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The
TANDEM-
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vocoder

Vowel resynthesis workshop

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Speech perception research often calls for fine-grained control over parameters of speech stimuli

Trade-off between naturalness and control

Detailed description and evaluation of speech synthesis methods lacking

Often limited to one sentence or less in description of methods, despite wide range of experimenter degrees of freedom

'Naturalness' may be particularly important for sociophonetic perception research

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Possible to re-group based on experience with Praat scripting?

Demo scripts available at:

https://github.com/danielplawrence/synthesis_workshop

Latest Praat available at:

<http://www.fon.hum.uva.nl/praat/>

I will set small tasks for you to try using these scripts

Disclaimer: Praat scripts are notoriously unstable across versions and platforms!

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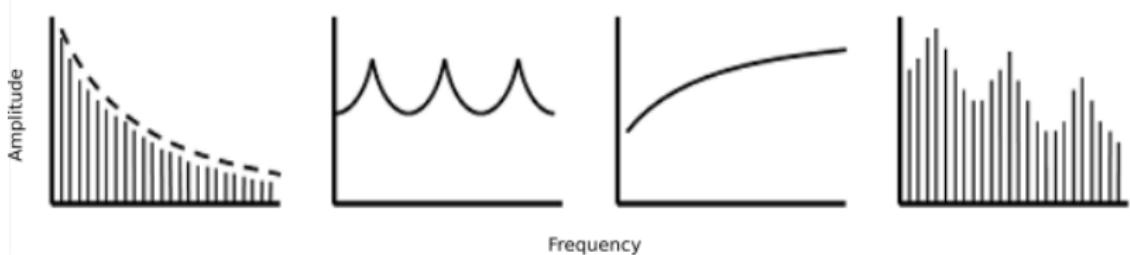
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Source-filter theory (Fant, 1960):

Treat the speech signal as a combination of an excitation source and vocal tract resonances, plus the effect of radiation from the lips:



Source
(represents
glottal flow)

Filter
(represents vocal
tract setting)

Radiation
characteristic
(represents effect
of sound passing
out of vocal tract
and into the
world)

Speech spectrum

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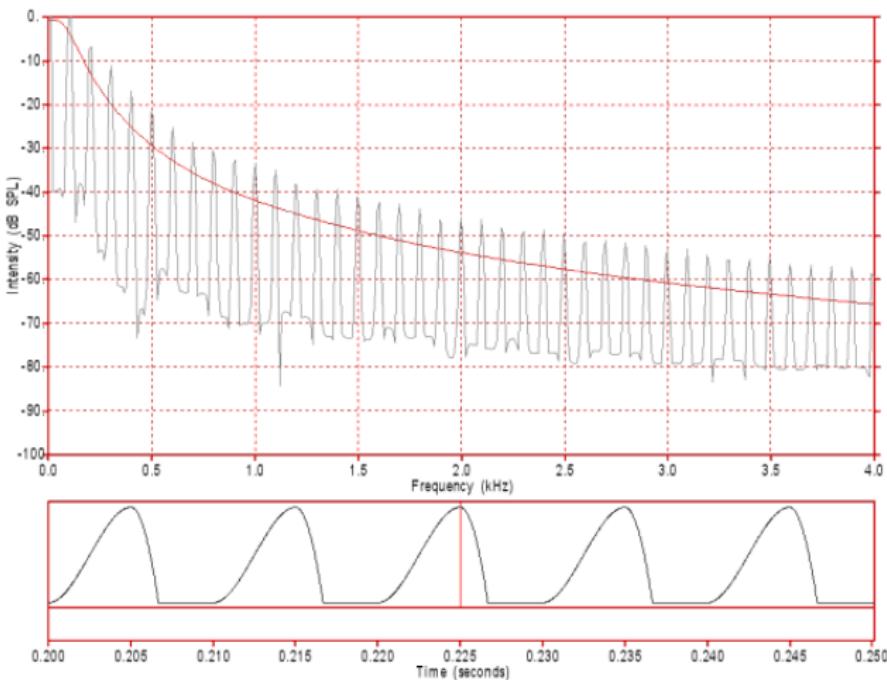
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To synthesize speech, we need to simulate an excitation source and boost/attenuate the spectrum to simulate the vocal tract resonances.

The acoustic characteristics of the voicing source and vocal tract resonances can be simulated digitally

The source is simulated as a series of repeating pulses.

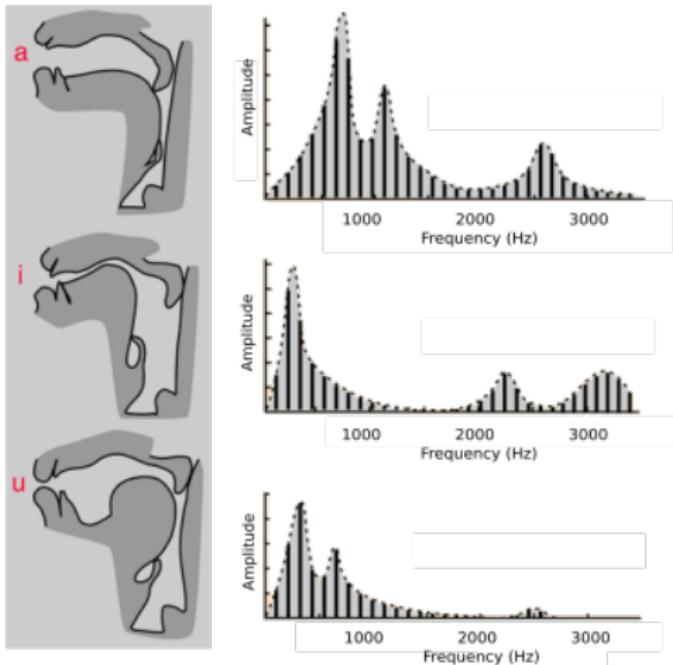


This produces a complex wave with an amplitude peak at the fundamental frequency and relatively smooth amplitude decay with increasing frequency.

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The vocal tract resonances are represented by a digital filter, which boosts and attenuates frequencies of the source.



