Interface Method for Speech Modelling

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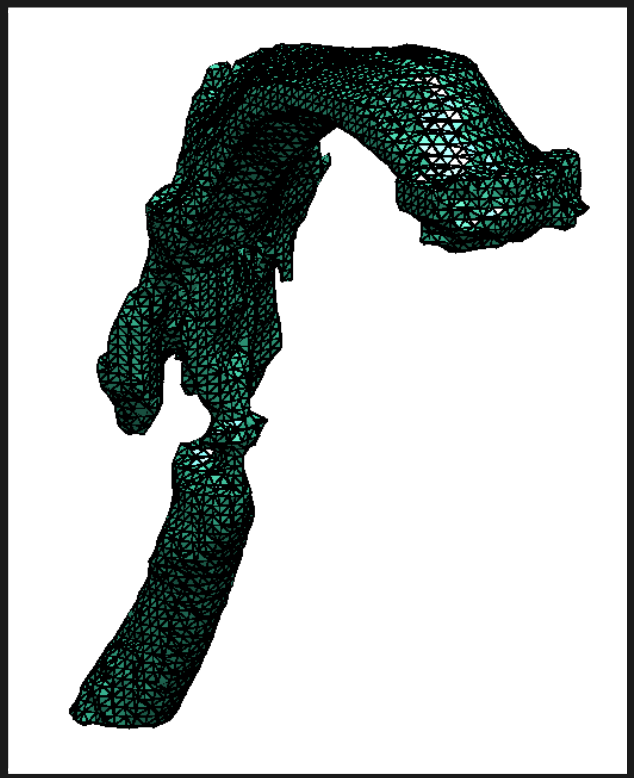
Introduction

Motivation

What is a Vocal Tract (VT)?

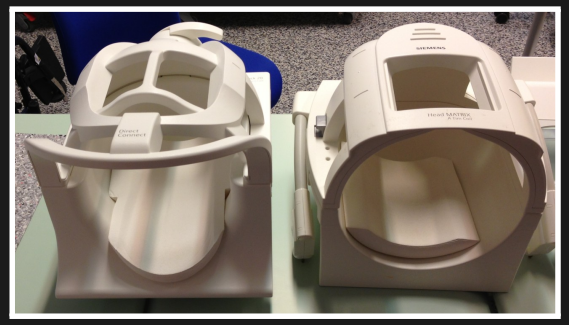


- An "old-school" analog filter.
- Input: Almost periodic signal produced by air flowing past vocal chords.
- Output: Speech.
- State: Geometric configuration.

Introduction

Motivation (2)

