Lecture 4: Analog Synthesizers

1. The Problem Of Electronic Synthesis
2. Oscillators
3. Envelopes
4. Filters

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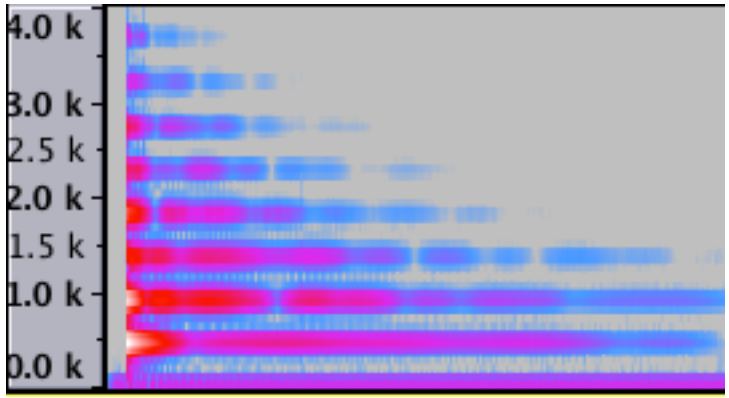
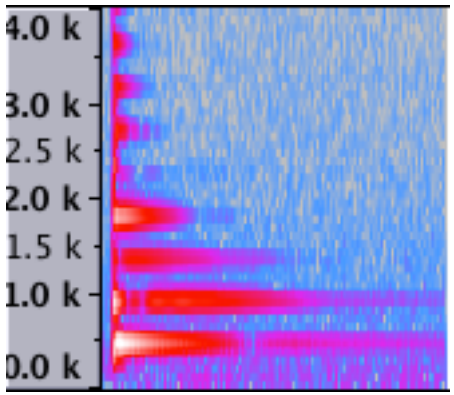
1. The Problem of Electronic Synthesis

- How can we synthesize notes and music
  - ... and have it sound as good as real instruments?
- Real instrument tones are complex

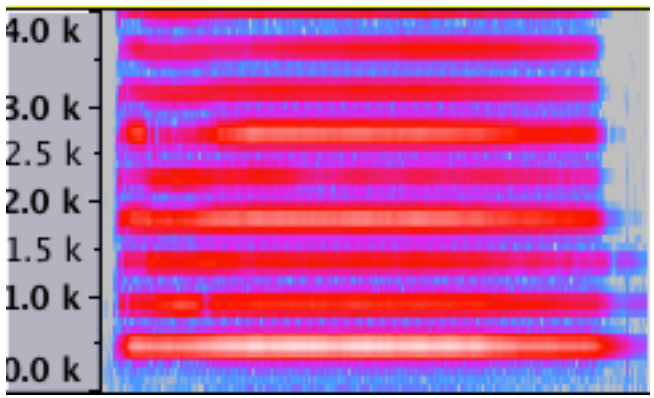


Piano

Trumpet



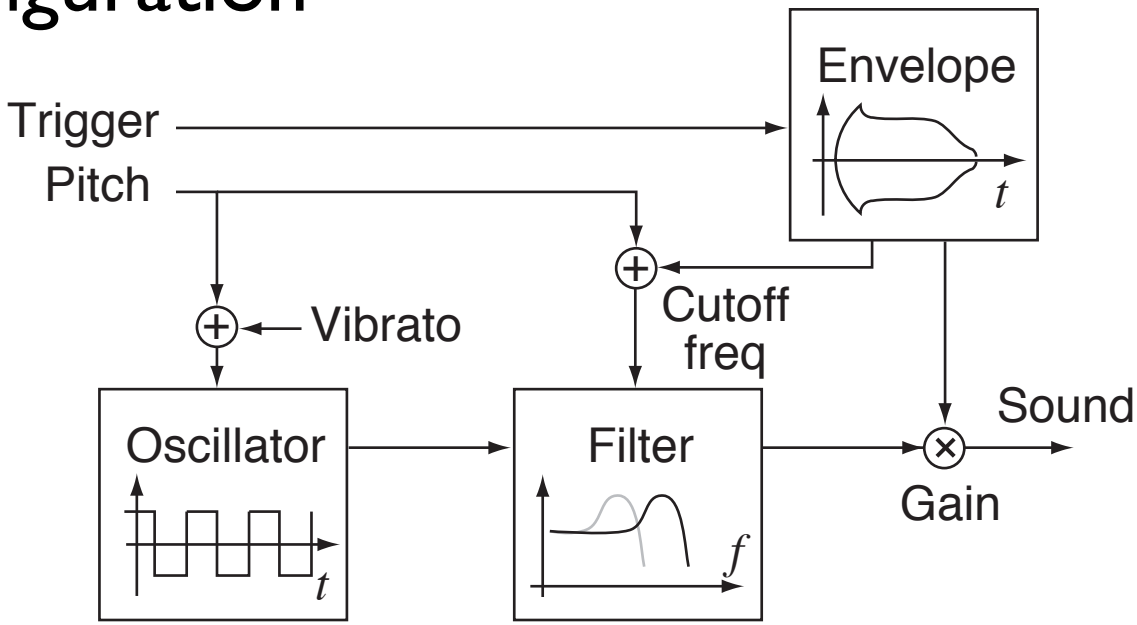
Plucked Violin



Bowed Violin

The Analog Synthesizer

- Minimum "useful" configuration
  - Pitch + harmonics
  - Amplitude variation (dynamics)
  - Spectral variation
  - (1970s technology)