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First, we generate an impulse train using Praat's *PointProcess* object:

```
1 pitchTier = Create PitchTier: "source", 0, 0.5
  Add point: 0.0, 150
3 Add point: 0.5, 100
  pulses = To PointProcess
5 source = To Sound (phonation): 44100, 0.6, 0.05,
    0.7, 0.03, 3.0, 4.0
  removeObject: pitchTier, pulses
7 selectObject: source
View & Edit
```

Acoustic synthesis using Praat

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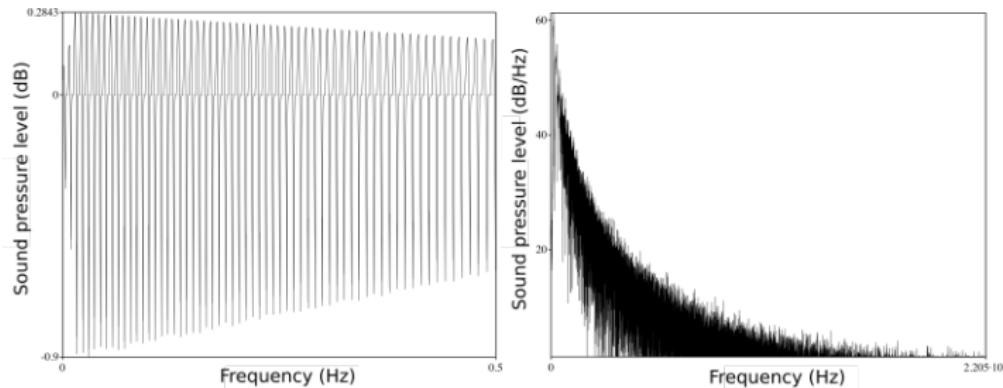
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Now, we create a vocal tract transfer function using a FormantGrid object:

```
filter=Create FormantGrid: "filter", 0, 0.5, 10,  
      550, 1100, 60, 50  
2 Remove formant points between: 1, 0, 0.5  
Add formant point: 1, 0.00, 350  
4 Add formant point: 1, 0.05, 700  
Remove formant points between: 2, 0, 0.5  
6 Add formant point: 2, 0.00, 700  
Add formant point: 2, 0.05, 1100  
8 selectObject: filter  
View & Edit
```

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Filtering the FormantGrid and the source together produces a vowel-like sound:

```
1 selectObject: source , filter  
vowel=Filter  
3 selectObject: vowel  
View & Edit
```

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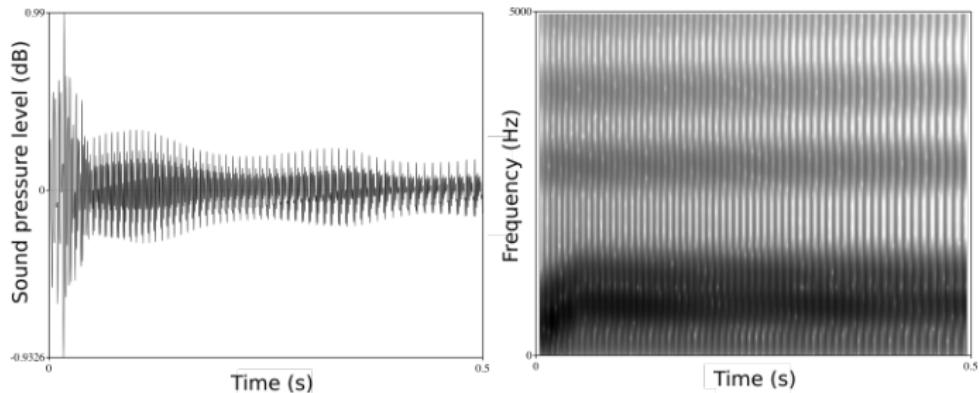
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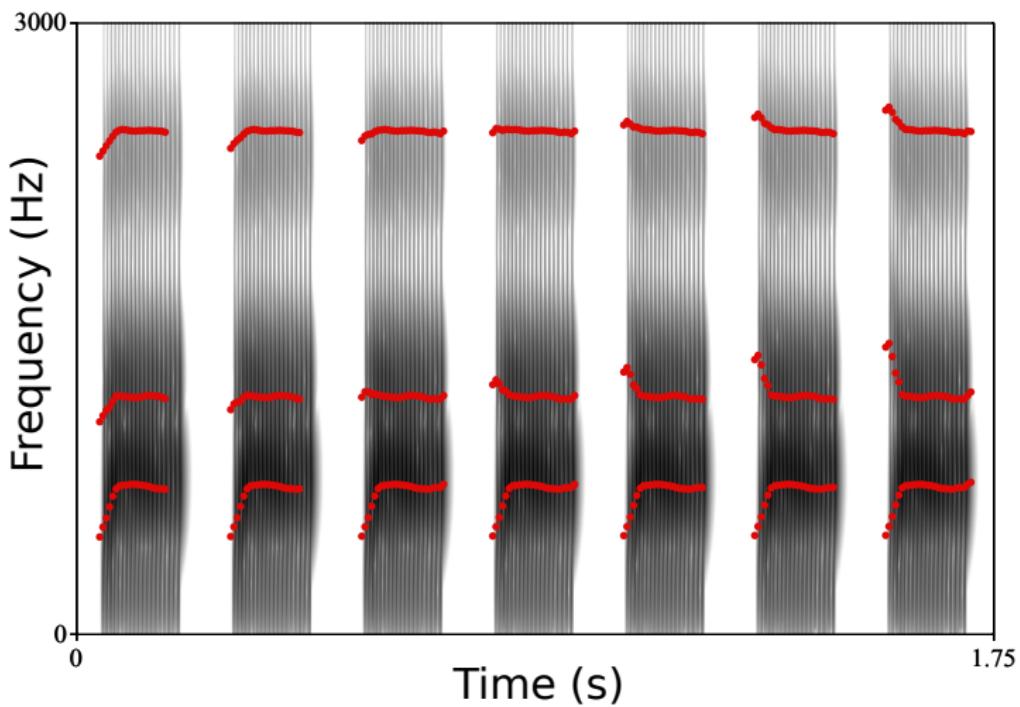
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Practical example: ba-da continuum



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Praat also includes an implementation of the Klatt synthesizer

