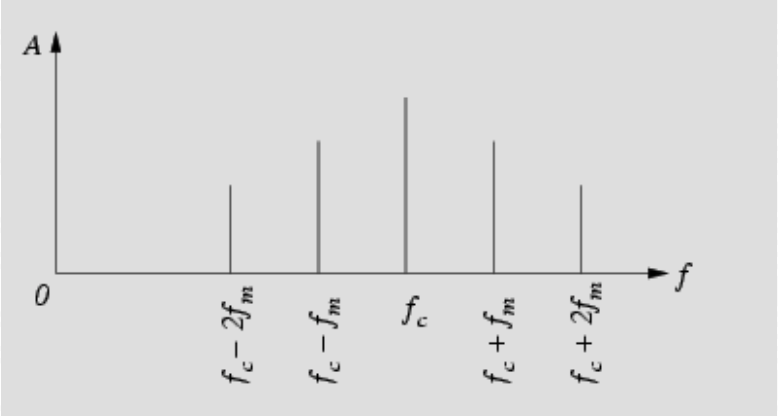
***AM** is now more often used as an audio effect instead*

- "Ring Modulation" is a simpler AM (good for alien voices!)

***FM** synthesis has been popular for its flexibility and lightweightedness*

- Fundamental frequency perceptual to human ear is the GCD of the carrier frequency and modulation frequency, e.g.
  - With a carrier frequency at 330 Hz and a modulation frequency at 220 Hz, the pitch would sound like 110 Hz
- FM index controls the number of sidebands

Phase Modulation (PM) is also possible!



SUBTRACTIVE SYNTHESIS

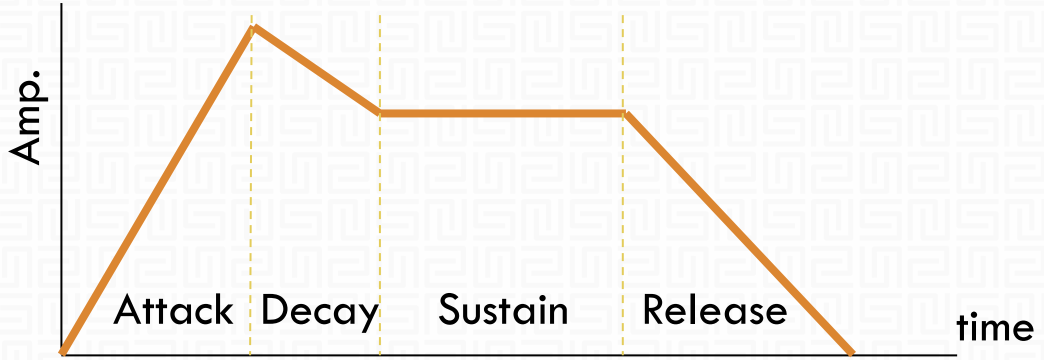
Starting with a complex sound, subtractive synthesis allows change in the sound in:

- Time domain: ADSR envelopes
  - This ensure the amplitude is not always maximum and can change through time
- Frequency domain: filters
  - Low-pass, high-pass, or band-pass filters remove certain frequency components
  - To be discussed in the Filters lecture

To be discussed more in the ***Filters*** *lecture*

ADSR ENVELOPE CONTROLLERS

A natural sound from real musical instruments can be split into:



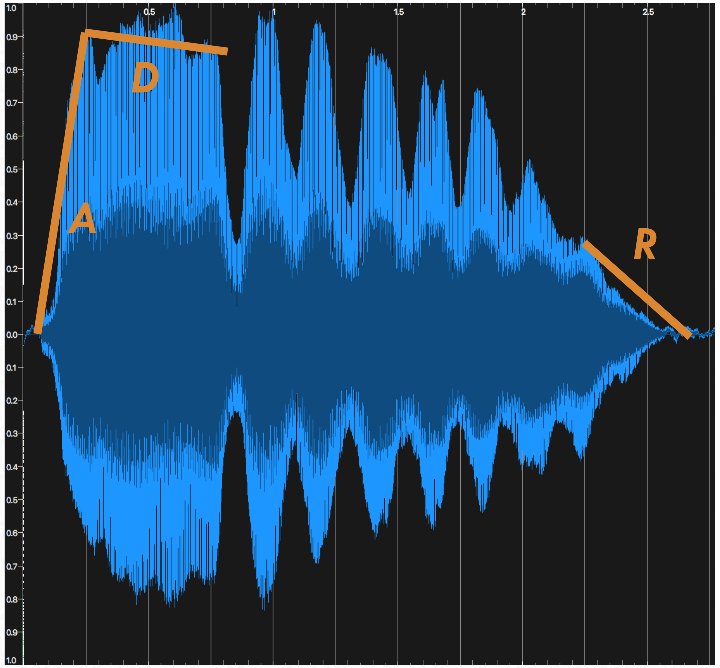
Usually we talk about time taken for A, D, and R, but level for S

