Lecture 17: Transformation of formants for voice conversion using artificial neural networks

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ECE 537, Fall 2022

1. Voice Conversion
2. Formant Synthesis: Spectral Envelope
3. Formant Synthesis: the Voice Source
4. Formant Analysis
5. Summary

Outline

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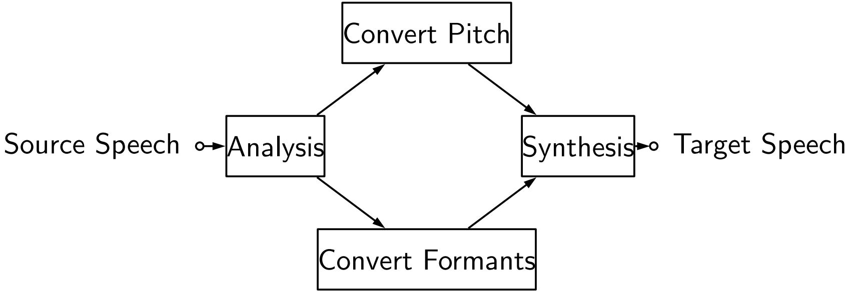
Voice Conversion



Voice conversion generates a **target speech** that has the same text content as the **source speech**, but sounds as though produced by a particular target speaker.

Usually, voice conversion is performed separately for **excitation parameters** and **spectral envelope parameters**.

	Excitation Parameters	**Envelope Parameters**
Formant Synthesis	F_0, V/UV, Gain, LF model parameters	F_1, F_2, F_3, F_4, B_1, B_2, B_3, B_4
LPC	$e[n]$, F_0, $\vec{\beta}$, Gain	$\vec{a}$
WORLD Synthesizer	Periodicity, Aperiodicity	Envelope
Factored Autoencoder	Pitch, Rhythm	Timbre

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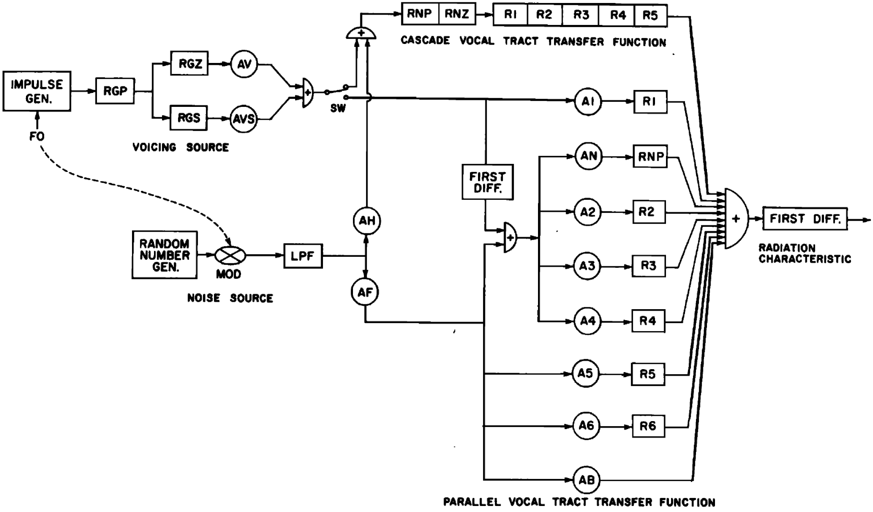
Formant Synthesis: Overview



Formant Synthesis: Envelope

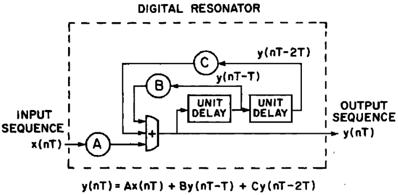
Formant synthesis computes speech by filtering an excitation, $e[n]$, through a transfer function, $h[n]$:

$$s[n] = h[n] * e[n]$$

The **transfer function**, $h[n]$, may include:

- **Regular formants (cascade synthesis):** appropriate for vowels, glides, and nasal consonants
  - **+Nasal Pole, Nasal Zero:** appropriate for nasal consonants
- **Selected formants (parallel synthesis):** appropriate for fricatives and plosives

The Formant Resonator

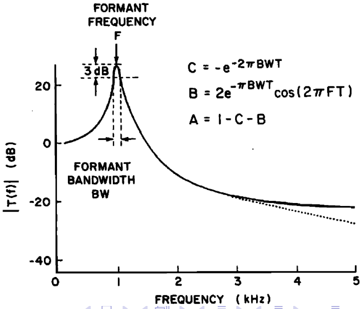


A formant resonator is:

$$R_k(z) = \frac{a_k}{1 - b_k z^{-1} - c_k z^{-2}},$$

which is implemented as:

