Inharmonic Speech:

A Tool for the Study of Speech Perception and Separation

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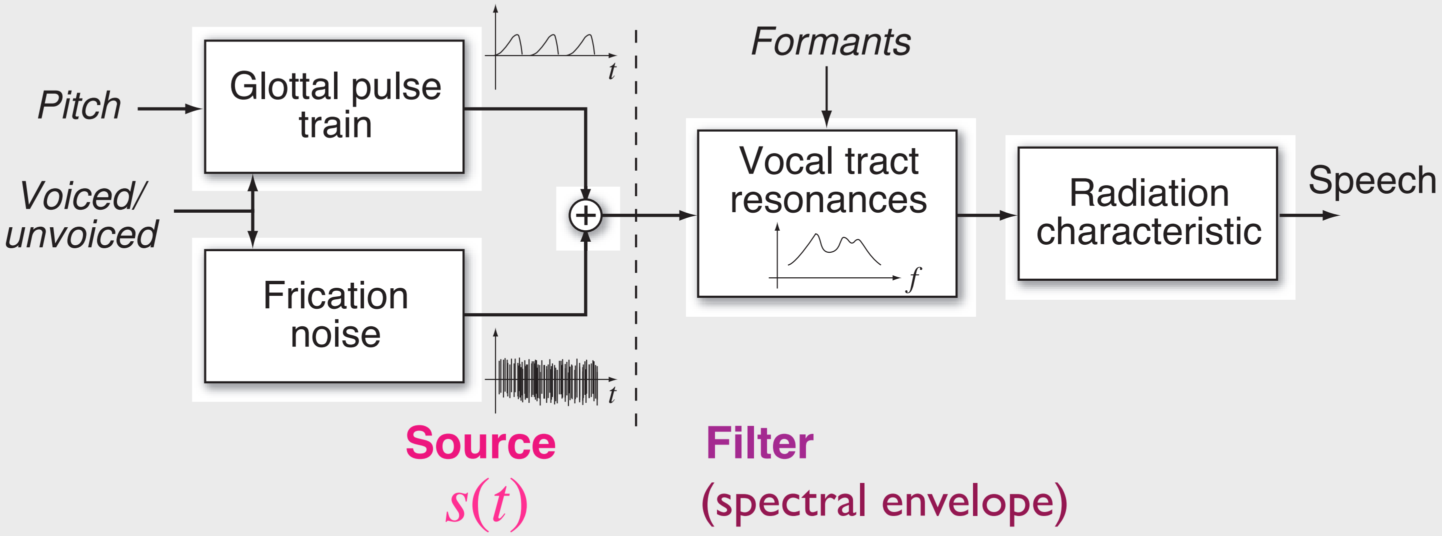
1. What is inharmonic speech?
2. Why make inharmonic speech?
3. How to make inharmonic speech
4. Psychoacoustic experiments

