Delft University of Technology

Project: Convolutional Neural Networks for Time-Dependent Fluid Flow

Supervisor(s):
Alexander Heinlein

December 20, 2021

Project Description

Computational fluid dynamics (CFD) simulations are a numerical tool to model and analyze the behavior of fluid flow. However, accurate simulations are generally very costly because they require high grid resolutions. Therefore, there is a high demand for reduced order models which reduce the computational costs of computing fluid flow fields. The project builds upon [1, 2], where convolutional neural network models are used to predict the stationary flow fields for varying geometries. The goal of this project is to move from predicting stationary Navier-Stokes flow

$$\begin{aligned} -\nu \Delta u + (u \cdot \nabla)\, u + \nabla p &= 0 \text{ in } \Omega, \\ \nabla \cdot u &= 0 \text{ in } \Omega, \end{aligned} \tag{1}$$

to predicting the flow field of time dependent Navier-Stokes equations

$$\begin{aligned} \rho \frac{\partial u}{\partial t} - \nu \Delta u + (u \cdot \nabla)\, u + \nabla p &= 0 \text{ in } \Omega, \\ \nabla \cdot u &= 0 \text{ in } \Omega. \end{aligned} \tag{2}$$

with certain boundary conditions on $\partial\Omega$, kinematic viscosity $\nu > 0$, velocity u, density ρ, and pressure p on a computational domain Ω.

A closely related approach can be found in [3]. Here, however, the focus will be on constructing a single reduced order model that can account for different boundary conditions, material parameters, or, again, geometries. If time allows, an extra step towards 3D geometries could be made.

This project aims to support the high level goal of making blood flow predictions based on MRI (magnetic resonance imaging) images, that is, using MRI images for describing the geometry as an input.

Tasks

- Install and familiarize with the software packages:
  - The open-source CFD software OpenFOAM[1]
  - The Python machine learning libraries TensorFlow 2.0[2] and Keras[3]
- Implement and train a CNN for a simple data set
- Set up a software pipeline based on OpenFOAM to automatically generate (stationary) fluid flow data depending on certain parameters, such as viscosity, inflow velocity, etc. and varying geometries
- Based on the previous tasks, train a CNN for predicting stationary flow fields based on certain input parameters
- Based on the previous tasks, use a CNN for time-stepping in reduced order (for example blood flow during one heartbeat)
- Optimization of the model and comparison against the reference data

Contact

If you are interested in this project and/or have further questions, please contact Alexander Heinlein, a.heinlein@tudelft.nl.

References

[1] M. Eichinger, A. Heinlein, and A. Klawonn. Surrogate convolutional neural network models for steady computational fluid dynamics simulations. Technical report. Accepted for publication in ETNA. October 2021. Preprint `https://kups.ub.uni-koeln.de/29760/`.

[1] https://www.openfoam.org
[2] https://www.tensorflow.org
[3] https://keras.io

[2] M. Eichinger, A. Heinlein, and A. Klawonn. Stationary flow predictions using convolutional neural networks. In F. J. Vermolen and C. Vuik, editors, *Numerical Mathematics and Advanced Applications ENUMATH 2019*, pages 541–549, Cham, 2021. Springer International Publishing. ISBN 978-3-030-55874-1. doi: 10.1007/978-3-030-55874-1_53.

[3] B. Kim, V. C. Azevedo, N. Thuerey, T. Kim, M. Gross, and B. Solenthaler. Deep fluids: A generative network for parameterized fluid simulations. In *Computer Graphics Forum*, volume 38, pages 59–70. Wiley Online Library, 2019.