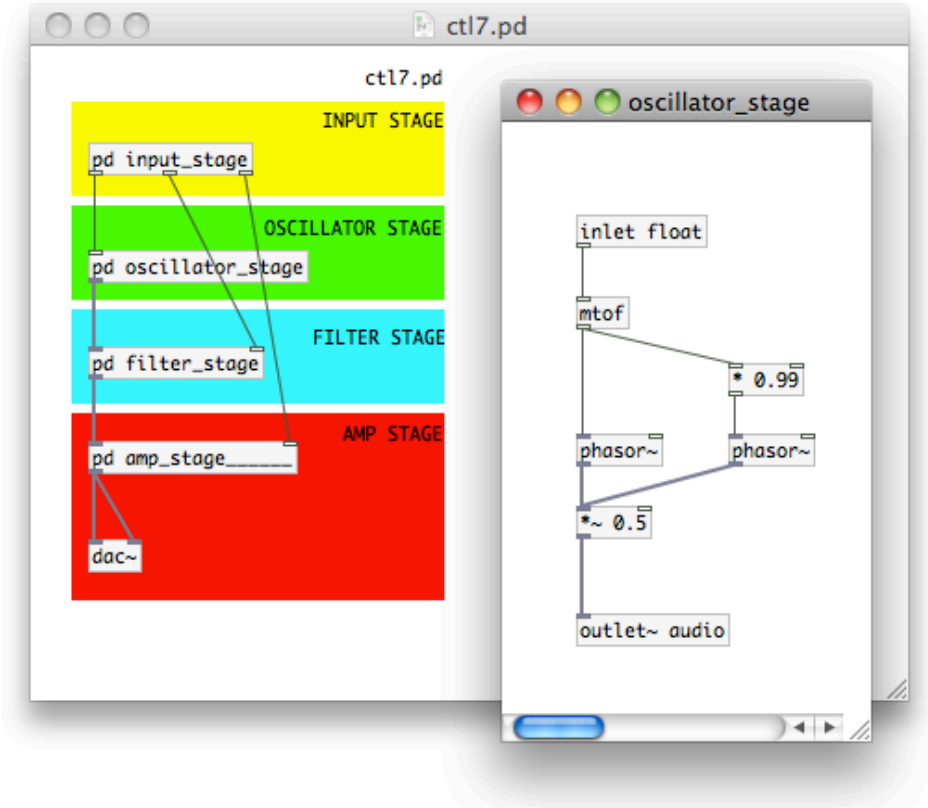
Minimoog, 1972

Digital Simulation of Analog

- E.g. Loomer Aspect
  http://www.loomer.co.uk/aspect.htm

PureData (Pd)

