Particle identification in Cherenkov Detectors using Convolutional Neural Networks

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Introduction

- Charged particles emit cone-shaped Cherenkov Radiation along trajectory when above c/n.
- Light is absorbed by PMTs on detector walls.
- Primarily need to distinguish between e^- and μ^- light patterns:
  - Electron rings are fuzzy because trajectory is scattered.
  - Muon rings are well-defined because trajectory is straight.
- Current separation uses likelihood fit. Can machine learning do better?

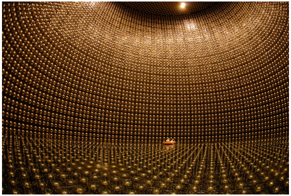


Figure: Interior of Super-K Detector in Japan

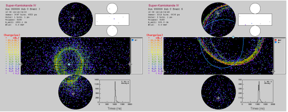


Figure: Muon and Electron Event Displays

Convolutional Neural Networks (CNNs)

- Basic neural network takes N inputs, and optimizes weights of each input to P possible classifications ($P \times N$ matrix).
- No localization with this method, use model based on mammalian visual cortex instead:
  1. Scan image with series of filters to select out edges, colour gradients, etc.
  2. Scan set of feature maps to select shapes, and again to select objects.
  3. Classify objects by passing output through fully connected network.
- Training process optimizes filters as well as neuron weights for classification.

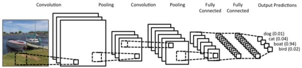


Figure: Summary of Neuron Layers in a Typical CNN.

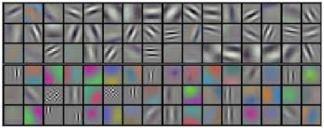
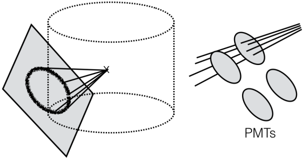


Figure: Examples of filters used to scan image for features.

Data Processing

- Want algorithm only to learn features of the Cherenkov pattern.
- Project PMT data onto a 30x30 image in the transverse plane.
  - Scale rings to the same radius in 4 data sets to reduce complexity.
- Find vertex and direction through standard analysis fitting procedure.
- Train algorithm on 240,000 images, and test on 160,000.



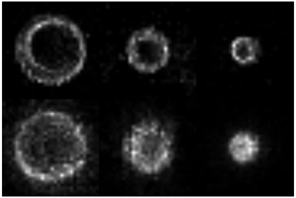


Figure: Conical projection of PMT signal.

Network Architecture

- Very Simple Convolution Network
  - One convolution layer with 5x5 filters to separate smooth from sheer edges.
  - Manually input filters to get algorithm off the ground.
  - One fully connected layer with 20 neurons before output prediction.
- Simple because does not have to connect edges into more complicated shapes.

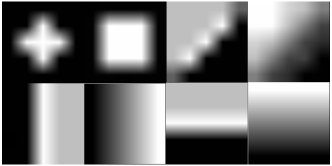


Figure: Examples of initial filters used by algorithm (usually left unchanged).

Results

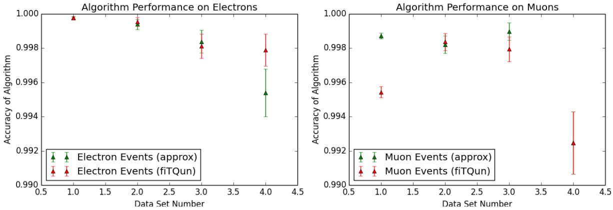


Figure: Efficiencies of identifying e^- and μ^- versus data set (red: standard analysis, green: CNN).

- Algorithm reaches same level of accuracy as standard analysis.
- Standard analysis fails in set-1 muons when the rings are segmented.
- Total accuracy, Standard: 99.77%, Algorithm: 99.89%

Conclusion

- Image recognition via machine learning is a natural solution to a visual problem.
- Robust at learning features of Cherenkov emission without fine tuning.