Music 209
Advanced Topics in Computer Music
Lecture 9 – Spectral Methods

2006-3-16

Professor David Wessel (with John Lazzaro)

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www.cs.berkeley.edu/~lazzaro/class/music209

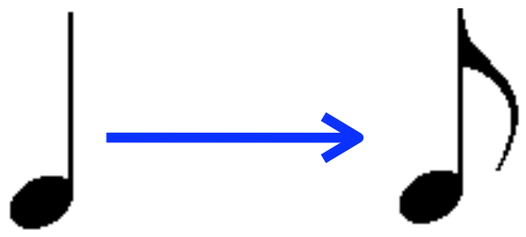
Over the past 2 months ...

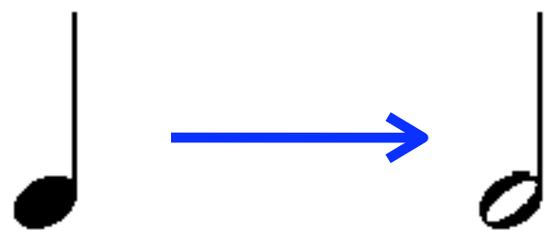
Time-Domain Algorithms for Sound Modification and Analysis

Recall: Note-level Time Warping

We now look at time warping algorithms for this problem ...

Time Shrink





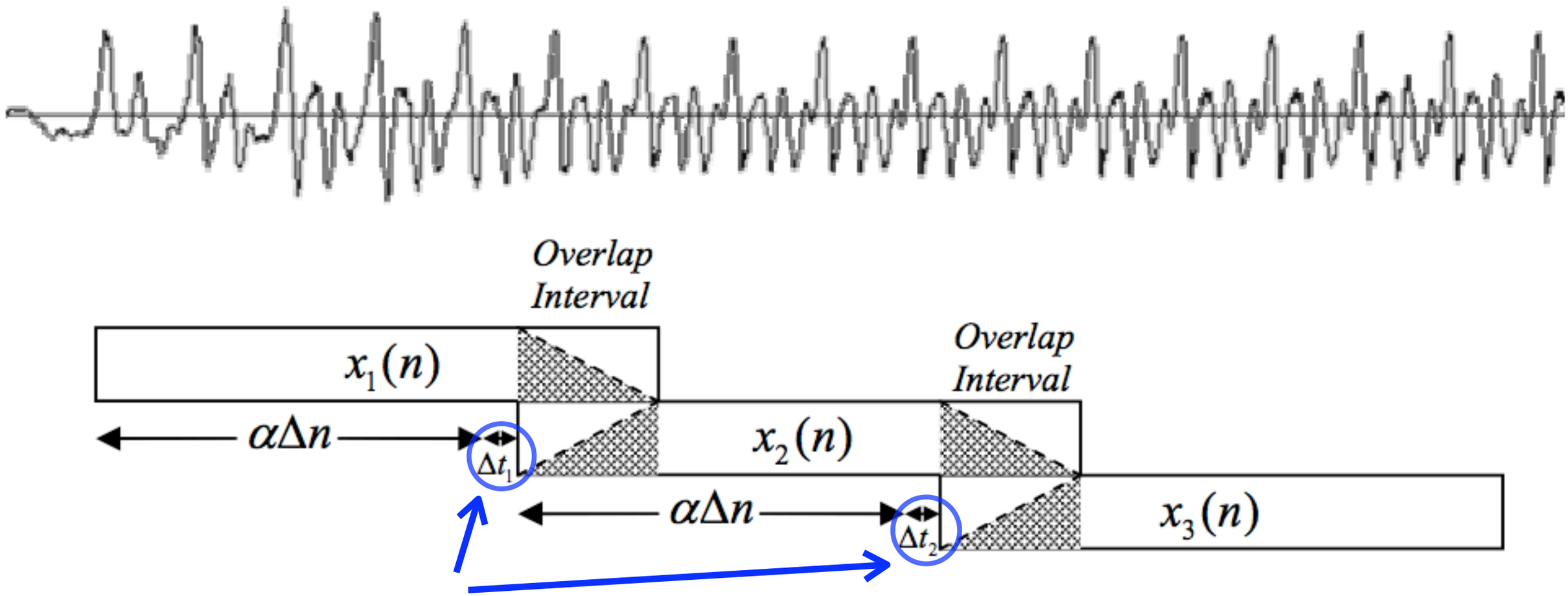
Time Stretch

- **Length of attack transient unchanged. Time warp only affects sustained region.**
- **Local temporal properties of sustained region unchanged (example: vibrato speed)**
- **Long-range properties of sustained region stretch or shrink (example: crescendos).**

"Synchronous OLA" - SOLA

Recall: Tune each Δt_i to minimize artifacts, and then create final waveform by summing all blocks, doing a **crossfade** at the **overlaps.**

"overlap and add" - OLA

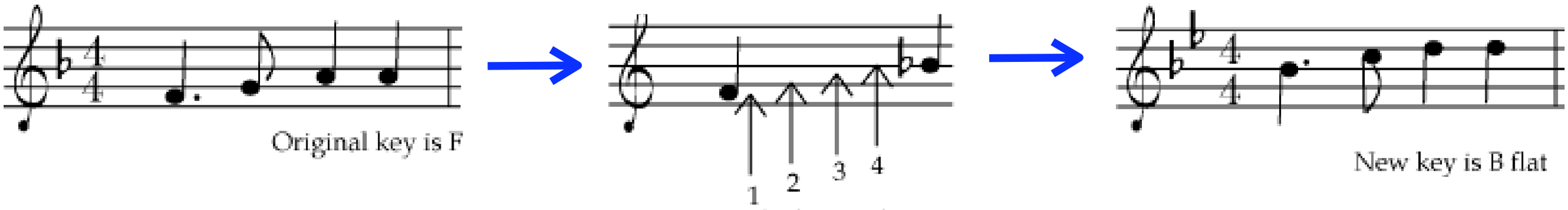


Tuning Δt_i is primary way methods differ.

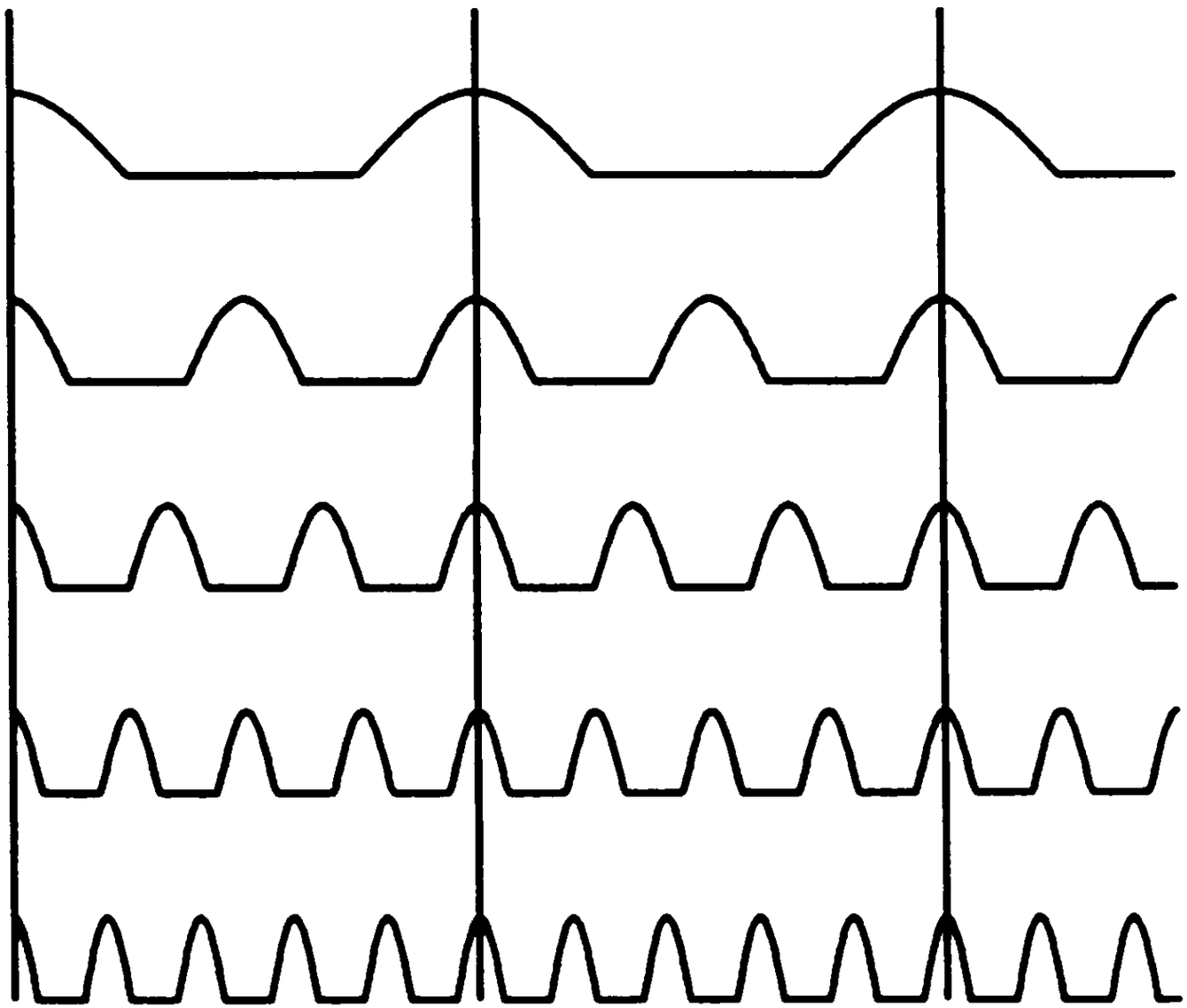
PSOLA, WSOLA, PICOLA, ...

Another trick: Detect transients, don't OLA them. First use: Lexicon 2400, 1986.

