A Multi-modal Graph Neural Network (GNN) for Neutrino Event Reconstruction

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Introduction

- In past years, the use of GNNs in high energy physics has been of large interest.
- Recent work by the Exa.TrkX project has developed NuGraph2: a GNN for filtering neutrino-interaction generated particles from background noise in addition to semantic labelling of the particle types in Fermilab's MicroBooNE detector [1].
- With NuGraph3, one step is to enhance the model's accuracy by combining optical data that has more time precision.

Experimental Setup

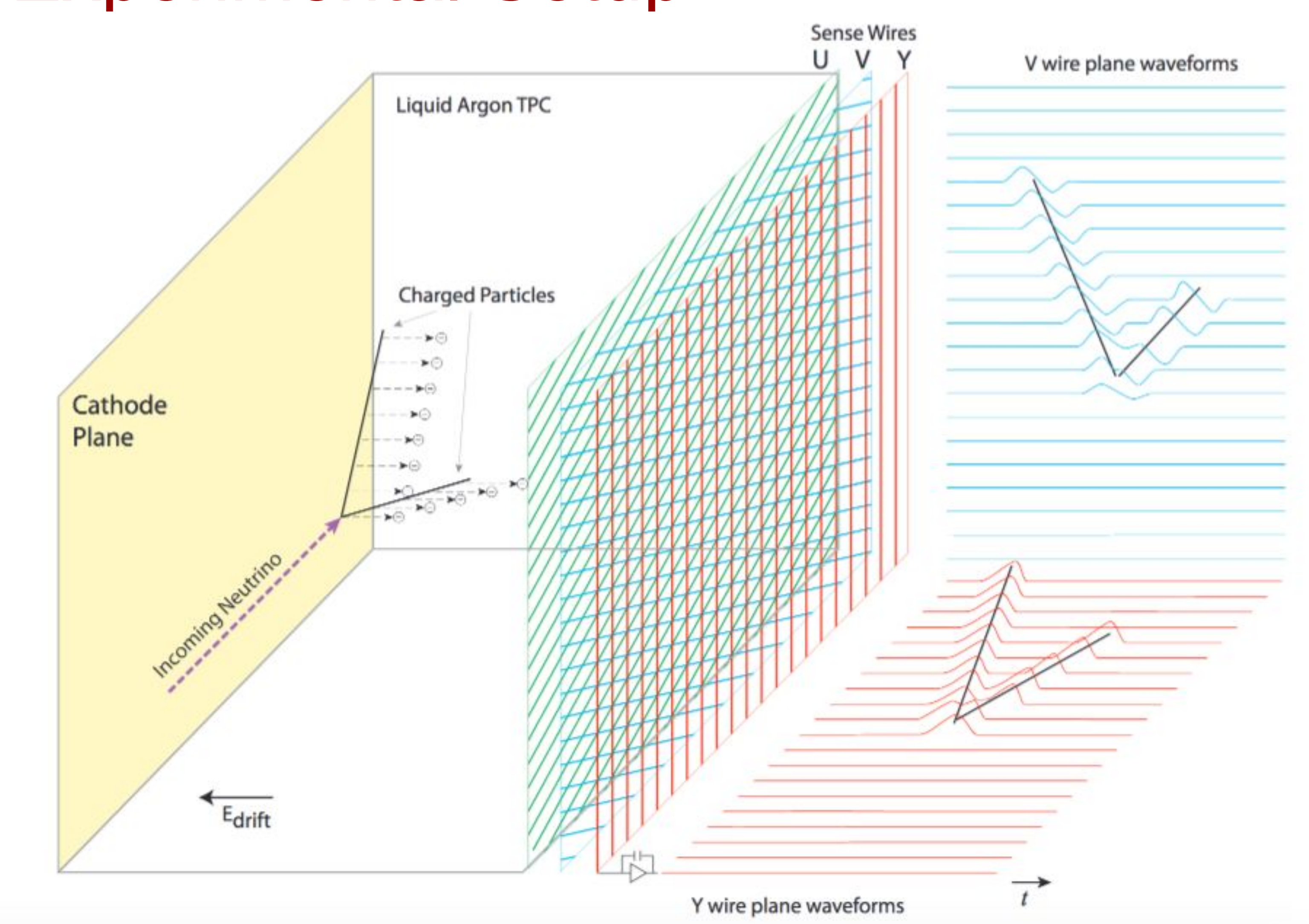

Figure 1. Design of the MicroBooNE TPC wire planes

Dataset

- Multi-modal data was obtained from MicroBooNE open data set [2].
- Original model uses particle hits data on the sense wires.
- Our model incorporates data from the Photomultiplier Tubes (PMTs).

