Optimization of Machine Learning Algorithms for LArTPCs

Katie Edwards
Iowa State University
Mentors: Dr. Jin Tian(ISU), Dr. Hongyang Gao(ISU), Dr. Jane Nachtman(UI)
Machine Learning Overview

- Used in many AI-like programs
- Completes tasks in a way that is similar to humans
- Can identify images or other patterns that they are trained to recognize
  - Good for analyzing neutrino interactions
LArTPC

- Neutrinos have weak interactions which makes them hard to detect
- LArTPC is a particle imaging detector used to detect neutrino interactions
- Takes multiple 2D images using wires, or takes a 3D image using pixels
- Recent technology developed specifically for neutrino physics purposes

DUNE

Goal: to answer fundamental questions using neutrino analysis
- Role of neutrinos and how they contribute to matter
- Understand proton decay in nature to determine matter's stability
- The role of neutrinos in black hole formation

Two LArTPCs
- Near Detector examines neutrinos before oscillation
- Far Detector analyzes neutrinos after oscillation (detects flavor change)
- Will use a total of 40,000 tons of liquid argon once built

Problem statement

- Algorithms vary in effectiveness
- Focusing on increasing accuracy in algorithms for better reconstruction results
- Sometimes it’s more important to have accuracy in one field over another

Deghosting Accuracy: 0.9850
Segmentation Accuracy: 0.9954
PPN Accuracy: 0.8681
Clustering Accuracy: 0.9582
Clustering Edge Accuracy: 0.1975
Shower fragment clustering accuracy: 0.9733
Shower primary prediction accuracy: 1.0000
Track fragment clustering accuracy: 0.9976
Interaction grouping accuracy: 0.9869
Particle ID accuracy: 1.0000
Primary particle score accuracy: 1.0000
LArTPC MLReco3D

- GitHub repository made for training machine learning models with images from LArTPCs

- Steps:
  - Semantic segmentation
  - Identifies points of interest
  - Clusters particles together
  - Identifies particles

http://deeplearnphysics.org/lartpc_mlreco3d_tutorials/_images/semantic.png
LArTPC MLReco3d Pipeline

Dataset

- Simulated data from the MINERvA experiment
- 10 different images used in training
Optimization Example

- Manipulated value that determines the radius that orphan particles get matched with neighboring clusters
- Original value was 1.0
Optimization Example

- Increases one field but decreases another field
  - Track fragment clustering accuracy clusters small track pieces together that are left by initial clustering algorithm
  - Interaction grouping accuracy predicts which edges should be kept
- The larger the radius value, the more orphan particles will get incorrectly matched to clusters that are far away, but more edge particles will be retrieved
- Sometimes some accuracy fields are more important than others

Before change:

- Deghosting Accuracy: 0.9850
- Segmentation Accuracy: 0.9954
- PPN Accuracy: 0.8681
- Clustering Accuracy: 0.9582
- Clustering Edge Accuracy: 0.1975
- Shower fragment clustering accuracy: 0.9733
- Shower primary prediction accuracy: 1.0000
- Track fragment clustering accuracy: 0.9976
- Interaction grouping accuracy: 0.9869
- Particle ID accuracy: 1.0000
- Primary particle score accuracy: 1.0000

Radius = 10.0:

- Deghosting Accuracy: 0.9850
- Segmentation Accuracy: 0.9954
- PPN Accuracy: 0.8681
- Clustering Accuracy: 0.9582
- Clustering Edge Accuracy: 0.1975
- Shower fragment clustering accuracy: 0.9733
- Shower primary prediction accuracy: 1.0000
- Track fragment clustering accuracy: 0.9905
- Interaction grouping accuracy: 0.9882
- Particle ID accuracy: 1.0000
- Primary particle score accuracy: 1.0000
Optimization Example

- Causes a similar increase in interaction grouping accuracy, but decreases a different accuracy field than before
  - Primary particle score accuracy classifies which particles are closest to the vertex
- When the radius decreases, more primary particles might be misidentified as non-primary

Before change:

- Deghosting Accuracy: 0.9850
- Segmentation Accuracy: 0.9954
- PPN Accuracy: 0.8681
- Clustering Accuracy: 0.9582
- Clustering Edge Accuracy: 0.1975
- Shower fragment clustering accuracy: 0.9733
- Shower primary prediction accuracy: 1.0000
- Track fragment clustering accuracy: 0.9976
- Interaction grouping accuracy: 0.9869
- Particle ID accuracy: 1.0000
- Primary particle score accuracy: 1.0000

Radius = 0.5:

- Deghosting Accuracy: 0.9850
- Segmentation Accuracy: 0.9954
- PPN Accuracy: 0.8681
- Clustering Accuracy: 0.9582
- Clustering Edge Accuracy: 0.1975
- Shower fragment clustering accuracy: 0.9733
- Shower primary prediction accuracy: 1.0000
- Track fragment clustering accuracy: 0.9976
- Interaction grouping accuracy: 0.9879
- Particle ID accuracy: 1.0000
- Primary particle score accuracy: 0.9688
Conclusion

- Machine learning is very useful for analyzing neutrino interactions
- The better the models are, the more accurate predictions will be
- The more machine learning models are trained now, the better the reconstruction models will perform, which will lead to more ground-breaking discovery in particle detection
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