Recall: Pitch shifting



+5 semitones = $(\sqrt[12]{2})^{5}$ = 1.33483985



+5 semitones

1.33483985 f

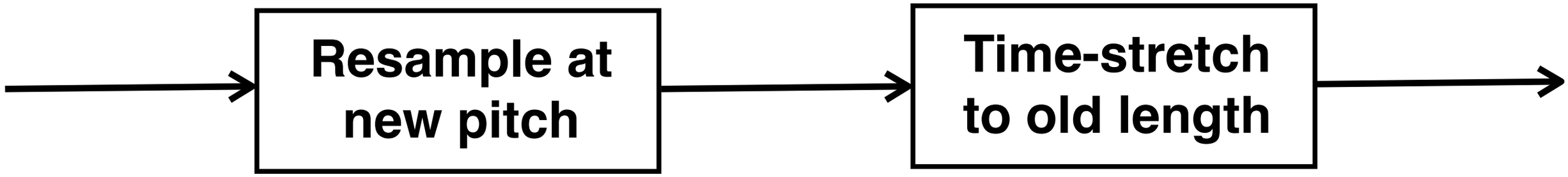
2.66967971 f

4.00451956 f

5.33935942 f

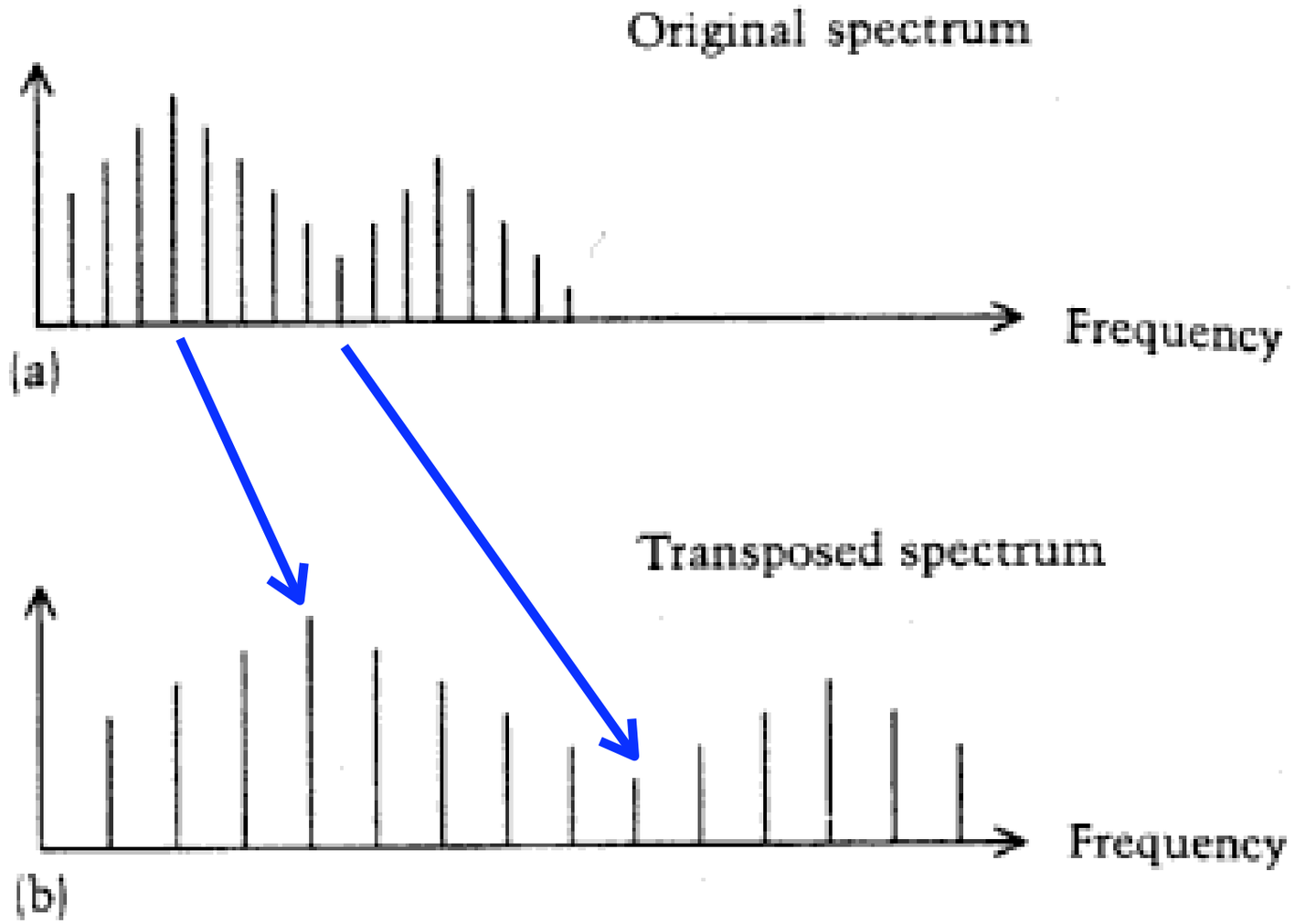
6.67419927 f

Recall: Resample + Time Stretch

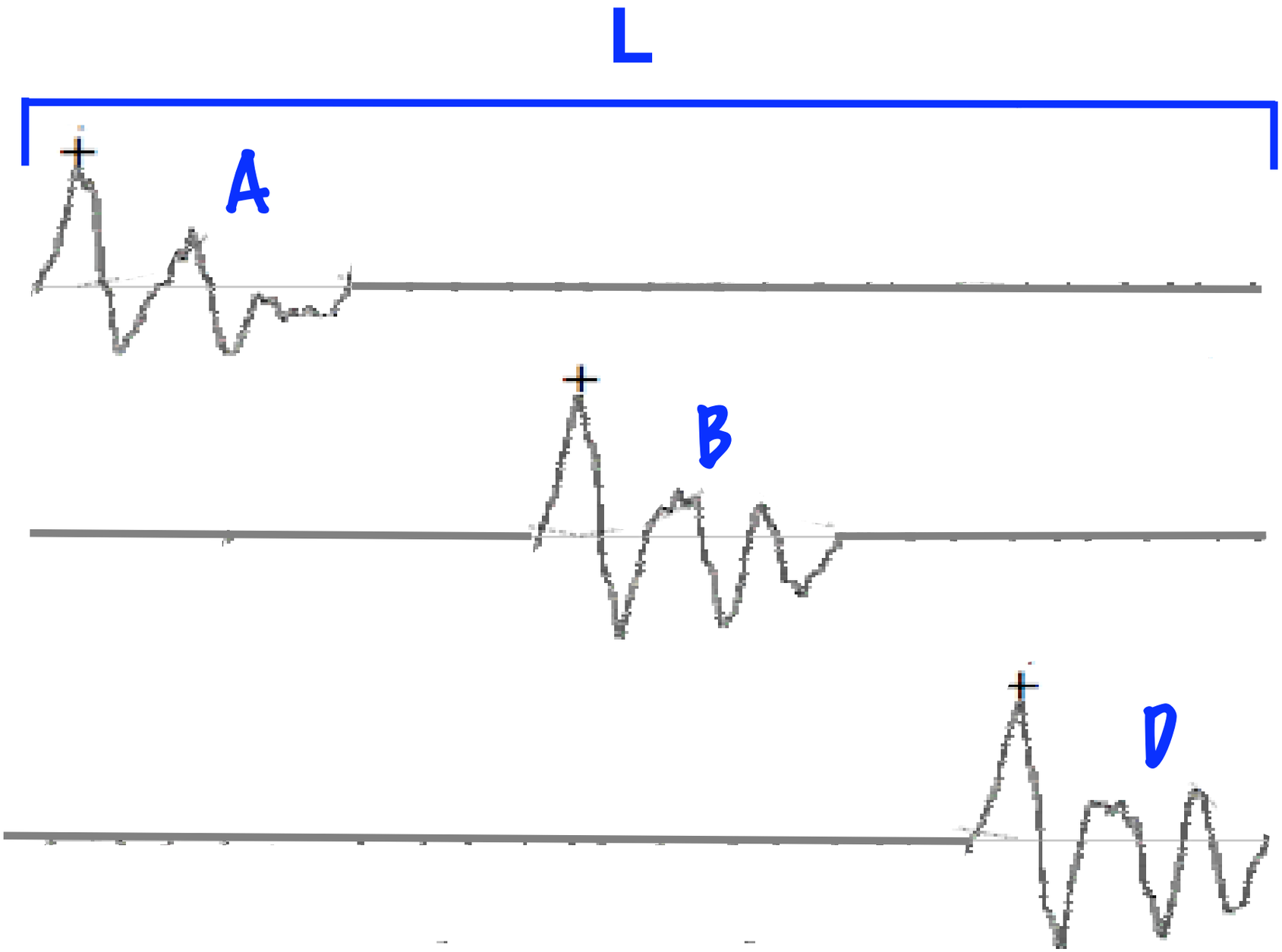


Resampling preserves the magnitude of each partial.

Instead, we want formant frequencies to stay fixed ...



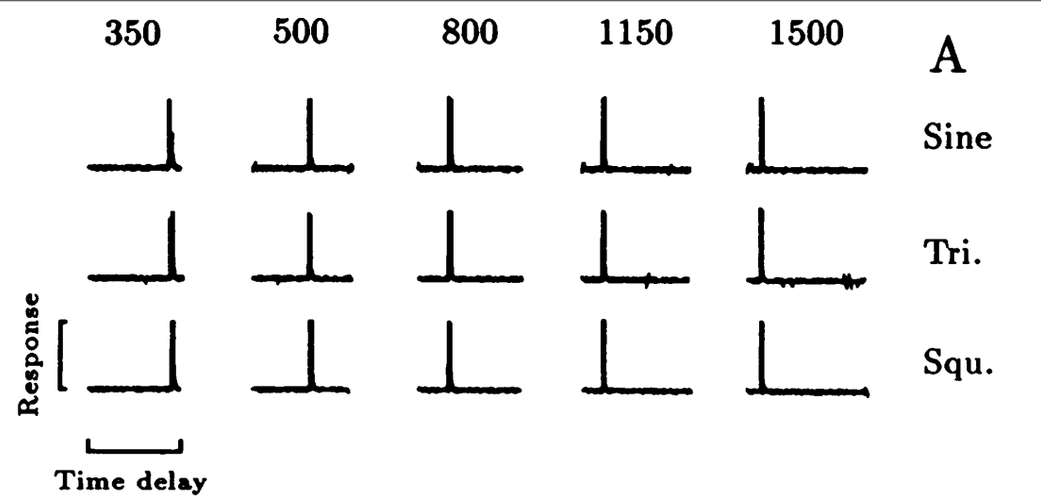
Recall: Beat-slicing pitch periods

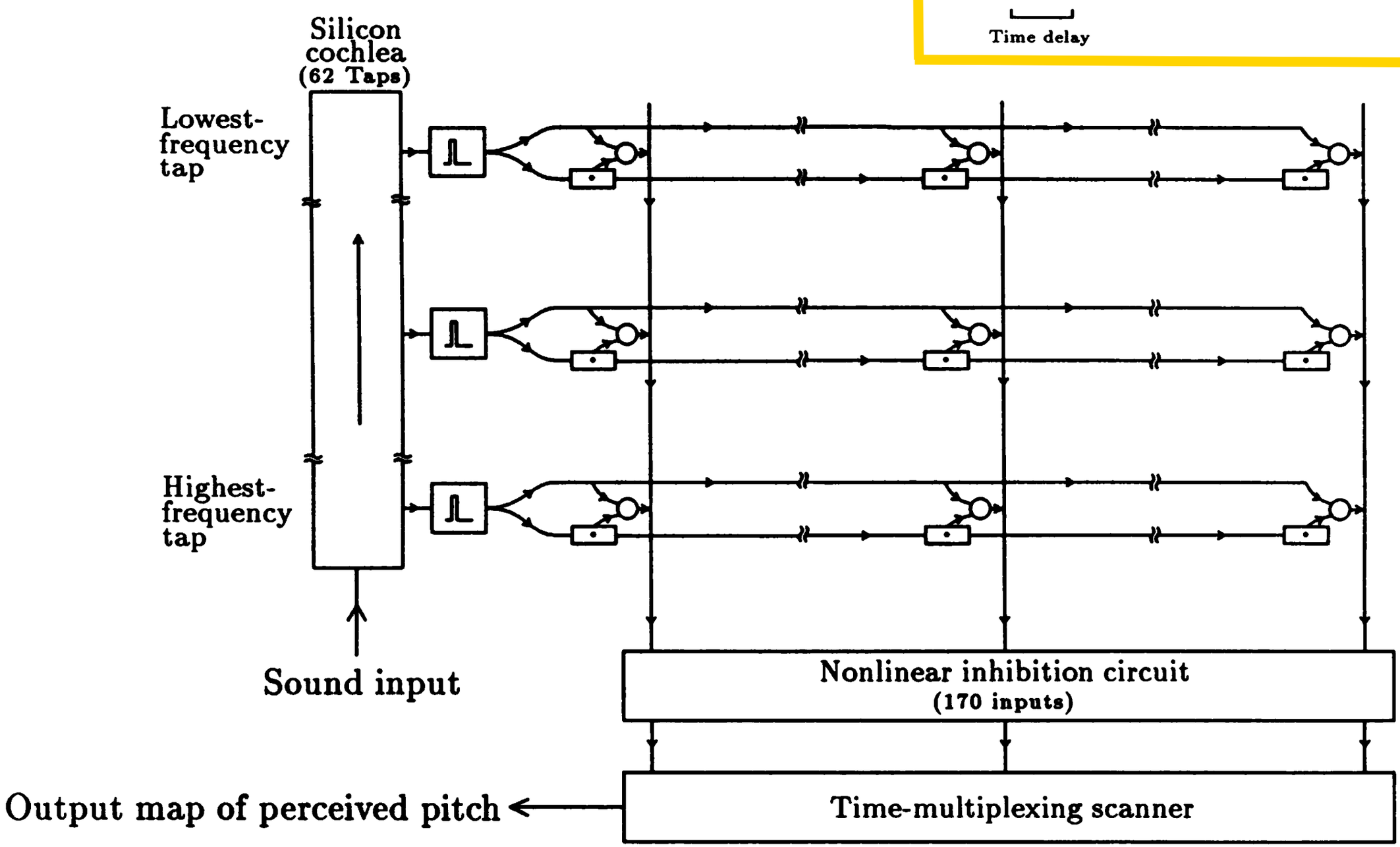


New local pitch: Three pitch periods per unit "L"

Apart from "edge artifacts", spectral shape is not changed by this operation ...

Recall: Computing pitch





Licklider model: Autocorrelate filtered waveforms.

Topics for today: Spectral processing

- **Analysis-synthesis:** Model sound as a set of parameterized sound generators.

- **Psychophysics:** Keeping sound object fusion as we modify the sound.

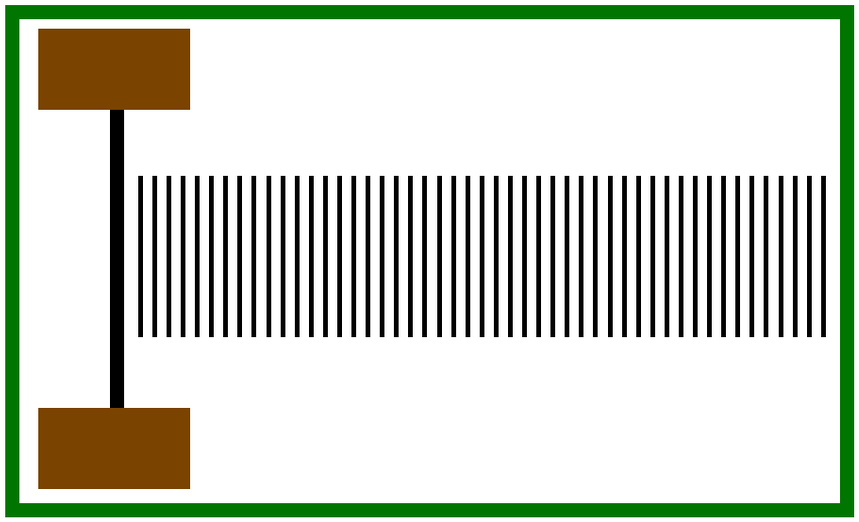
- **Time/Frequency Tradeoffs:** Narrow filters are slow, fast filters are wide.

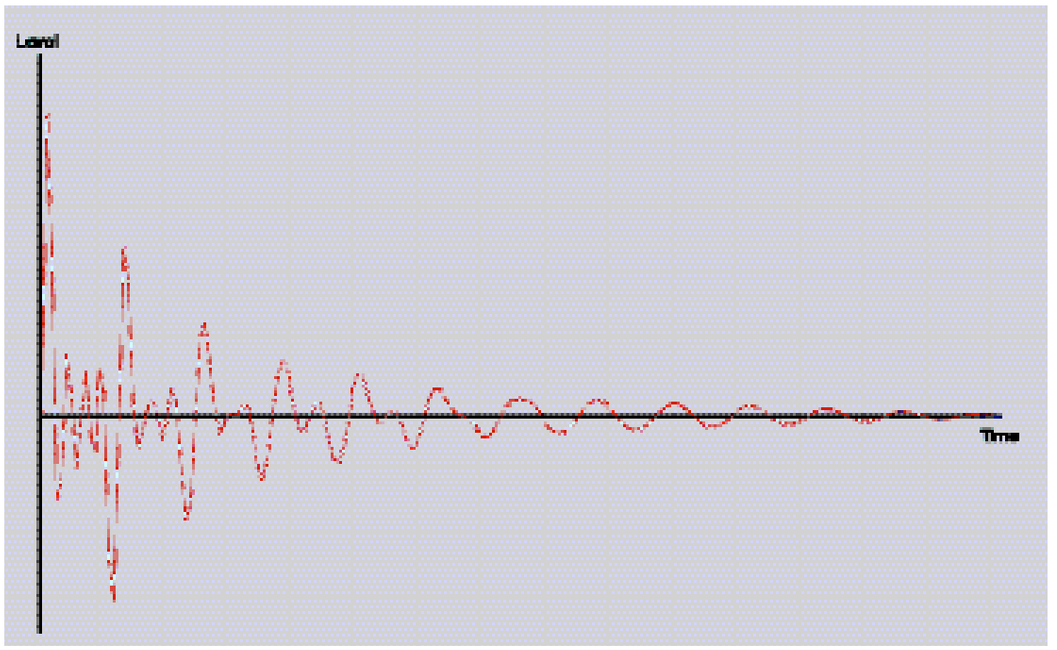
- **Phase Vocoding:** The “Audio Image Processing” approach.

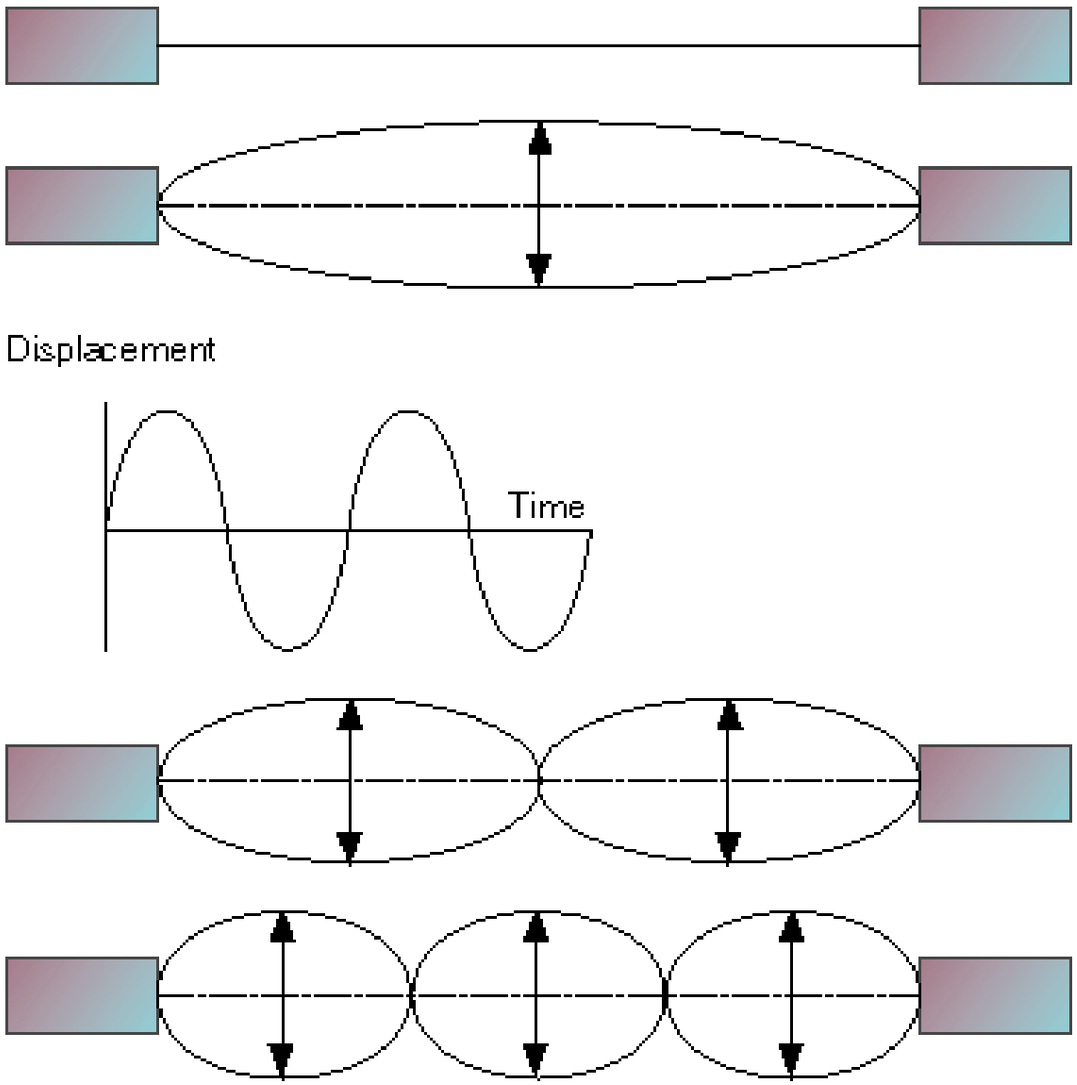
Observation:

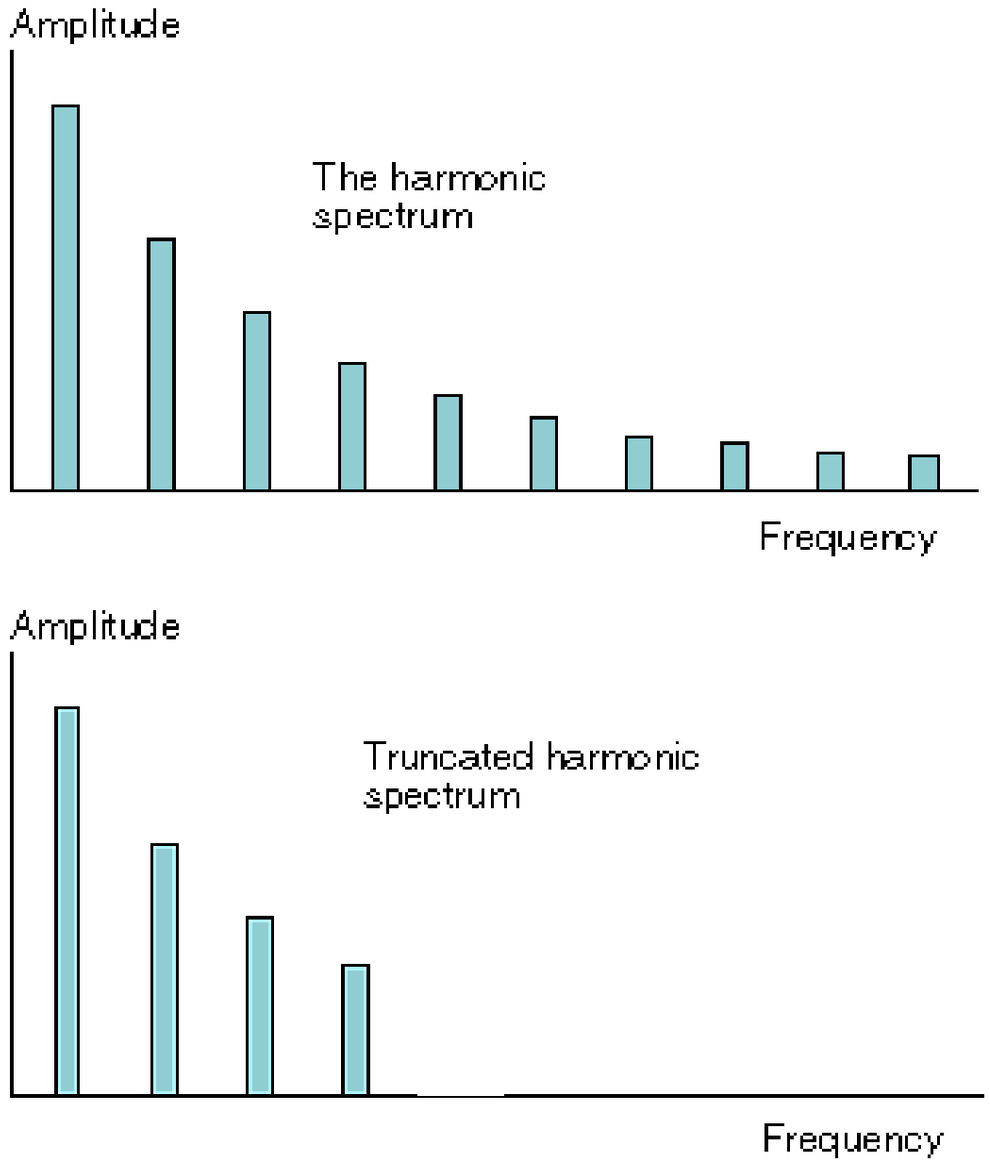
If you can fit a sound to a model with slowly-varying parameters,
time-and pitch modification can be done in parameter space.

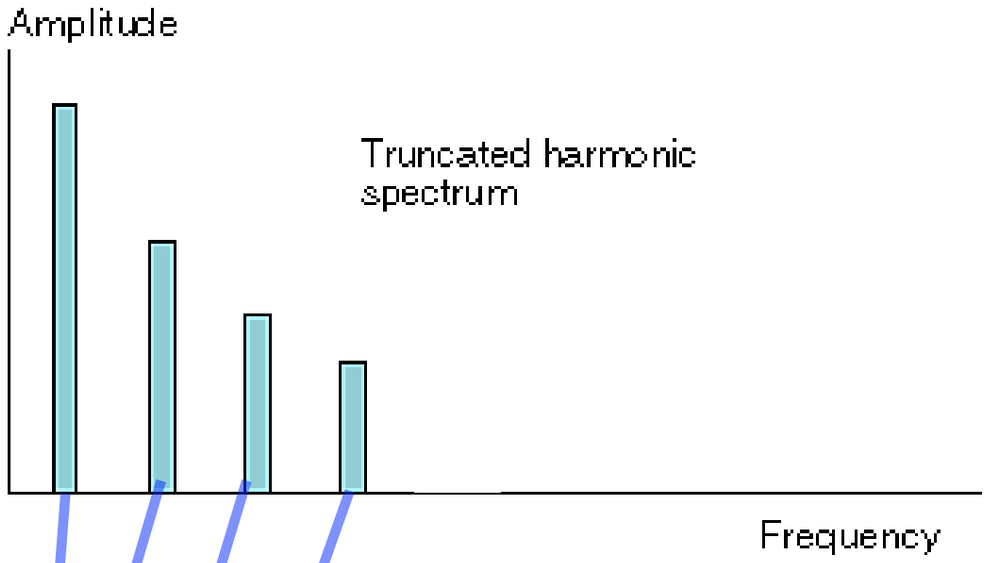
Example: Plucked string




Level
Time


Displacement
Time


Amplitude
The harmonic spectrum
Frequency
Amplitude
Truncated harmonic spectrum
Frequency



$$x(t) = A\sin(\omega t + \phi)$$

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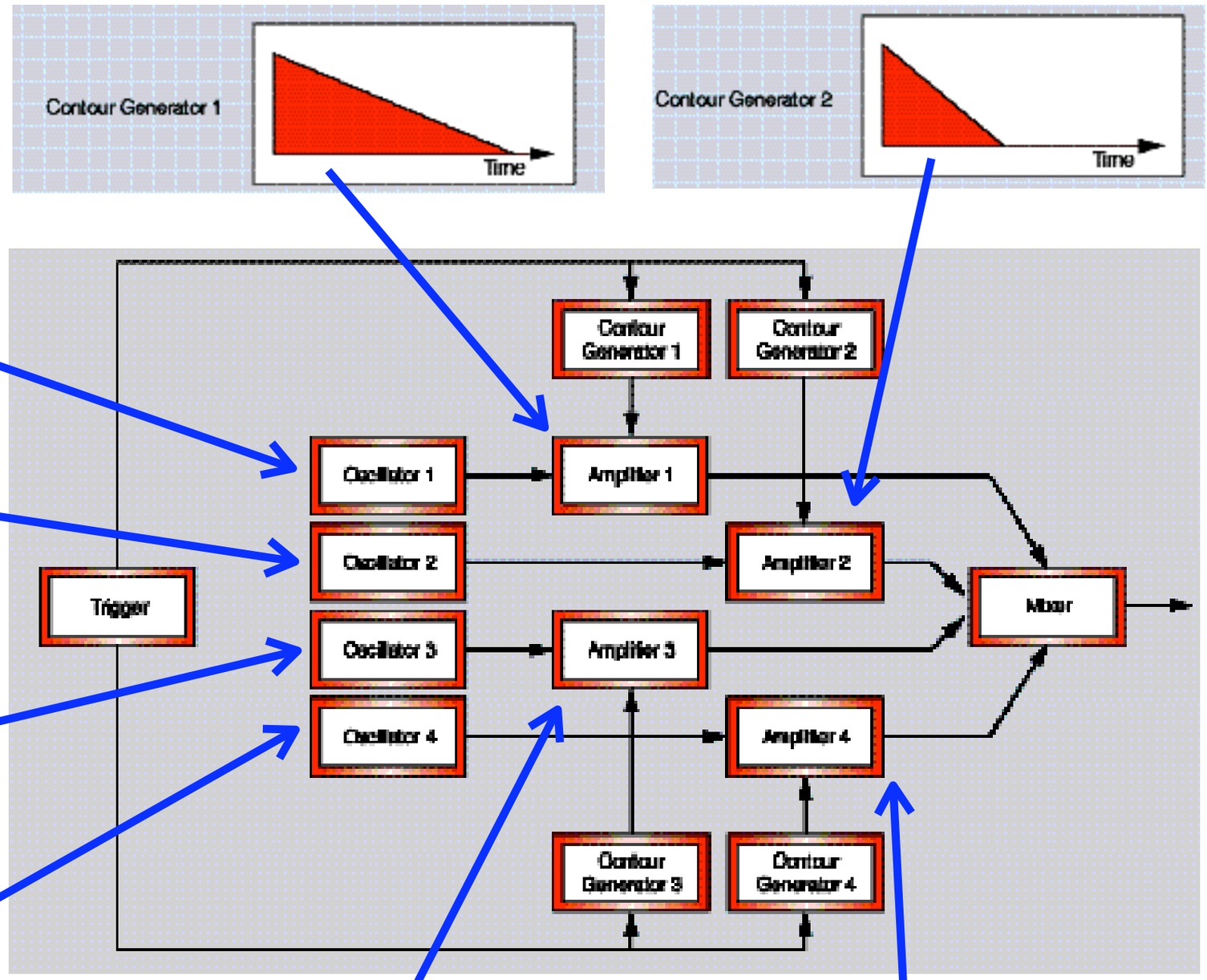
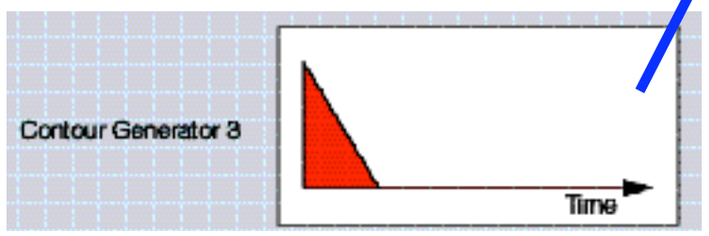
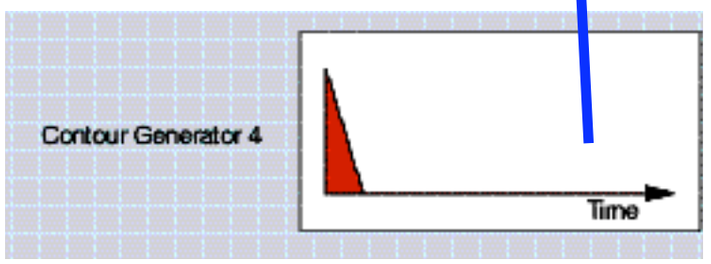
$A_1(t)$