MRI Machine



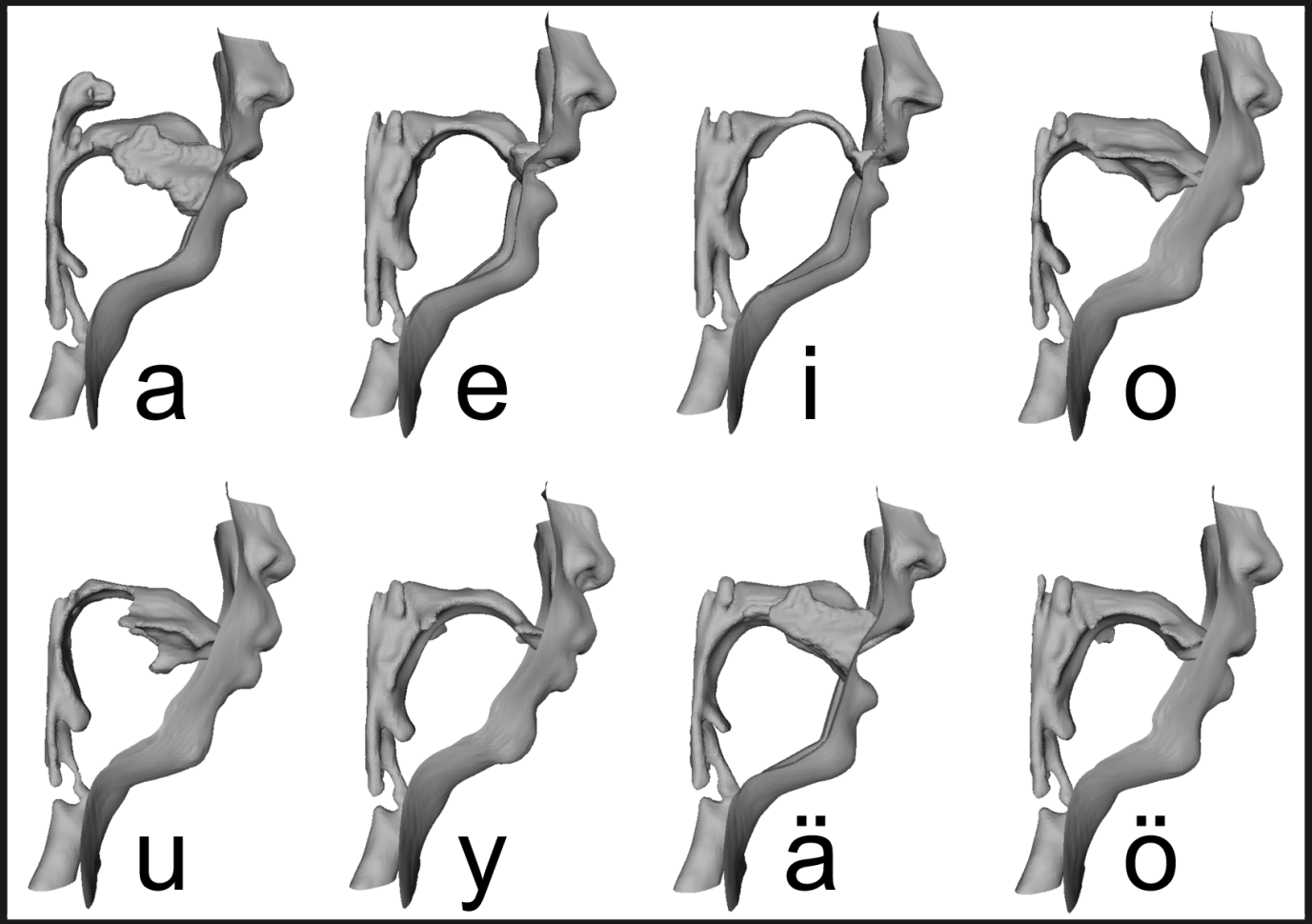
Head Coil

Sagittal Plane

- Non-intrusive, safe 3D imaging.
- VT geometry automatically extracted from the sequence.

Introduction

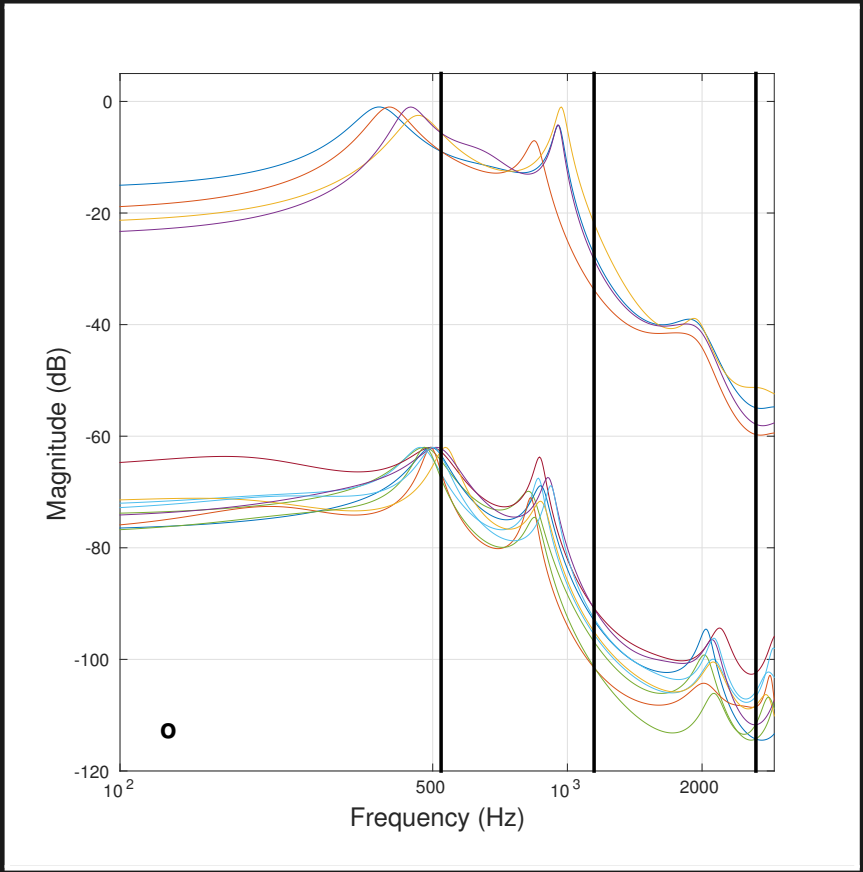
Vowels



Finnish Vowels

Challenges

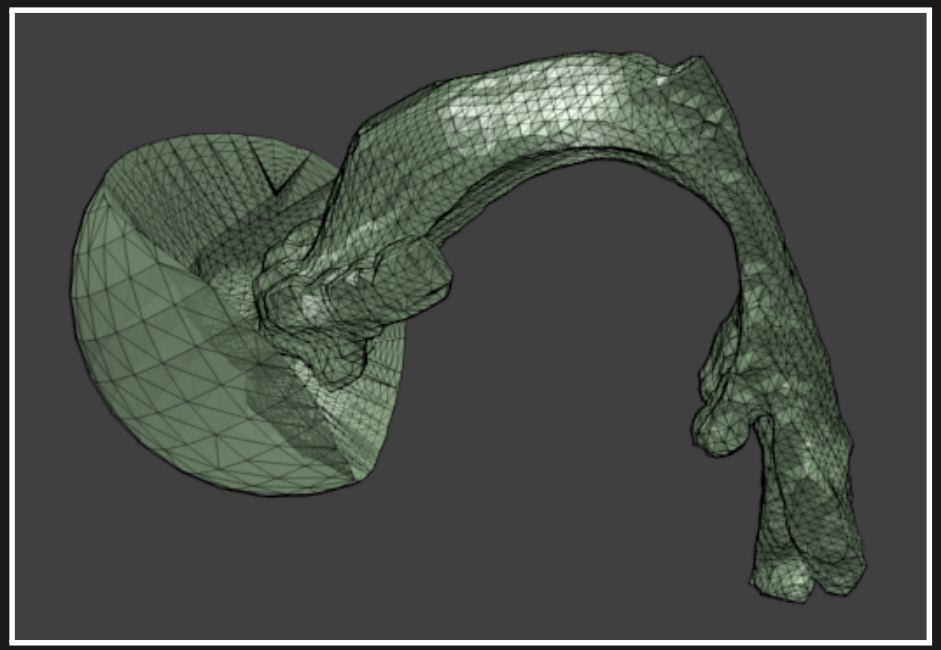
- Vowels can be modelled by solving the Helmholtz equation in VT geometry.
- Validation against sound data which is simultaneously recorded.
- Acoustics of the MRI machine causes systematic error in resonances.



