BAI PhD Proposal, June 2023

Title: Physics based machine learning for electronic devices.

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Abstract: Machine learning (ML) is a subfield of computer science that focuses on the use of data and algorithms to mimic the operation of the human brain, with the goal of improving accuracy over time. ML algorithms can detect patterns in vast volumes of data, such as numbers, texts, images, and so on. To learn the parameters of the algorithm, we must go through a training process with data that we already have. And, as the adage goes -- "garbage in, garbage out"-- the data we enter will be replicated to the output we want to retrieve later. We cannot expect accurate prediction if our input dataset is biased, inconsistent, or even wrong. But what if we could constrain (or bias) these ML models by enforcing a Physics framework that consistently obeys natural law? Combining physics and machine learning is in fact a rapidly expanding subject of study.

In this project, we try to develop a physics-based machine learning model for various electronic devices such as MOSFET (metal oxide semiconductor field effect transistors). In particular, we wish to solve differential equations governing such electronic devices using ML. We emphasize on understanding if a machine can learn the physical principle of an electronic device. Though an approach called PINN (Physically Informed Neural Network) has already become very popular to solve differential equations arising from physical sciences (Burger equation, Schrodinger equation, etc.), we observed that PINN fails severely to solve a simple Poisson equation that governs the electrostatic of a MOS capacitor where the charge carriers follow Boltzmann (or Fermi-Dirac) distribution and thus makes the potential profile super-exponential. This is difficult to learn by the standard PINN approach and calls for new ideas. This project has two objectives: (i) develop ML techniques to solve nonlinear differential equations (Poisson, Continuity, Schrodinger etc.) governing various electron devices in a data-free fashion; (ii) use ML to discover the same differential equations from the device data.

We aim to publish our work in high-impact venues (e.g. IOP Machine Learning Science and Technology), which promote machine learning in Physics. The prospective student would benefit from rigorous training in diverse fields such as deep learning, physics of electronic devices, semiconductor science and technology, and high-performance computing.

Reference: M. Raissi et al., Journal of Computational Physics 378 (2019) 686–707.