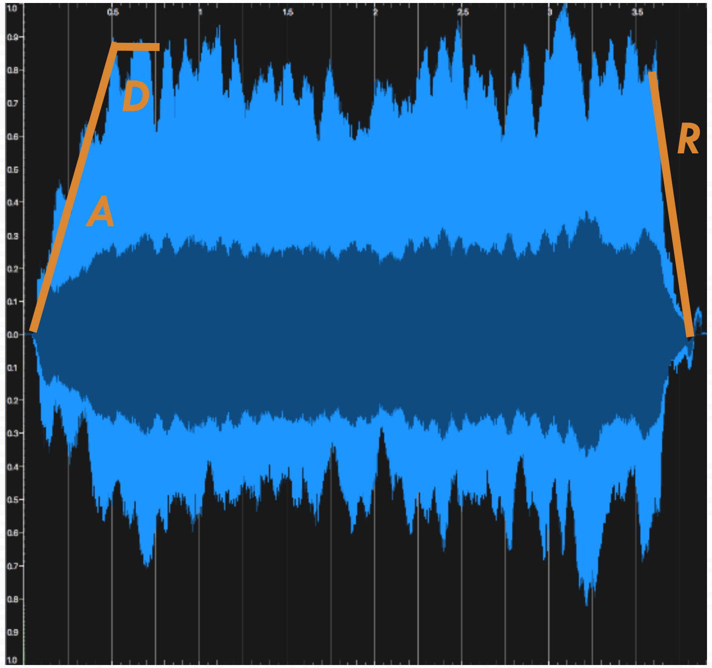
- **A** From the sound onset to the peak
- **D** Decrease of energy after the peak
- **S** In some musical instruments, continuous playing could hold the sound
- **R** When the sustaining mechanism ends, the sound dampens naturally

Some sophisticated synthesizer models can allow AHDSR

- Hold: the time after the first peak, before decay
- Multiple peaks are allowed

ADSR ENVELOPES





WHITE NOISE: THE FULLEST SPECTRUM

Broadband noises provide a good start for subtractive synthesis

- ***White noise***: signal of random sequence of a flat spectrum of equal power in linear frequency dimension
  - ***Pink noise***: flat spectrum of equal power in log frequency, i.e. more low-frequency components
  - Red (Brownian) noise: even more low frequencies
  - Blue noise: more high frequencies
  - Grey noise: A-weighted white noise
- Try this: https://mynoise.net/NoiseMachines/whiteNoiseGenerator.php