Lab ROSA
Laboratory for the Recognition and Organization of Speech and Audio

The Structure of Speech

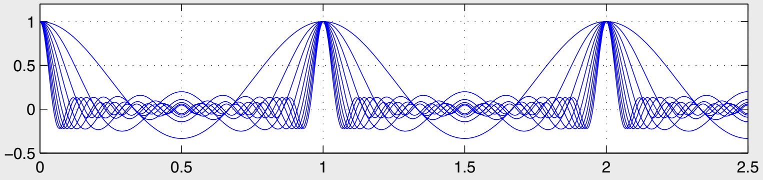
- Classic source/filter model

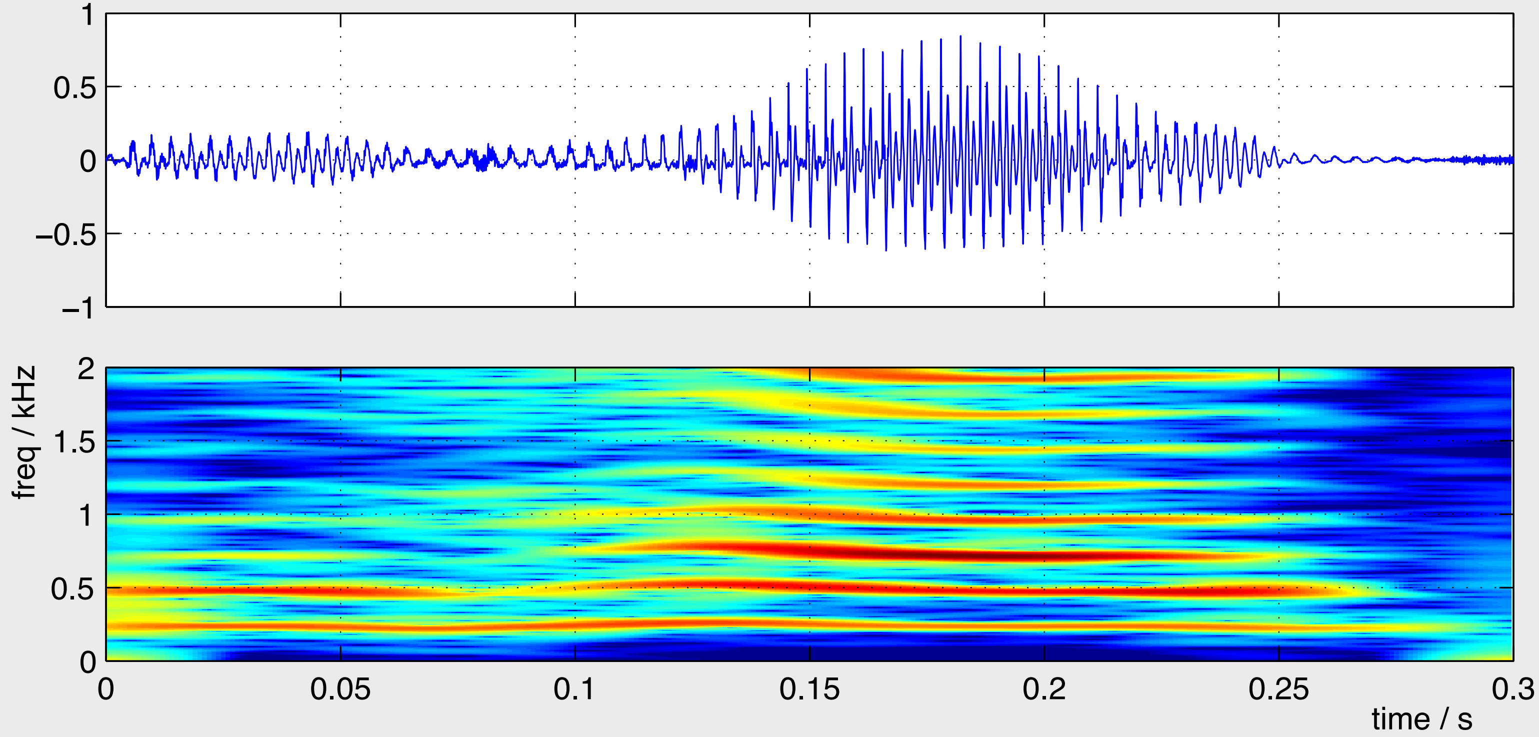


Harmonic Speech

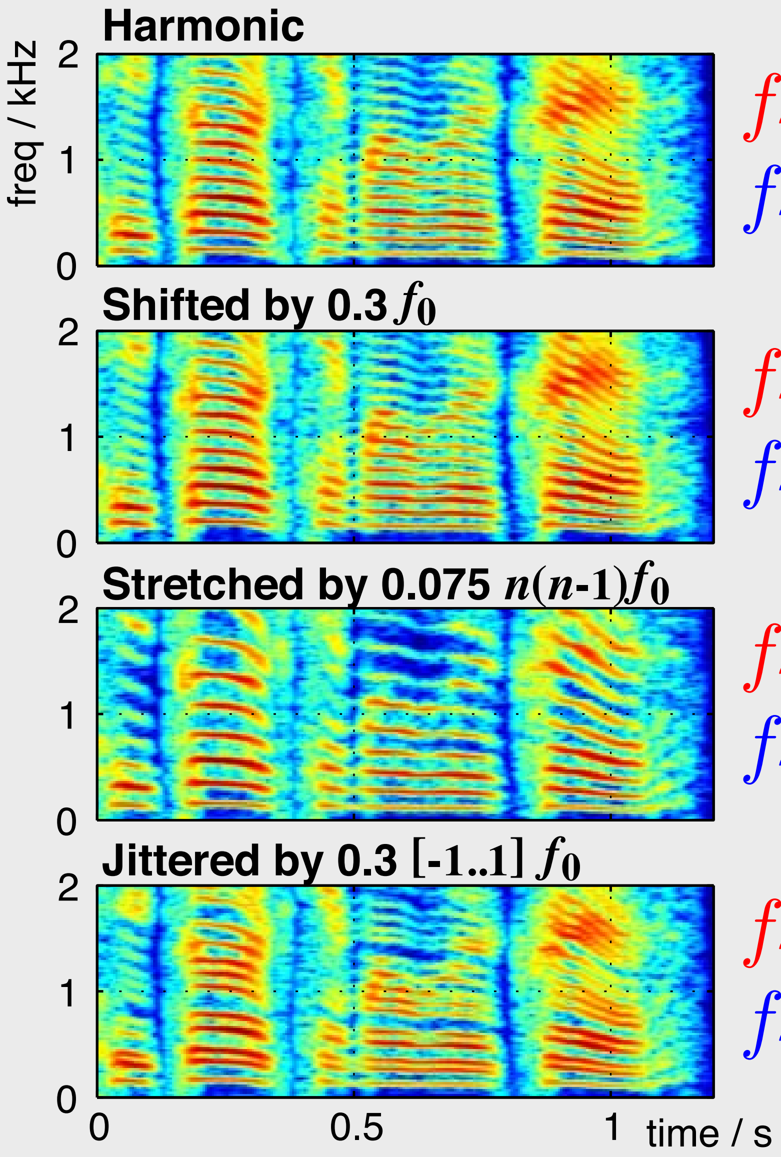
- Periodic source pulses as a Fourier series:

$$\sum_{n=-\infty}^{\infty} \delta(t - n\tau) = \frac{1}{\tau}\left(1 + \sum_{k=1}^{\infty} 2\cos k\frac{2\pi}{\tau}t\right)$$