To use this, specify parameters as a function of time in a 'KlattGrid' object

```
#Create a KlattGrid  
2 Create KlattGrid... aa 0 0.5 6 1 1 6 1 1 1
```

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Klatt synthesis in Praat:

```
#Add voicing amplitude, vowel formants, and pitch
targets
2 Add voicing amplitude point... 0.0 0
Add voicing amplitude point... 0.04 90
4 Add voicing amplitude point... 0.25 90
Add voicing amplitude point... 0.5 90
6 Add pitch point... 0.0 150
Add pitch point... 0.5 150
```

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Klatt synthesis in Praat:

```
1 Add oral formant frequency point... 1 0.1 750
2 Add oral formant bandwidth point... 1 0.1 70
3 Add oral formant frequency point... 2 0.1 1250
4 Add oral formant bandwidth point... 2 0.1 120
5 Add oral formant frequency point... 3 0.1 2500
6 Add oral formant bandwidth point... 3 0.1 200
7 Add oral formant frequency point... 4 0.1 3900
8 Add oral formant bandwidth point... 4 0.1 300
9 #Synthesis
10 Play
11 To Sound
```

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Try modifying the code in `source_filter.praat` to alter the pitch contour of the vowel

The vowel produced by `source_filter.praat` has a unnaturally flat intensity contour. Could you modify this using an `IntensityTier`? (see `ba-da_continuum.praat` for an example)

Try modifying the code in `source_filter.praat` to create different vowels (there's a list of formant frequencies at <http://bit.ly/1RPZizv>)

Try modifying the code in `ba-da_continuum.praat` to create a different kind of continuum (e.g. [i] to [u])

Try running `klatt_cardinal.praat` to generate a set of vowels using the Klatt synthesizer

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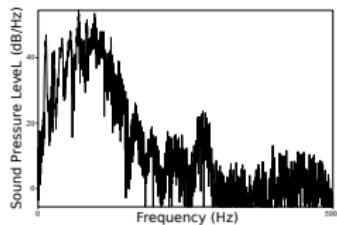
Some issues with the approach we have used so far:

- Modeled formant contours as straight lines
- Modeled the source as regular and fully periodic

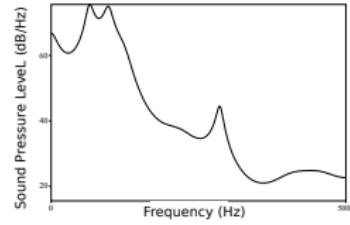
...if we could extract these characteristics from natural speech,
we could manipulate them independently and recombine them.

Spectral envelope estimation and inverse filtering

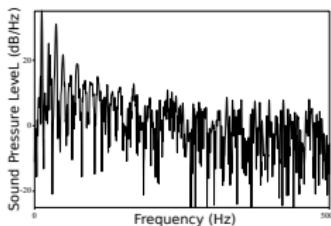
Intuition: estimate the spectral envelope of a natural sample, then use it as an *inverse filter* to ‘undo’ the filtering effect of the supralaryngeal vocal tract.



(a) Natural speech



(b) Spectral envelope



(c) Inverse filtered spec-
trum

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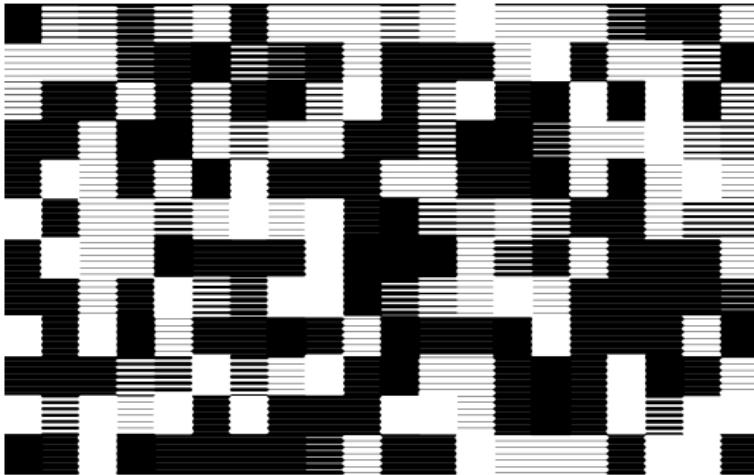
Advanced inverse filtering methods

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Linear Predictive Coding

A technique for estimating the spectral envelope of a time-varying speech signal.

Origins in early television encoding – black and white TV images are 3D grids (x,y,brightness) which vary over time.



However, values do not vary randomly – the brightness of any point is likely to be related to the adjacent points

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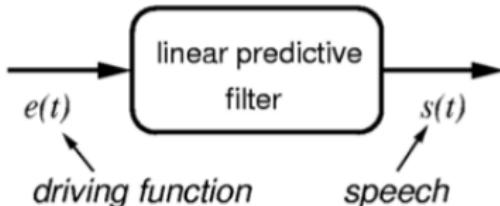
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Linear Predictive Coding



$$\hat{s}(t) = \sum_{j=1}^p a_j s(t-j)$$

$$s(t) = e(t) + \sum_{j=1}^p a_j s(t-j)$$

t = discrete time; p = filter order

= 'Estimate the value at time t as a linear combination of p previous samples'