$A_2(t)$

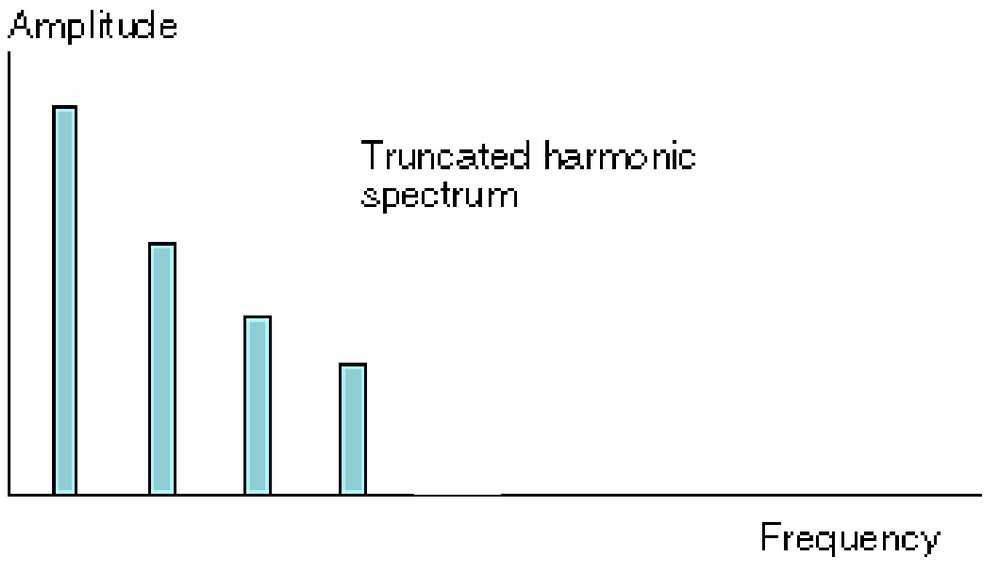


$A_3(t)$

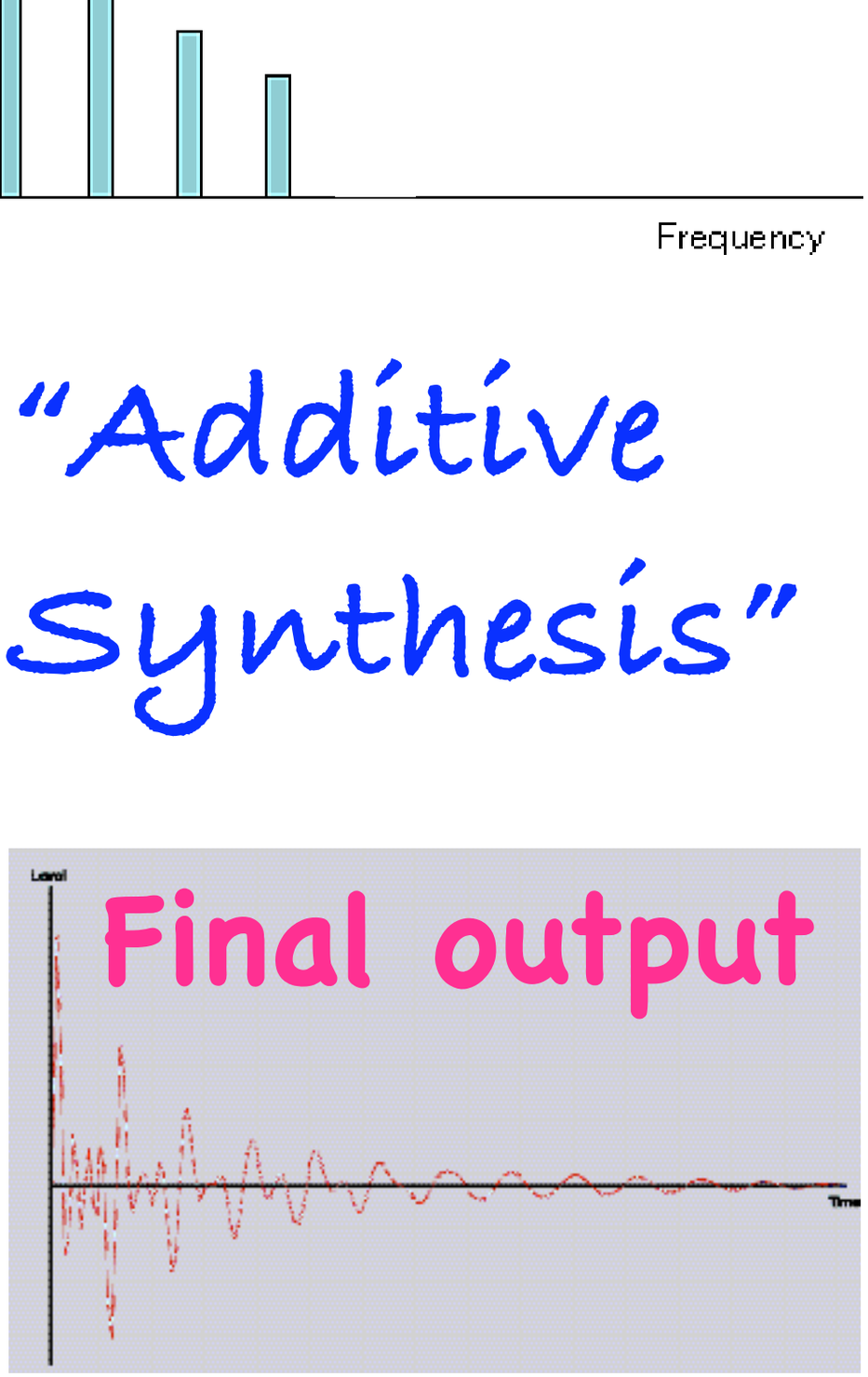


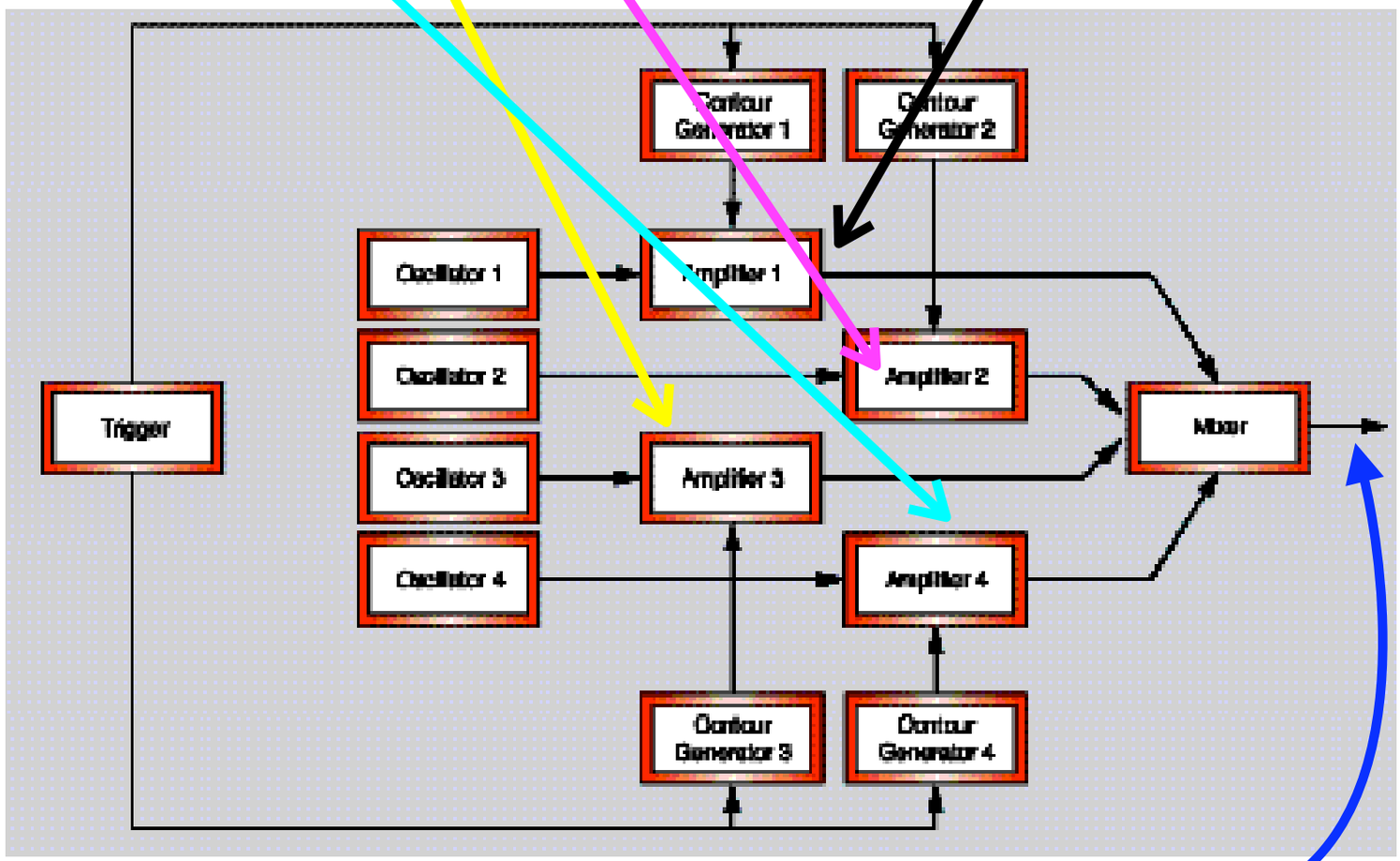


$A_4(t)$



"Additive Synthesis"





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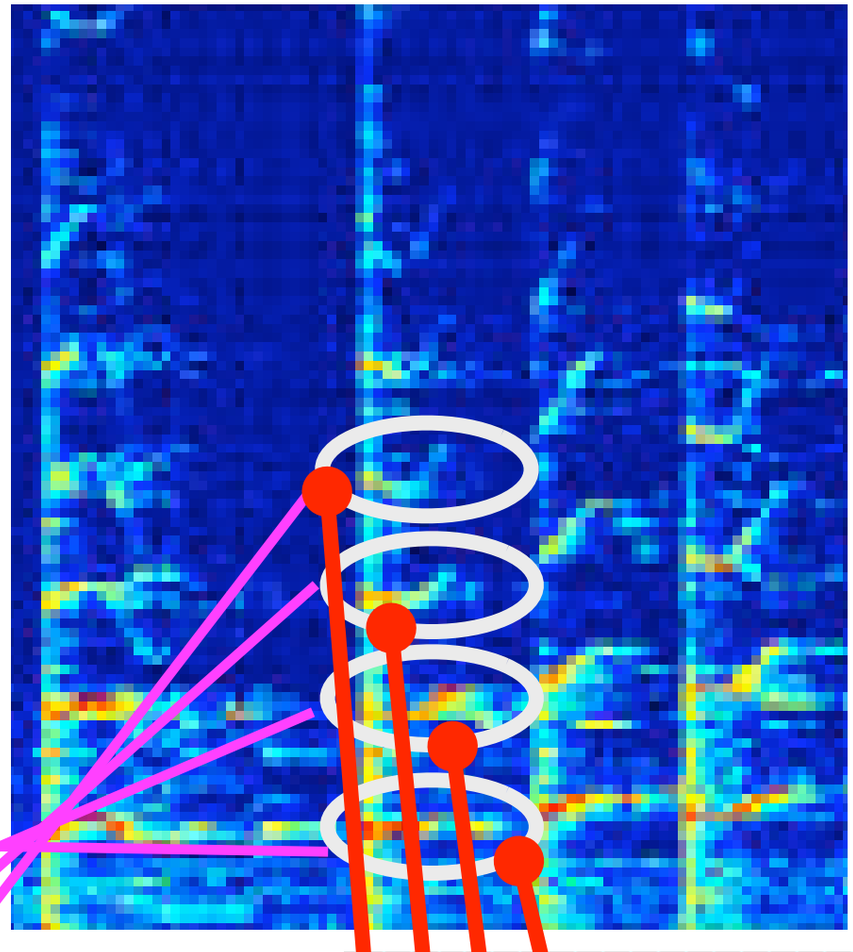
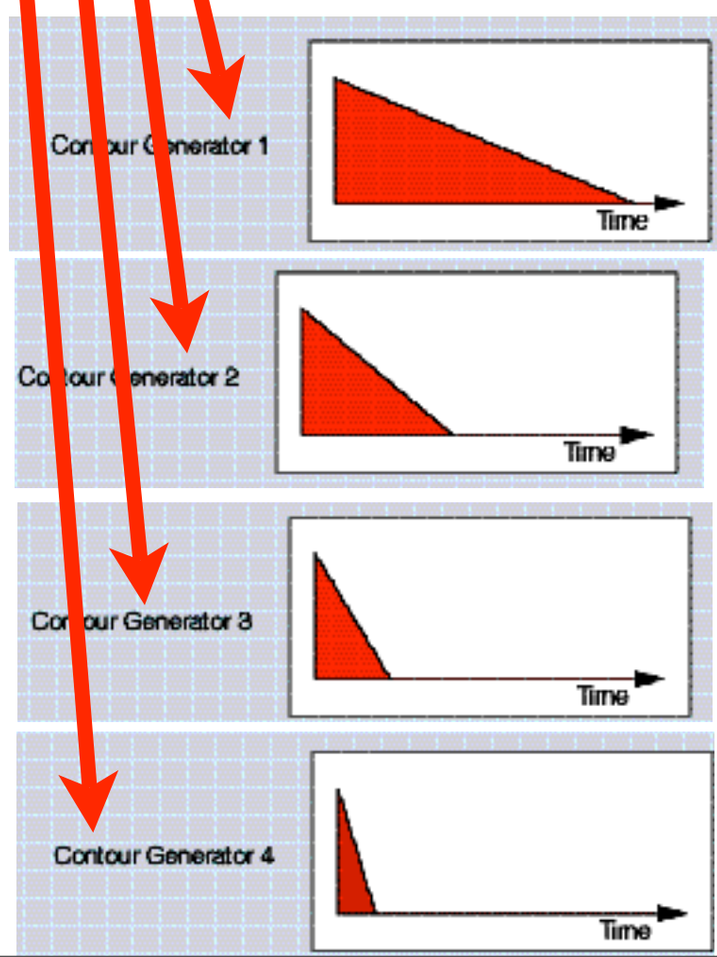
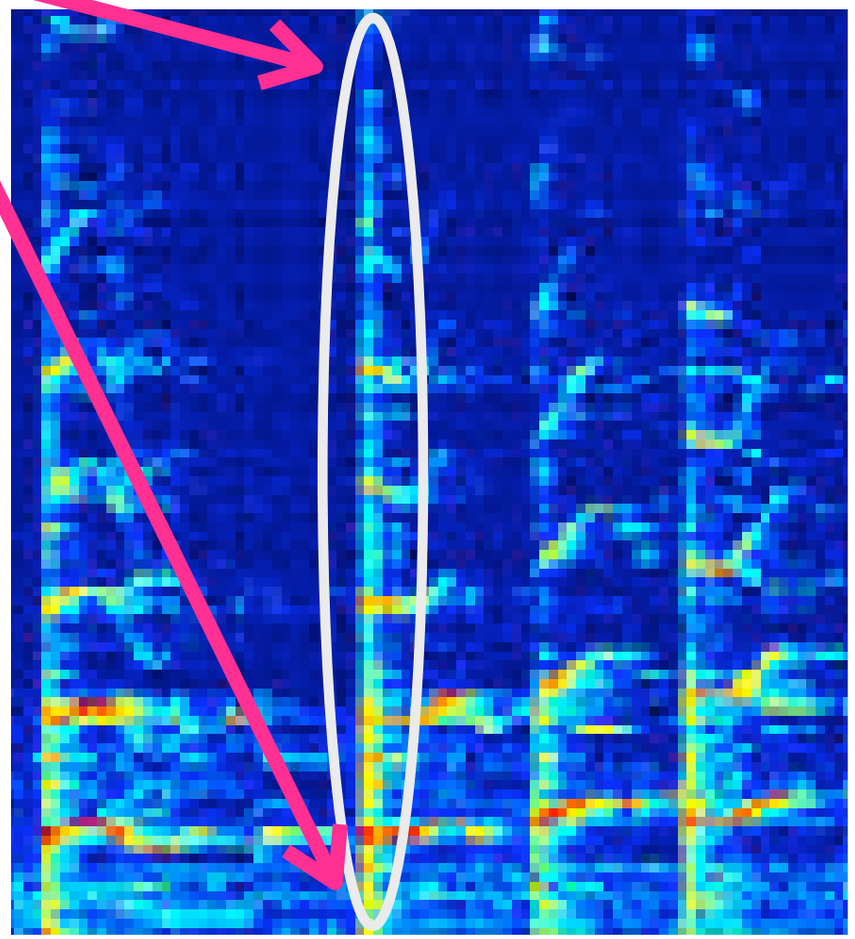




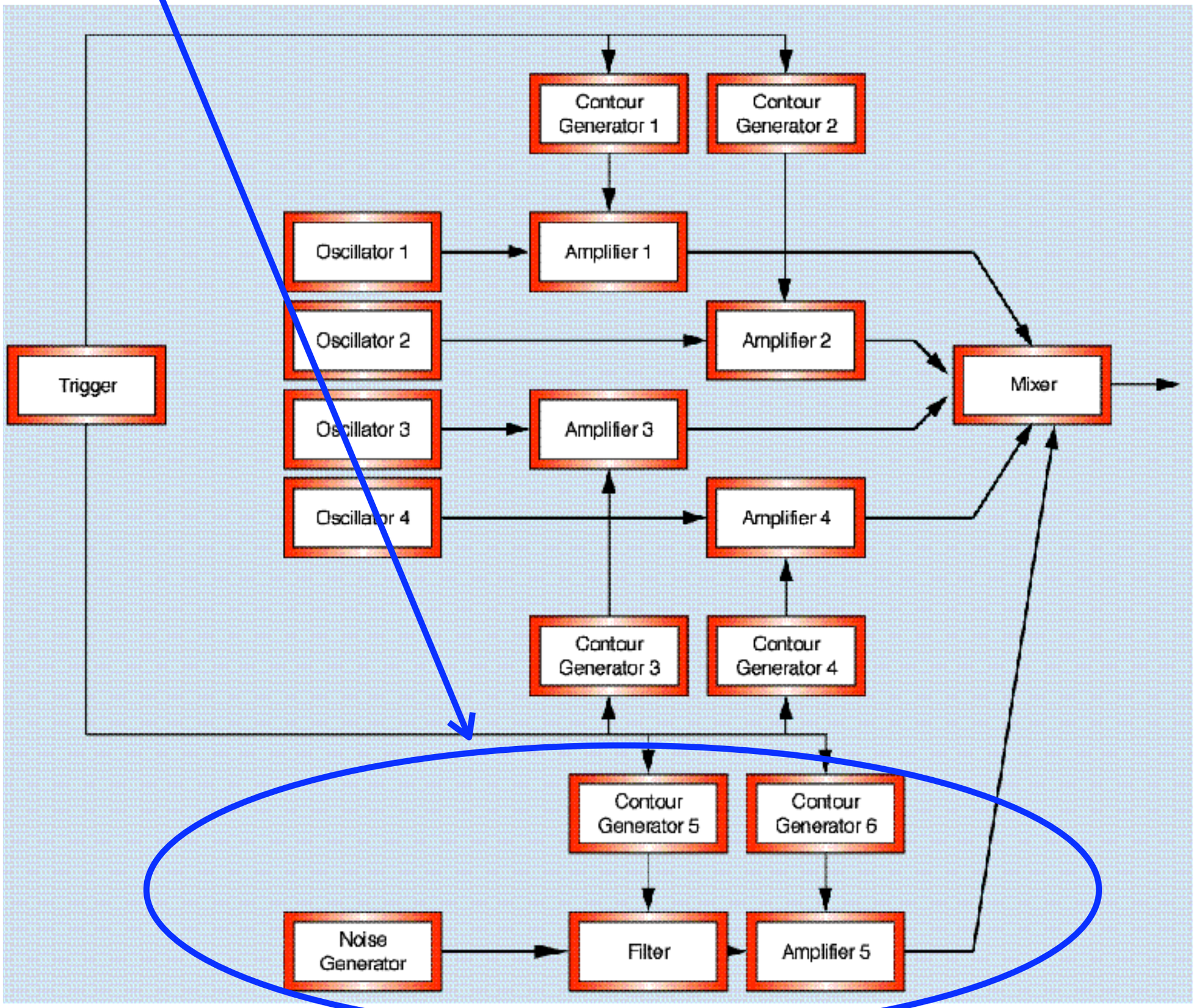
Manage lifecycle of tracks:
Birth, evolution, death.

Some sound components are not well modelled by sinusoids.



Sine + filtered noise models ...

Sine +
transients,
Sine +
residue,
etc ...