Inharmonic Speech



$$f_n = nf_0$$
$$f_{n+1} - f_n = f_0$$

$$f_n = nf_0 + af_0$$
$$f_{n+1} - f_n = f_0$$

$$f_n = nf_0 + b(n^2 - n)f_0$$
$$f_{n+1} - f_n = (1 + 2bn)f_0$$

$$f_n = nf_0 + cr_nf_0 \quad r_n \in [-1 \ldots 1]$$
$$f_{n+1} - f_n = (1 + c\Delta r_n)f_0$$

source

$$s(t) = \sum_{n=1}^{N} \cos 2\pi f_n t$$

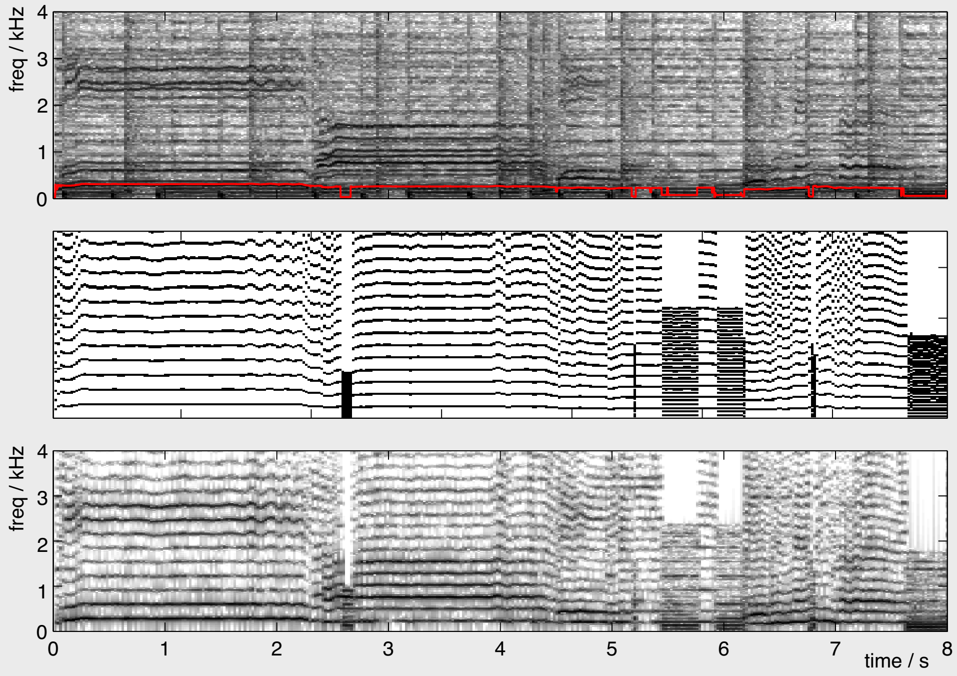
Why Inharmonic Speech?