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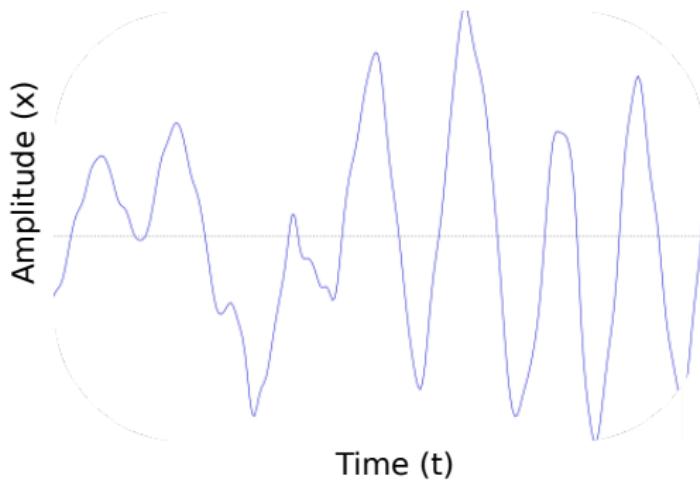
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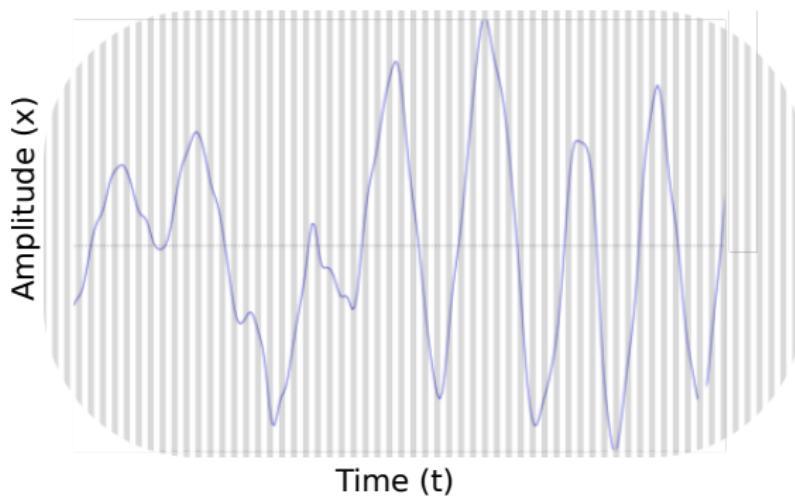
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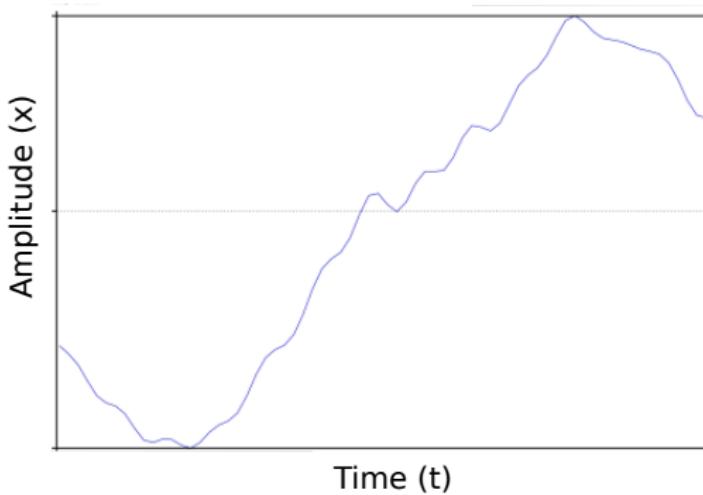
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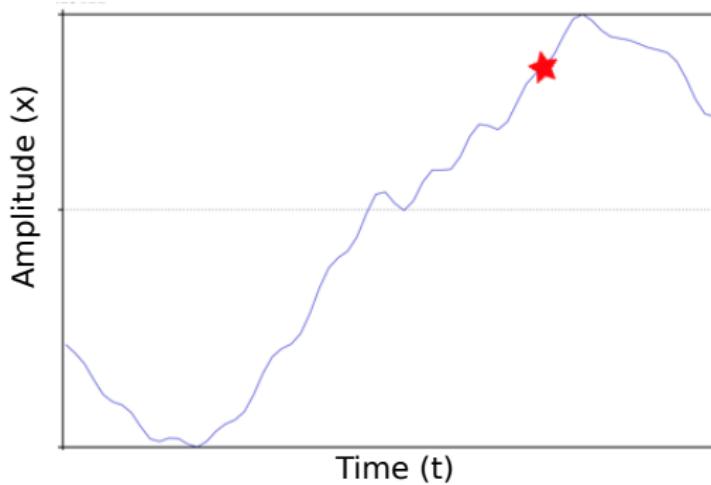
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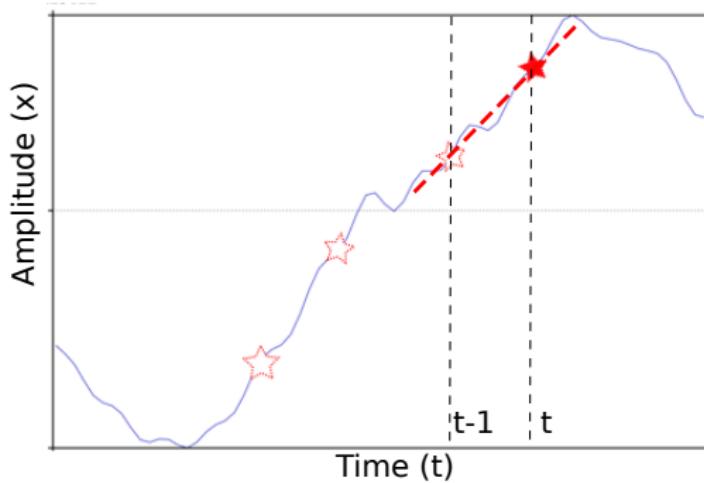
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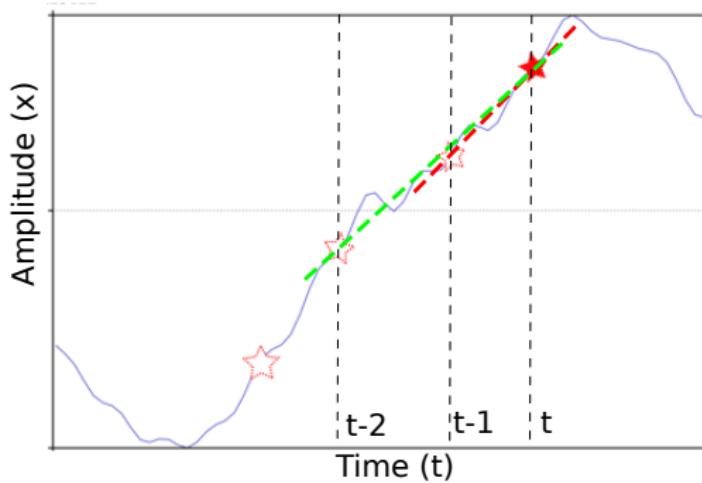
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$$x(t) = ax(t - 1)$$