- Visual metaphor based on analog synths
  - "wires" connect modules



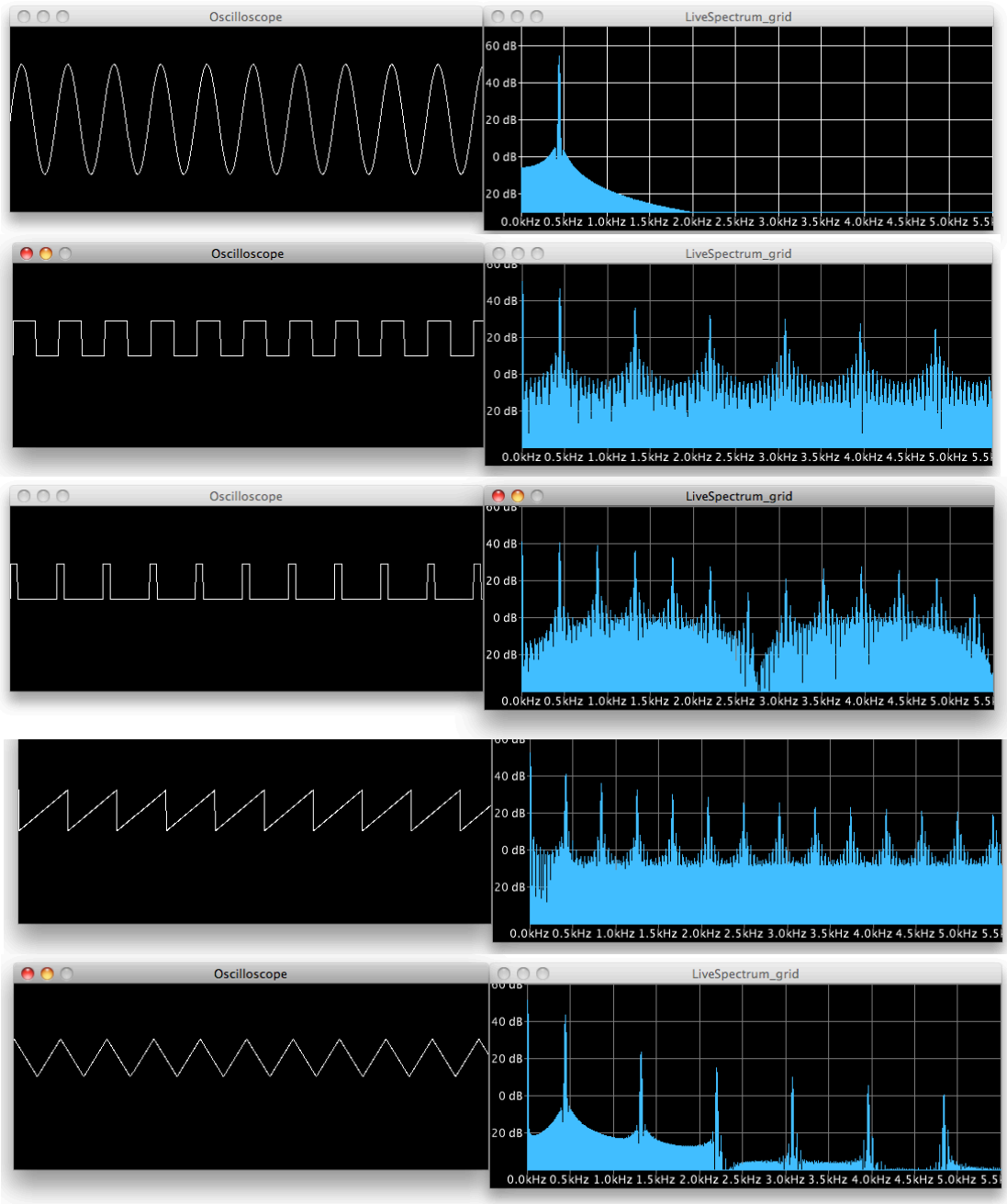
- Tutorial: http://en.flossmanuals.net/PureData/

2. Oscillators

- Pitch = sinusoid?
  - only a single color
- Real instruments have more harmonics
  - static spectrum determines instrument sound?
- Additive: Combine individual harmonics
  - calculating sinusoids in real time is expensive...
- Subtractive: Shape harmonics with filters
  - start with a spectrally rich signal
  - "shape" harmonics efficiently with LTI filters

Basic waveforms

- Sinusoid
- Square wave
- Pulse waveform
- Sawtooth
- Triangle



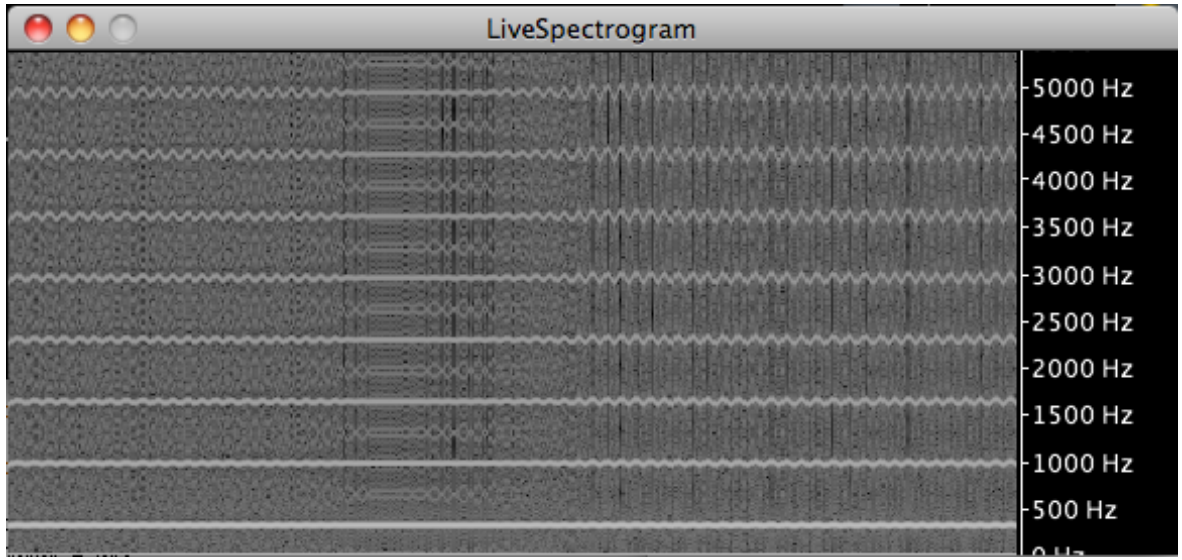
Aside: Bandlimiting

- It's easy to sample "ideal" simple waveforms
  - but the ideal ones are not bandlimited
    → lots of aliased energy
- Solution: Bandlimited waveforms
  - e.g. fill a table with precalculated sum of sinusoids up to a fixed frequency