- Harmonicity is believed important
  - .. to the fusion of sounds in auditory organization
  - .. for pitch perception (prosody, speaker identity)
- Voiced speech has...
  - multiple (resolved) harmonics = "sparse" spectrum
  - .. with similar modulation properties
  - .. in a harmonic pattern
- How important is the "harmonic pattern"?
  - See how well people (& machines) can organize and separate inharmonic speech
  - .. which is otherwise "natural"
  - maybe it's enough to have a "sparse" spectrum?

Harmonicity for Separation

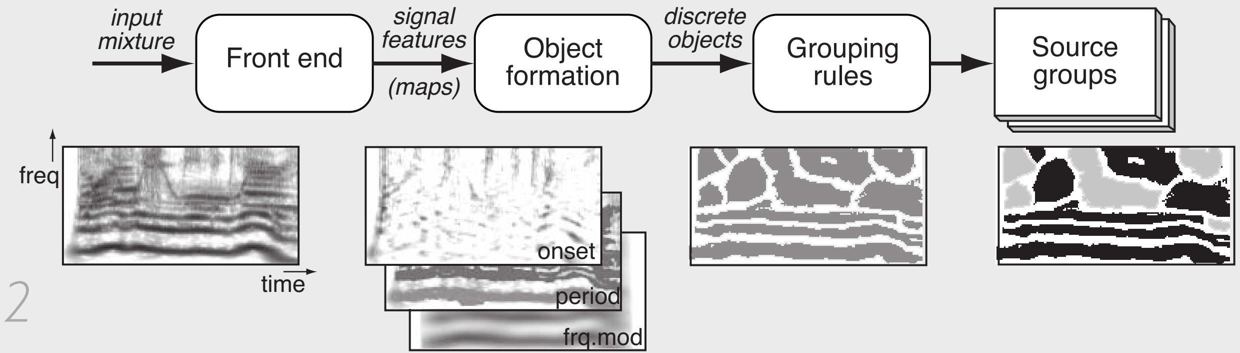
- **Filtering of harmonics**
  - after f0 is found