Recall: If you can fit a sound to a model, time-and-pitch modification can be done in parameter space.

$$x(t) = A\sin(\omega t + \phi)$$

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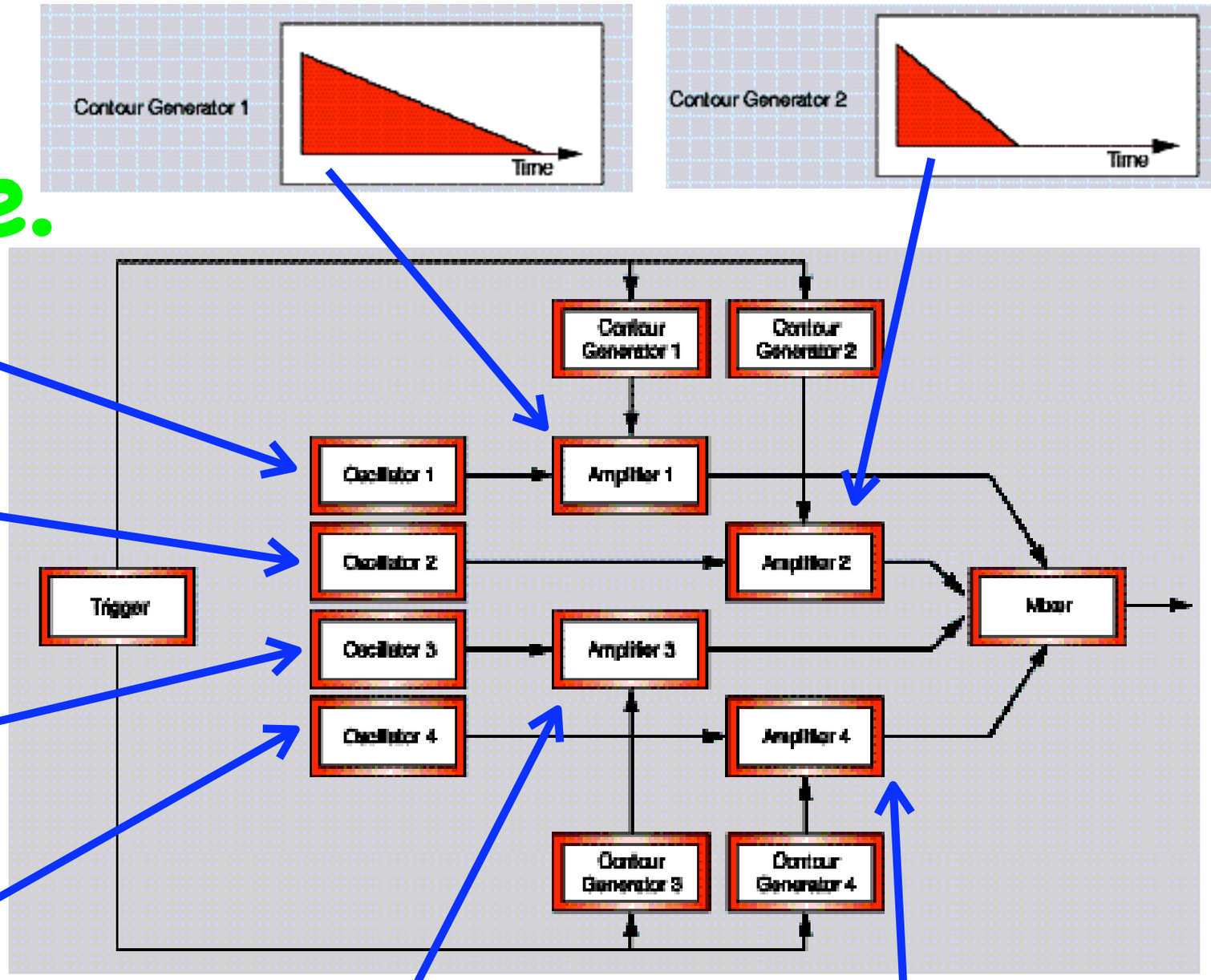
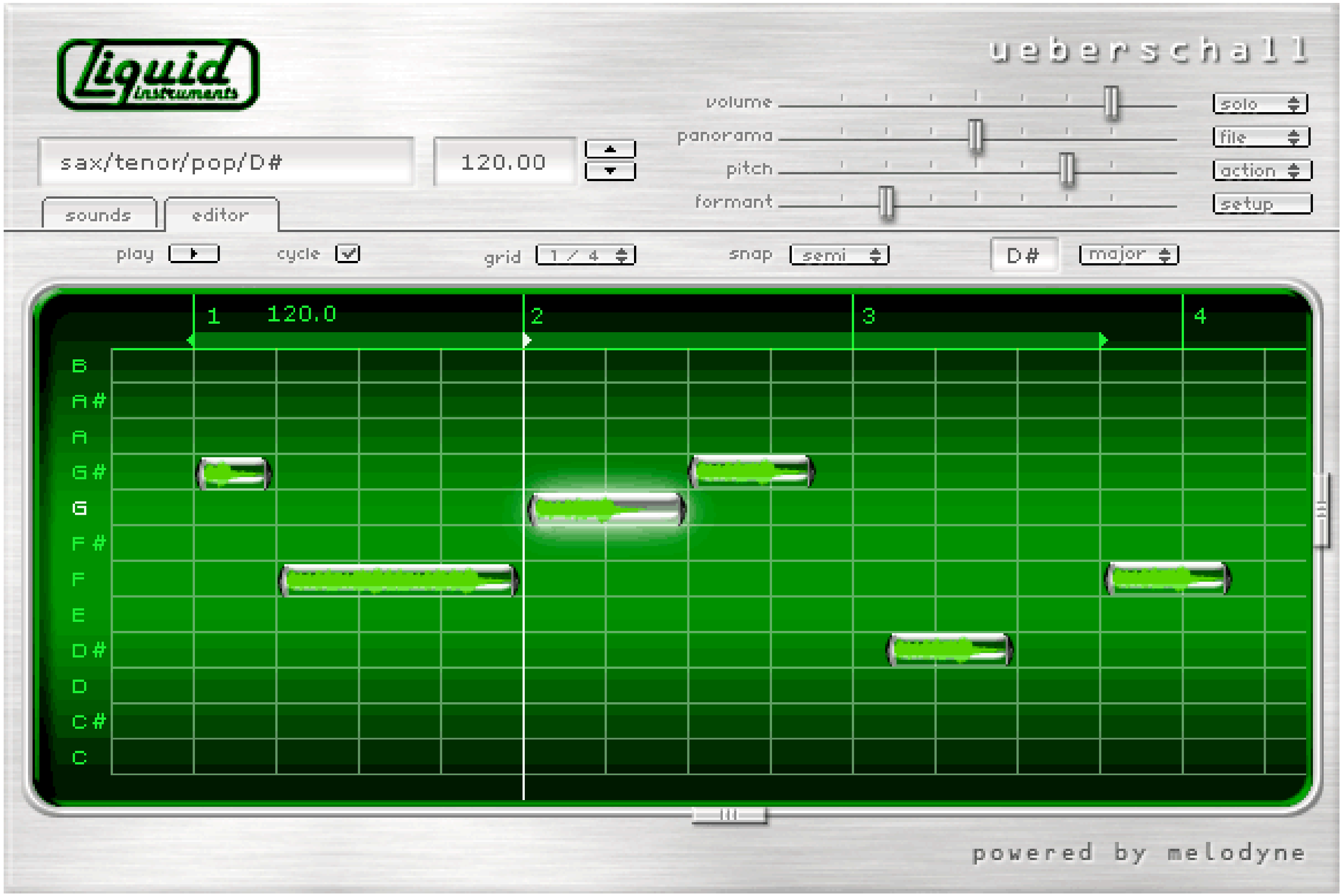


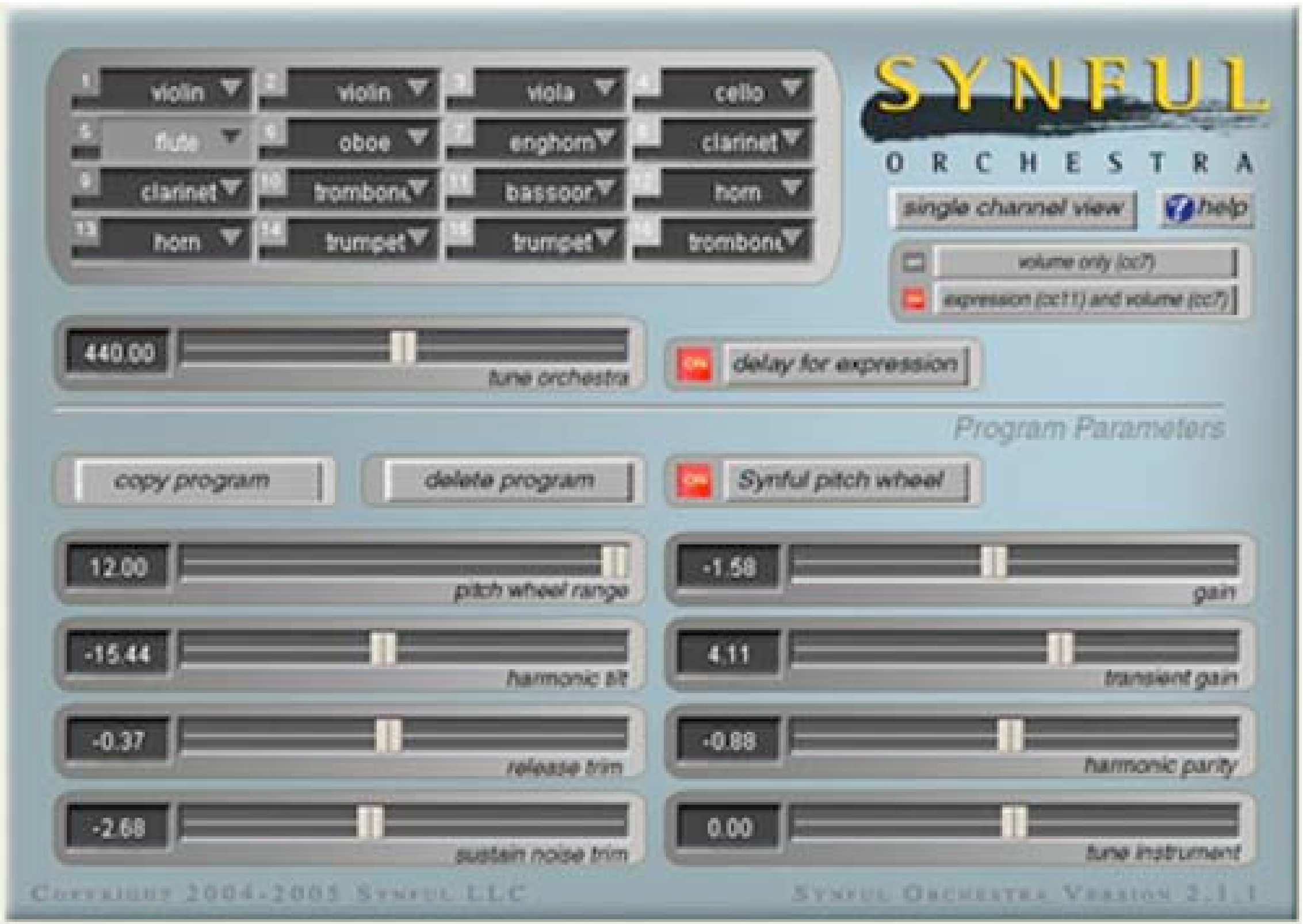
Commercial example:

Celemony Melodyne resynthesis editor.



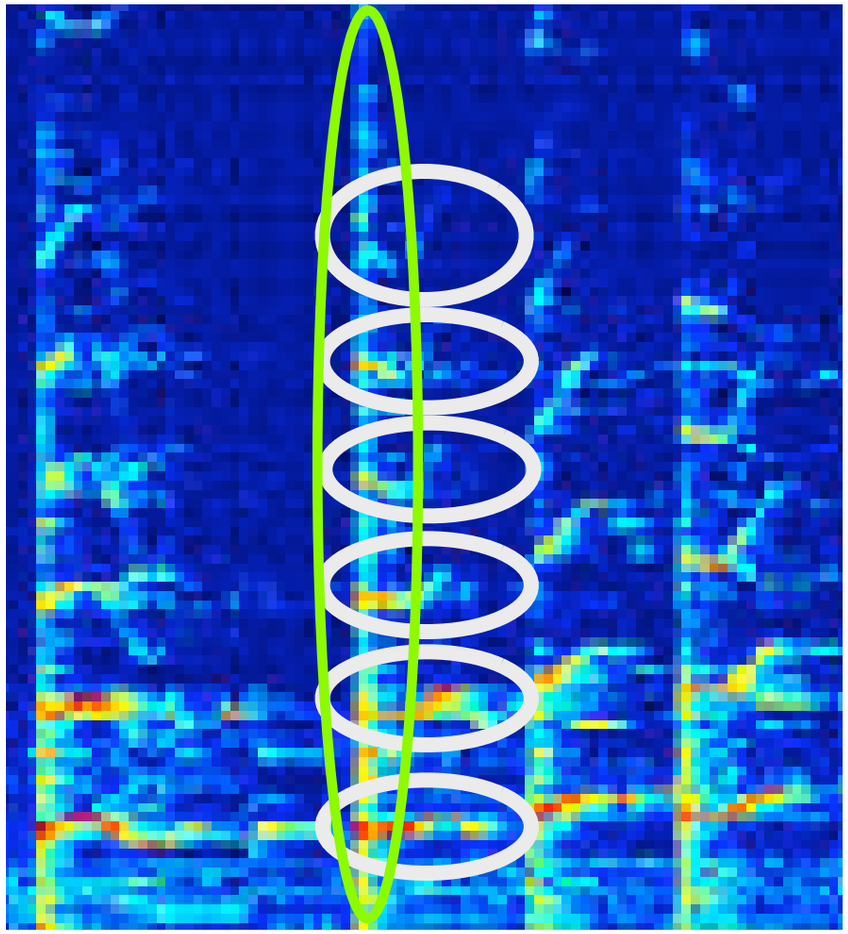
Commercial example:
Synful Orchestra

"about 100 sinusoids per note, + noise models"



Concept: Common Fate

Changes to sine tracks and other components that belong to the same note should not "break" object percept.

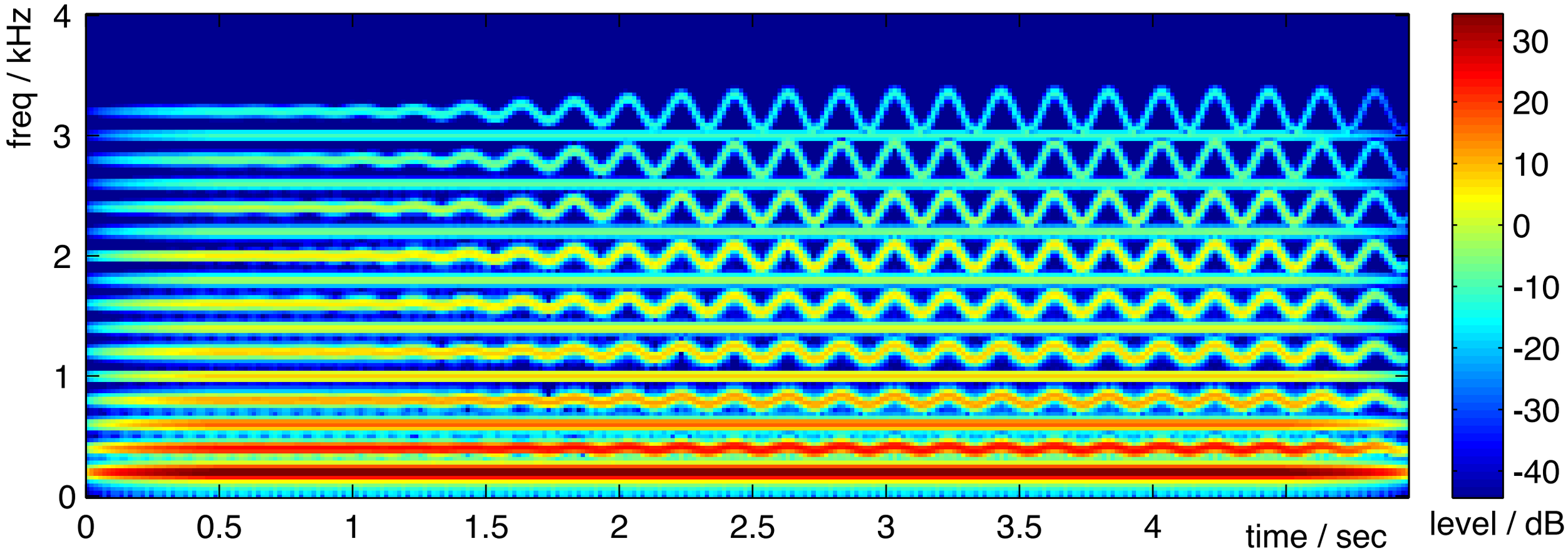


Pitch changes (vibrato, bends).