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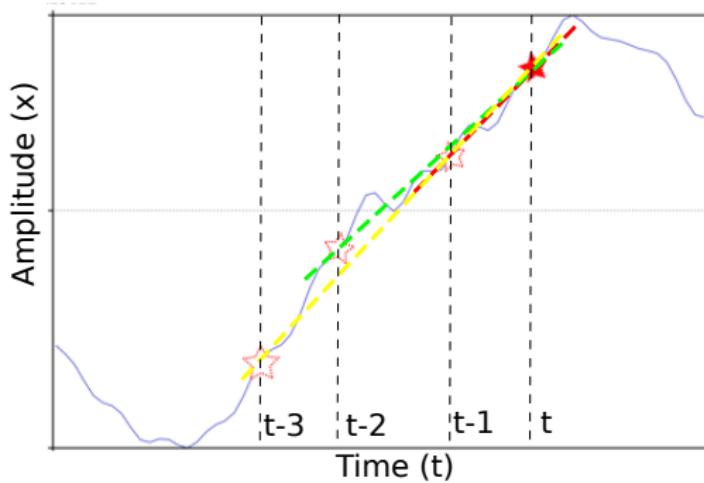
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$$x(t) = a_1 x(t-1) + a_2 x(t-2)$$

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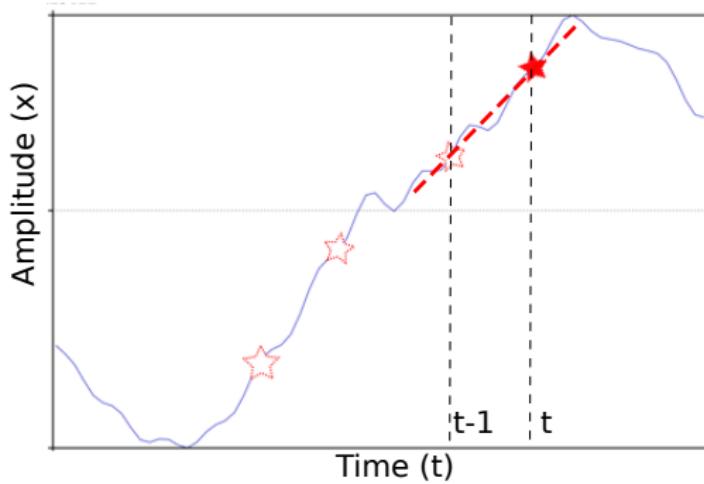
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$$x(t) = a_1x(t-1) + a_2x(t-2) + a_3x(t-3)$$

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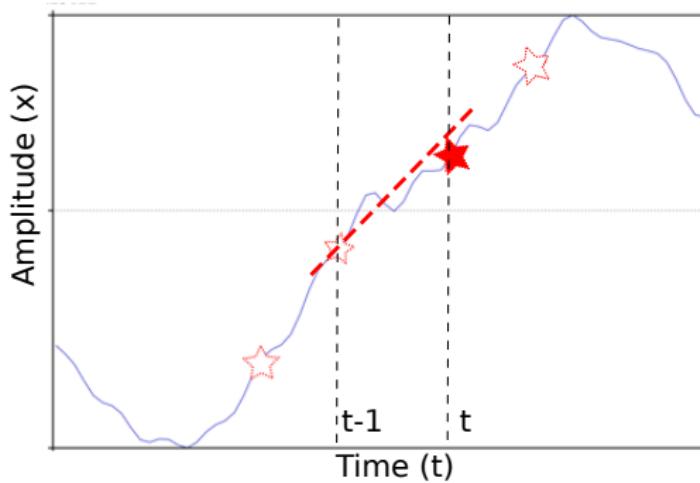
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$$x(t) = \textcolor{red}{as}(t - 1)$$

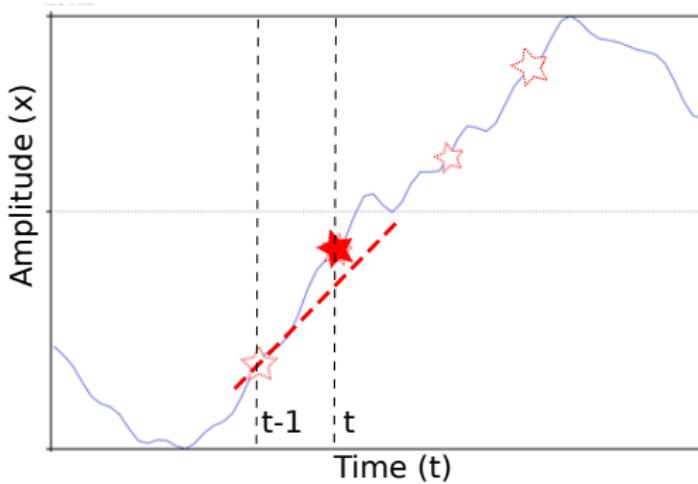
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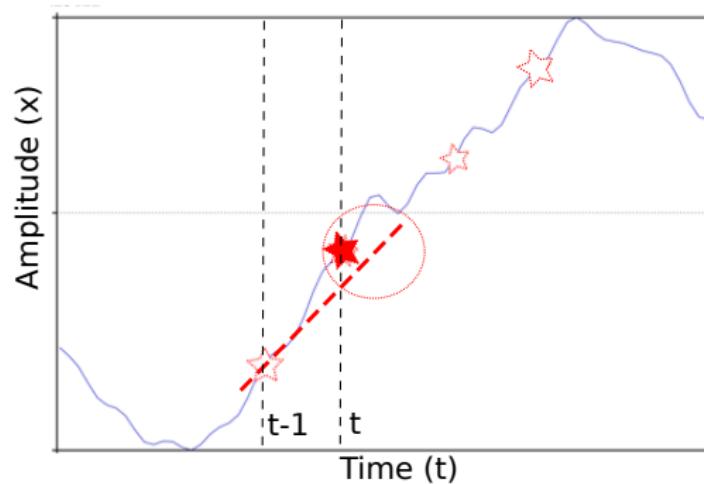


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Linear Predictive Coding



$$x(t) = \sum_{j=1}^p a_j s(t-j) + \mathbf{e(t)}$$

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$$[a_1 \ a_2 \ a_3 \ \dots \ a_n]$$