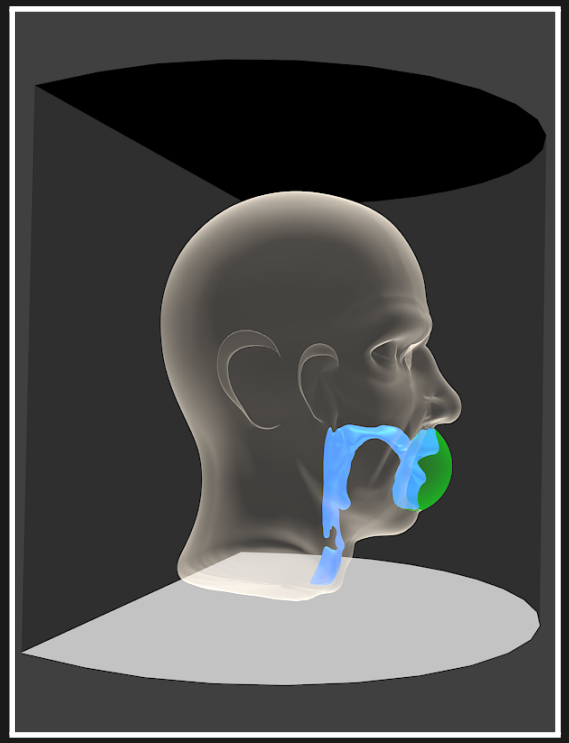
Spectral envelopes from sound data.
Resonances denoted by vertical lines.

Geometries

- VT geometry is stitched to a fixed interface. Easy to swap geometries
- Effect of exterior space can be pre-computed to some extent.



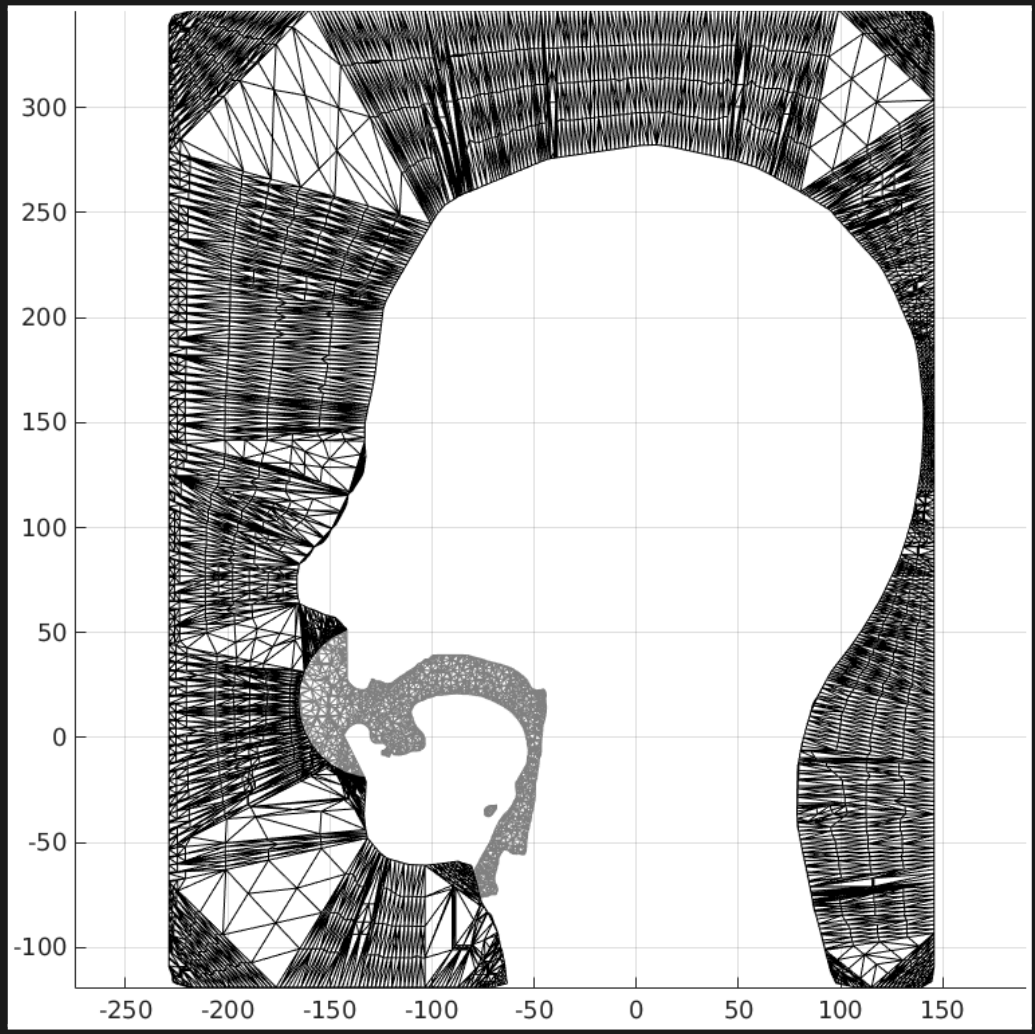
VT & interface.



