MACHINE LEARNING IN JET PHYSICS

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Introduction

- Jets are collimated streams of particles produced by particle collisions.
1. Protons collide at high energies.
2. Quarks and gluons produced are hadronized.
3. The decay products are clustered into jets using algorithms.

Is the jet quark initiated or gluon initiated?
In many searches for new physics signals at the LHC, jets are initiated by light-flavor quarks (u, d, s), while the jets background processes are initiated by gluons.

We are currently working on,

- Classification of quark and gluon initiated jets.
- Bias between the event generators.
- Bias between real and simulated data.
Quark/Gluon Jets

- Quark initiated jets are narrower

\[ C_F = \frac{4}{3} \]

- Gluon initiated jets are more wide.

\[ C_A = 3 \]

B.R. Webber, Quark and Gluon Jets in Quantum Chromodynamics, Physica Scripta, vol 25, no 1B, p 198, 1982
Jet images are 2D representation of energy deposits in the calorimeter.
Event Generation

PYTHIA

HERWIG

Jet Clustering

FASTJET

Graph showing data points with color coding.
Processes

- **Quark-initiated jets**
  - $qq \rightarrow qq$
  - $q\bar{q} \rightarrow q\bar{q}$
  - $gg \rightarrow q\bar{q}$

- **Gluon-initiated jets**
  - $gg \rightarrow gg$
  - $q\bar{q} \rightarrow gg$

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Parameters

- Radius = 0.4
- Pseudorapidity $|\eta| < 2.5$
- Transverse momentum in ranges 100-110 GeV, 200-220 GeV, 500-550 GeV and 1000-1100 GeV.

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1. Centering: The jet is rotated and boosted so that the central pixel is at (0, 0).

2. Crop: Crop the image with \((\eta, \phi) \in (-R, R)\).

3. Normalize: Total pixel intensity of the image is \(\sum l_{ij} = 1\).

4. Zero-center: \(l_{ij} \rightarrow l_{ij} - \mu_{ij}\), where \(\mu_{ij}\) is the average of the training set.

5. Standardize: \(l_{ij} \rightarrow l_{ij}/(\sigma_{ij} + r)\) where \(\sigma_{ij}\) is the standard deviation of the training set and \(r = 10^{-5}\).
(a) Average gluon image before preprocessing steps 4-5

(b) Average quark image before preprocessing steps 4-5

**Figure:** Jet-Images
(a) Average gluon image after preprocessing

(b) Average quark image after preprocessing

**Figure:** Jet-Images
Convolutional Neural Networks

- Convolutional Neural Network (CNN) are neural networks for image recognition and image classification.
- CNN scans over the two dimensional pixel intensities of an RGB image.

Figure: Convolutional Neural Network

Figure: Components of a CNN
Deep Learning on Jet-Images

▶ Jet images of size $33 \times 33$.
▶ 3 convolutional layer and 2 fully connected layer.
▶ ReLU (Rectified Linear Unit) activation.

Figure: ReLU and Sigmoid activations

▶ Filters of size $8 \times 8$, $4 \times 4$ and $4 \times 4$ are used.
▶ Maxpooling layers $2 \times 2$ is also applied to the CNN with a stride length of 2.
▶ The fully connected layer consists of 128 units.
The jet images produced are fed into the network as grayscale images.

An additional information of charge is applied to improve the accuracy of the model.

“Colour” images with colour channels,

- **RED** = Transverse momentum of charge particles.
- **GREEN** = Transverse momentum of neutral particles.
- **BLUE** = Charge particle multiplicity.

The “coloured” images are then trained.

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CNN is trained on Tensorflow using NVIDIA GeForce 1080Ti GPU on Cuda 9.0 platform.
The network is trained over 100 epochs with a learning rate $\alpha$ of 0.001.
180000 jet images are used for training, 20000 images for validation and 40000 images are used for testing.
Results and Future Works

- Pythia test images are better than Herwig test images.

Comparison of machine learning algorithms trained on Herwig and Pythia.
Domain adversarial neural network is a new learning approach for data trained and tested on similar but different distributions.

Figure: DANN architecture

Y. Ganin et al., Domain-Adversarial Training of Neural Networks, arXiv:1505.07818 [stat]
Thank you!