**PhD in Physics - Physics Department, University of Pavia**

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Lecturer: Jennifer Ngadiuba (Fermilab, Chicago)
A.A. 2022-2023

# Machine Learning Applications in Physics

Approximate duration: 20h-24h

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**Lesson 1**: May 8th 2023

**Morning: ML basic concepts (lecture)**

1. statistics concepts/notation
2. linear regression
3. gradient descent
4. logistic regression
5. figure of merits
6. overfitting
7. regularization

**Afternoon: Intro to python and data science tools (interactive/handson)**

1. python basics
2. github, colab, jupyter notebook
3. numpy, matplotlib, pandas, scikitlearn
4. Exercise: Manipulate/plot datasets [Datasets TBD]

**Lesson 2**: May 9th 2023

**Morning: Neural Networks (lecture)**

1. basics: non linearity, loss functions, backpropagation, training, dropout, activation functions
2. architectures: multilayer perceptrons and convolutional neural networks (+ ResNet)
3. types of learning
4. hyperparameter optimization

**Afternoon: Classification of images with Keras/Tensorflow (interactive/handson)**

1. Introduction to LHC jet dataset
2. Dataset exploration

3. Introduction to Keras/Tensorflow
4. Train MLP with HLF
5. Train CNN with jet images
6. Hyperpar opt example [if time allows]
7. Exercise: improve CNN model

**Lesson 3**: May 10th 2023

**Morning: Recurrent neural networks (lecture+handson**

1. All types of RNNs: vanilla RNNs, LSTMs, GRUs
2. Classification of LHC jet dataset with RNNs with Keras/Tensorflow

**Afternoon: Graph Neural Networks - part 1 (lecture+handson)**

1. Graph representation learning
2. Message Passing Neural Networks (MPNN) and Graph Convolutional Networks (GCN)
3. Edge vs Node vs Graph classification
4. Introduction to PyTorch and PyG [Karate Club dataset]
5. Graph data classification on the TU (molecules) and Cora (scientific publications) datasets with PyTorch
6. Exercise: Train a GNN architecture of your choice on the LHC jet dataset with Keras or PyG, compare with other architectures

**Lesson 4**: May 11th 2023

**Morning: Graph Neural Networks - part 2 (lecture+handson)**

1. Interaction Networks
2. Graph Attention Networks
3. Interaction Networks for prediction on datasets of mechanical systems [Keras/TF]
4. IGraph Attention Networks for classification in TU dataset [PyTorch]

**Afternoon: Transformers (lecture+handson)**

1. Introduction to transformers
2. Apply transformers to a language dataset with Keras and PyTorch
3. Exercise: Train a transformer architecture on the LHC jet dataset with Keras or PyTorch

**Lesson 5**: May 12th 2023

**Morning: Generative models - part 1 (lecture+handson)**

1. Introduction to GANs and Normalizing Flows

2. Application of GANs and Normalizing Flows [Dataset TBD]

**Afternoon: Generative models - part 2 + anomaly detection (lecture+handson)**

1. Variational Autoencoders for generation and anomaly detection
2. Variational Autoencoders for generation [Dataset TBD]
3. Variational Auteoencoders for anomaly detection
4. Exercise: Train a graph-based variational autoencoder for the jet LHC dataset

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Lectures will be held in Aula Dottorato of the Physics Department (University of Pavia). Upon request and approval, the course can be attended online. In this case, Zoom links will be provided few days before.