Image from: ***Comp. Music Instruments***, *p.73*

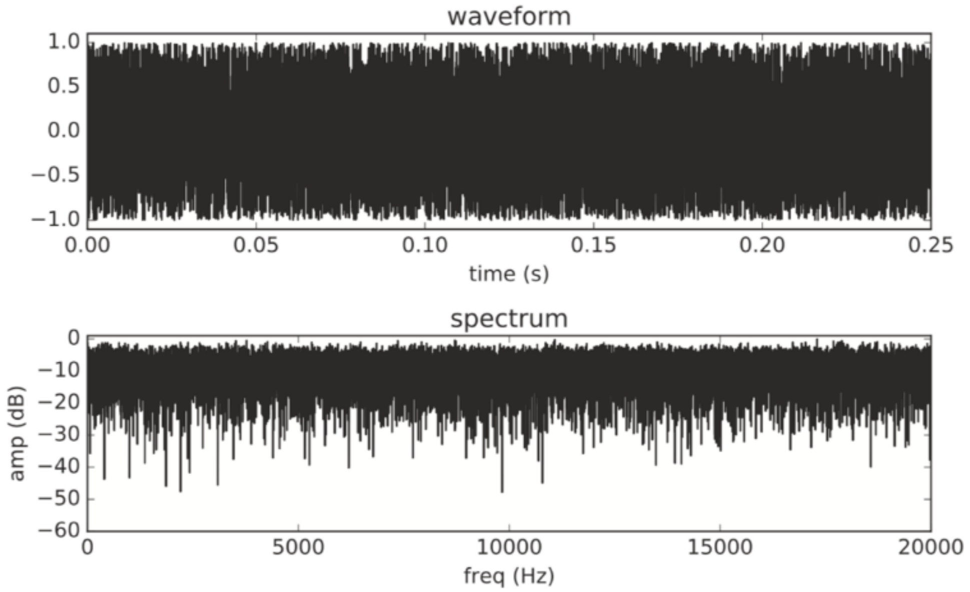
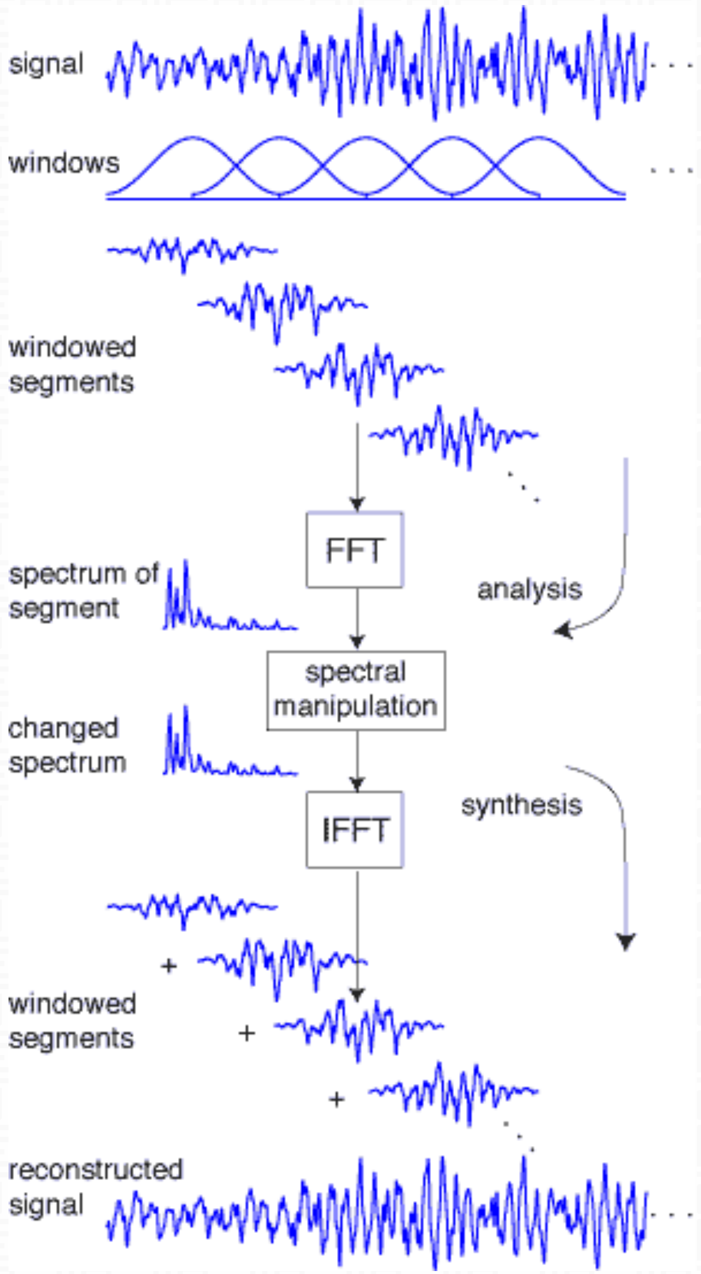


Image from: *https://sethares.engr.wisc.edu/vocoders/phasevocoder.html*



SPECTRAL ALTERNATION

The original "Phase Vocoder" involves analysis of the sound, alternation at the spectrum and resynthesis

1. *Converting time-domain wave into frequency and phase data*
2. *Editing frequency magnitude information to alter the spectrum*
   - E.g., changing harmonic ratios
3. *Resynthesis using inverse FFT with frequency and phase data*

PHYSICAL MODELLING

Using real-world physics, sound waves are generated by model simulation, sometimes termed "waveguide" synthesis

- Vibrating strings
- Acoustic tubes
- Wooden/metal bars
- Stochastic noises for percussion

"Virtual acoustic musical instruments"

- Read: https://ccrma.stanford.edu/~jos/jnmr/

SAMPLE-BASED SYNTHESIS

The recorded sound of a musical instrument (or something else) is played back directly

