Machine Learning Analysis of PROSPECT Data

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On behalf of the PROSPECT collaboration
PROSPECT took data at ORNL’s High Flux Isotope Reactor from 2018-2019. It is a highly enriched uranium reactor with a compact core.

14 x 11 array of 6Li doped liquid scintillator for detecting inverse beta decay from reactor antineutrinos (6m from compact highly enriched uranium reactor core)
Machine Learning Activities

• Particle identification using sparse convolutional neural networks
• Single ended event reconstruction
• Antineutrino energy and position reconstruction with deep networks
Convolutional neural networks with PROSPECT data

Convolutions are nxn windows consisting of trainable weights that move over the 14x11 segments of the detector.

Each weight is multiplied with the physics quantities at each segment and summed together to form a transformed output.

The final stage consists of “fully connected” layers used to transform the outputs into a classifier.

2 models - one with calibrated physics quantities (energy, timing, position, pulse shape), one with full waveform.

```
11x14x300  11x14x252  12x9x158  10x7x64  4480  116  3
conv 1x1    conv 3x3    conv 3x3    flatten
```

Dense layers
CNNs for Positron Identification - Test dataset (simulation)
CNNs for Positron ID results (simulated data)

Waveform model

<table>
<thead>
<tr>
<th></th>
<th>Gamma</th>
<th>Electron</th>
<th>Positron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>0.50</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>Electron</td>
<td>0.08</td>
<td>0.87</td>
<td>0.04</td>
</tr>
<tr>
<td>Positron</td>
<td>0.18</td>
<td>0.05</td>
<td>0.77</td>
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</table>

Calibrated Physics Quantities model

<table>
<thead>
<tr>
<th></th>
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<th>Electron</th>
<th>Positron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>0.51</td>
<td>0.25</td>
<td>0.24</td>
</tr>
<tr>
<td>Electron</td>
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</tr>
<tr>
<td>Positron</td>
<td>0.22</td>
<td>0.08</td>
<td>0.70</td>
</tr>
</tbody>
</table>
CNNs for single ended Z position reconstruction

- Dataset is gamma, electron, and positron simulations (0-9 MeV, randomly distributed throughout detector volume)
- Neural network is only trained on Single Ended segment predictions
- Network consists of series of pointwise (kernel size = 1) and 3x3 convolutions with padding set to 1 to obtain z predictions for each cell
- Train weights by minimizing the single ended z position error based on simulation true z position
Z position reconstruction results

Single Ended Error

Dual Ended Calibration Error

- Neighbor Average
- Calibrated Physics CNN
- Waveform CNN

True Energy Deposited [MeV]

mean absolute error [mm]

True Energy Deposited [MeV]

mean absolute error [mm]
Simulated IBD Energy Reconstruction (work in progress)

- R-squared scores show an outperformance of fully connected neural net over traditional maximum likelihood estimate with large gap in performance for 'non-ideal' detector (except very low energies)
- Thin band artifact in middle bottom plot is not correlated with energy spectrum (shows up in both training with uniform or reactor spectrum) - likely related to dead neurons associated with poor events.
Summary

• Neural network is able to distinguish between positron and gamma events; work is ongoing to apply this to current IBD selection
• There is some evidence that we can extract more information from the detector pulses for the purposes of particle identification and single ended position reconstruction
• Preliminary results from IBD energy reconstruction using neural networks is promising
• Work is ongoing to apply the models to real data
Thanks!

https://prospect.yale.edu/