Computational modeling of human speech

... FEM in the human vocal tract

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Computational speech modelling

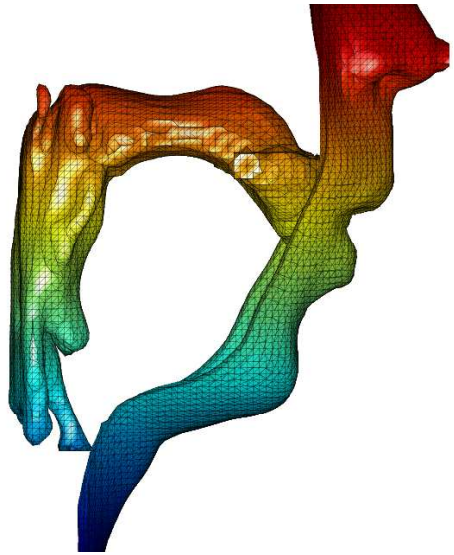
- Multidisciplinary research combining technology, modelling, phonetics and medicine.
- Telephony
- Speech synthesis
- Planning of maxillofacial surgeries

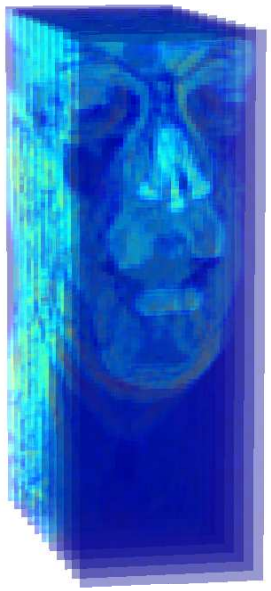
$$\Phi_{tt} = c^2 \Delta \Phi \quad \text{in} \quad \Omega \times \mathbb{R}$$

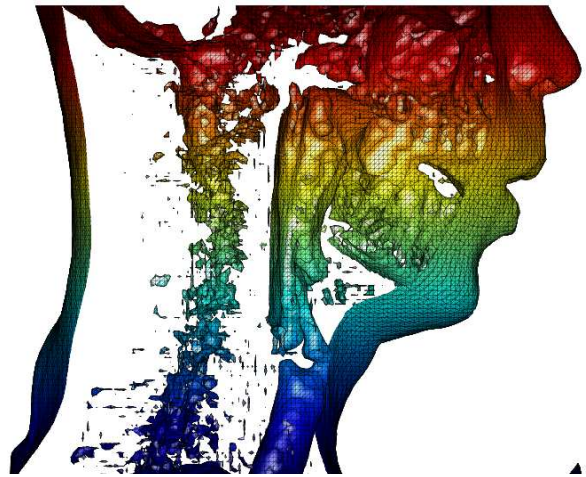
$$\Psi_{tt} = \frac{c^2}{A(s)} \frac{\partial}{\partial s} \left(A(s) \frac{\partial \Psi}{\partial s} \right) \quad \text{in} \quad [0, l] \times \mathbb{R}$$

Geometry extraction

- Magnetic Resonance Imaging
- Things to worry about:
  - Teeth
  - Artefacts
  - Registration
  - Automation