$$y[n] = a_k x[n] + b_k y[n-1] + c_k y[n-2]$$



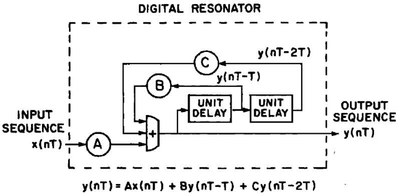
The Formant Resonator

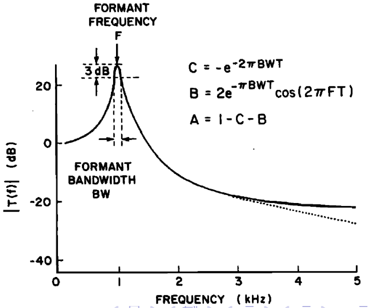
The filter parameters are related to the formant frequency, F_k, formant bandwidth, B_k, and sampling frequency $1/T$ by

$$c_k = -e^{-2\pi B_k T}$$

$$b_k = 2e^{-\pi B_k T}\cos(2\pi F_k T)$$

$$a_k = 1 - b_k - c_k$$





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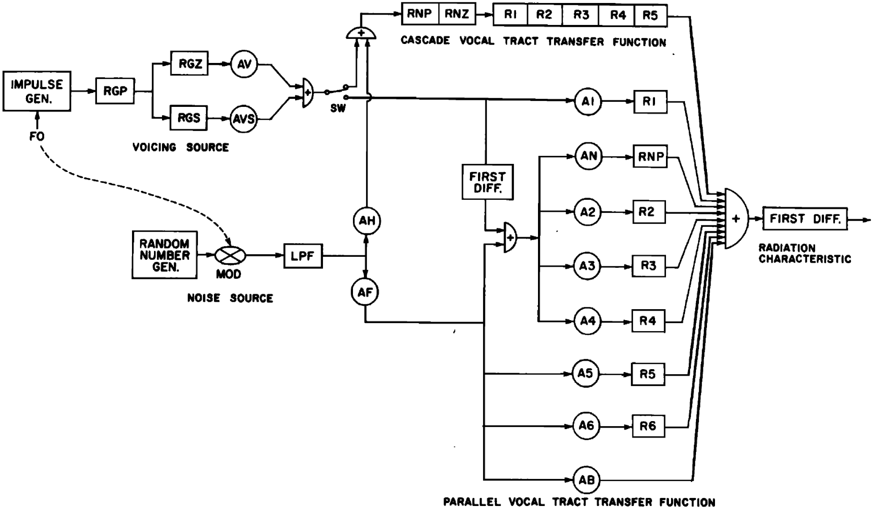
Formant Synthesis: Overview



Formant Synthesis: Excitation

$$s[n] = h[n] * e[n]$$

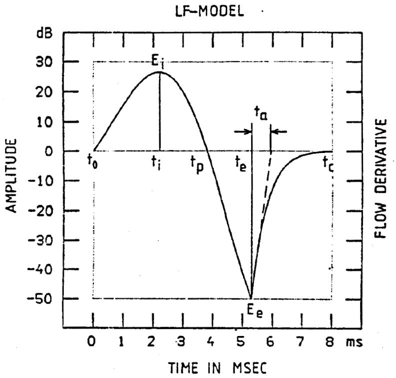
The **excitation signal**, $e[n]$, may include:

- **Regular voicing:** a parametric model of the air pressure immediately above the glottis (proportional to $u_g'(t)$, the derivative of the volume velocity through the glottis)
- **Sinusoidal/breathy voicing:** a parametric model of $u_g'(t)$ when the glottis doesn't close completely
- **Aspiration:** turbulent noise at the glottis, filtered by the whole vocal tract.
- **Frication:** turbulent noise at a supraglottal constriction, filtered by only part of the vocal tract

Regular Voicing: The LF Model

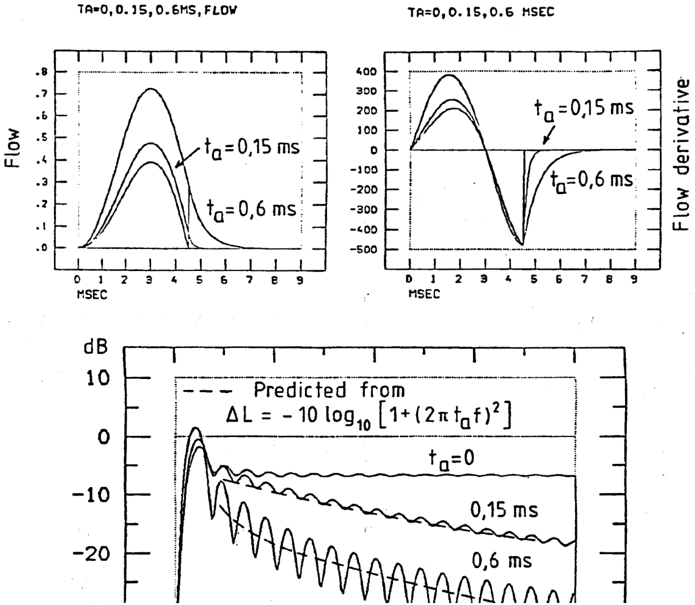
The LF (Liljencrants-Fant) model is a parametric model of $e(t) = u_g'(t)$, the derivative of volume velocity through the glottis. From time 0 to time t_e, $u_g'(t)$ is an unstable oscillation. At time t_e, the vocal folds start to collide, and start to slow down.

$$u_g'(t) = \begin{cases} E_0 e^{\alpha t} \cos(\omega_g t) & t < t_e \\ \frac{E_0}{\epsilon t_a}\left(1 - e^{\epsilon(t_c - t)}\right) & t > t_e \end{cases}$$



(c) Fant, Liljencrants & Lin, 1985.

