2D MHD Equilibrium Solver using Physics-Informed Neural Networks

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\section*{Motivation}

- Magnetohydrodynamic equilibrium calculations are a crucial tool for magnetic confinement.
- A fast solver for MHD equilibrium is needed for real-time reconstructions and incorporation in optimization loops such as those that occur in stellarator shape optimization.
- Here we explore physics-informed neural networks (PINNs) as a solver for producing 2D MHD equilibria.

\section*{Grad-Shafranov Equation}

- Grad-Shafranov Equation is a 2D ideal MHD equilibrium equation.
- We are looking at a particular set of analytic solutions: Solovev Profile.
- The reason we use an analytic solution is not to train but to check.

\section*{Physics-Informed Neural Network}

- PINN calculates residual of PDE and Boundary condition.
- Optionally, we can add data (e.g. experimental or numerical solution).

\section*{Collocation Points}

- Collocation points are where the PDE residuals are evaluated.
- Possible to add data from numerical simulation or experiment.

\section*{Boundary Conditions}

\begin{itemize}
  \item Shafranov Equation in NSTX
  \item Using 1024 Dirichlet Boundary Conditions
  \item Divertor Configuration – X-points Using Cerfon Boundary Conditions

\end{itemize}

\section*{Hyperparameter Scan}

- Activation Function
- Activation functions should be differentiable to solve GS equation with PINN.
- BFGS vs. Adam
- Number of Adam optimization steps does effect BFGS convergence.

\section*{Future Works}

- Expand to 3D MHD to reconstruct equilibrium for stellarator optimization.
- Parametric-PINN to expand our input to included A(central/pressure profile) and shape parameters (i.e. eps, kappa, and delta).

\section*{References}