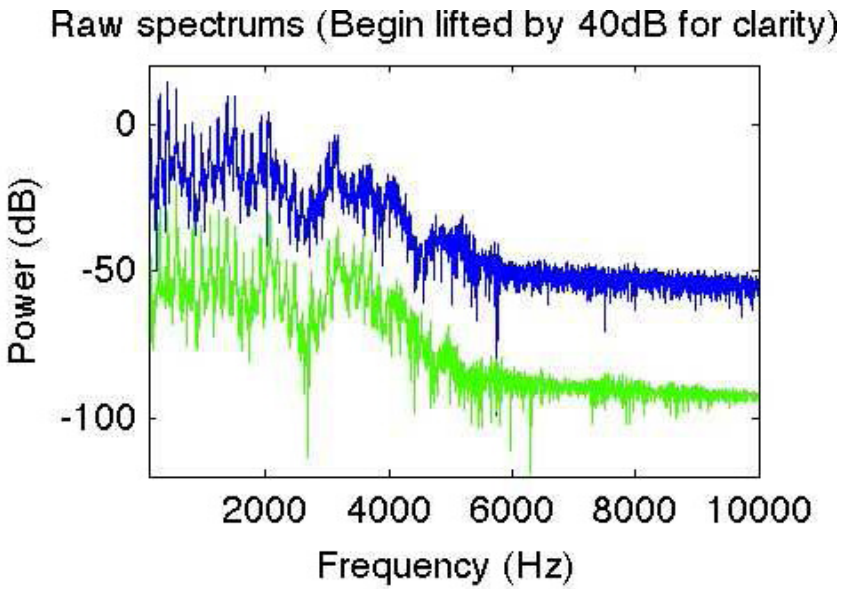


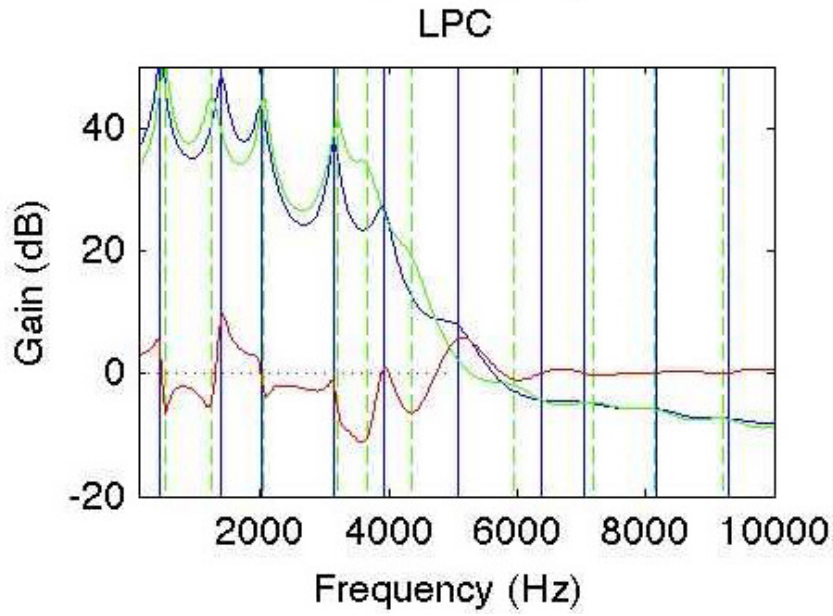




Formant

Formant A resonance frequency determined from audio recording F_i





Resonance

Resonance A numerically determined resonance frequency λ_i

$$\begin{cases} \lambda^2 \Phi_\lambda = c^2 \Delta \Phi_\lambda, & \text{in VT} \\ \Phi_\lambda = 0, & \text{at mouth} \\ \frac{\partial \Phi_\lambda}{\partial \nu} = 0, & \text{on VT walls} \\ \lambda \Phi_\lambda + c \frac{\partial \Phi_\lambda}{\partial \nu} = 0, & \text{at glottis} \end{cases}$$

$\longrightarrow$ formulation as an eigenvalue problem

$\longrightarrow$ estimates for λ_i

Some results

Vowel	R_1	R_2	R_3	R_4
[ɑ]	720	1547	2721	4138
[i]	246	2135	3592	4667
[u]	324	659	2262	3091
[œ]	562	1612	2519	3602

Table: First four resonances (in Hz) for the Helmholtz problem by FEM.

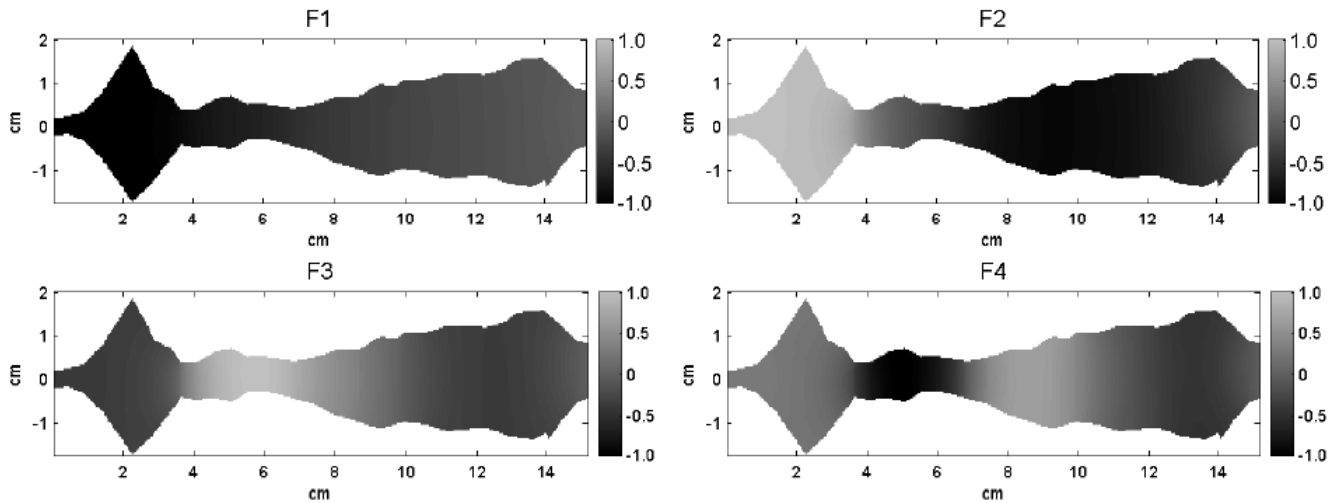
Vowel	F_1	F_2	F_3	F_4
[ɑ]	651 ± 7	1024 ± 35	2647 ± 117	3679 ∓ 36
[i]	247 ± 9	2183	3304 ∓ 46	4407 ∓ 251
[u]	306 ∓ 37	675 ∓ 39	2173 ± 13	3242 ± 139
[œ]	483 ∓ 35	1249 ± 74	1994 ∓ 50	3188 ∓ 17

Table: Formants (in Hz) computed as means of those extracted from the beginnings and ends of the sound samples.

How good is it?

Vowel	D_1	D_2	D_3	D_4	mean discr.
[ɑ]	1.7	7.1	0.5	2.0	2.8
[i]	-0.1	-0.4	1.4	1.0	0.7
[u]	1.0	-0.4	0.7	-0.8	0.7
[œ]	2.6	4.4	4.0	2.1	3.3

Table: Discrepancy (in semitones) between computed resonances and mean formant frequencies.



Future

- Geometry extraction is (to this point, more or less) robust
  - so new vowels can be computed
  - the code will most likely also be released in some form
- Getting data from patients undergoing orthognathic surgery.
- Teeth models
- Mechanical models