Interface in green.

Interface

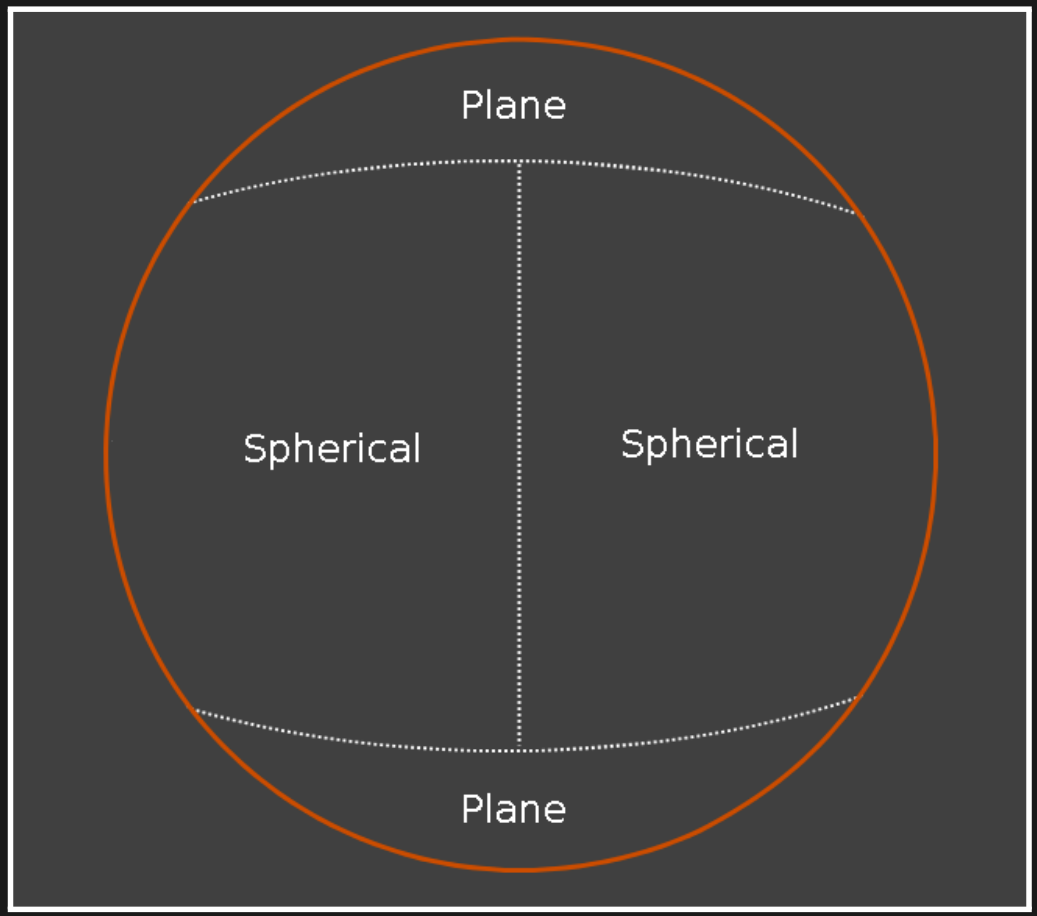
- Nitsche's method on the interface.
- Works on non-matching grids.
- Allows swapping of exterior & interior geometries.



Middleslice from a mesh.

Interface (2)

- Integration over the interface requires a parametrisation of the surface.
- Split the interface into four pieces.
- Project caps to plane.



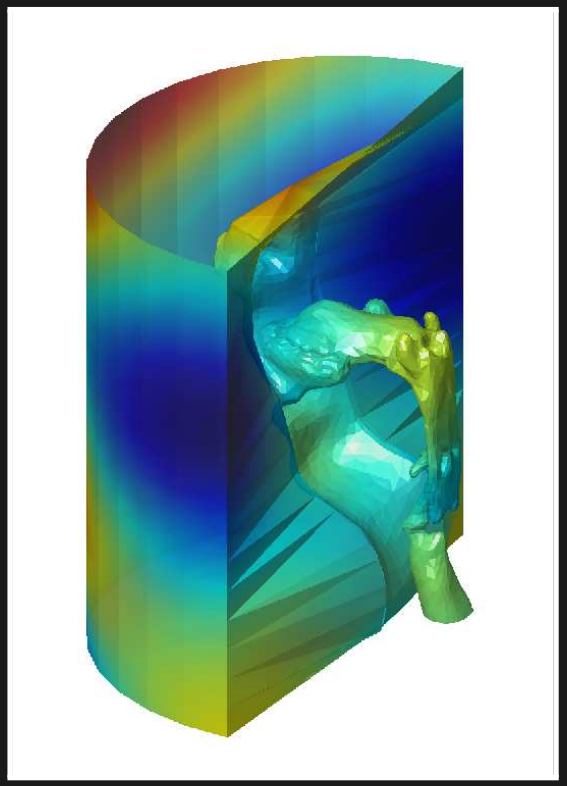
Coordinates used on different parts.