Graph Architectures

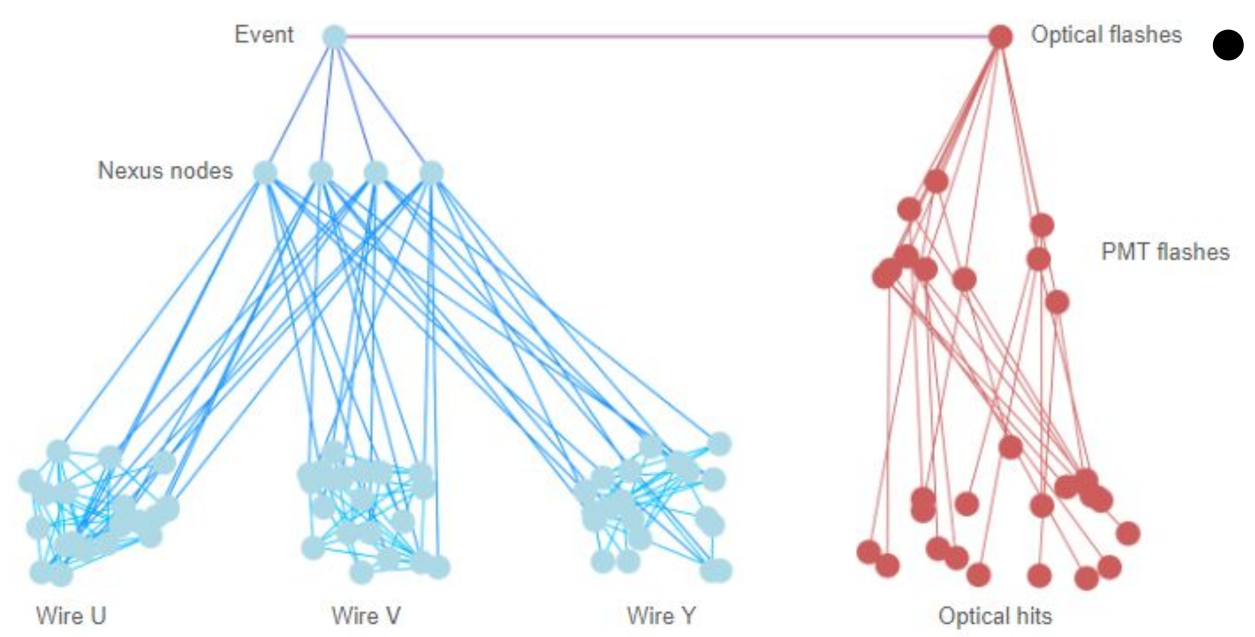

Figure 2. Graph Architecture A

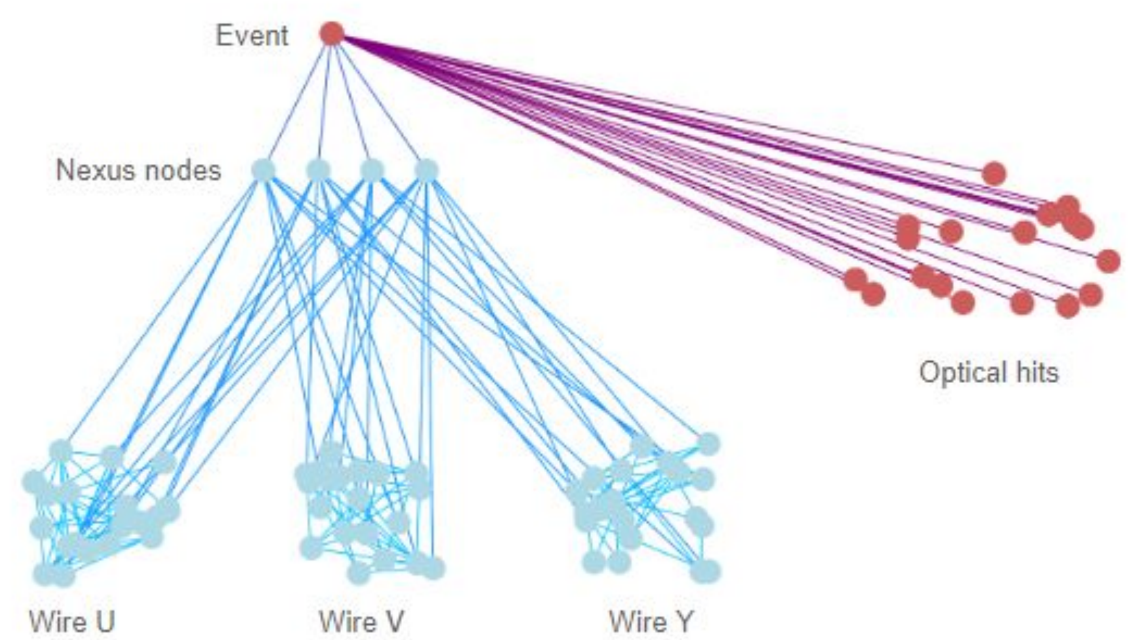

Figure 3. Graph Architecture B

- The blue graph represents the original graph, which consists of connected nodes from Wires U, V, and Y. Each particle hit in the wire is aggregated to a nexus node and finally an event.
- Graph A aggregates the optical hits to one of the 32 PMTs which is further aggregated to one flash representing the interaction.
- Graph B directly connects the hits to the event node.

Model Architecture

- The graphs in Figures 1 and 2 are constructed as PyG Heterogenous Data Objects.
