Physics Informed Neural Networks for MHD modelling

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A deep learning technique called physics informed neural networks (PINNs) is developed for solving magnetohydrodynamic (MHD) equations. The method leverages the prior knowledge of the differential equations in the training process of neural networks in order to constrain a solution driven by the sole data knowledge representing the boundary/initial conditions [1].

As a first application, we show that two-dimensional (2D) axisymmetric static equilibria solutions of Grad-Shafranov equations representative of tokamak-like configurations with various shapes are easily reproduced in agreement with analytical Solov'ev solutions and previous results [2]. This is illustrated in left/middle panels of Figure 1 below.

PINNs are also shown to have powerful capabilities for modelling dynamic behavior like magnetic reconnection. Indeed, a PINN code has been developed to this aim. As a first step, benchmark problems involving 2D steady-state magnetic reconnection are solved in agreement with analytical solutions of reconnective annihilation [3-4], as shown in right panel of Figure 1. Future extensions are under development like expanding to more complex 3D configurations and time dependent MHD equations, and also learning multiple solutions for different parameter (e.g. resistivity) values with the same network.

The advantages and drawbacks of PINNs are highlighted in comparison to classical numerical methods. In particular, they are meshfree with no need of complex numerical discretization. Additional data knowledge from experiments can be easily incorporated into the process. The differential operators are evaluated exactly thanks to automatic differentiation. Due to their different philosophy, PINNs clearly offers a complementary approach to traditional schemes.

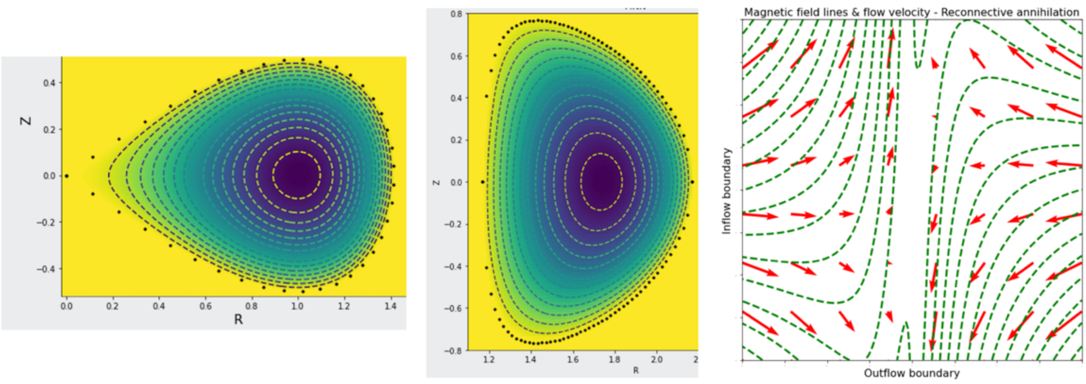

Figure 1: *(Left/middle) Magnetic field lines (flux contours) obtained using PINNs for 2D Solov'ev equilibria with two different shaped-plasmas (black dots indicate the location of boundary data). (Right) Steady-state magnetic reconnection obtained with the PINN code for reconnective annihilation solution in 2D cartesian geometry.*

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