- Variable waveforms can be derived
  - PWM by integrating bandlimited impulses
  - https://ccrma.stanford.edu/~stilti/papers/blit.pdf

Modulation

- Stationary spectra sound unnatural
  - real sources have random "jitter"
- Variations in pitch
  - "Low Frequency Oscillator" frequency modulation

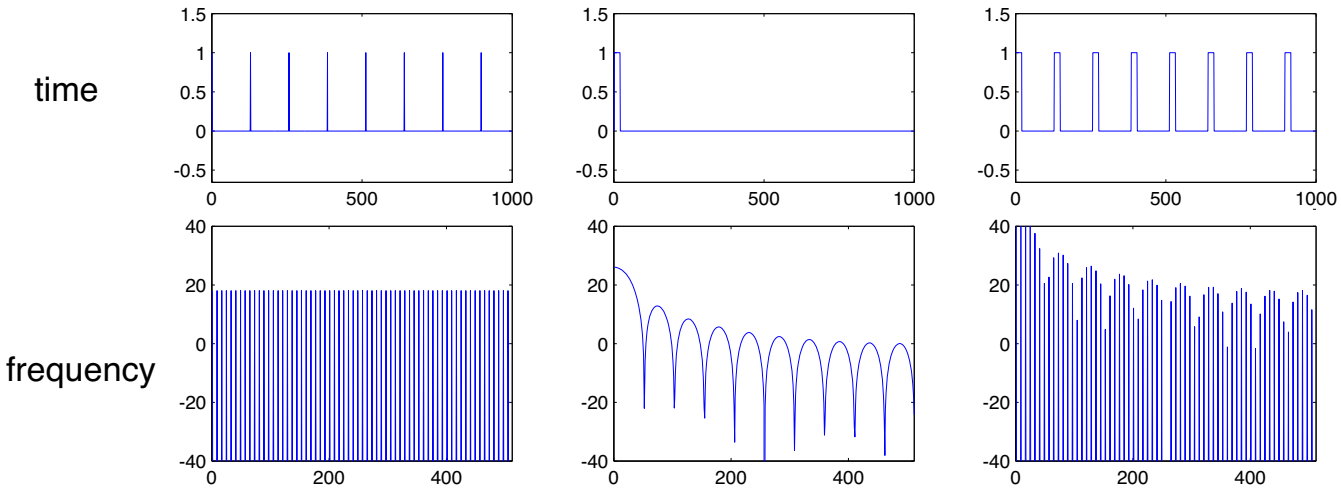


  - random noise
- Variations in timbre
  - can be imposed by filters...
  - Pulse-width modulation

Aside: PWM Spectrum

- What are harmonics of Pulse-Width Modulated (PWM) waveforms?
  - consider as impulses convolved with a pulse W
    → Fourier transforms multiply