Phase continuity (noise to sines).

Amplitude envelope relations.

Example: Reynolds/McAdams Oboe



Adding vibrato to even partials makes them separate from the odd partials. (spectrum by Dan Ellis).

As shown

Reduced

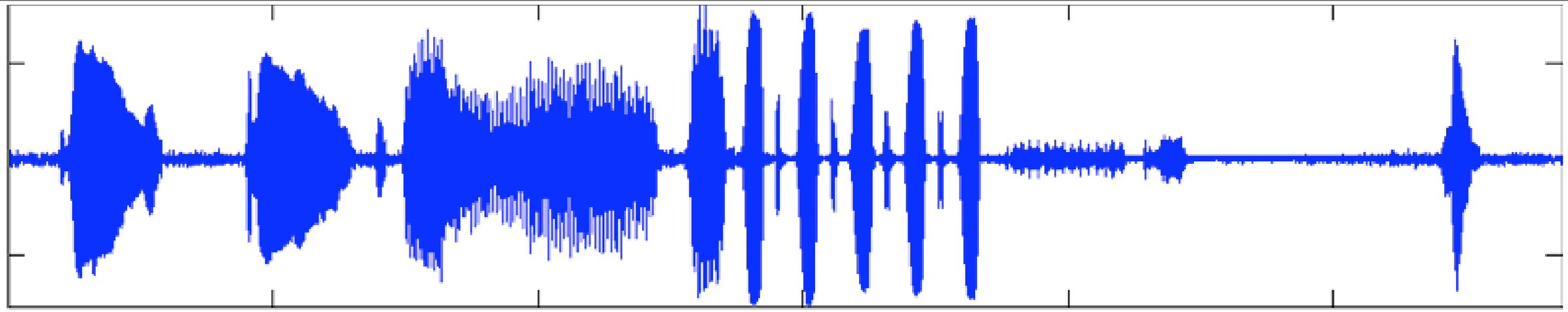
Recall: Fusing onset snippets

SYNTHESIZING TRUMPET PERFORMANCES

Istvan Derenyi and Roger B. Dannenberg

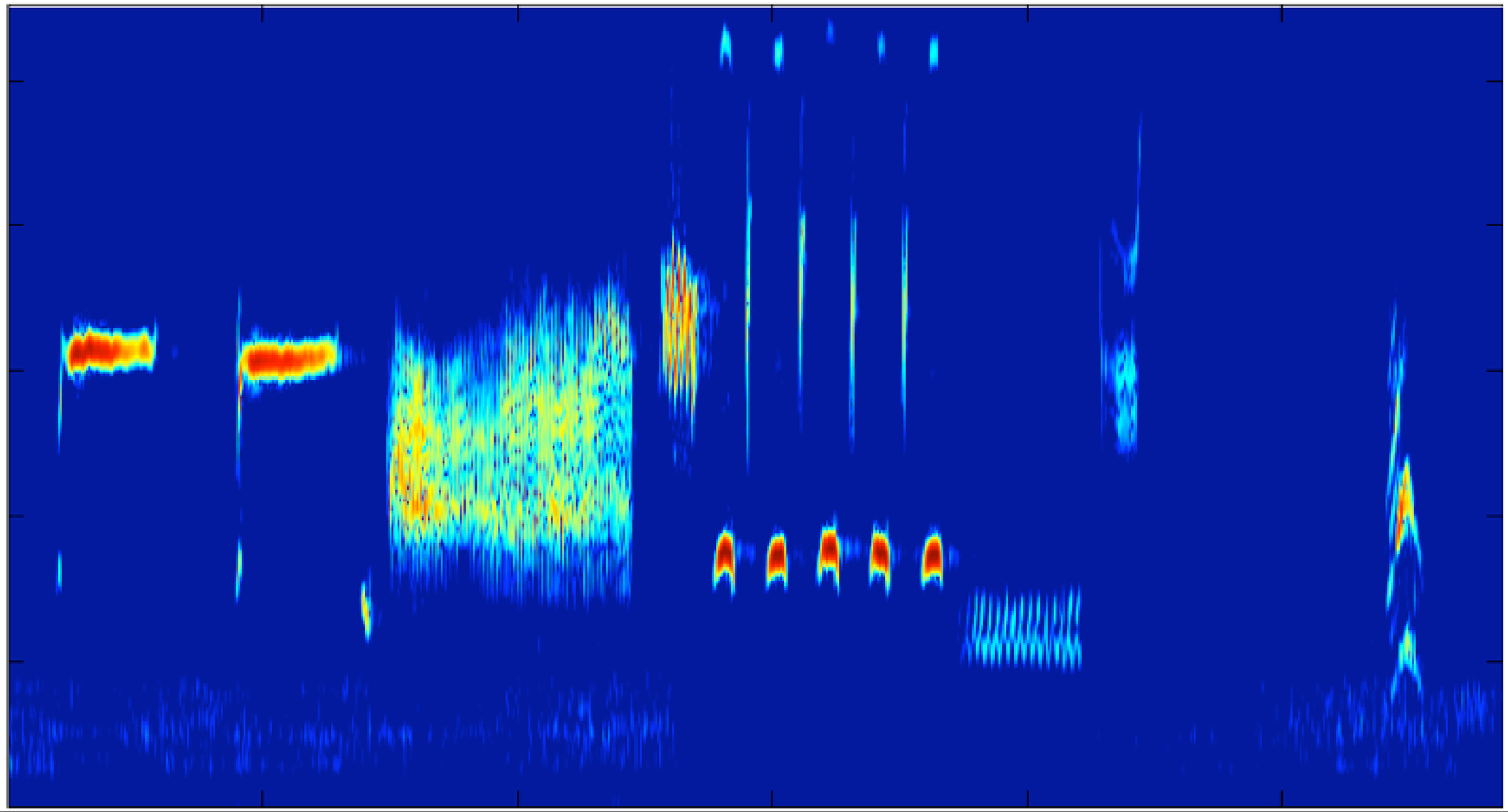
School of Computer Science, Carnegie Mellon University
Pittsburgh, PA 15213, USA
{derenyi, rbd}@cs.cmu.edu

- **Each scale note has a trumpet onset sample.**
- **Measure the amplitude and phases of trumpet harmonics at the end of onset sample.**
- **To begin the sustained sound, a waveform is calculated whose phases and amplitudes match the onset.**
- **Over 50 ms, interpolate to the desired amplitude spectrum of the sustained sound.**



Sparrow Bird Call

Play

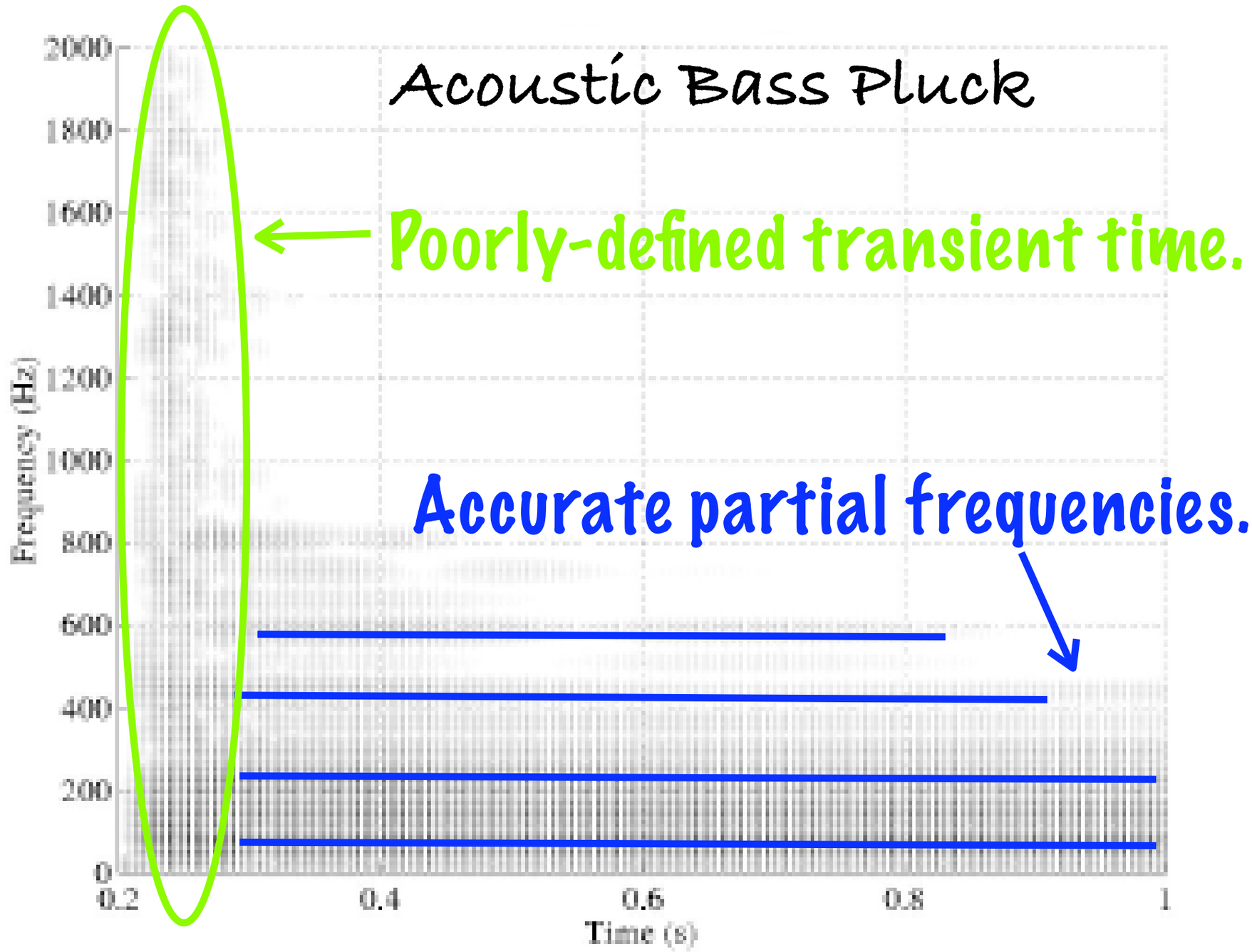


Time/Frequency Tradeoffs

Fast linear filters are wide.

Narrow linear filters are slow.

Playing

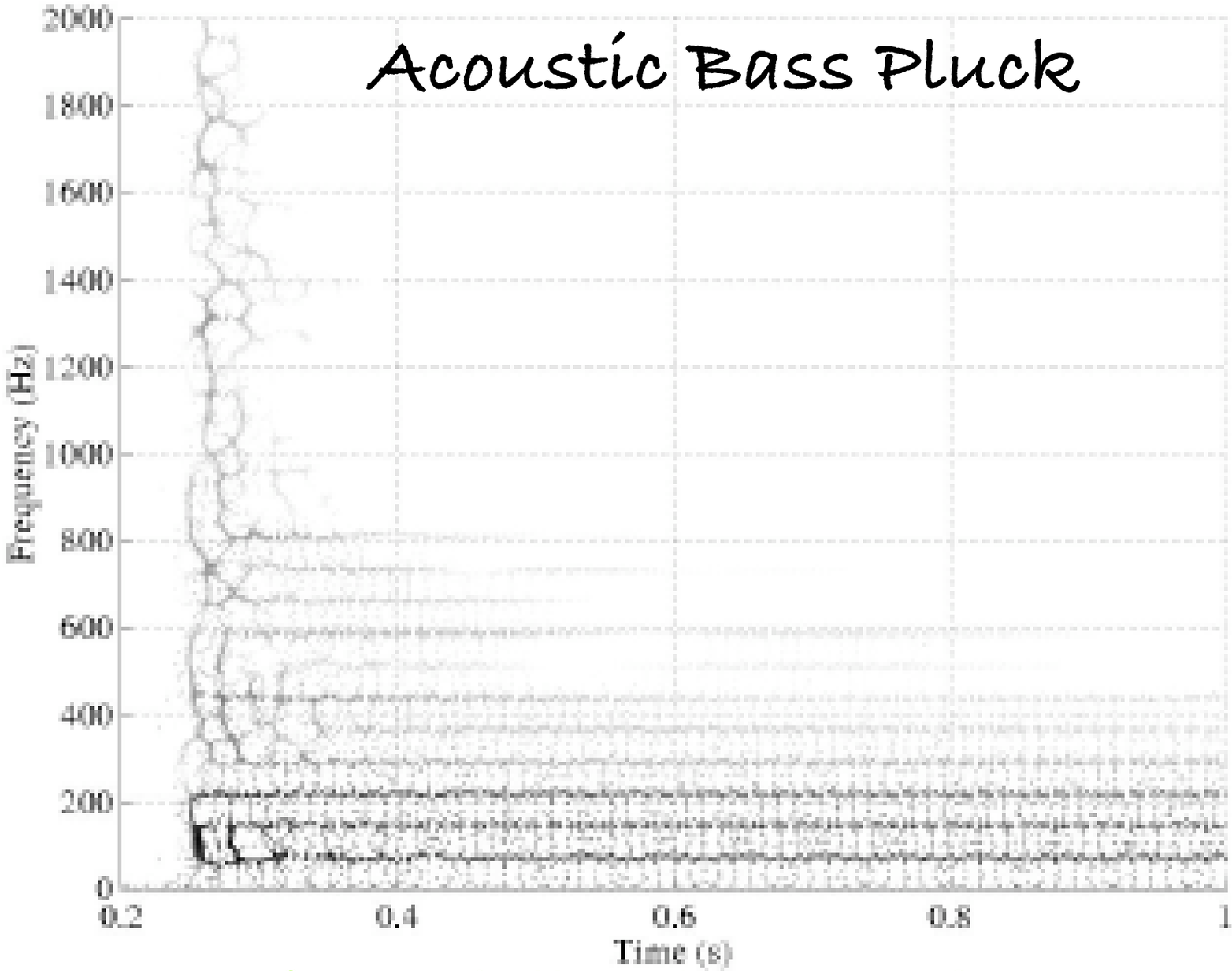


Time/Frequency Reassignment

Dedicate **phase** of spectrum to adjust **center of mass** of each "grid point".

Not a free lunch.

No phase information for the reassigned spectrum.

