On Exterior Acoustics and Speech Modelling

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What is a Vocal Tract (VT)?

Vocal folds,
Glottis

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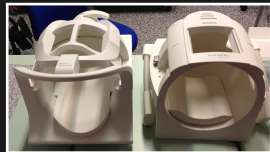- State: Geometric configuration.

MRI Machine

Head Coil

Sagittal Plane

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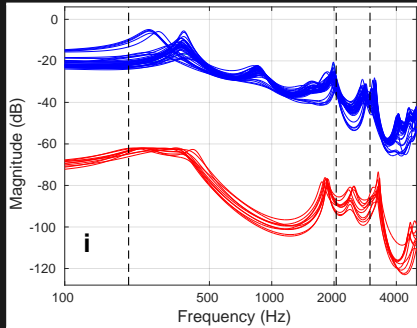- VT geometry automatically extracted from the sequence.
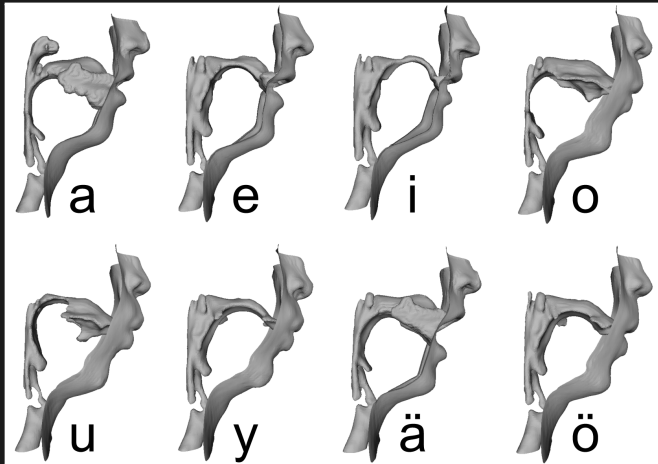
Finnish Vowels

Validation

- 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 error in the resonances.
- Environmental acoustic modelling needed.

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

- Resonances can also be validated experimentally.
- Sweeping the printed geometries yields frequency responses with similar peaks.
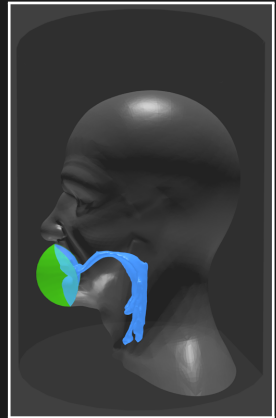- Open space exterior model required.

- VT geometry and exterior acoustic space connected via a fixed interface. Easy to swap geometries
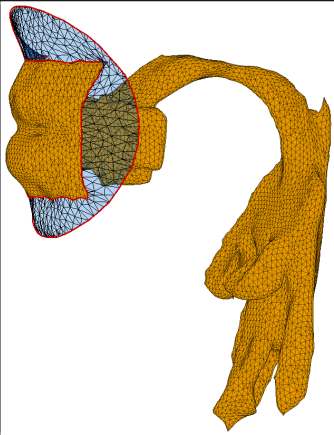- Effect of exterior space can be pre-computed to some extent.
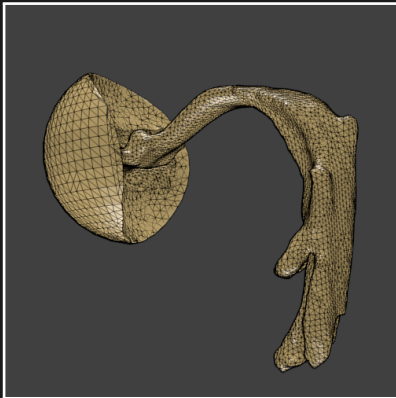
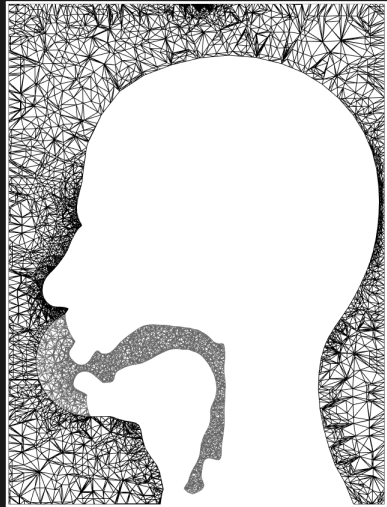VT & interface.

Interface in green.

- The interface is automatically stitched to the VT geometry.
- Project the edge polygons (red) into two dimensions and triangulate.
- Solve a 2D heat equation to obtain smooth depth interpolation.
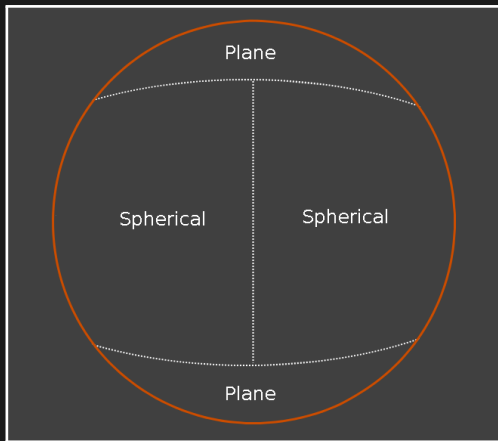
- Nitsche's method on the interface.
- Works on non-matching grids.
- Allows swapping of exterior & interior geometries.