Denbigh & Zhao 1992
Avery Wang 1995



- **Labeling of regions**
  - by shared f0 candidate

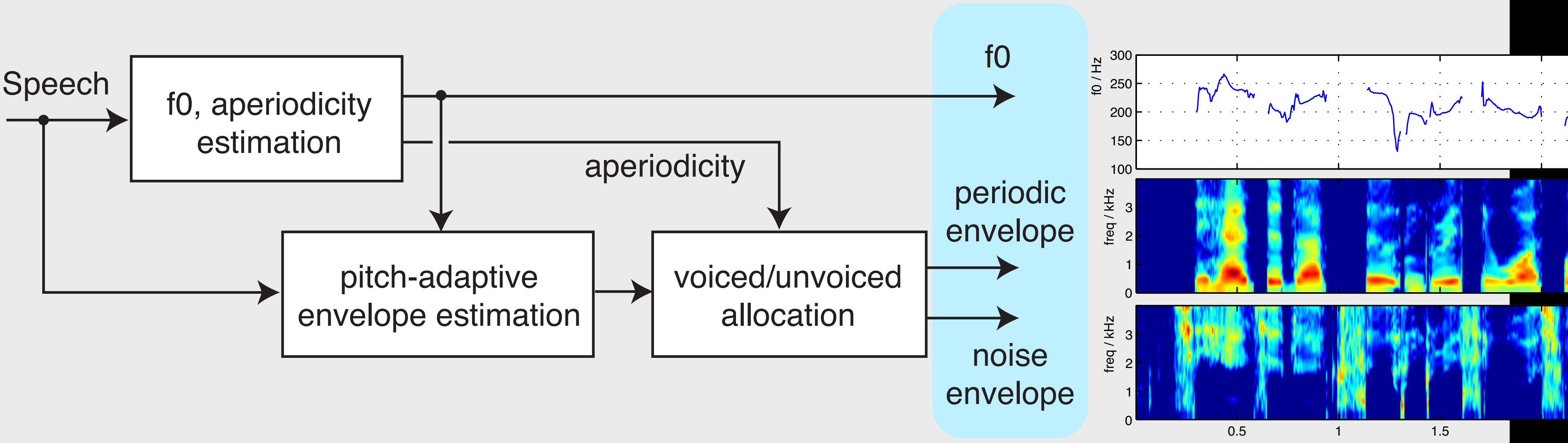
Brown 1992
Hu & Wang 2004



input mixture → Front end → *signal features (maps)* → Object formation → *discrete objects* → Grouping rules → Source groups

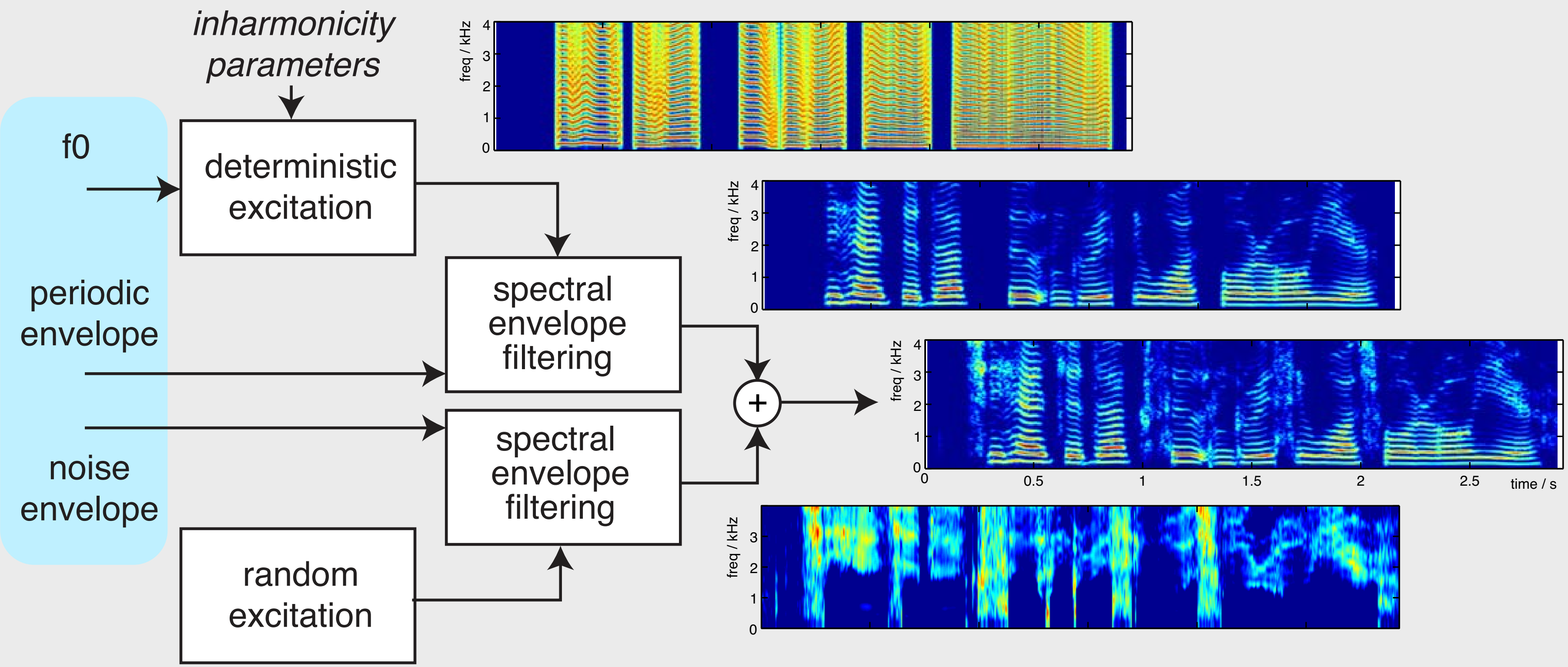
Synthesizing Inharmonic Speech

- Based on STRAIGHT *Kawahara 1999, 2006 ...*
  - decompose speech into:
    - f0 (pitch track)
    - periodic envelope (voiced speech)
    - noise envelope (unvoiced speech component)