$$p(t) \quad * \quad w(t) \quad = \quad p_w(t)$$

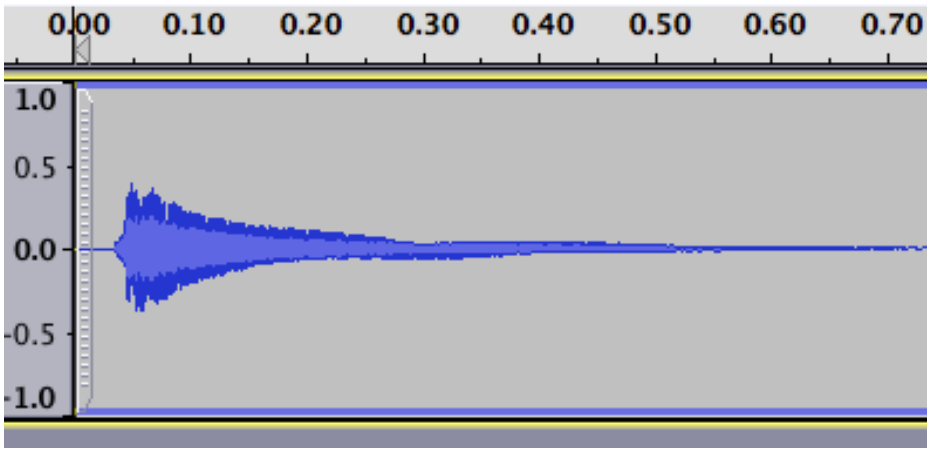


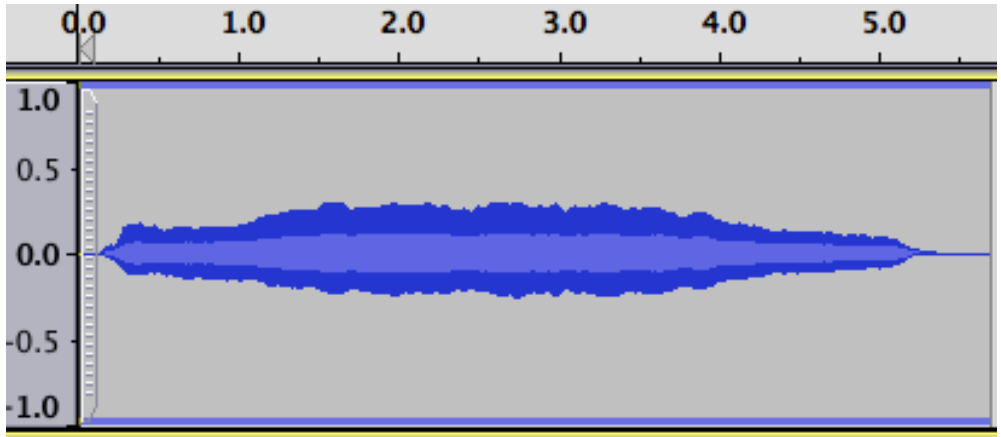
  - or integral of sum of two opposite impulse trains with relative delay W
  - (good for bandlimiting)

$$p_w(t) = \int p(t) - p(t - W)dt$$

3. Envelopes

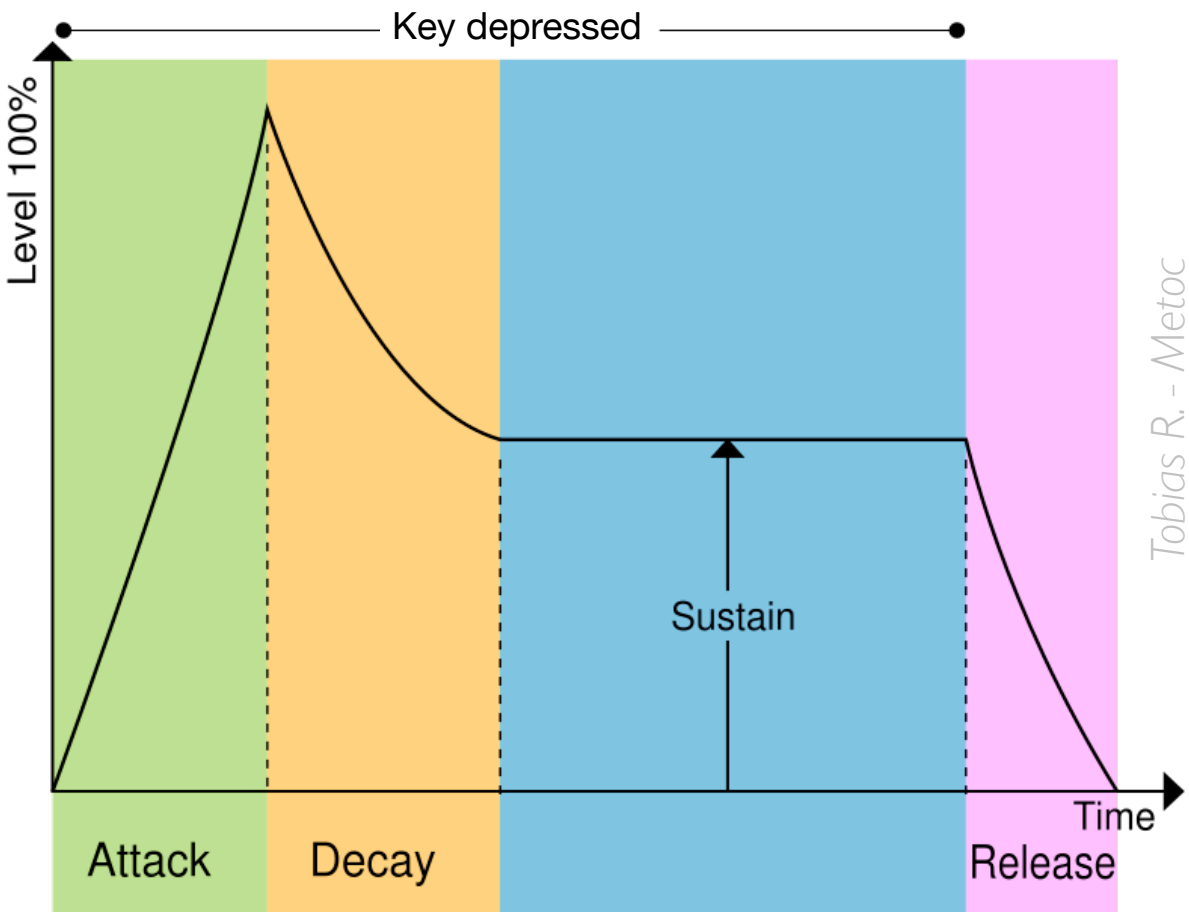
- Notes need to be limited in time
  - simple gating not enough
  - amplitude envelope
- Different (real) instruments have clear variations in envelope
  - struck/plucked vs. bowed/blown