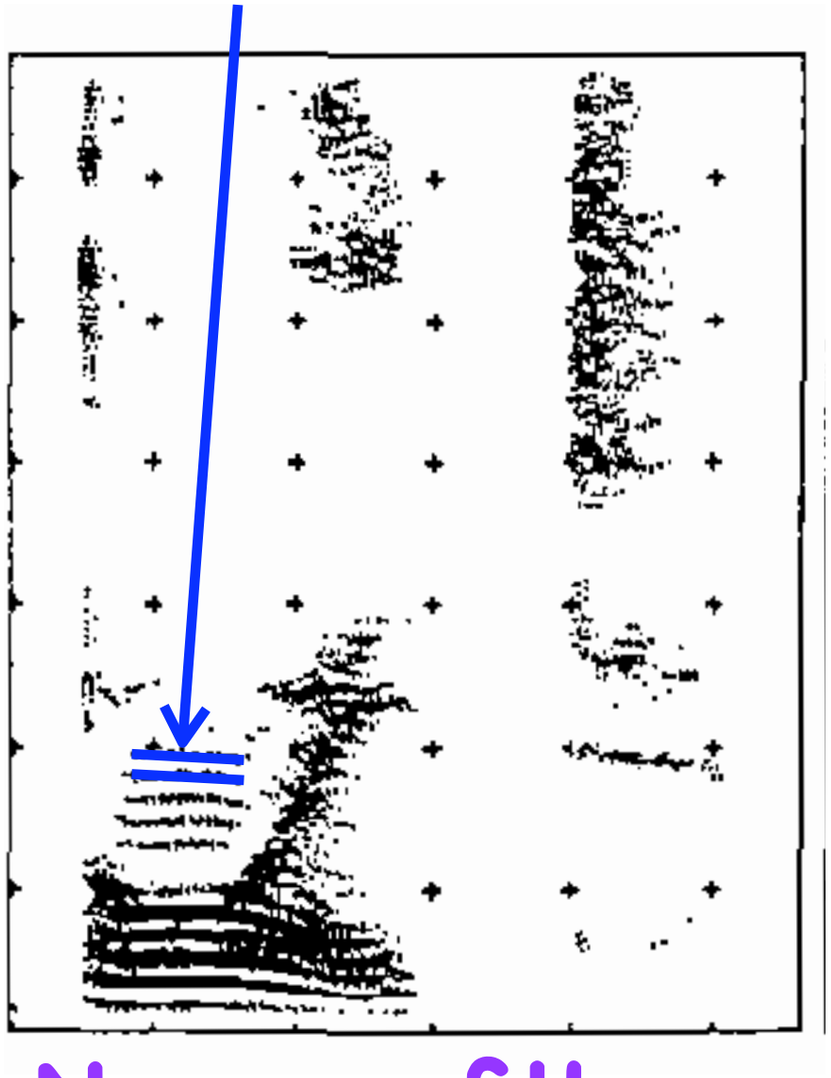


Data from Kelley Fitz and Sean Fulop

Scale-Space Approach

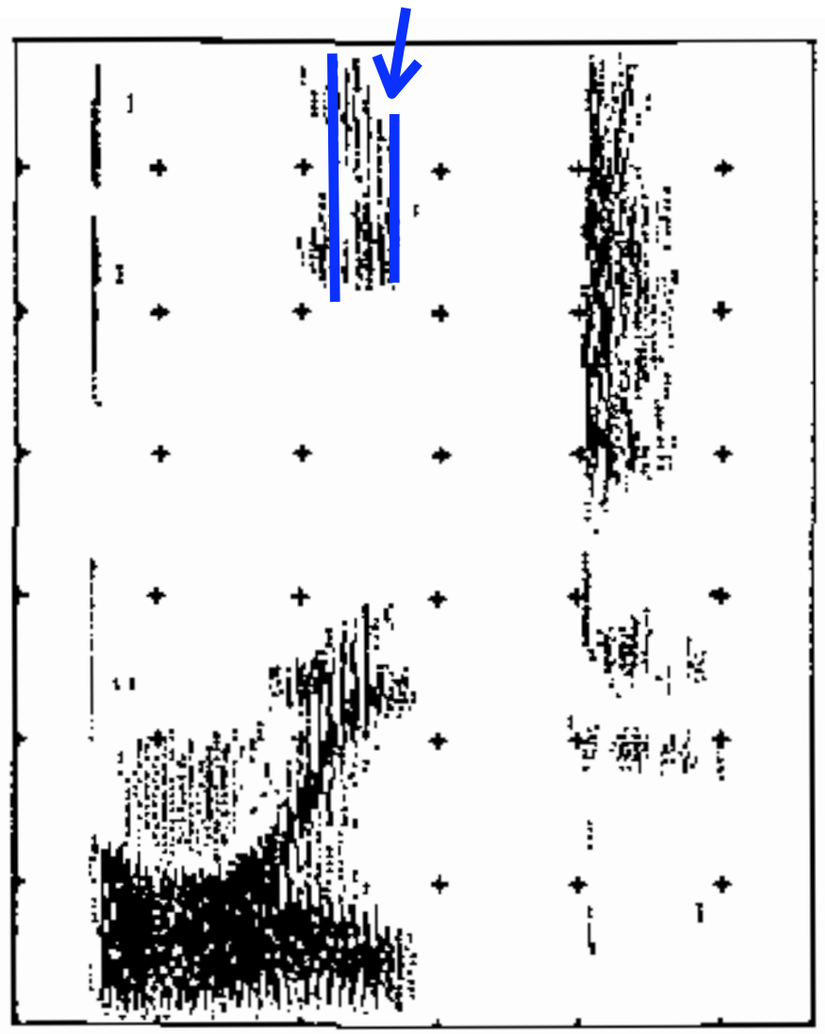
Spoken word "boyt" processed by two filterbanks.

Accurate pitch harmonics.



Narrow filters

Good glottal pulse timing.

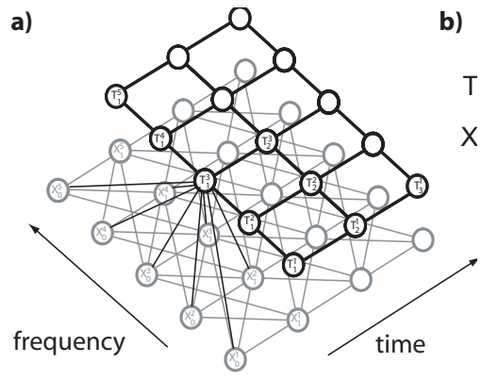


Fast filters

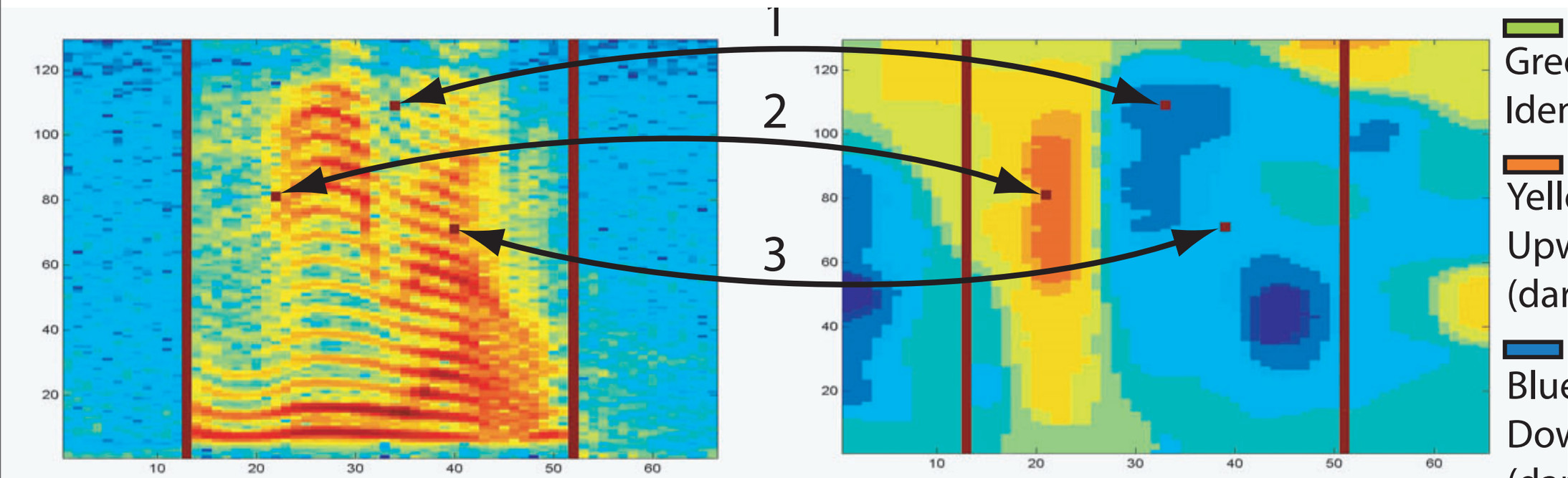
Data from Hong Leung and Victor Zue

Multi-Level Maps

Data from Reyes-Gomez, Jojic, and Ellis



Derive motion maps from spectrogram.



a) Signal

b) Transformation Map

Green:
Identity transform

Yellow/Orange:
Upward motion
(darker is steeper)

Blue:
Downward motion
(darker is steeper)

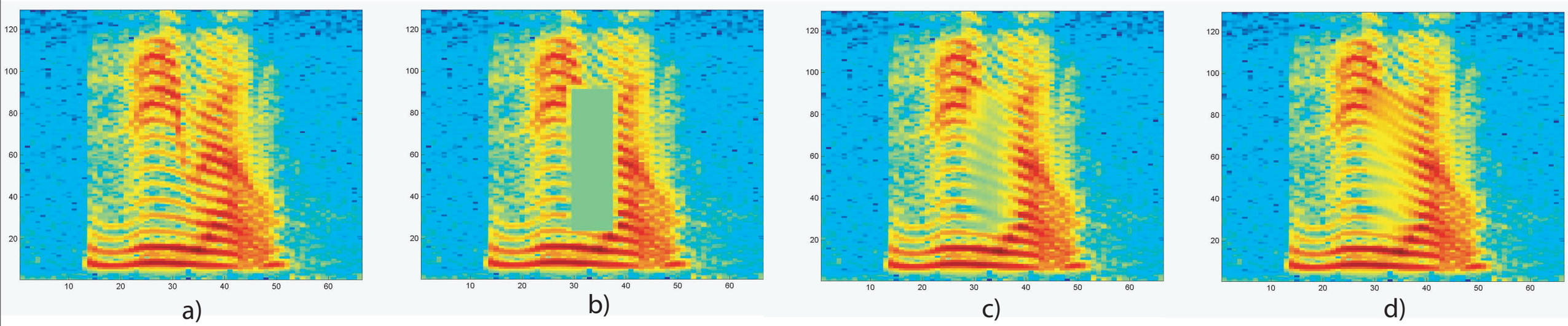


Figure 3: Missing data interpolation example a) Original, b) Incomplete, c) After 10 iterations, d) After 30.

My Former Life ...

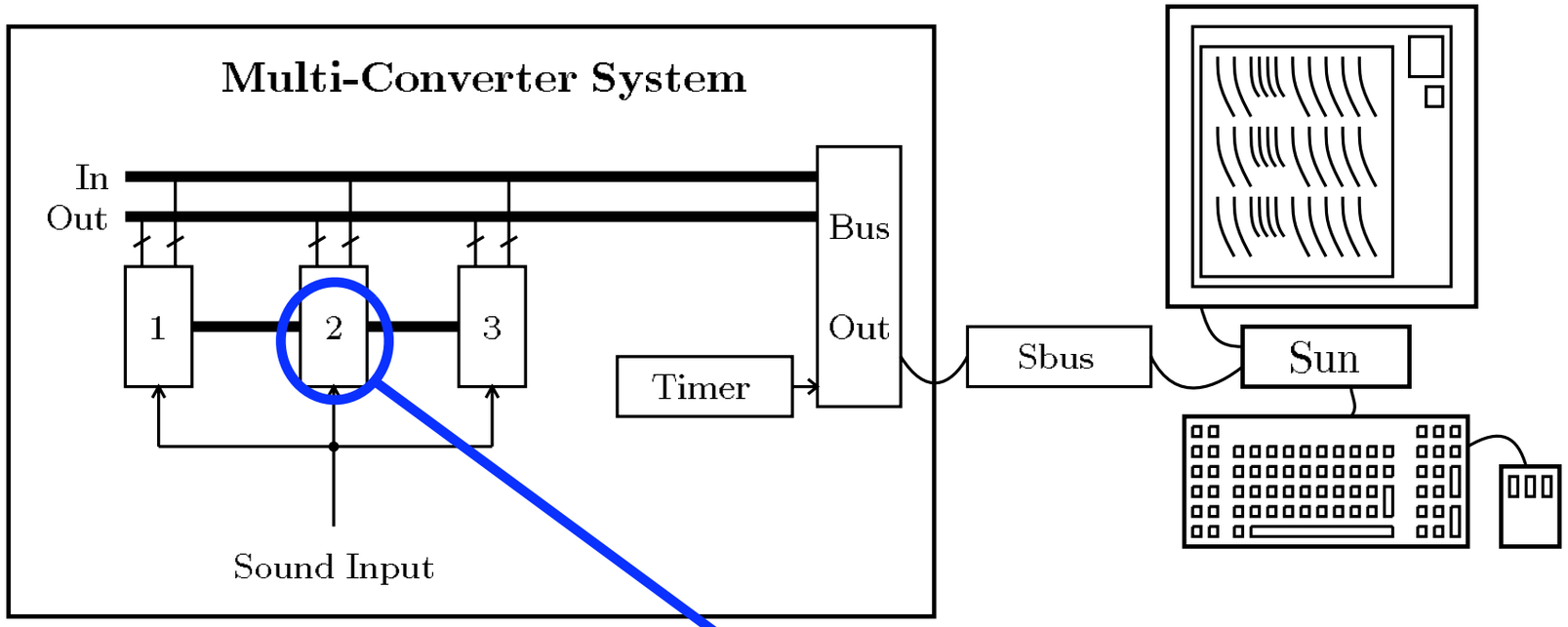


Figure 1. Block diagram of the multi-converter system.

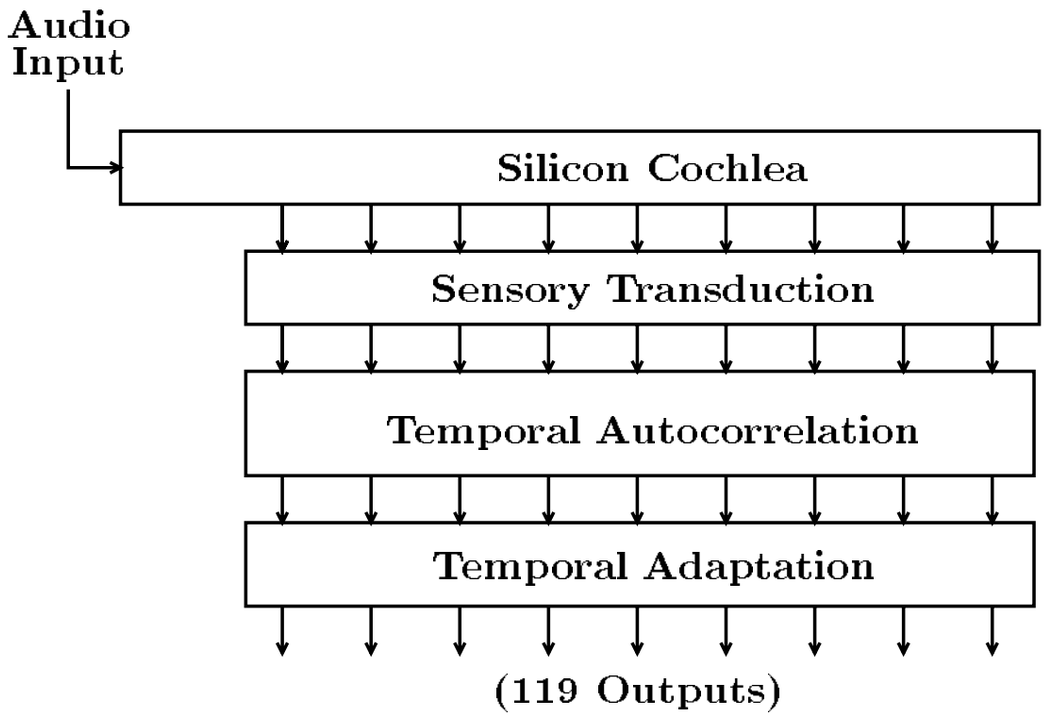


Figure 2. Analog signal path of the silicon auditory model.

My Former Life ...