LPC coefficients

$$[e_1 \ e_2 \ e_3 \ e_4 \ \dots \ e_s]$$

LPC residual

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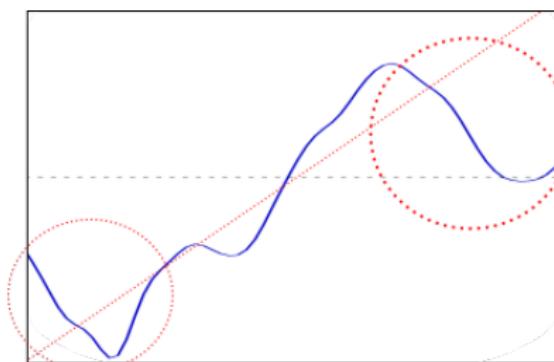
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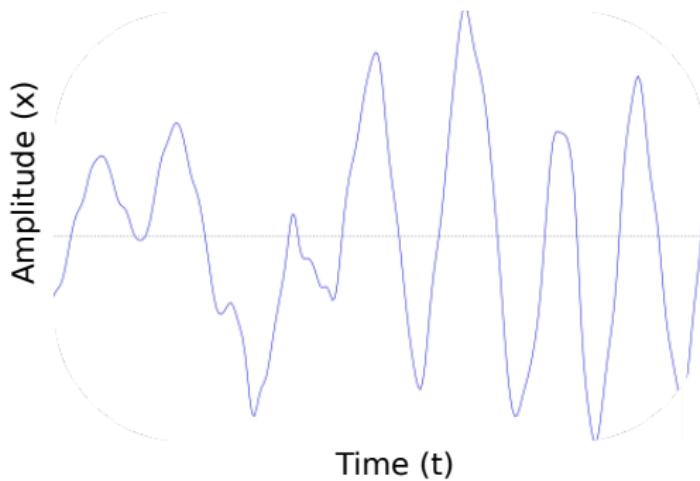
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Largest errors tend to be where the signal changes the fastest,
so the peaks of the residual approximate pitch periods.

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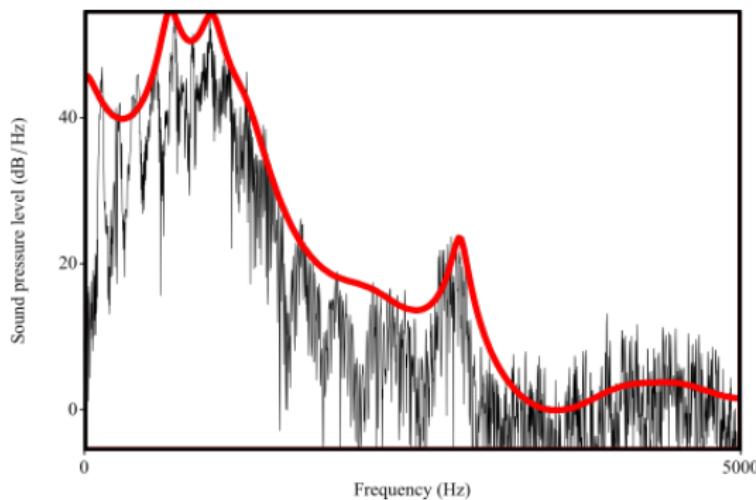
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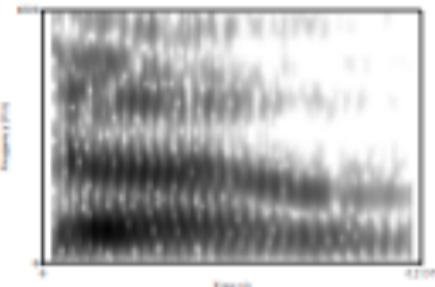
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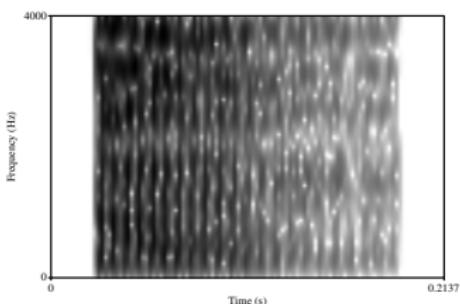
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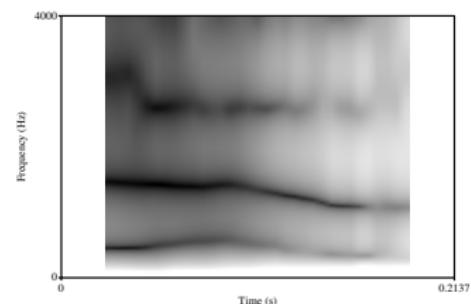
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(a) Natural vowel token



(b) Inverse-filtered source

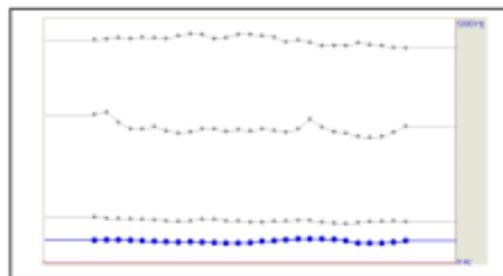


(c) LPC spectrogram

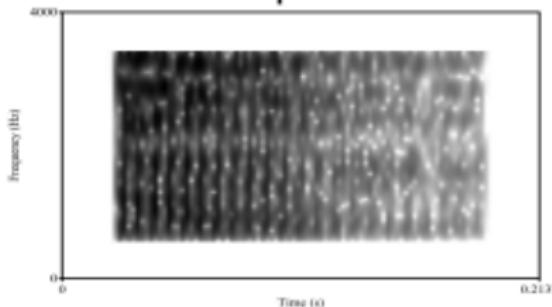
Now we can excite a digital filter with our natural source representation

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Modified filter



Source representation



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- 1) Resample to around 10000 Hz ($\sim 2 * nf * 1000$)
- 2) Perform LPC analysis with order $\sim 2 * nf + 2$
- 3) Inverse filter resampled original with LPC object
- 4) Estimate formants using 'To Formant...'
- 5) Manipulate formants using 'To FormantGrid'
- 6) Filter modified FormantGrid with inverse-filtered source