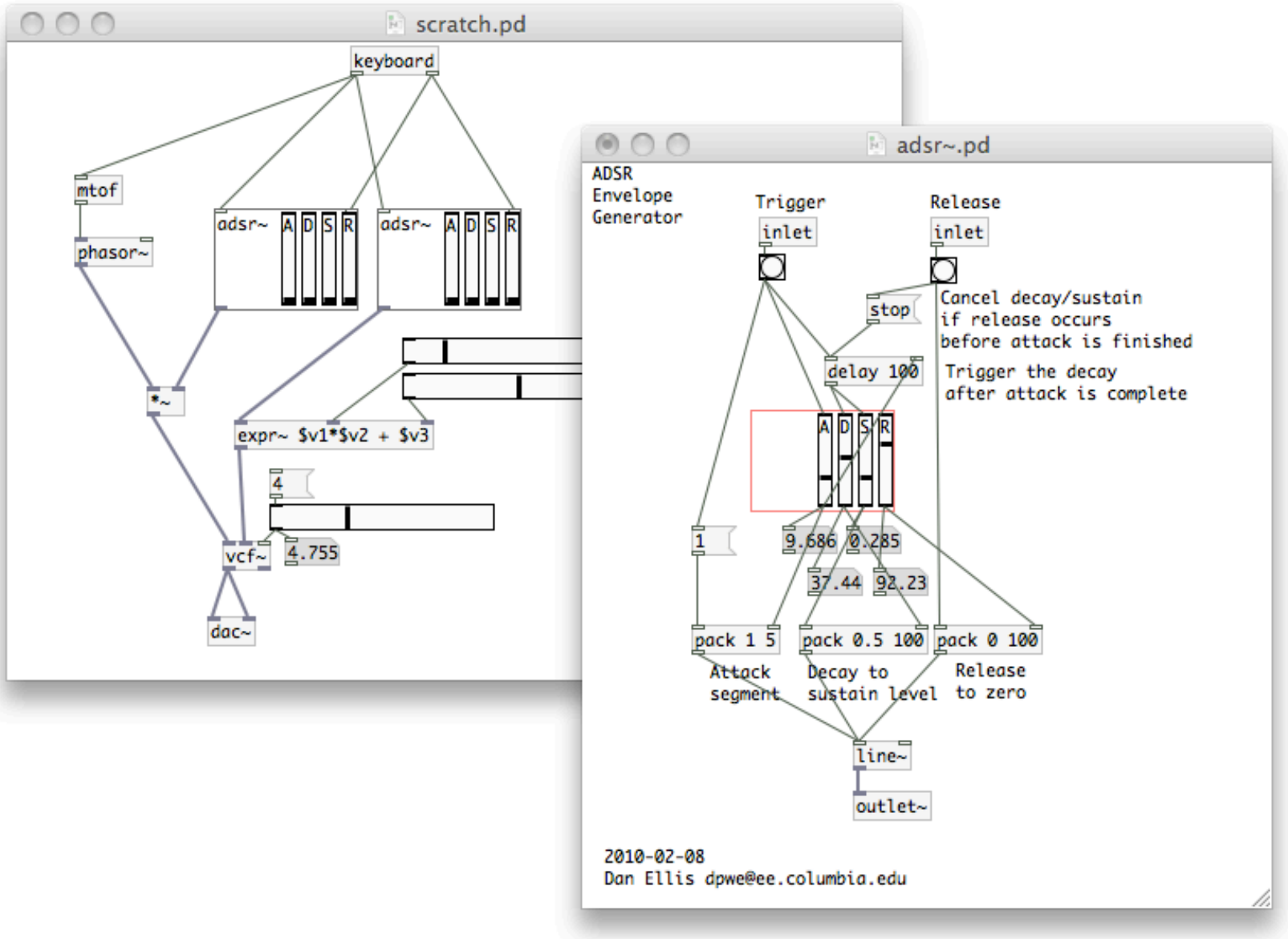
ADSR

- **4-parameter classic envelope model**
  - Attack - initial rise time
  - Decay - fall time immediately following initial attack
  - Sustain - amplitude of asymptote of decay while key is held down
  - Release - decay from sustain to zero after key released



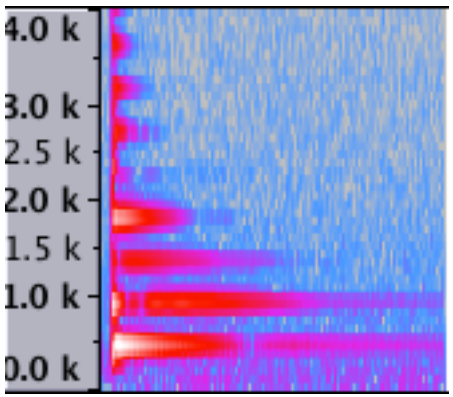
Pd ADSR Abstraction

- Any patch can become a "unit"