Resonances

- The resonant frequencies are related to the eigenvalue problem: Find $(\lambda, u) \in \mathbb{C} \times V$ such that

$$-c^2 \Delta u = \lambda^2 u,$$

  where V is the solution space.
- Realistic boundary conditions lead to a strictly quadratic, complex-valued eigenvalue problem.



Pressure distribution for the vowel [ae]. Mixed resonance structure.

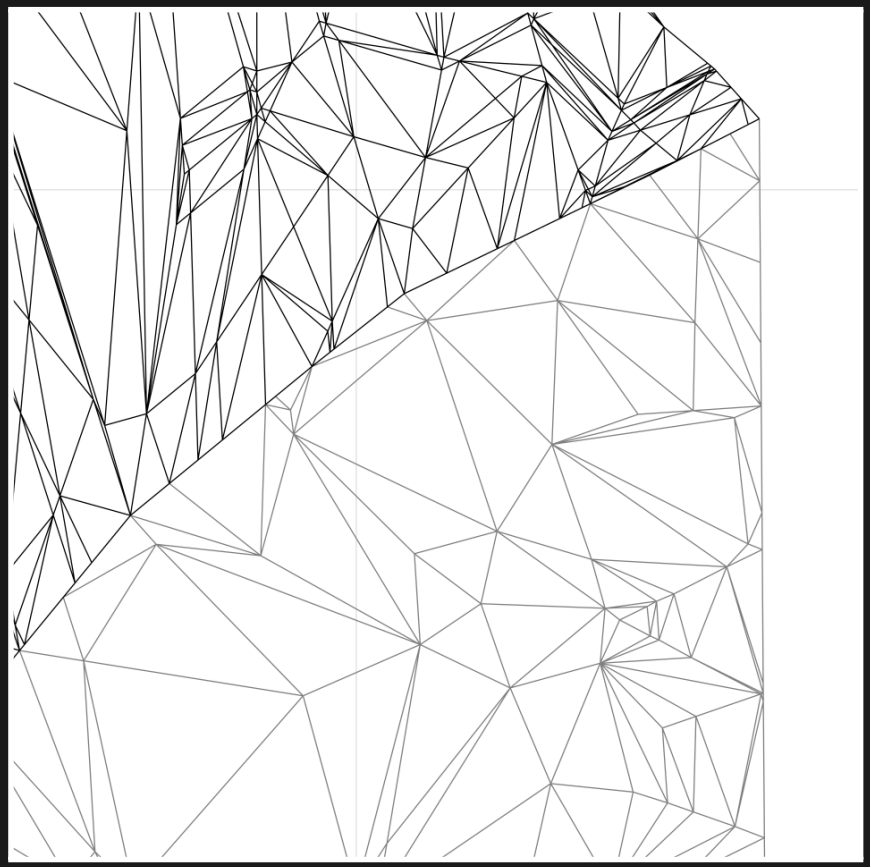
Test Case

Simplified problem for now:

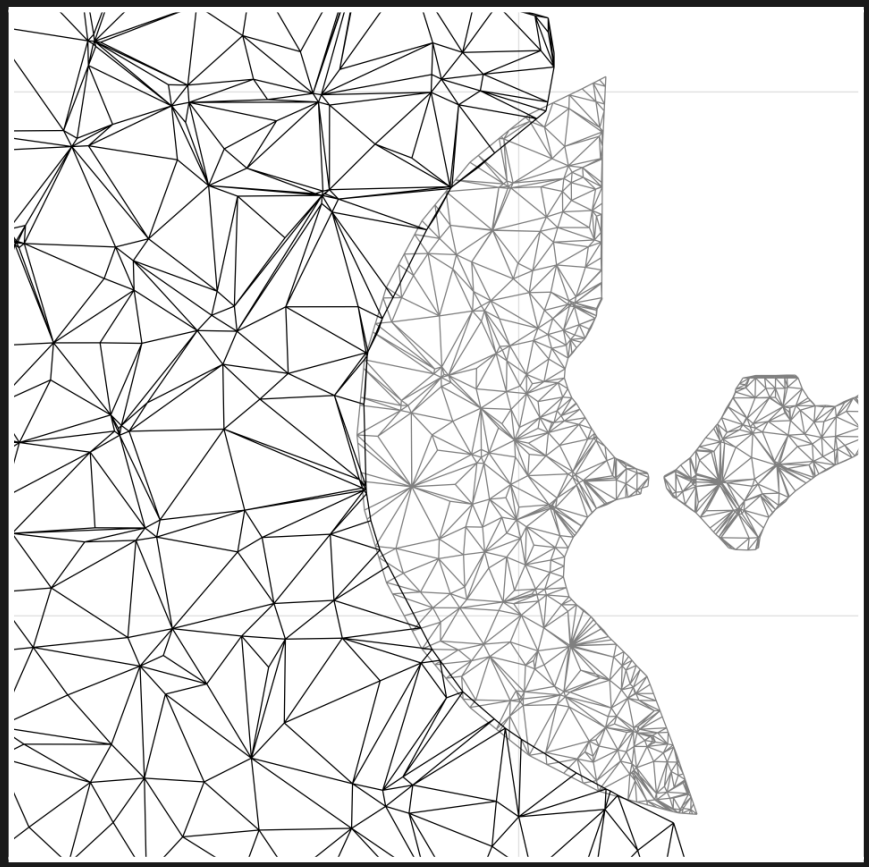
$$\begin{aligned} \Delta u &= \lambda u, \\ u &= 0, \quad \text{on the cylinder caps.} \\ \frac{\partial u}{\partial n} &= 0, \quad \text{elsewhere.} \end{aligned}$$

