Inferring Functional Properties from Fluid Dynamics Features

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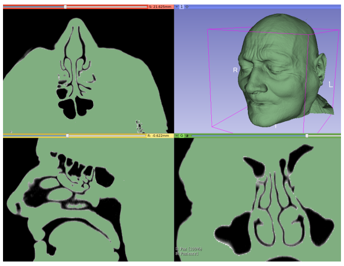
Problem Description

Given a CT scan determine the pathology/surgical maneuver

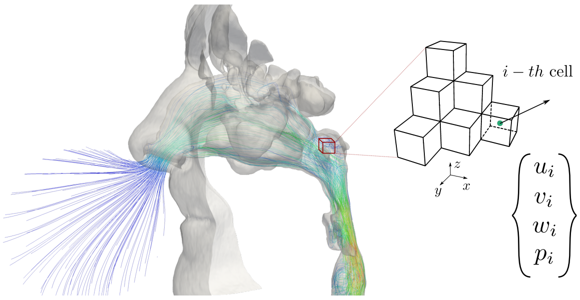


Proposed solution

combine ML algorithms and CFD data to infer diagnostic information

Fluid dynamics system:

- Given an object is possible to compute a fluid dynamic field $\Omega \subset \mathbb{R}^3$
- The CFD output is a large matrix $\mathbf{C} \subset \mathbb{R}^{4xn}$, in our scenarios $n \sim 10^6$
- CFD provides detailed quantitative information on the flow field
- Databases costly to produce and analyse



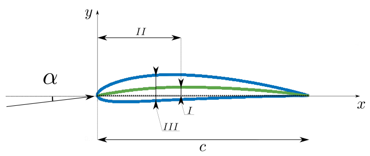
Challenges

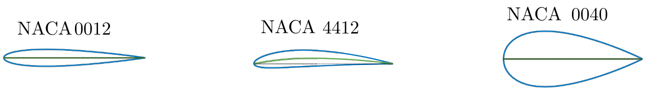
- When the goal is the the surgery of the nasal pathologies, it is difficult to write an optimization problem as function of CFD data only
- CFD provides additional information, but the output is very large.
- Difficult to generalize results due to high anatomical variability between subjects

Simplified framework: Parametric geometries

Airfoils

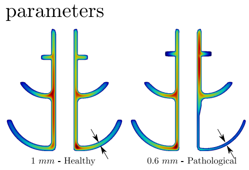
- 3026 airfoils, 2D problem, 3 geometrical parameters
- Goal: predict the airfoil parametrization

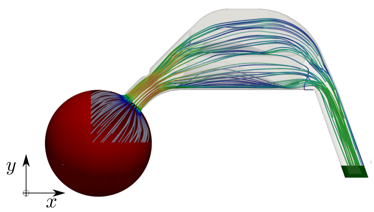




Parametric Noses

- 200 noses, 3D problem, 7 parameters (3 pathological)
- Goal: predict the pathological parameters

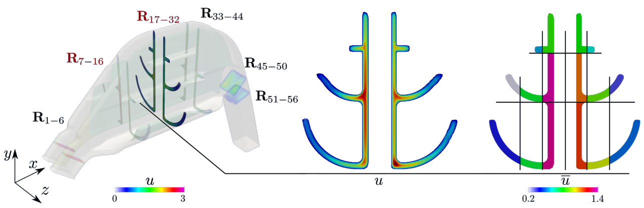


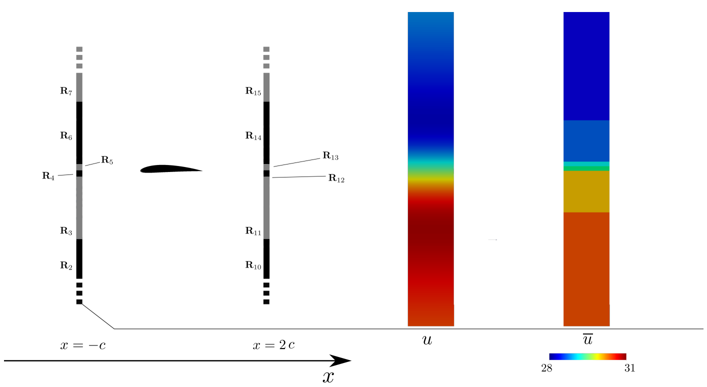


Feature Extraction

Regional Averages

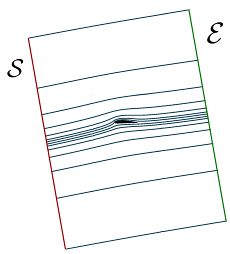
Averaging flow quantities over r regions $\mathbf{R} \subset \Omega$, $k = 1, \ldots, r$.
E.g. the average velocity $\overline{u_k}$ over the region $\mathbf{R_k}$ is defined as: $\overline{u} = \frac{\sum_i u_i V_i}{\sum_i V_i}$.
Where V_i is the volume of the cell.

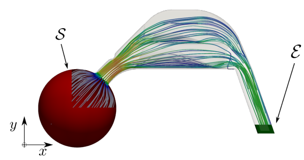




Streamlines

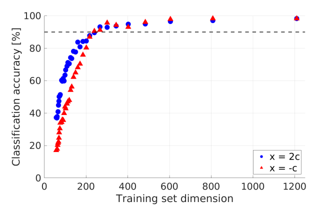
Defined as the lines locally tangent to the velocity field.
Starting from region $\mathcal{S}$ and ending in region $\mathcal{E}$, compute the first 5 statistical moments $\mu_1 \ldots \mu_5$ of the arrival time.





Results and Conclusions

The features are fed to a 3 layer fully connected neural network.



Airfoil dataset: high accuracy with relatively small training set. Shown with different set of features (Regional Averages)

- Both features have good predictive capabilities
- Regional Averages perform better than streamlines
- Nasal pathologies are more challenging to predict than airfoils parameters
- ML algorithms are powerful tools to infer functional properties from CFD data

Dataset is available: https://doi.org/10.5281/zenodo.4106752