Auditory Models
Adaptive Sampling
Specialized Features
Multiple Representations
High-Dimensional
Correlated Features

Speech Recognition
Uniform Sampling
General-Purpose Features
Single Representation
Low-Dimensional
Uncorrelated Features

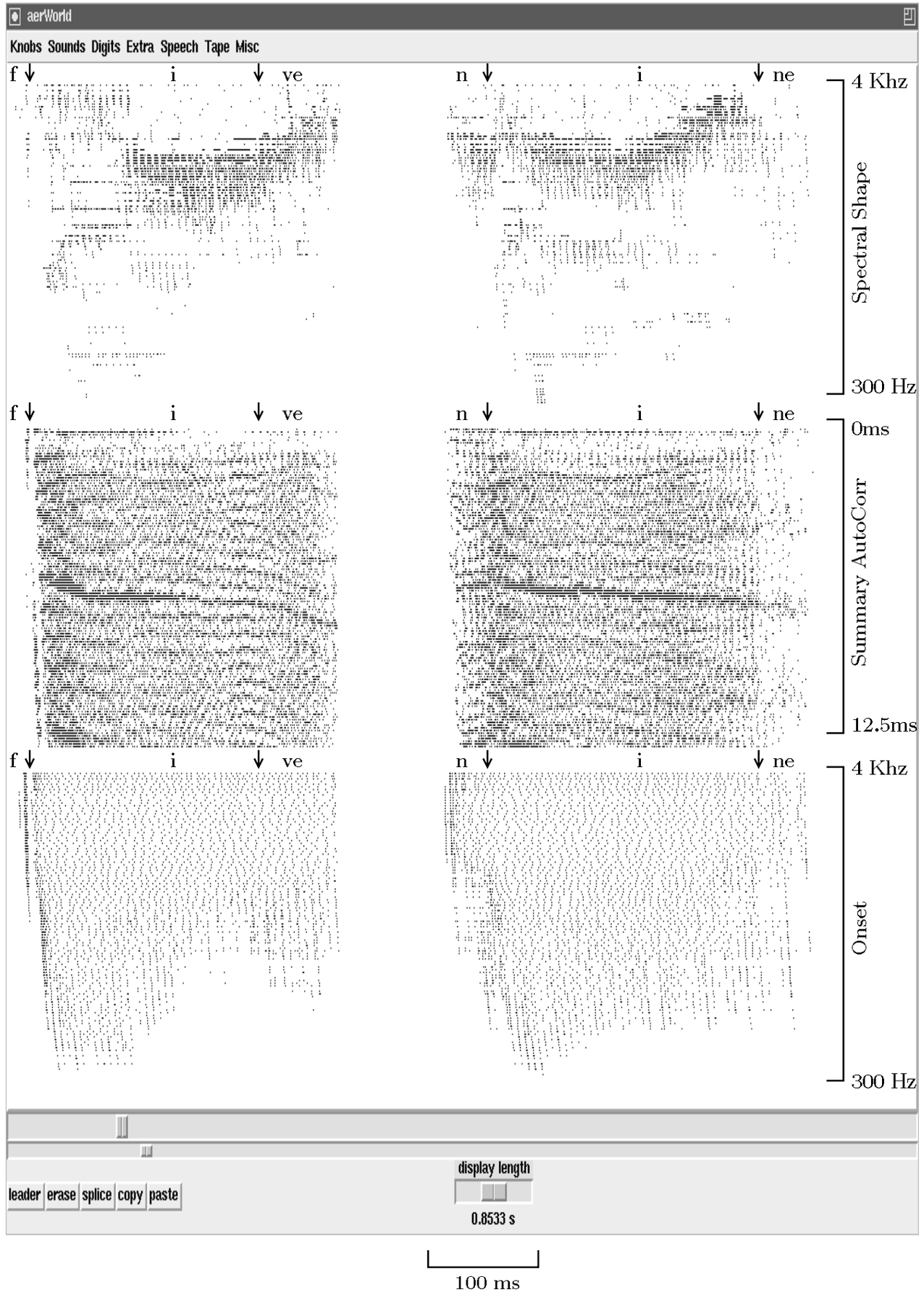


Figure 7. Data from the multi-converter system, in response to the word "five" followed by the word "nine".

My Former Life ...

Features	Parameters	Hidden Units	1	2	3	4	Average
SS	65,586	326	6.6	6.9	5.4	8.0	6.7
SS + Auto	65,468	276	5.7	5.8	4.5	5.5	5.4
SS + Onset	65,531	225	4.9	5.1	4.3	4.9	4.8
SS + Auto + Onset	65,456	200	4.9	4.2	3.2	4.0	4.1

Figure 12. Percent error for feature vectors derived from auditory representations (four database partitions). Other fields show number of hidden units and number of parameters in the MLP classifier net. Code: SS = spectral shape features, Onset = onset features, Auto = autocorrelogram features.

Features	Total	9/5	oh/no	others
SS	6.7	1.4	1.0	4.4
SS + Auto	5.4	1.1	0.8	3.5
SS + Onset	4.8	1.0	0.7	3.1
SS + Auto + Onset	4.1	0.7	0.6	2.8

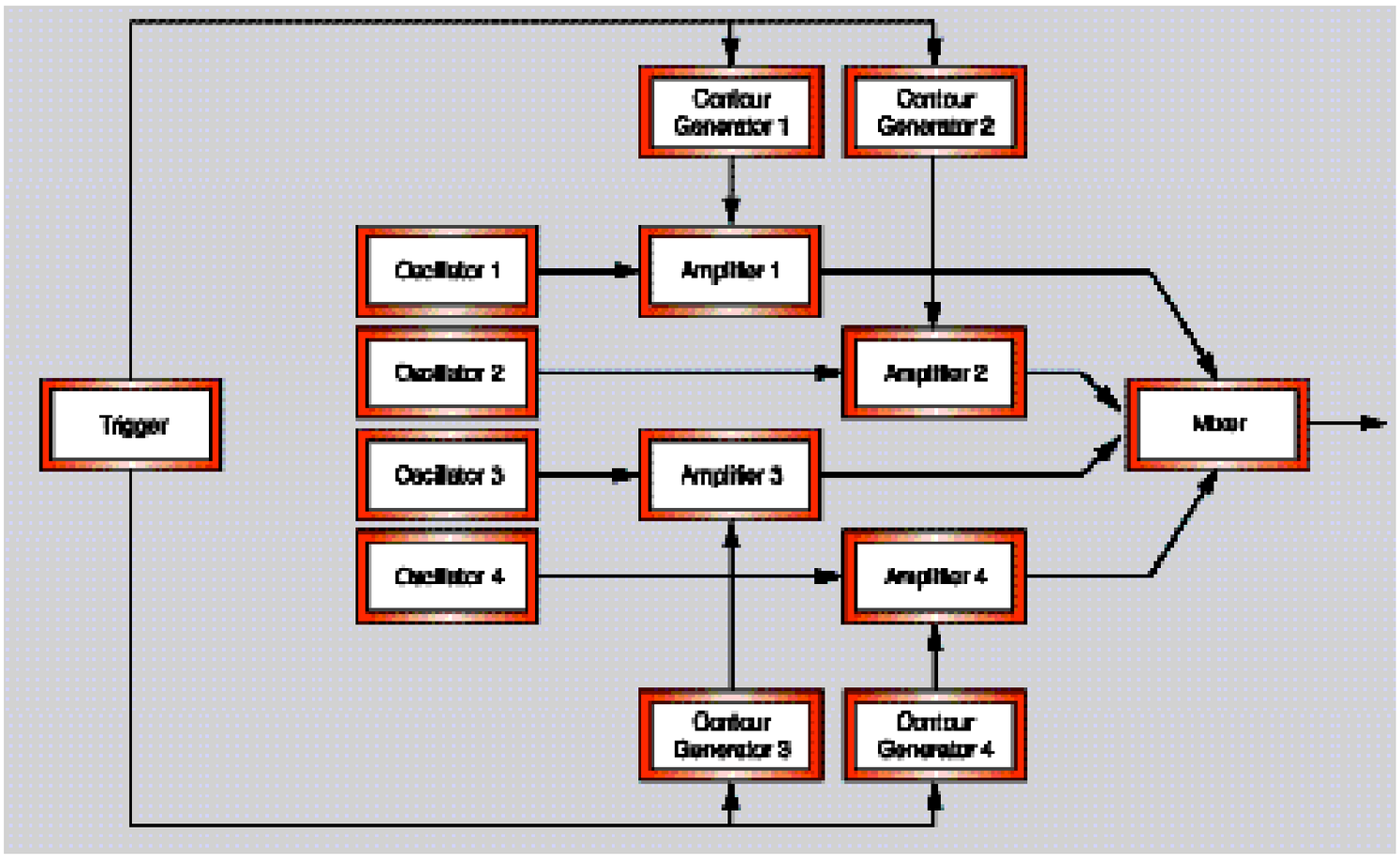
Figure 13. Error analysis of the recognition experiments in Figure 12 (averaged over partitions). Errors due to the two leading word confusions are listed (confusing "five" and "nine", and confusing "oh" and "no"), as well as the residual error.

Auditory Scene Analysis

Al Bregman

A field like computer vision, but for audio.

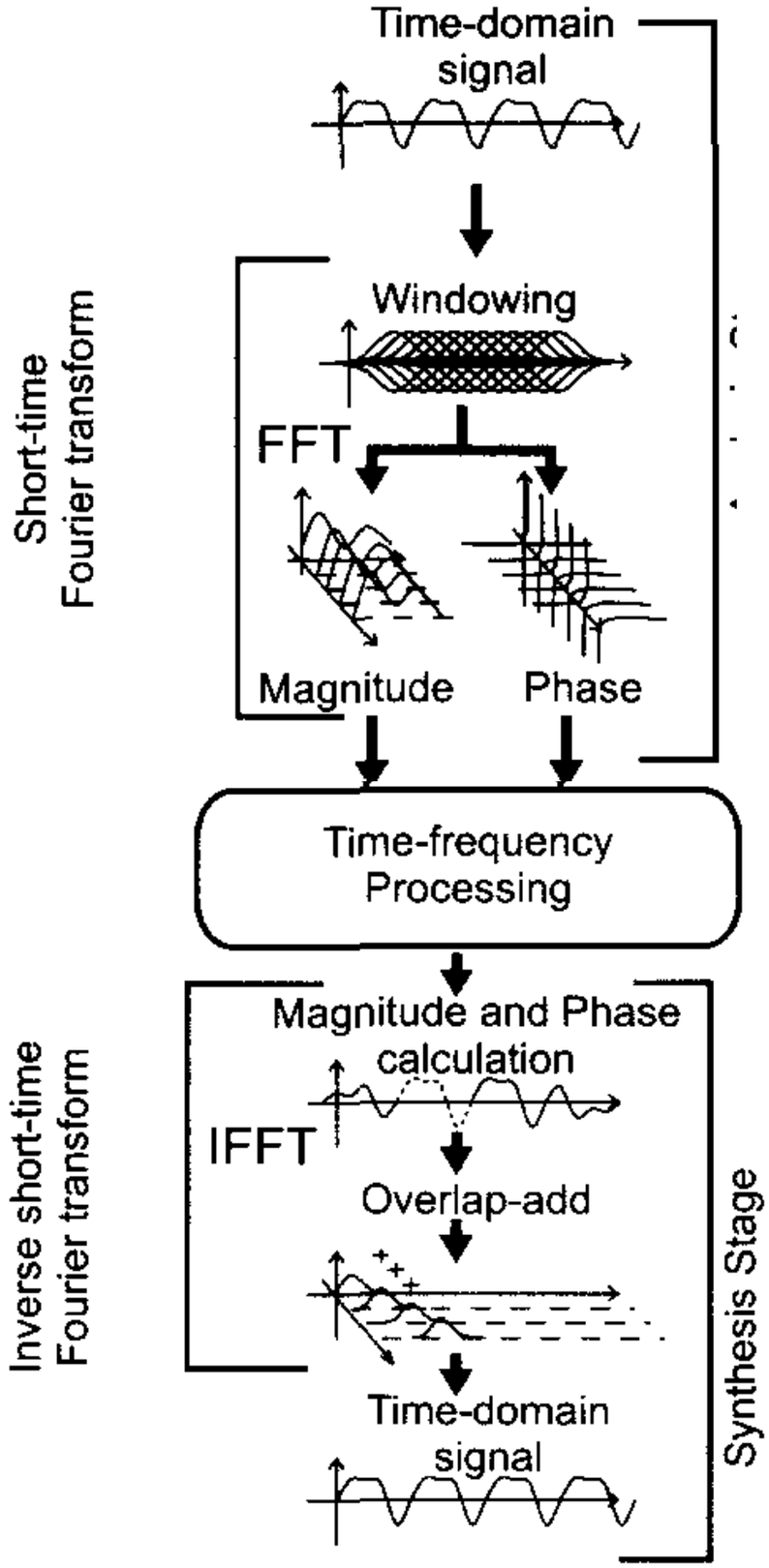
Like vision, we start with raw data, and build models of the world.



Resynthesis is playing back the model.

Contrast with ...

Audio Image Processing



"Audio Photoshop"

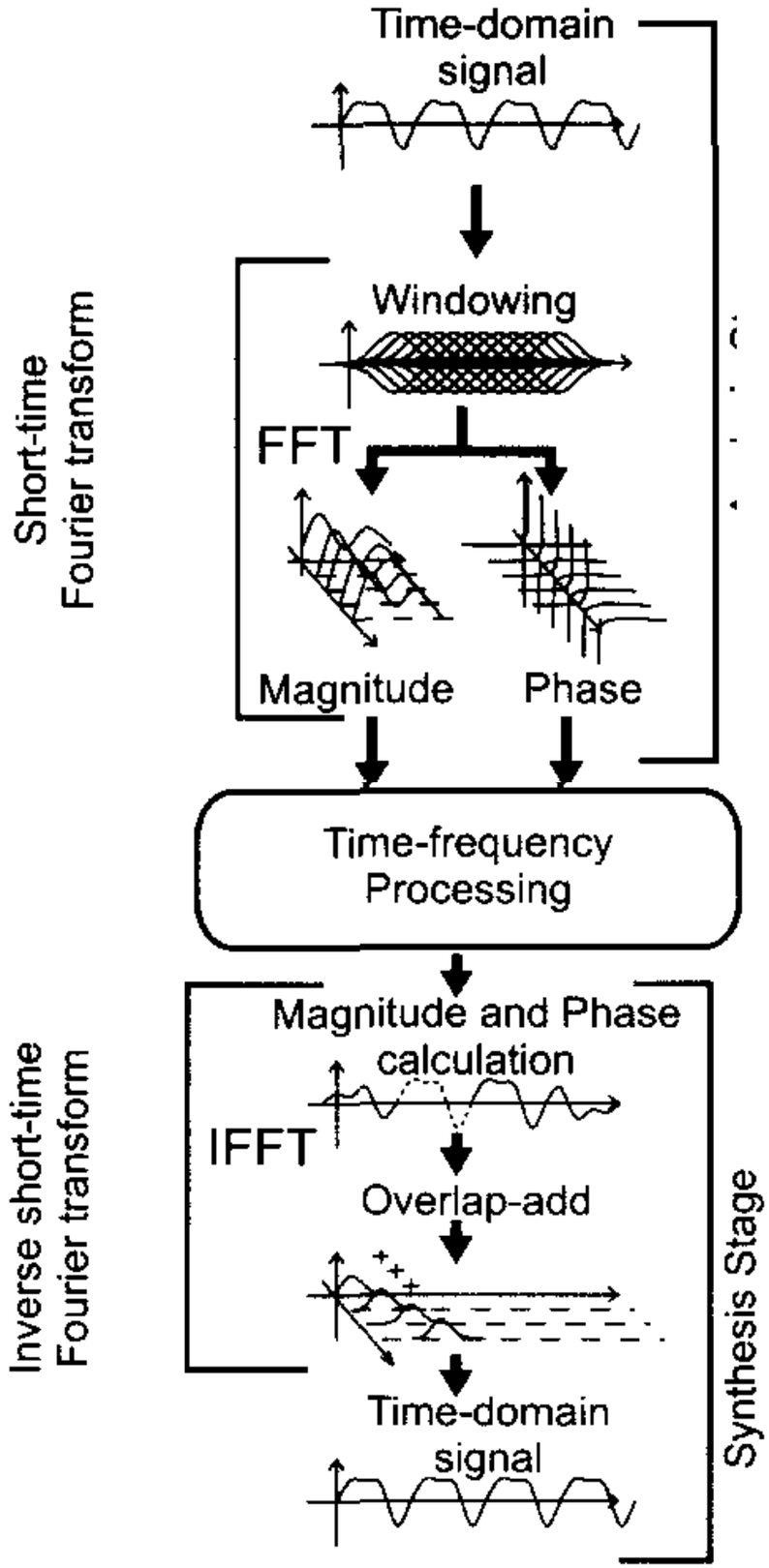
Convert audio into a "spectral photo".

Transform "photo" to be "better" (time-shift, pitch-shift, etc).

To recreate audio, "invert" photo-making process.

Example: Phase Vocoding

Original
2X slower



Advantages

No model to build: easier to design, faster to run.

Disadvantages

Without a model, harder to maintain "common fate" and avoid artifacts.

Admin: Progress Report Presentations

Progress Report Presentation	March 23 in class	A 10-15 minute presentation to the class, describing the current status of the project. Group projects should share presentation duties between all members. Audio demos of work in progress is encouraged. Primary purpose of presentation is to solicit feedback from the audience.	15 percent

Cynthia

Psyche (Apr 6)

Jeremy

Bradley

Carlos

Eric

If you are enrolled (or are auditing and doing a project) and not on the list, let us know!