Inferring Functional Properties from Fluid Dynamics Features

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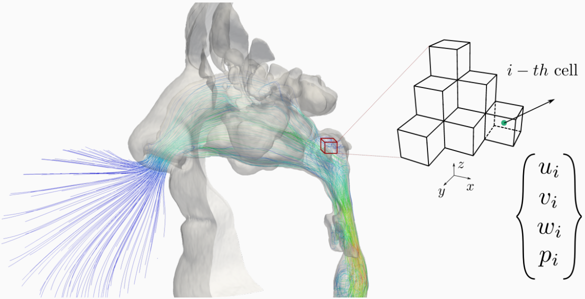
Fluid dynamics systems

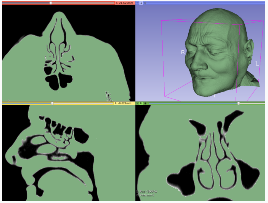
- Given an object is possible to compute a fluid dynamic field $\Omega \subset \mathbb{R}^3$
- The CFD output is a large matrix $\mathbf{C} \subset \mathbb{R}^{4xn}$, in our scenarios $n \sim 10^6$
- CFD provides detailed quantitative information on the flow field
- Databases costly to produce and analyse

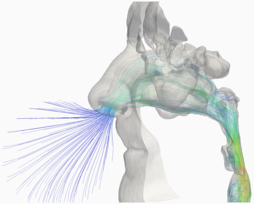


Problem description

Given a CT scan determine the pathology/surgical maneuver

- Difficult to make a decision using only a CT scan
- CFD provides additional information, but results are difficult to analyse and generalise
- The goal is difficult to write as function of CFD variables



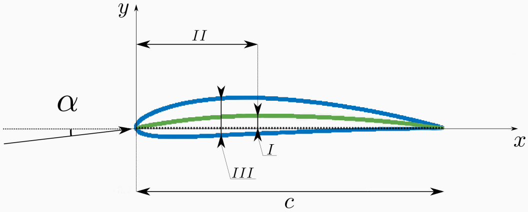


Proposed solution: combine ML algorithms and CFD data to infer diagnostic information

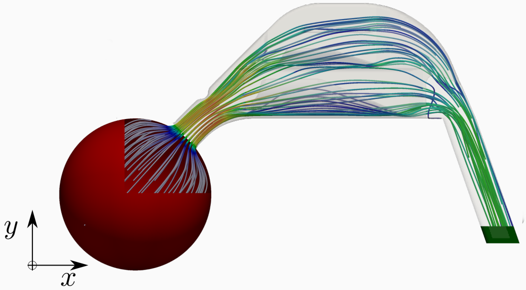
Test problems

Simplified framework: parametric geometries

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



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



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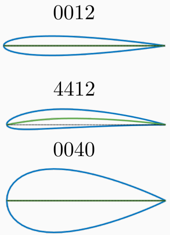

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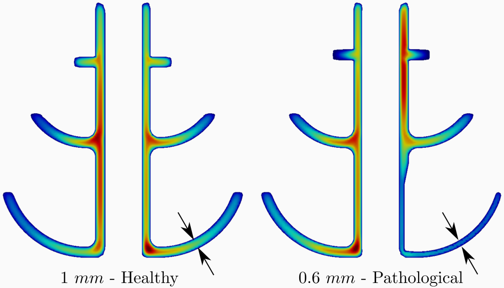
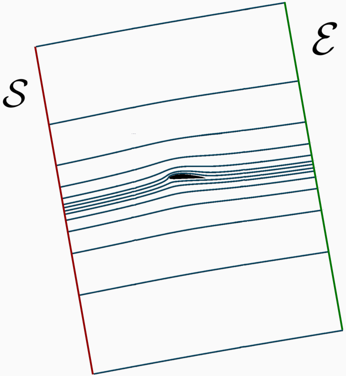
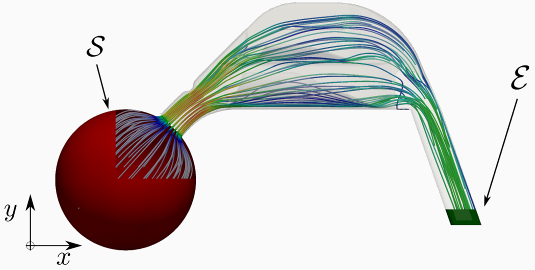


Feature extraction: streamlines

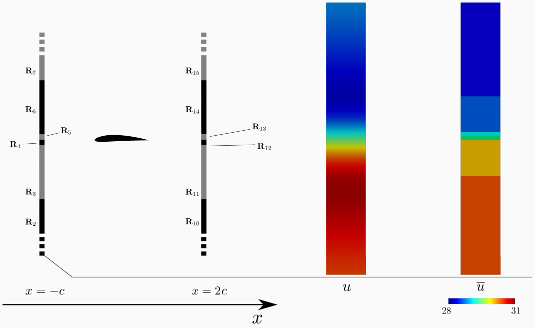
Streamlines: defined as the lines locally tangent to the velocity field. Starting from region $\mathcal{S}$ and ending in region $\mathcal{E}$, compute the first 5 statistical moments $\mu_1 \ldots \mu_5$ of the arrival times.

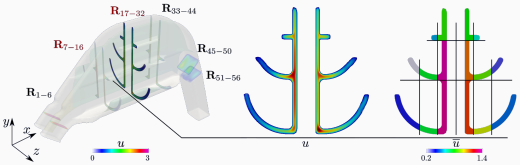




Feature extraction: regional averages

Informative features can be extracted by 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.

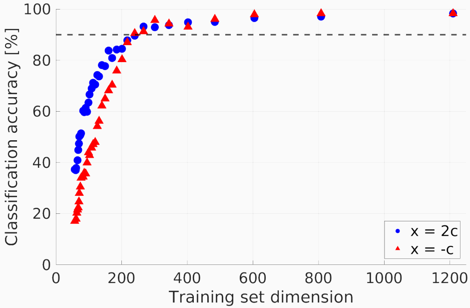




Results

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

- Both features have good predictive capabilities
- Regional Averages perform better than streamlines
- Nasal pathologies are more challenging to predict than airfoils parameters
- Relatively high classification accuracy with small training sets



Conclusion

- Fluid dynamics data contains functional information
- It is not always possible to write the goal as a function of CFD data
- ML algorithms are powerful tools to infer functional properties from CFD data
- The airfoil dataset is available online: https://doi.org/10.5281/zenodo.4106752