Nuclear Physics Experiments and Machine Learning

Master of Science thesis project

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Machine Learning for interpreting Nuclear Physics experiments

Machine Learning plays nowadays a central role in the analysis of large data sets in order to extract information about complicated correlations. This information is often difficult to obtain with traditional methods. For example, there are about one trillion web pages; more than one hour of video is uploaded to YouTube every second, amounting to 10 years of content every day; the genomes of 1000s of people, each of which has a length of 3.8×10^9 base pairs, have been sequenced by various labs and so on. This deluge of data calls for automated methods of data analysis, which is exactly what machine learning provides. Developing activities in these frontier computational technologies is thus of strategic importance for our capability to address future science problems.

These thesis projects aim at using deep learning methods such as convolutional neural networks, recurrent neural networks, variational autoenconders, generative adversarial networks (GAN) for both supervised and unsupervided problems from experimental physics. Here in particular we will explore experimental results from nuclear physics experiments.

There are two main projects:

β-decay Experiments. The classical picture of spherical nuclei is far from the reality of the true nuclear structure. Shape coexistence is a nuclear phenomenon, where the nucleus exists in two stable shapes at the same excitation energy.

Nuclear properties provide unique information on the impetuses that foster changes to the nuclear structure of rare isotopes. In some neutron-rich nuclei, 0^+ states are predicted to exhibit shape coexistence. Therefore they are compelling to study, but experimentally challenging. At low energies, where the only energetically allowed decay mode is $0^+ \rightarrow 0^+$, conversion electron spectroscopy is the only viable technique to probe their properties.

At the National Superconducting Cyclotron Laboratory at Michigan State University Sean Liddick's group employs conversion electron spectroscopy to study these transition rates. When a neutron-rich nucleus beta decays, a neutron transforms into a proton and emits an electron β. The excited nucleus can then interact electromagnetically with the surrounding orbital electrons. This can result in the ejection of an internal conversion electron e^- from the atom. Because this process is essentially simultaneous in time, it is pivotal to differentiate between the electron β emitted from the nucleus and the internal conversion electron e^- emitted from the atom.

This project attempts to use supervised machine learning algorithms as a means to distinguish between one and two electron events and predict the electron(s) corresponding initial position(s) in a scintillator.

Classification in the Active-Target Time Projection Chamber. In this thesis project, the aim is to evaluate machine learning methods for event classification in the Active-Target Time Projection Chamber (AT-TPC) detector at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. The AT-TPC detects products from nuclear physics reactions to study the nuclear structure of rare isotopes. The detector records many different types of events, but experimentalists are typically only interested in one reaction product. We will develop an automated method to single out the desired reaction product, which may result in more accurate physics results as well as a faster analysis process. Single-class, binary, and multi-class classification methods based on deep neural networks will be developed and tested against earlier and recent experiments at the NSCL. This project is a continuation of a previous thesis project which ended in a recent scientific publication. For more information see the Master of Science Thesis of Robert Solli.

The focus is to use and explore convolutional neural networks, recurrent neural networks, variational autoenconders and generative adversarial networks for analyzing nuclear physics experiments.

The milestones are as follows

1. Spring 2020: Analyze simulated data with Convolutional Networks and reproduce results from simulations
2. Fall 2020: Include other deep learning methods such as reinforcement learning and autoencoders and analyse data from experiments at Michigan State University
3. Spring 2021: Finalize thesis project.

The thesis is expected to be handed in May/June 2021.