Meshes

Tests using different interfaces:

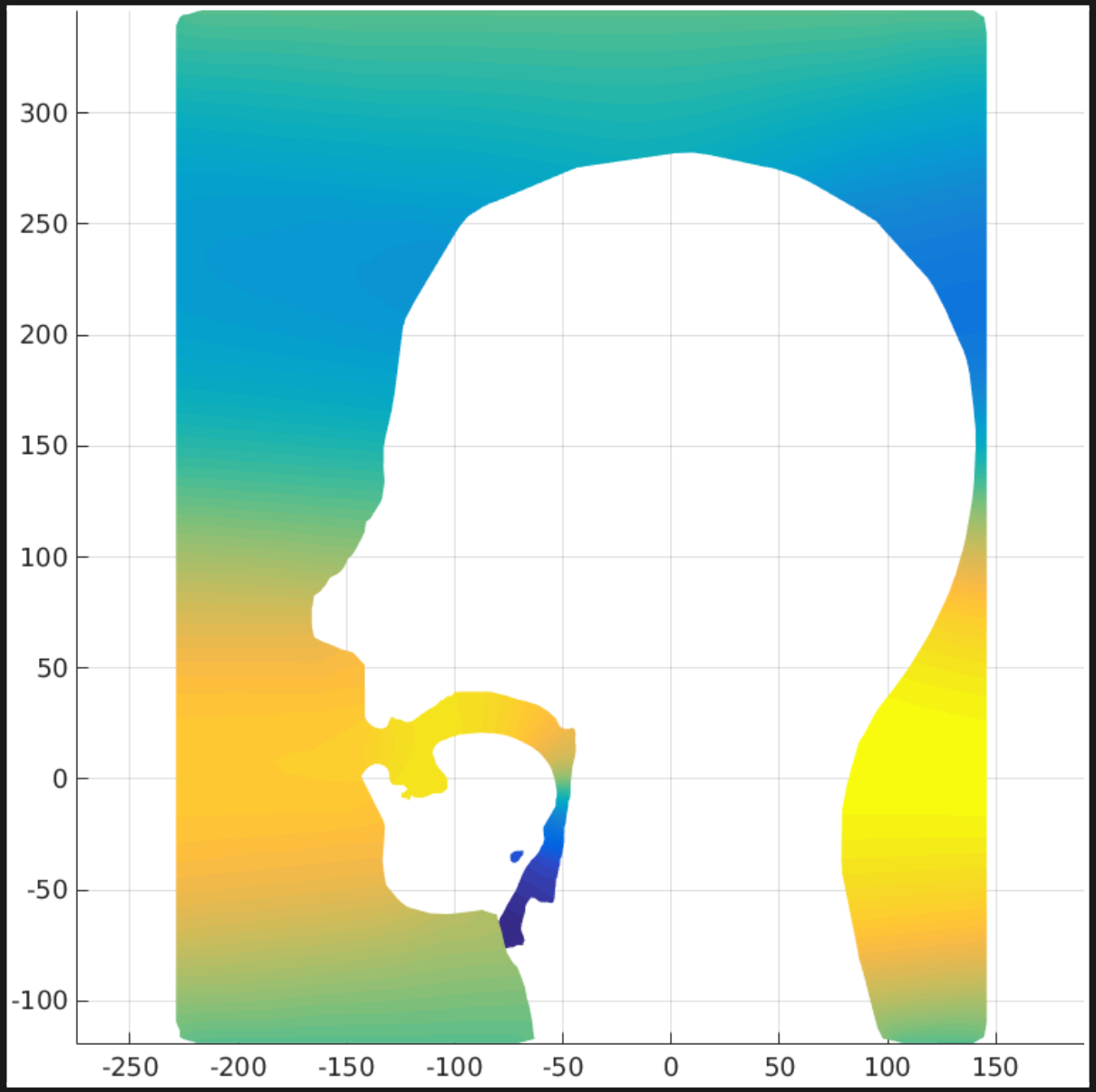


Matching border.