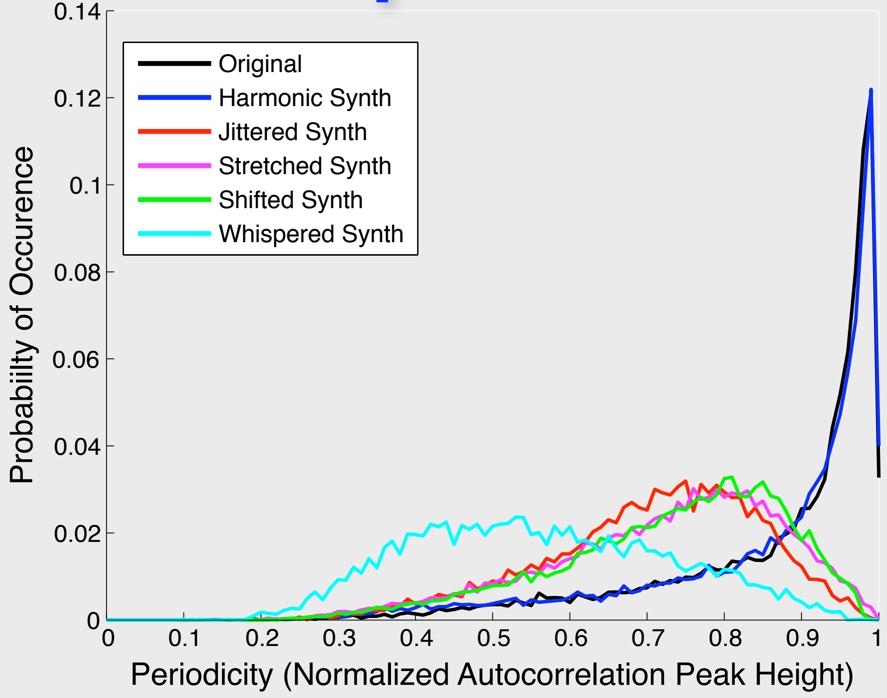
STRAIGHT Synthesis

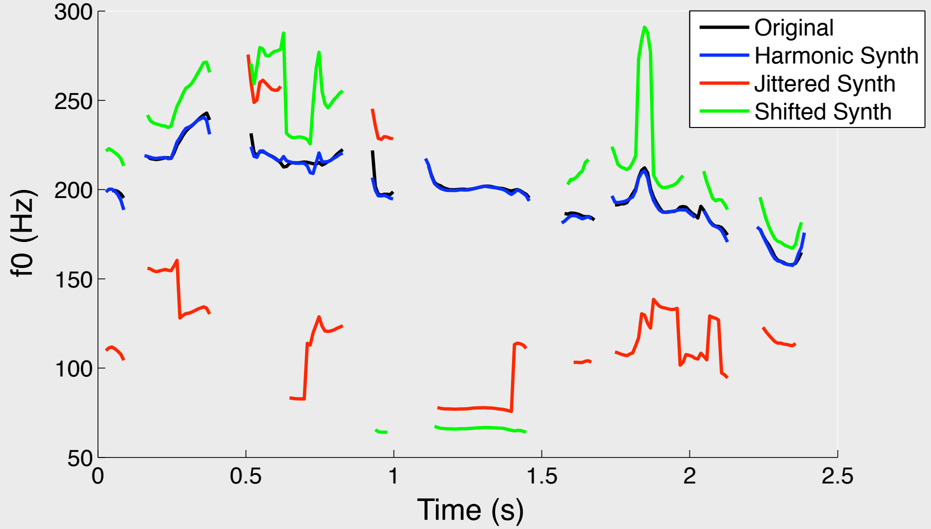
- STRAIGHT periodic source resynthesis
  - ... as individual pitch pulses
  - ... or as a set of Fourier components
    - which can be made inharmonic