- The sustain part in ADSR can be manipulated to fit the synthesis duration

Nowadays most synthesis is done this way for realism

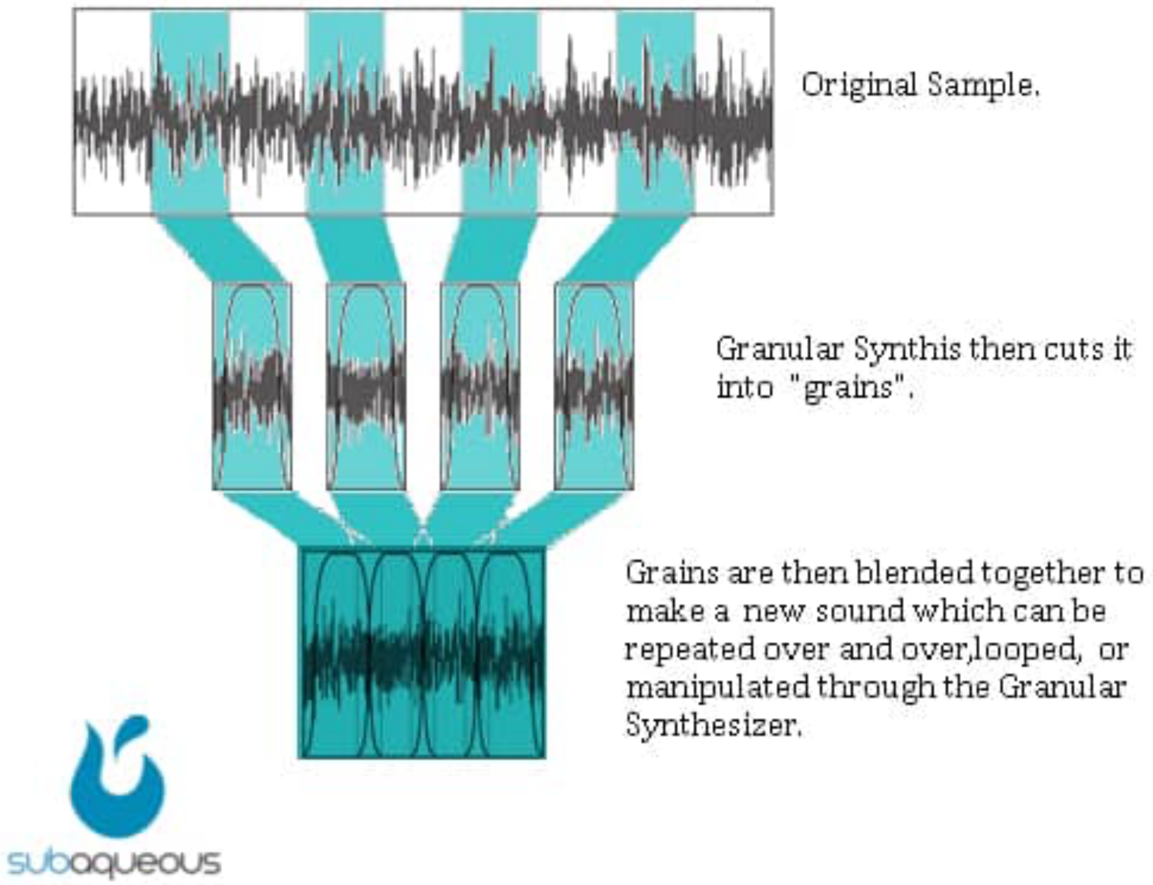
- ***Computer storage is cheap***: recordings of all pitches, dynamics, and articulations are available in a commercial sampler package
  - Recordings can be also made for selected intervals of pitches and ***morphed*** in between
  - Dynamics can be morphed for section instruments such as strings or brass

"Zones" in Logic Pro EXS24 sampler

Audio File	Pitch			Mixer				Key Range	
Name	Key	Coarse	Fine	Vol	Pan	Scale	Output	Lo	Hi
Strs In 1 c.aif	C1	0	0	0	0	0	Group	C-2	C#1
Strs In 1 d#.aif	D#1	0	0	0	0	0	Group	D1	E1
Strs In 1 f#.aif	F#1	0	0	0	0	0	Group	F1	G1
Strs In 1a.aif	A1	0	0	0	0	0	Group	G#1	A#1
Strs In 2 c.aif	C2	0	0	0	0	0	Group	B1	C#2
Strs In 2 d#.aif	D#2	0	0	0	0	0	Group	D2	E2
Strs In 2 f#.aif	F#2	0	0	0	0	0	Group	F2	G2
Strs In 2a.aif	A2	0	0	0	0	0	Group	G#2	A#2
Strs In 3 c.aif	C3	0	0	0	0	0	Group	B2	C#3
Strs In 3 d#.aif	D#3	0	0	0	0	0	Group	D3	E3
Strs In 3 f#.aif	F#3	0	0	0	0	0	Group	F3	G3
Strs In 3a.aif	A3	0	0	0	0	0	Group	G#3	A#3
Strs In 4 c.aif	C4	0	0	0	0	0	Group	B3	C#4
Strs In 4 d#.aif	D#4	0	0	0	0	0	Group	D4	E4
Strs In 4 f#.aif	F#4	0	0	0	0	0	Group	F4	G4
Strs In 4a.aif	A4	0	0	0	0	0	Group	G#4	A#4