Middleslice from a mesh.

Interface (3)

- Integration over the interface requires a parametrisation of the surface.
- Split the interface into four pieces.
- Use appropriate projections on different parts.
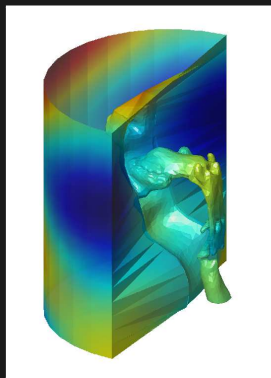

Coordinates used on different parts.

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.

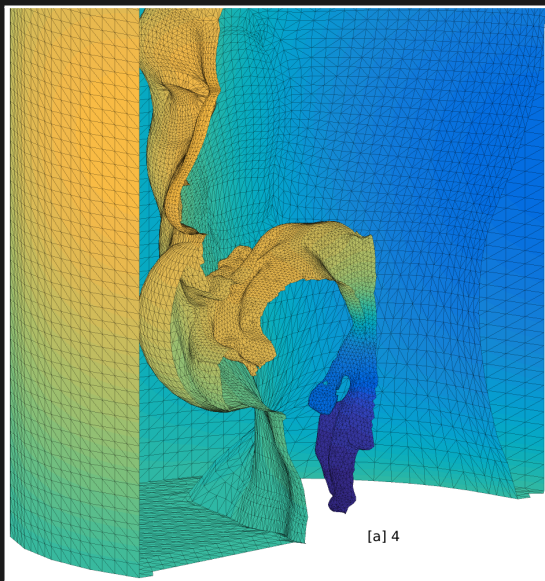Pressure distribution for the vowel [ae]. Mixed resonance structure.

Simplified problem for now:

$$\Delta u = \lambda^2 u,$$
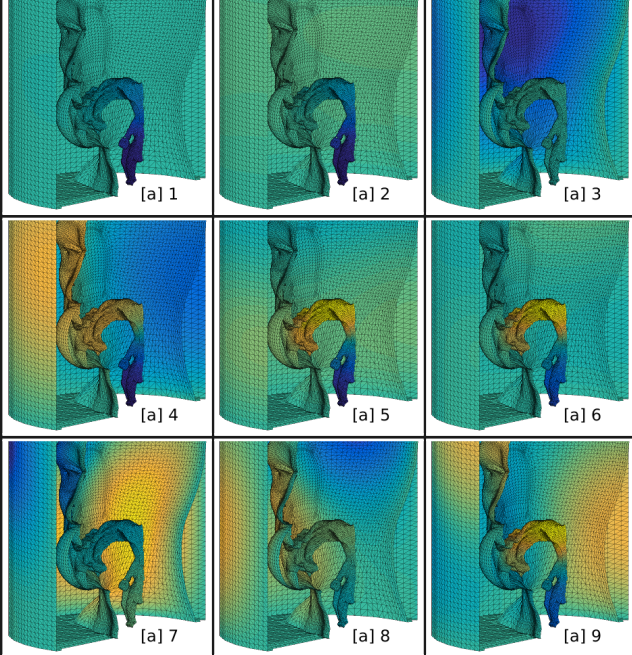$$u = 0, \quad \text{on the cylinder caps.}$$
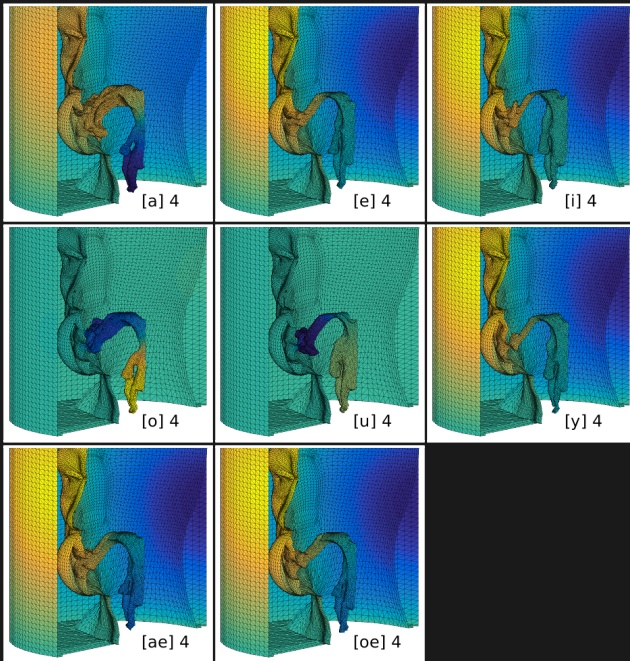$$\frac{\partial u}{\partial n} = 0, \quad \text{elsewhere.}$$

[a] 4

4th mode for [a].

9 first modes for [a].

4th mode for every vowel.

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

Thank you

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