Inferring Functional Properties from Fluid Dynamics Features

A.Schillaci¹, M.Quadrio¹, C. Pipolo², M.Restelli³, G.Boracchi³

¹DAER, Politecnico di Milano
²ASST Santi Paolo e Carlo, Milano
³DEIB, Politecnico di Milano
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 \( \mathbf{C} \subset \mathbb{R}^{4 \times n} \), 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
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
Feature extraction: streamlines

Streamlines: defined as the lines locally tangent to the velocity field. Starting from region $S$ and ending in region $E$, 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 $\overline{u}_R$ 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.
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