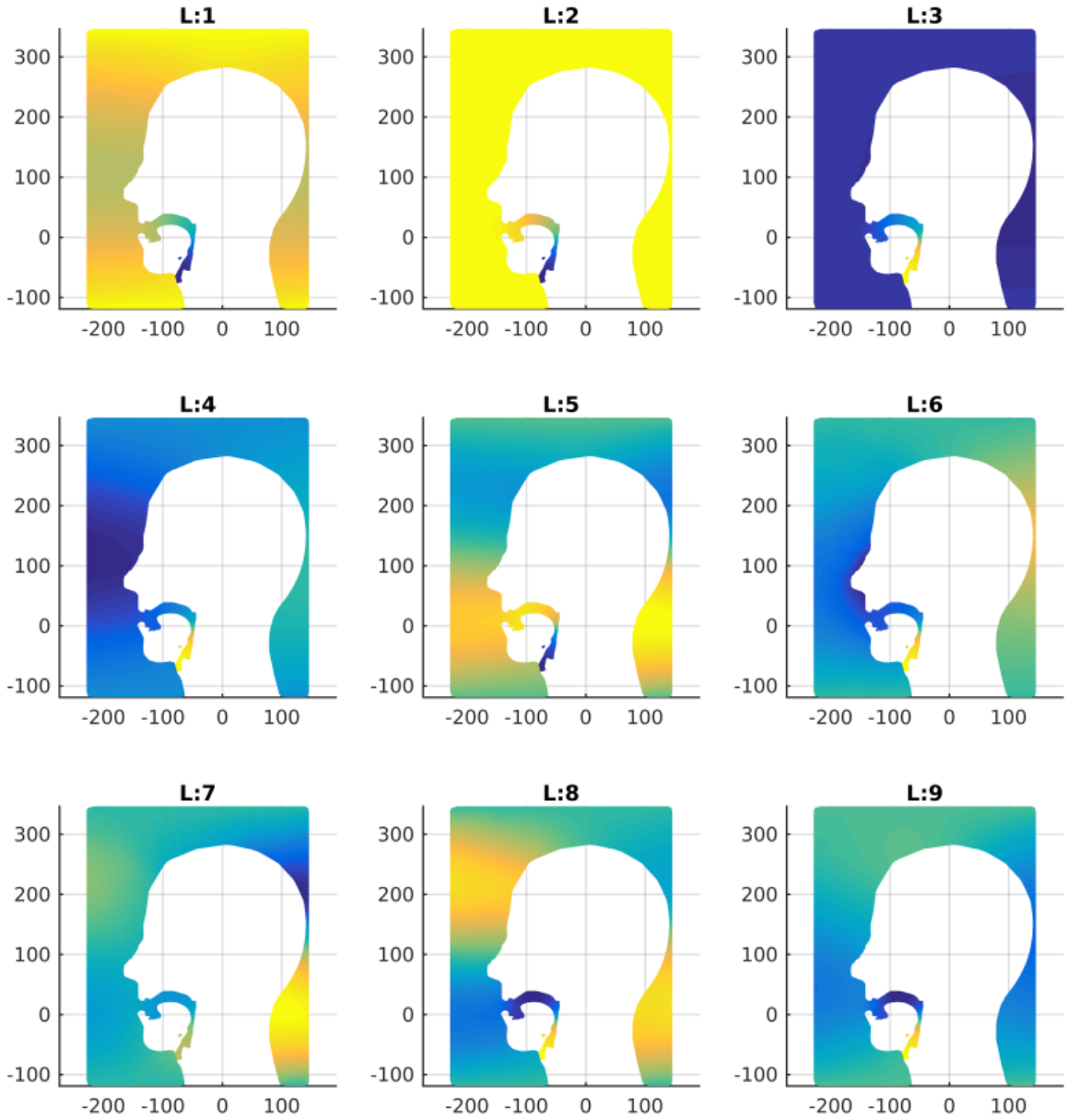


Non-matching border.