WAVELET/GRANULAR SYNTHESIS

Image from: https://www.subaqueousmusic.com/granular-synthesis-in-ableton-live/



Samples are only used partially

Grains: tiny chunks of sound of 1 to 100 ms long

- Can be layered together
- Can be played reversed or at different speeds

Long grains (>50ms)

- Original sound fragments still audible

Short grains (>30–50Hz)

- A pitch can be heard at repetition rate

OBJECTIVES OF SOUND SYNTHESIS

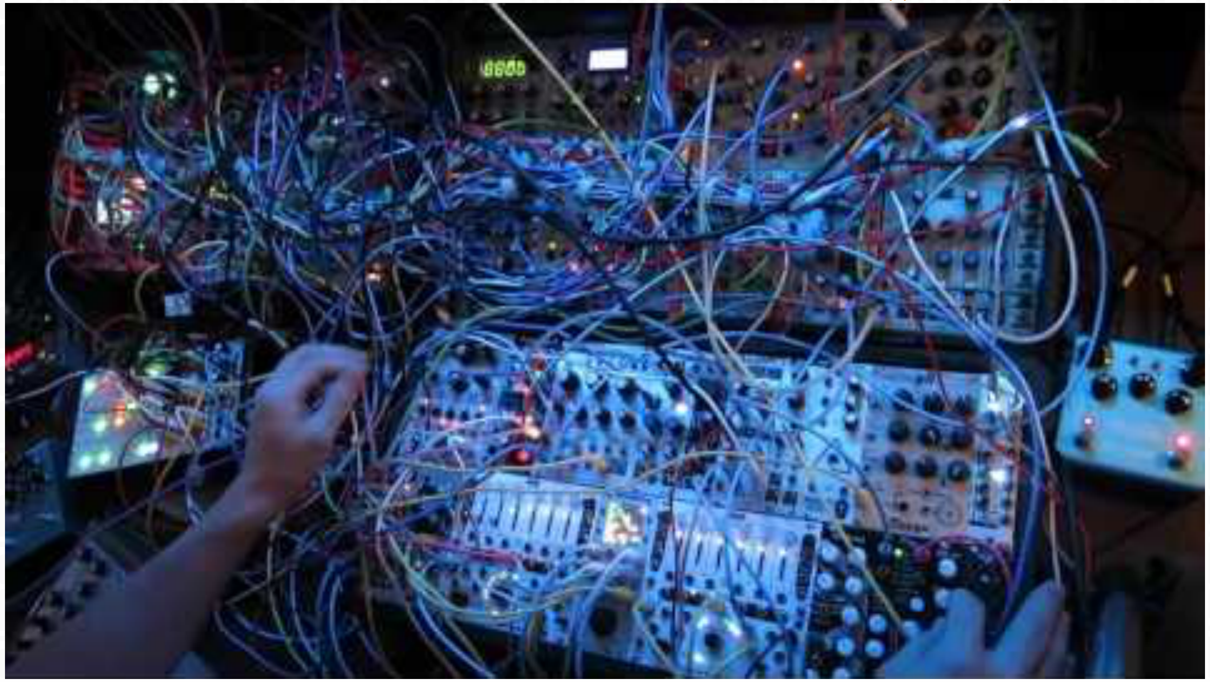
There are different goals of synthesis

- ***Realism***: to emulate real-life musical instruments, as realistic as possible
  - Both acoustic and electronic instruments
- ***Creativity***: to expand the gamut of musical possibilities

Considerations:

- Computation power
- Ease of use for users (HCI)

Video from: https://youtu.be/o791hgNvGlg



Computers? Synthesizers? Acoustic instruments?

- https://www.juliusdobos.com/the-philosophy-behind/analog-vs-digital-synthesizers-debate
- http://www.noiseaddicts.com/2014/07/electric-vs-acoustic-instruments/

THE SKY'S THE LIMIT…

Video from: https://youtu.be/Oym7B7YidKs

LECTURE REVIEW

We *have discussed:*

- Additive synthesis
- Modulation synthesis
- Subtractive synthesis
- Basics of spectral alternation, physical modeling, and sampling methods
- Basics the powerful synthesis programming language, CSound

READ FURTHER

Chapter 3, "Fundamentals", ***CSound.***

Useful websites:

- http://decoy.iki.fi/dsound/dsound-c-07