Examining Electron and Photon Classification Using Convolutional Neural Networks

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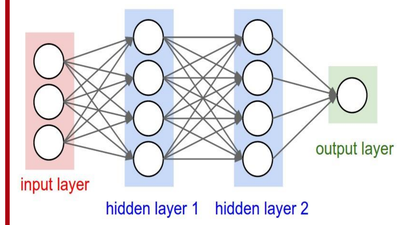
Large Hadron Collider at CERN

- World's largest particle accelerator
- Proton-proton collisions
- 27 km ring made of superconducting magnets
- Each proton given more energy upon reaching specific devices during its travel
- LHC designed to answer particle physics questions to complete a unified theory of physics
- Biggest discovery during first run was discovery of Higgs boson in 2012

Conventional Machine Learning

- Implements a *neural network,* makes use of fully-connected "hidden" layers
- Data imported into these layers and travel through set of neurons, much like human brain
- Last layer is where data is summarized as a final binary score (yes or no)
- pho_id is a variable that distinguishes a photon/electron from background noise

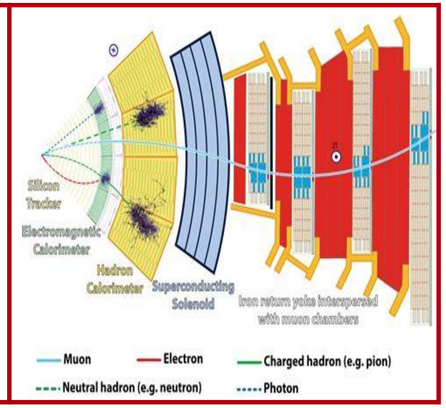


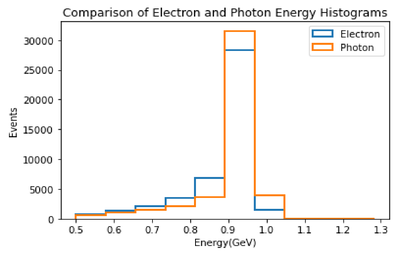
Essential NN Functions

- **Training strategy**
  - #training = 727414, #test = 843, loss = 0.63
  - #epochs = 100, learning rate = 5.10^{-4}, batch size = 512
- **Fully connected NN:** 144 nodes * 11 hidden layers = 1584 neural connections
- **Convolutional NN:** Image imported as 3D dataset of width/height/depth (e.g. 32x32x3), neurons not fully connected, each layer outputting more convolutional features than the last
  - Input—>CONV layer (dot product)—>dropout layer (keeps all pixels active or inactive)—> fully connected layers

CMS Experiment

- CMS (Compact Muon Solenoid) is component of LHC (Large Hadron Collider) at CERN
- Comprised of sub-detectors for subatomic particle detection
- Project focuses on ECAL (electromagnetic calorimeter)
- ECAL used to identify electrons and photons but cannot distinguish due to conventional methods
- Machine learning helps distinguish between both





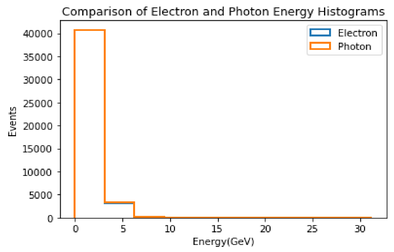
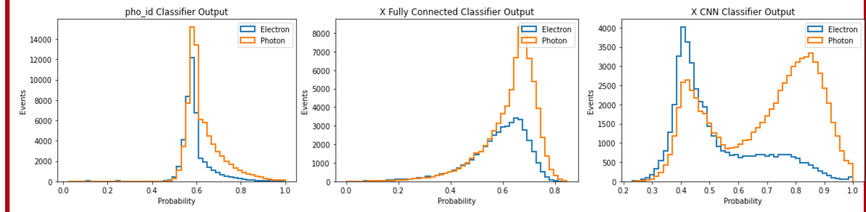


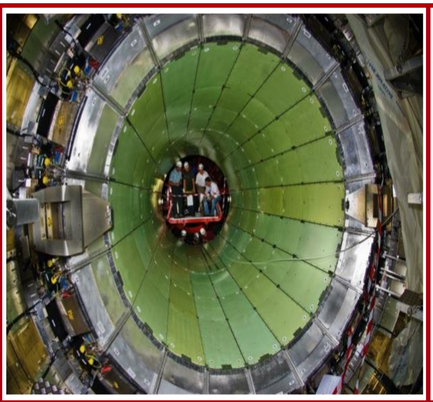
Image-Based Machine Learning

- Image-based machine learning uses convolutional neural networks
- Convolution essentially means "filter-modified input"
- CNN takes a step further by taking known pixelated input, maintaining 3D structure from each layer input to layer output, and returning a score that fits image dimensions
- Image class differences may be hard to discern visually, suggesting a difficult image class
- Goal is to extend recognition limitation
- X is the image variable

Results from One Epoch

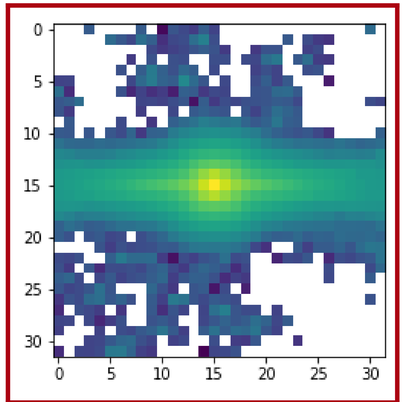


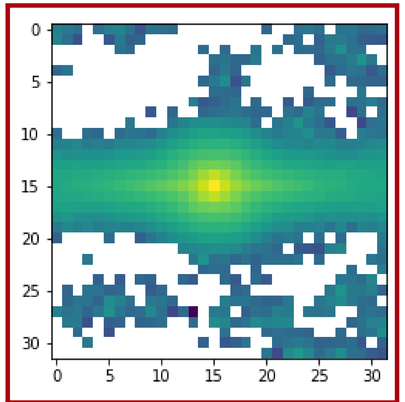
Average ROC AUC: 0.713566 **Average ROC AUC: 0.641307** **Average ROC AUC: 0.747840**



Electromagnetic Calorimeter

- Made of 75,848 lead tungstate crystals designed to facilitate light transmission
- Identifies electrons and photons from crystals pre- and post- shower
- Photodetectors equipped at each end display light
- Light intensity is a measure of electron or photon energy absorbed in crystals
- NN trains to determine which energy belongs to each particle based on deposit location and pixel luminosity





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References

The CMS collaboration., Sirunyan, A.M., Tumasyan, A. et al. Measurements of Higgs boson properties in the diphoton decay channel in proton-proton collisions at s√=13 TeV. J. High Energ. Phys. 2018, 185 (2018). https://doi.org/10.1007/JHEP11(2018)185

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