4. Filtering

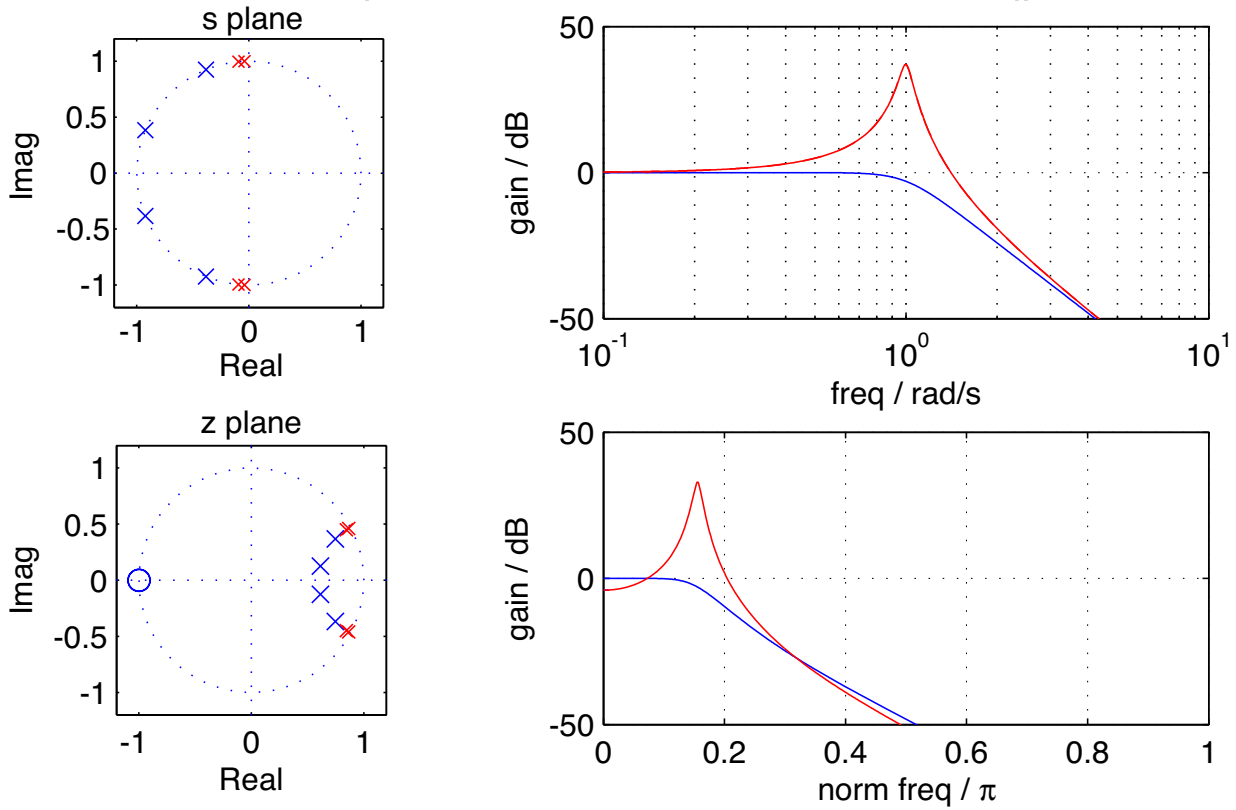
- **Amplitude modulation alone is not enough**
  - real instruments have time-varying spectra
  - e.g. plucked string



- **Generally just LPF (+ resonance)**
  - high frequencies die away after initial transient
  - resonance can give some BPF effect

The Biquad filter

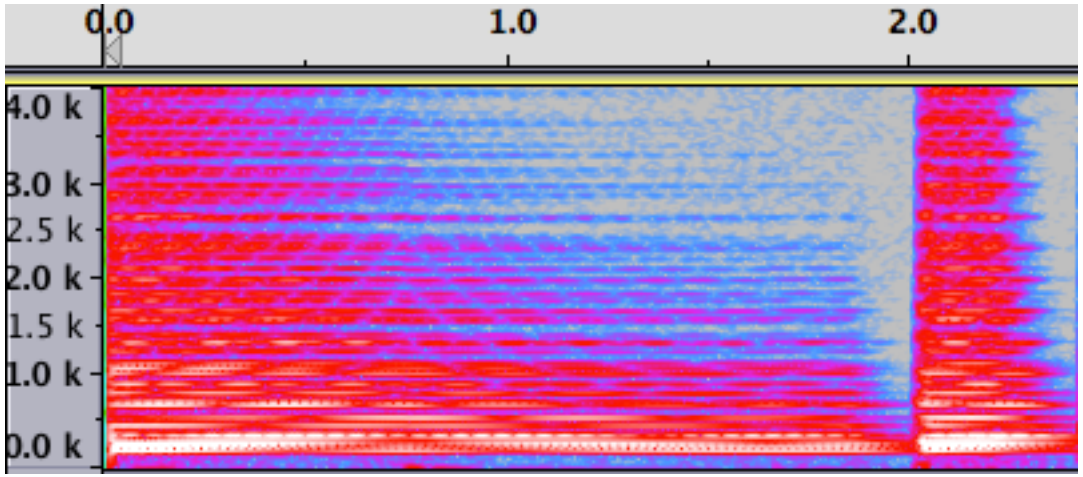
- Flexible circuit design to achieve variable cutoff frequency
  - but just single pole-pair LPF (or repeats)
  - constant Q (bandwidth/center freq) resonance