Inharmonic Speech Properties

- Periodicity index calculated by Praat
  - histogram over 76 TIMIT utterances

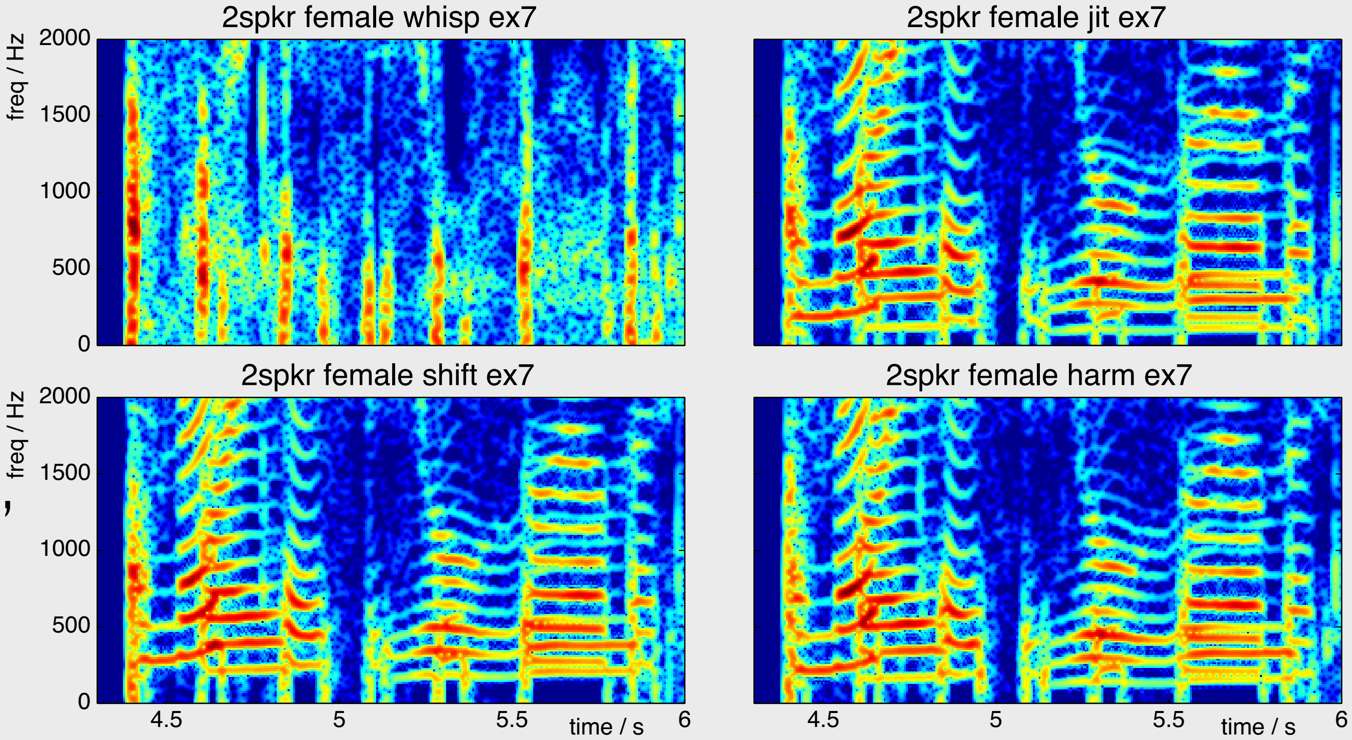




- Pitch tracks calculated by Praat for an example utterance

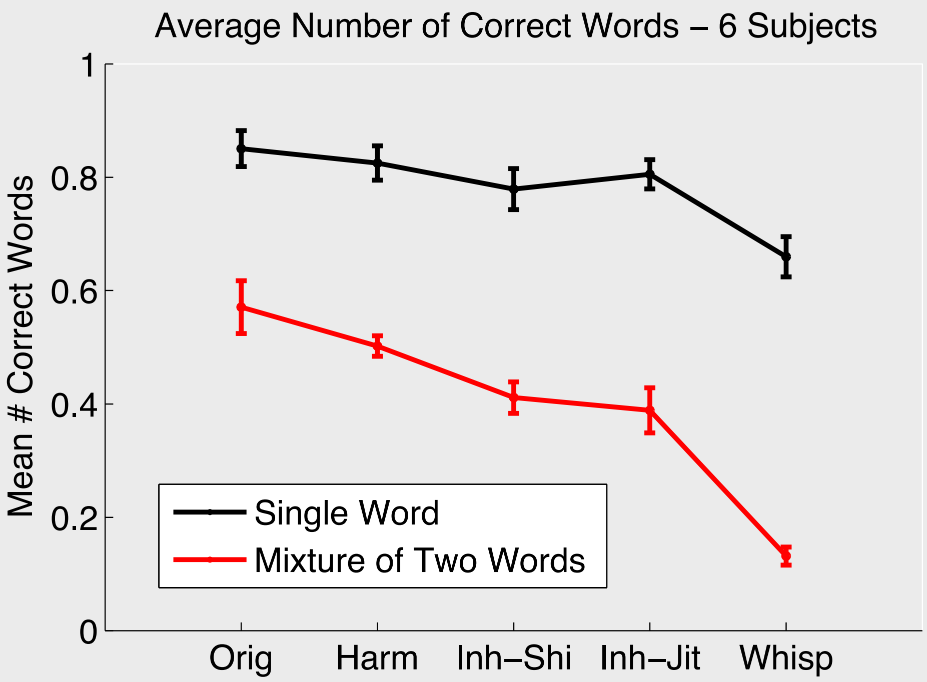
Psychological Experiment

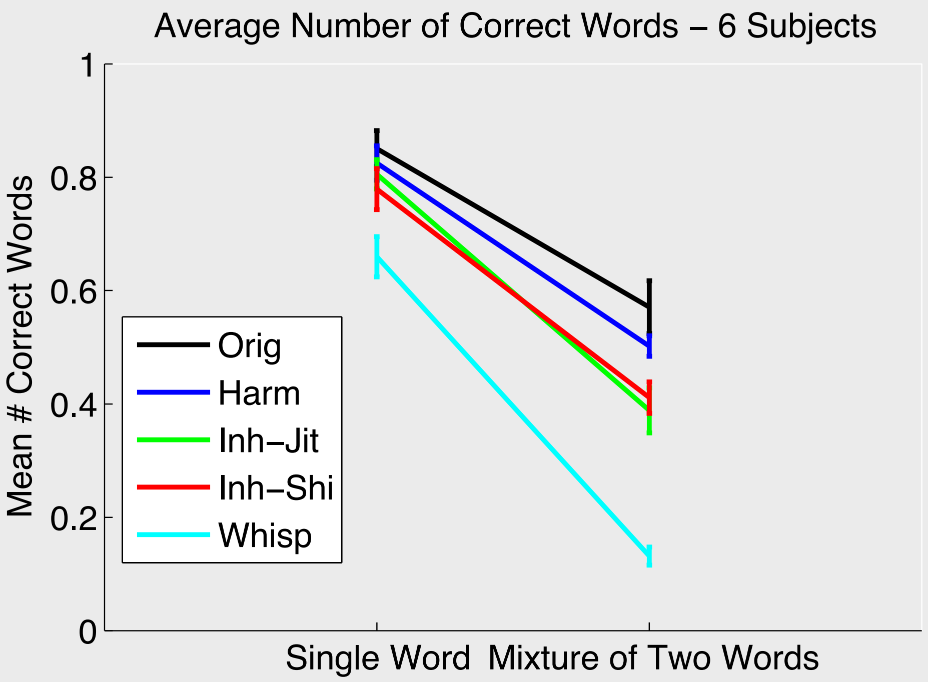
- Idea: See impact of removing harmonicity on ability to understand mixed words
- Listeners presented with one or two simultaneous words or utterances
  - measure accuracy at identifying all words
  - synthesized as harmonic, inharmonic, or whisper



Results

- Harmonic tokens a little easier to understand
  - but inharmonic tokens much better than whispered
  - different types of inharmonicity seem equivalent
  - Spectral sparsity is a big contributor to separation?





Conclusions

- Harmonicity of voice is thought to be important for auditory scene analysis
  - but hard to separate harmonicity and sparsity
- Modified STRAIGHT framework produces high-quality inharmonic tokens
  - excitation synthesized as sinusoids with arbitrary frequency tracks
- Preliminary experiments show that inharmonic tokens can still be separated
  - quantify contribution of harmonicity vs. sparsity