Deep Learning algorithms in phenomenological analysis in High Energy Physics

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1 Introduction

Six Hundred Million of events per second and one Million of Bytes per each one constitutes the rate of production of raw data, that experiments at the Large Hadron Collider (LHC) have to handle on average. Analyzing large amounts in data is an important task in High Energy Physics (HEP), the area of physical sciences that study fundamental particles and their interaction at the most fundamental level. Although, in the beginning this task was made through the study of astrophysical cosmic rays [1], posterior years carry out to the use of particle accelerators and detectors, progressively higher in scale. At present, the main HEP project is the LHC located at the European Organization for Nuclear Research (CERN). Several experiments at the LHC, such as ATLAS, CMS, LHCb and ALICE, analyze data from proton-proton and/or heavy ion collisions. Thus, the large amount of data that is processed by the HEP experiments, represent a computational challenge.

In order to attack this challenge, there was a progress in data analysis techniques used to exploit the amounts of data produced in experiments, along with the development of particles accelerators. In the beginning of 1960 the main technique was Multivariate Analysis (MVA) but in later years this would be known as Machine learning (ML). In 1959 Arthur Samuel, a remarkable computer scientist, defined Machine Learning (ML) as the science that gives computers the ability to learn without being explicitly programmed. In this field there are two main types of learning: supervised and unsupervised. The first one is compound by a set of algorithms where correct targets are given to the model in order to learn and then predict. Meanwhile, unsupervised learning tries to learn getting hidden patterns in the data, but without knowing the correct output.

Since the decade of 90's, in HEP it was usual to use some supervised learning algorithms like Boosted Decision Trees or Neural Networks [2, 3] in event classification, jet reconstruction or trigger systems. However, in recent years there is a lack of implementation of newer techniques in HEP, opposite to the explosion of usage of new techniques in different areas like technology, artificial intelligence or business. As a response to this phenomenon, some recent papers have proposed the use of others Machine Learning algorithms like Support Vector Machine (SVM) [4] or Deep learning (DL) [5] arguing improvements in performance and model fitting.

This project will explore the use of Deep Learning algorithms, a fruitful branch of ML highly used in computer vision and image recognition, in phenomenological analyses carried out by the HEP group at Universidad de los Andes. In order to achieve those goals, this project will use a phenomenological analysis performed by the HEP group at UNIANDES [6]. The analysis proposed a new search at the LHC to target compressed mass spectra regions in the electroweak sector with taus. With this particular phenomenological analysis defined as a target, this research will explore mainly Deep Learning algorithms used in classification problems. Some of the methods that will be studied are Convolutional Neural Networks (CNN) [7], Region Based CNN's [8], Generative Adversarial Networks (GAN's) [9] and Deep Boltzmann Machines. Thus, at the end the objective is to conclude if there is a improvement in performance and model fitting due to the use of these new techniques.

2 Main Objective

To implement a Deep Learning algorithm in phenomenological analysis of HEP group at Universidad de los Andes and establish if it helps to improve existent results.

3 Specific Objectives

1. To study most relevant and efficient Deep Learning algorithms.

2. To implement a couple of optimal Deep Learning algorithms and apply them in an analysis of the high energy physics group.

3. To establish differences among Deep Learning algorithms and other event classification techniques comparing if there is significant improvement in the signal to noise ratio in the analysis.

4 Methodology

As this project is mainly focused in theoretical and computational analysis, there are several stages that must be accomplish to get the final result. At the beginning, it will be mandatory to make a bibliographic review about the main Machine and Deep Learning algorithms used in classifications problems. In this item, it will give special attention to the canonical Machine Learning algorithms used in HEP in order to have a benchmark, and new Deep Learning algorithms used in areas like computer vision. From last ones, it will be selected a couple of algorithms to implement. Parallel to this, also there will be a bibliographic review in phenomenological analysis based on the Uniandes HEP group research.

As a second stage, it will study the main software available to implement the selected DL algorithms. Thus, together with the sample data provided by the Uniandes HEP group and the necessary software, it will test the algorithms and its model fitting and refinement. At the end, it will compare the obtained results with the published ones [6].

Requirements

- Access to the UNIANDES cluster, which will be provided by the HEP group.

5 Schedule

Week \ Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Bibliographic review	X	X	X	X	X											
2. Data study					X	X										
3. Software study and script development				X	X	X	X	X	X	X						
4. 30 % presentation						X	X	X								
5. Software testing											X	X				
6. Document writing										X	X	X	X	X	X	x

Table 1: Schedule of activities.

1. **Bibliographic review:**
   To study the phenomenological aspects of HEP event selected and the relevant Machine and Deep Learning theory in event classification.

2. **Data study:**
   To study the simulated data.

3. **Software study and script development:**
   To study the available software to implement the algorithms in order to code the final script.

4. **30% presentation:**
   To prepare the necessary presentations and documents.

5. **Software testing:**
   To try the code in the university cluster.

6. **Document writing:**
   To write the final document.

6 Knowledgeable People

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- Carlos Ávila, cavila@uniandes.edu.co

References

[1] J. C. Street and E. C. Stevenson. New Evidence for the Existence of a Particle of Mass Intermediate Between the Proton and Electron. *Phys. Rev.*, 52:1003–1004, Nov 1937.

[2] Lalit Gupta, Anand M. Upadhye, Bruce Denby, Salvator R. Amendolia, and Giovanni Grieco. Neural network trigger algorithms for heavy quark event selection in a fixed target high energy physics experiment. *Pattern Recognition*, 25(4):413 – 421, 1992.

[3] Bruce Denby. Neural networks in high energy physics: A ten year perspective. *Computer Physics Communications*, 119(2):219 – 231, 1999.

[4] M.Ö. Sahin, D. Krücker, and I.-A. Melzer-Pellmann. Performance and optimization of support vector machines in high-energy physics classification problems. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 838:137 – 146, 2016.

[5] Pierre Baldi, Kevin Bauer, Clara Eng, Peter Sadowski, and Daniel Whiteson. Jet Substructure Classification in High-Energy Physics with Deep Neural Networks. 2016.

[6] Andrés Flórez, Luis Bravo, Alfredo Gurrola, Carlos Ávila, Manuel Segura, Paul Sheldon, and Will Johns. Probing the stau-neutralino coannihilation region at the LHC with a soft tau lepton and a jet from initial state radiation. *Phys. Rev. D*, 94:073007, Oct 2016.

[7] Karen Simonyan and Andrew Zisserman. Very Deep Convolutional Networks for Large-Scale Image Recognition, 2014.

[8] Ross Girshick, Jeff Donahue, Trevor Darrell, and Jitendra Malik. Rich feature hierarchies for accurate object detection and semantic segmentation, 2013.

[9] Ian J. Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. Generative Adversarial Networks, 2014.

Advisor's Signature

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