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Interpretation of the machine learning attention matrix for flow analysis

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Abstract

As high-fidelity simulations of complex flow phenomena become feasible, extracting the key dynamics from the resulting data through applied mathematics and machine learning techniques gathers much attention. One notable area of research is interpretable machine learning, where comprehensible information about the flow is extracted from the learned machine learning model. In this talk, we propose an approach to analyzing flow data employing the attention mechanism originally introduced in the natural language processing community.

The attention mechanism identifies and learns the parts of the input data that are closely associated with other parts of the data. For example, in natural language processing, the word “boy” may be closely related to the word “he” in other parts of the sentence. Attention mechanisms learn such relationships in a matrix form called the attention matrix. In the proposed method, the attention mechanism is employed in the encoder part of an autoencoder, a widely used machine learning architecture for dimensionality reduction. The proposed approach aims to identify and extract the relationships between regions and flow structures to enable a similar analysis to the input/output analysis. More specifically, by visualizing the learned attention matrix, we extract the regions that are identified to be closely related to the phenomena of interest.

The proposed methodology was tested using the Kármán vortex street flow data behind a cylinder at the Reynolds numbers Re = 20, 60, and 100. The proposed method identified the upstream, sides, and slightly downstream regions of the cylinder as closely related to the vortex shedding. This result is similar to the findings from resolvent analysis, which extracts the input/output relationships of the flow phenomena. The agreement suggests that the proposed approach may be effective in analyzing flow data and their input/output relationships in the exhibited dynamics.

Keywords: Attention matrix, flow analysis, input-output analysis