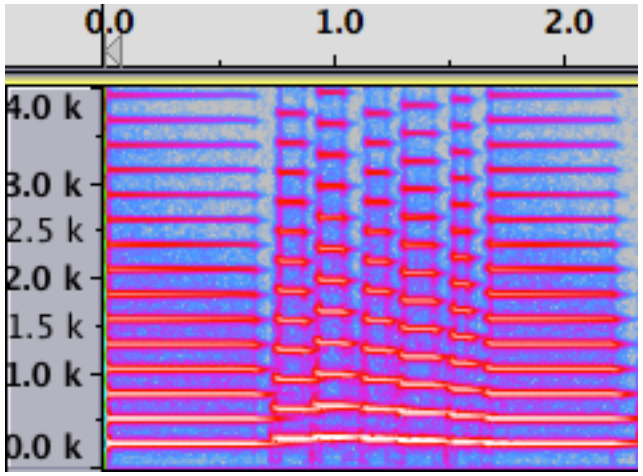
- Analog synths provided 12-24 dB/oct rolloff

5. Examples

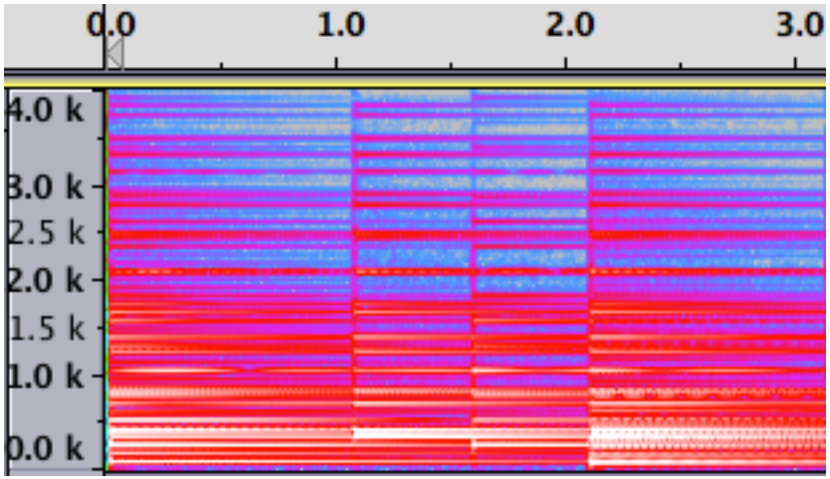
- Juno-106 preset patches
  - from http://www.synthmania.com/juno-106.htm



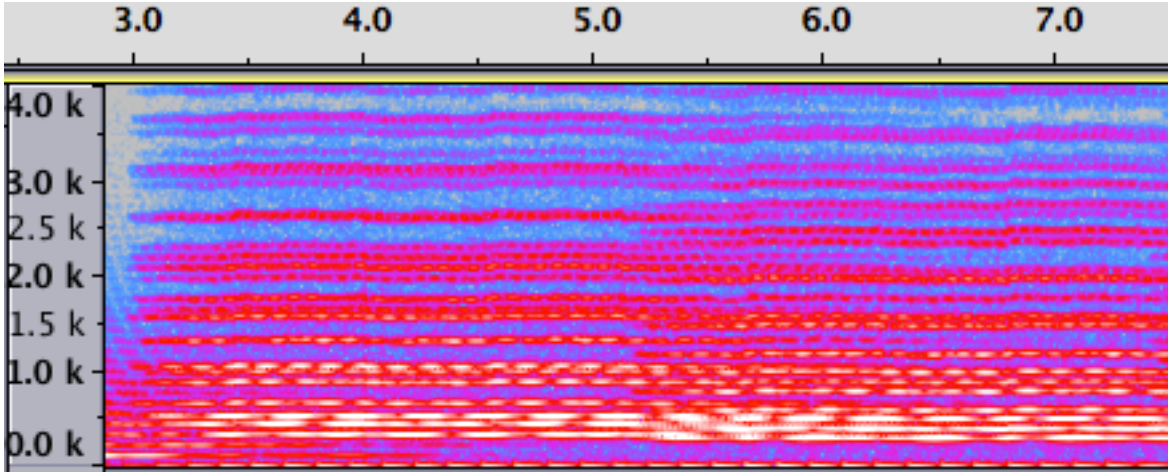
Brass



Trumpet



Piano



Strings

Summary

- Analog synthesizers provided musical flexibility with simple units
  - 20 years of evolution
- Need instrument-like dynamics to make an interesting sound
  - but only up to a point...
- Analog synths provide intuitive controls
  - each "knob" has a distinct effect