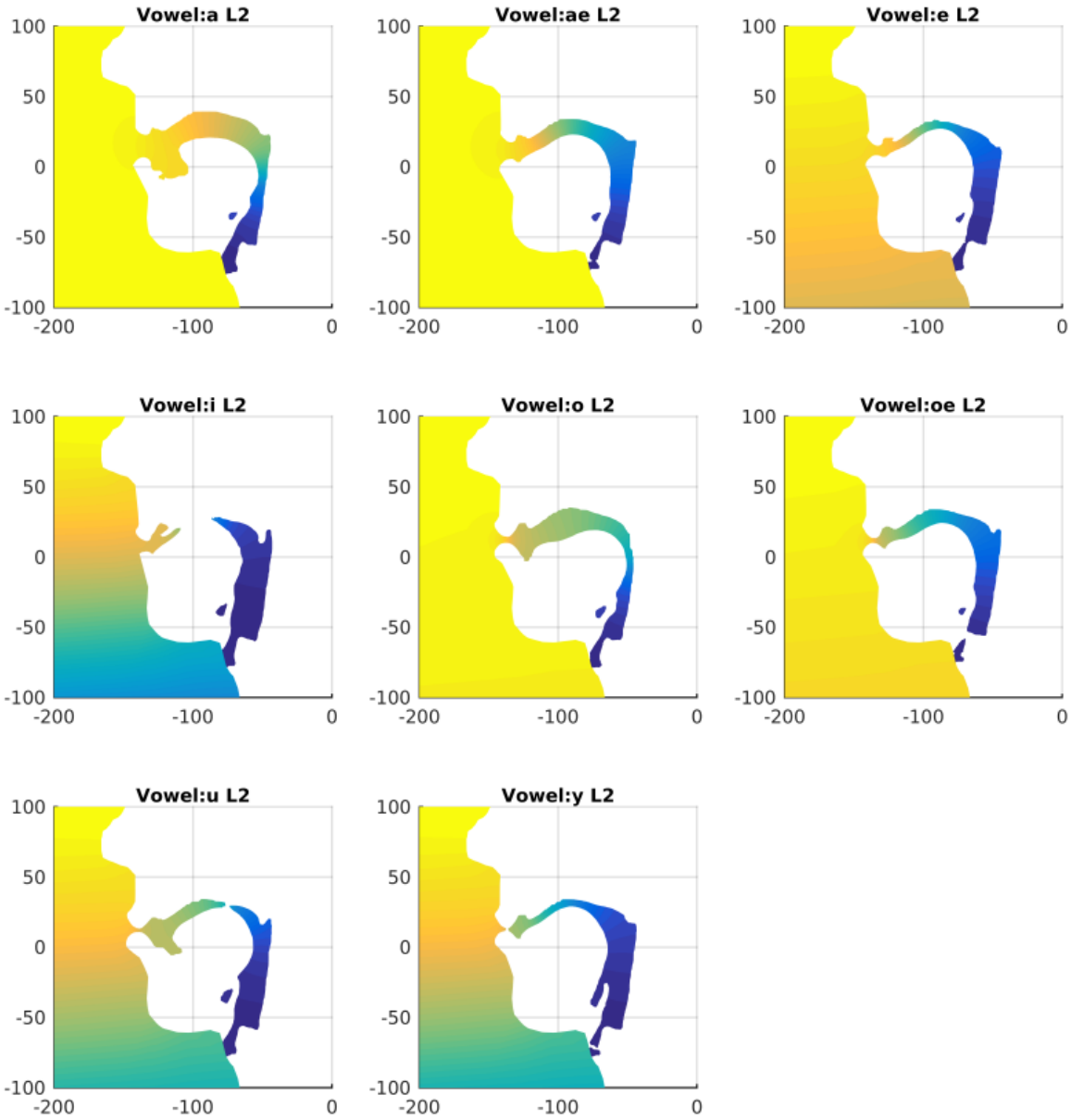
Results



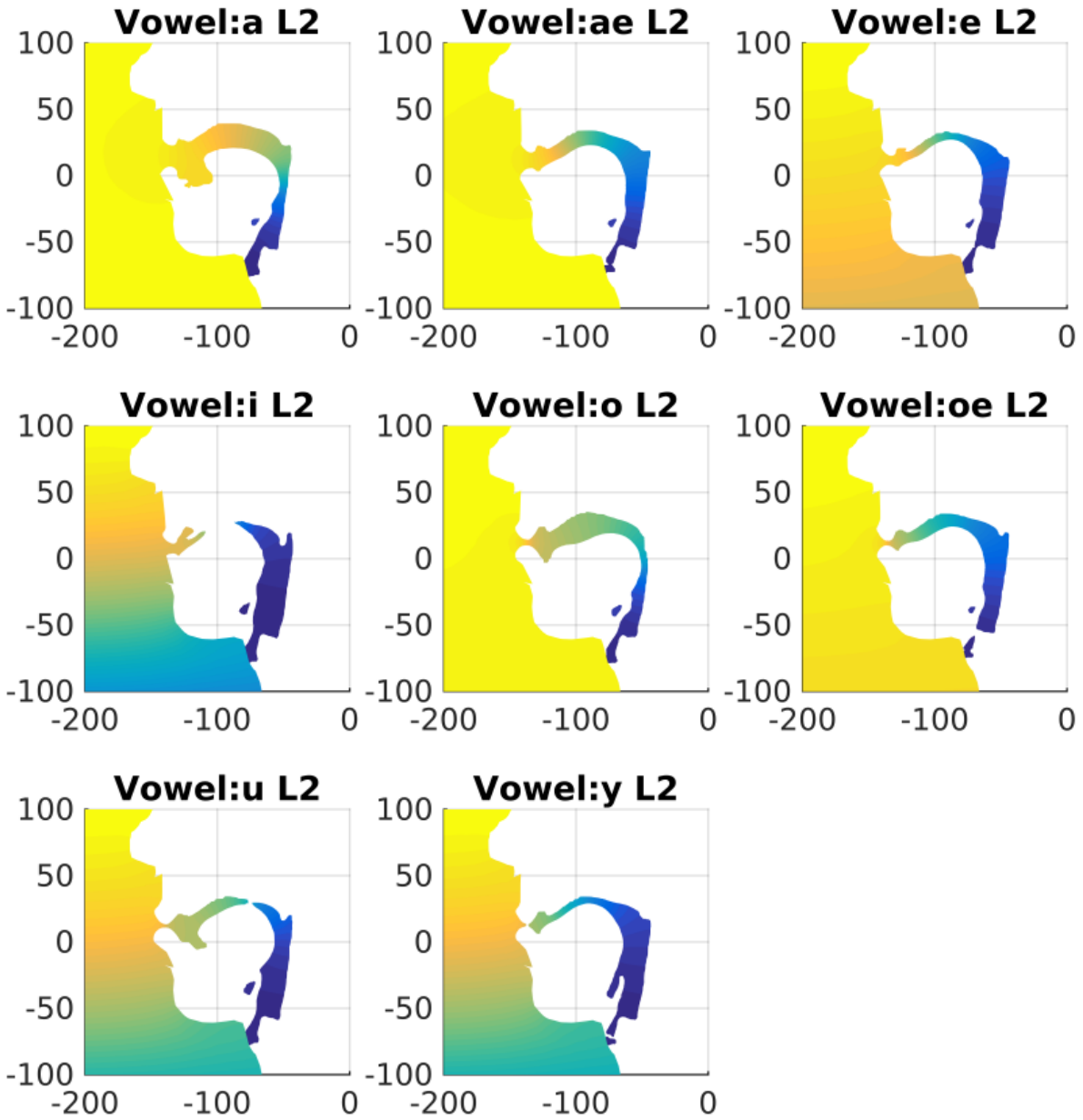
5th mode for [a].



9 first modes for [a].



Second mode for every vowel.



Second mode for every vowel, non-matching border.

Future Goals

- Robust stitching algorithm.
- Model-order reduction on the exterior domain.
- Validation with large dataset.

Thank you

http://speech.math.aalto.fi

Collaborators:

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Medical Imaging Centre of Southwest Finland at Turku University Hospital.