Inverse filtering using Praat

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LPC inverse-filtering in Praat:

```
1 #Estimate the LPC filter for a selected sound
#First we need to resample
3 Resample: 10000, 50
To LPC (burg): 10, 0.025, 0.005, 50
```

Inverse filtering using Praat

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```
#Take the inverse of this filter to get a
representation of the source
2 selectObject: "Sound untitled_10000"
plusObject: "LPC untitled_10000"
4 Filter (inverse)
```

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```
#Generate a formant object and add 400 Hz to F2
2 selectObject: "LPC untitled_10000"
To Formant
4 selectObject: "Formant untitled_10000"
Formula (frequencies): "if row = 2 then self + 400
                           else self fi"
```

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```
1 #Combine the source and filter representations to
   make a new vowel
2 selectObject: "LPC untitled_10000"
3 selectObject: "Sound untitled_10000"
4 plusObject: "Formant untitled_10000"
5 Filter
6 Play
```

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Some issues with inverse filtering:

- a) Difficult to get completely 'white' source representation
- b) We lose the higher-frequency component of the sound

Advanced inverse filtering methods

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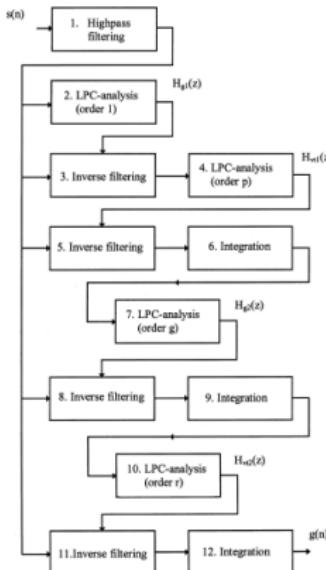
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a) Difficult to get completely ‘white’ source representation

Solution: Following Alku (1992), filter iteratively, estimating spectral characteristics of glottal flow and vocal tract with different LPC orders



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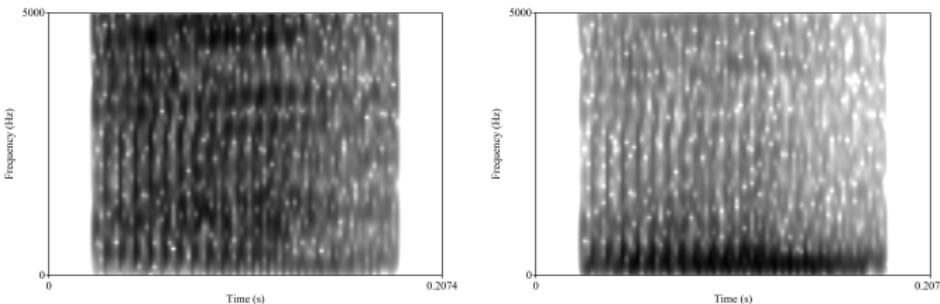
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a) Difficult to get completely 'white' source representation

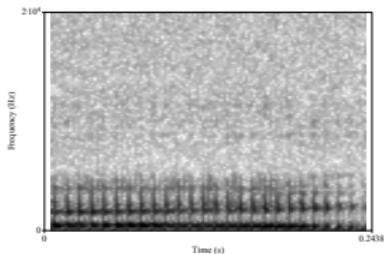
Solution: Following Alku (1992), filter iteratively,
estimating spectral characteristics of glottal flow and vocal
tract with different LPC orders



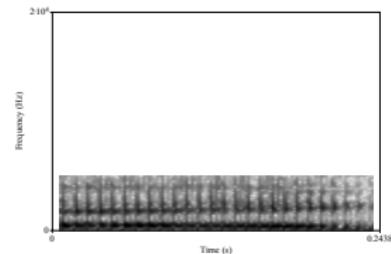
Advanced inverse filtering methods

b) We lose the higher-frequency component of the sound

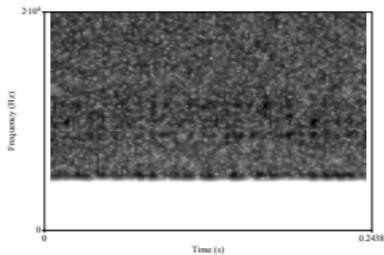
Solution: Restore the HF component of the original sound after synthesis



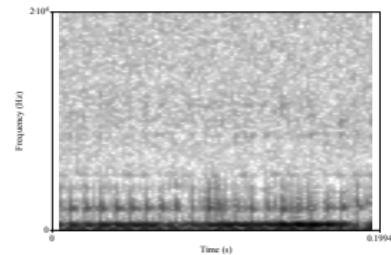
(a) Natural token @20Khz



(b) LF component



(c) HF component



(d) Semisynthetic token