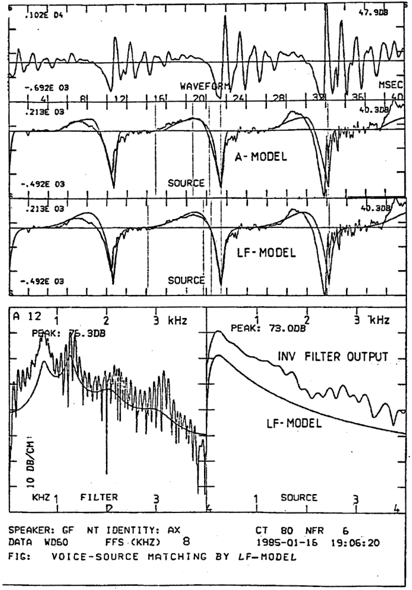
http://www.speech.kth.se/qpsr



(c) Fant, Liljencrants & Lin, 1985. `http://www.speech.kth.se/qpsr`

Shape of the LF model is determined by T_0 (the pitch period) plus four other parameters:

- E_e, amplitude of excitation
- t_e, time of the excitation
- time from upward-going zero-crossing, t_c, to downward-going zero-crossing, t_p
- slope of the return part, $\frac{E_e}{t_a}$



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How do we find formant frequencies and bandwidths?

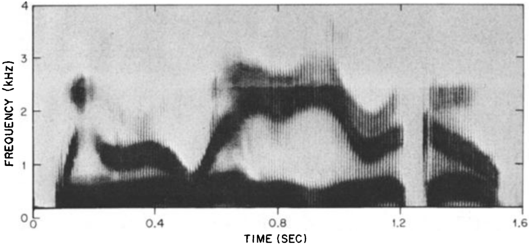
Basically, the formant frequencies and bandwidths are the roots of the LPC polynomial:

$$H(z) = \frac{G}{1 - \sum_{k=1}^{p} a_k z^{-k}} = \frac{G}{\prod_{i=1}^{p}(1 - p_k z^{-1})}$$

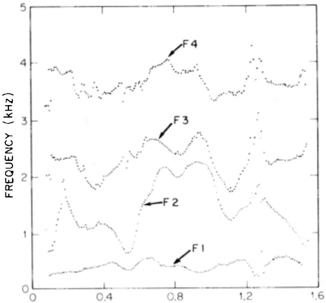
$$F_k = \frac{1}{2\pi T}\angle p_k$$
$$B_k = -\frac{1}{\pi T}\ln|p_k|$$

Utterance: "Why were you away a year ago?" Notice that formant tracking fails during the /g/.

Atal and Hanauer, "Speech Analysis and Synthesis by Linear Prediction of the Speech Wave," 1971; (c) Acoustical Society of America.



(a)

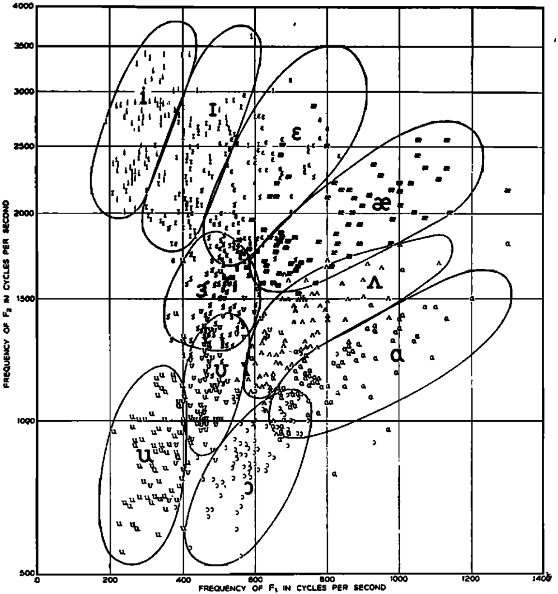


A few complications (but not many)

- Formant tracks are unreliable during consonants, creaky voice, & breathy voice.
- Use dynamic programming to find the most likely formant tracks during consonants, creaky voice, & breathy voice.
- A good implementation: `http://praat.org`.

Formant frequencies determine the vowel. Inside each ellipse, people with longer jaws (e.g., men) typically have lower formants, and vice versa.

Peterson and Barney, 1952.



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Summary

- Voice conversion usually separates excitation and envelope
- Envelope can be modeled using a formant synthesizer
- Excitation can be modeled using the LF model
- Formant analysis finds the roots of LPC