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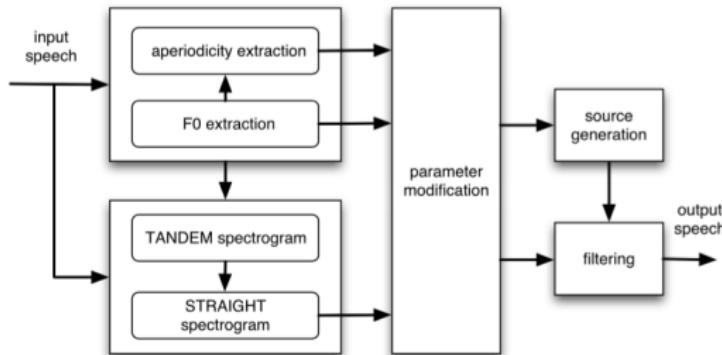
- a) Try recording yourself producing a vowel (ctr+r). Select your vowel token and run 'LPC_cardinal_iaif.praat'. Compare the output with that of 'klatt_cardinal.praat'
- b) Experiment with the 'formant_manipulation.praat' script:
 - i. Create a 'ba-da' continuum
 - ii. Create an [i]-[u] continuum
 - iii. Create a continuum between a diphthong and monophthong

The TANDEM-STRAIGHT vocoder

[http://www.wakayama-u.ac.jp/~kawahara/
STRAIGHTadv/index_e.html](http://www.wakayama-u.ac.jp/~kawahara/STRAIGHTadv/index_e.html)

Used in many commercial text-to-speech applications

Uses advanced techniques to estimate the glottal flow and spectral envelope, as well as the aperiodic components of natural speech.

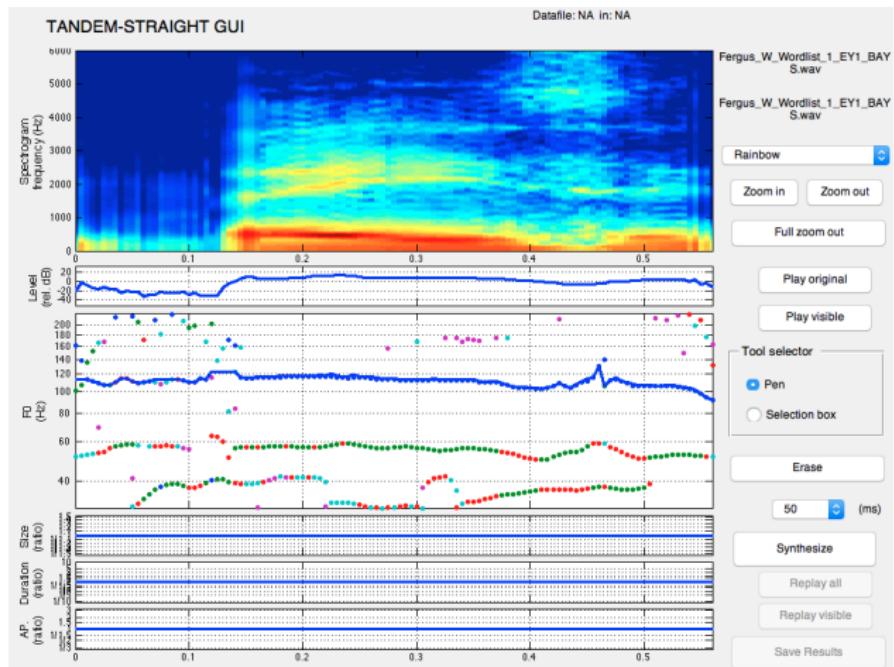


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Morphing GUI allows interpolation between two samples

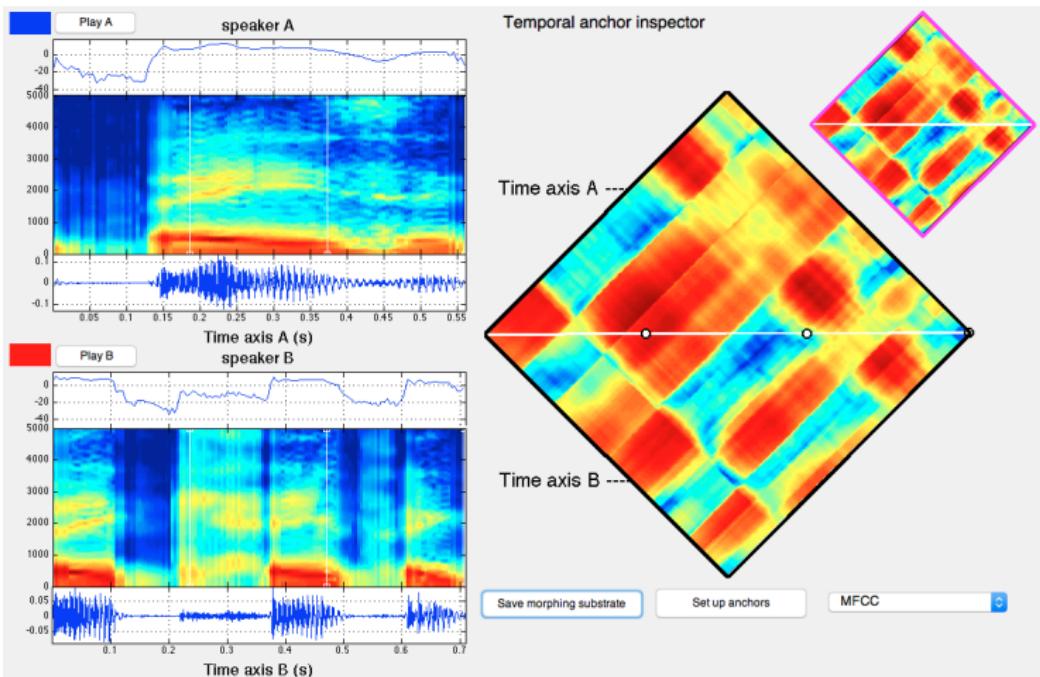
TANDEM-STRAIGHT GUI:



The TANDEM-STRAIGHT vocoder

Morphing GUI allows interpolation between two samples

TANDEM-STRAIGHT GUI:



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TANDEM-STRAIGHT emotional morphing demo:

[http://www.wakayama-u.ac.jp/~kawahara/
Miraikandemo/index-e.html](http://www.wakayama-u.ac.jp/~kawahara/Miraikandemo/index-e.html)

Less useful for manipulating individual formants (but still
possible)

Example TANDEM-STRAIGHT continuum

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Download and install TANDEM-STRAIGHT

Full package:

[https://www.dropbox.com/s/jq1butk6shnnox1/
LctrEdinburgh2012.zip](https://www.dropbox.com/s/jq1butk6shnnox1/LctrEdinburgh2012.zip)

Morphing GUI only:

[www.github.com/danielplawrence/synthesis_
workshop](https://github.com/danielplawrence/synthesis_workshop)

MATLAB runtime:

<http://uk.mathworks.com/products/compiler/mcr/>

Use the instructions on the handout to generate a
continuum

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- Fant, G. (1970). *Acoustic theory of speech production: with calculations based on X-ray studies of Russian articulations*. Mouton & Company.
- Kawahara, H., Morise, M., Takahashi, T., Nisimura, R., Irino, T., & Banno, H. (2008). TANDEM-STRAIGHT: A temporally stable power spectral representation for periodic signals and applications to interference-free spectrum, F0, and aperiodicity estimation. In *IEEE International Conference on Acoustics, Speech and Signal Processing*. 2008. (pp. 3933-3936).