- Each processed graph, representing one neutrino interaction, goes through an MLP encoder to generate the node embedding.
- Attention weights are formed on the graph edges.
- The resulted graphs go through 3 decoders that generate the model's output.

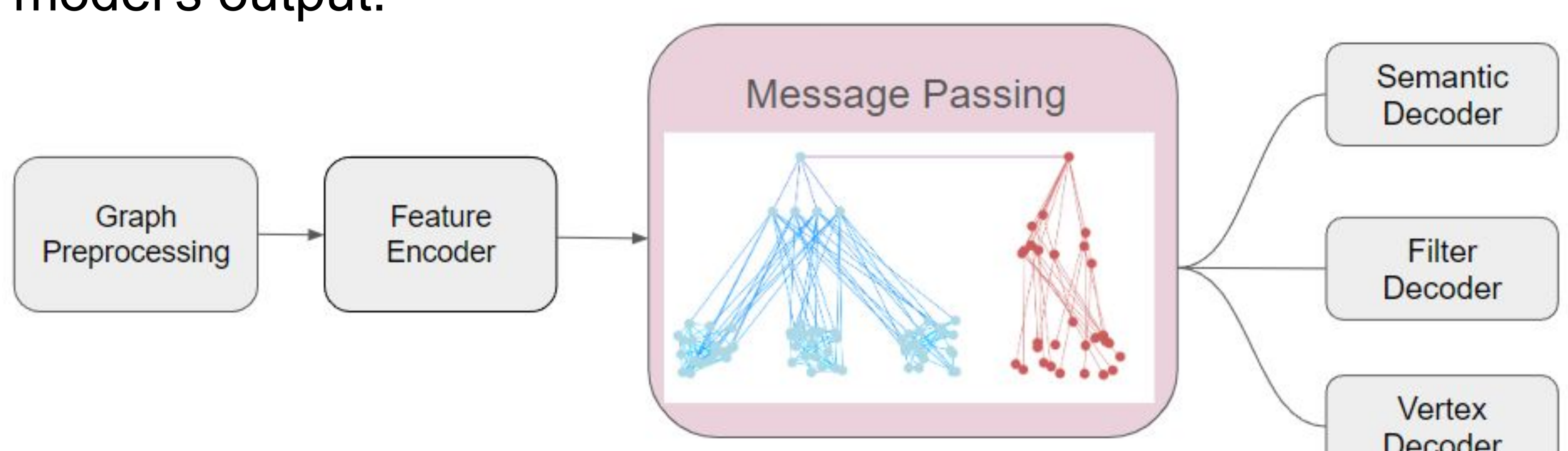

Figure 4. NuGraph3 Model Architecture

Results

- After incorporating the optical data, the model was trained successfully and yielded similar results to the original one.
- Although improvement were expected, this opens the door for experimenting with different hyperparameters and graph connections to maximize performance.

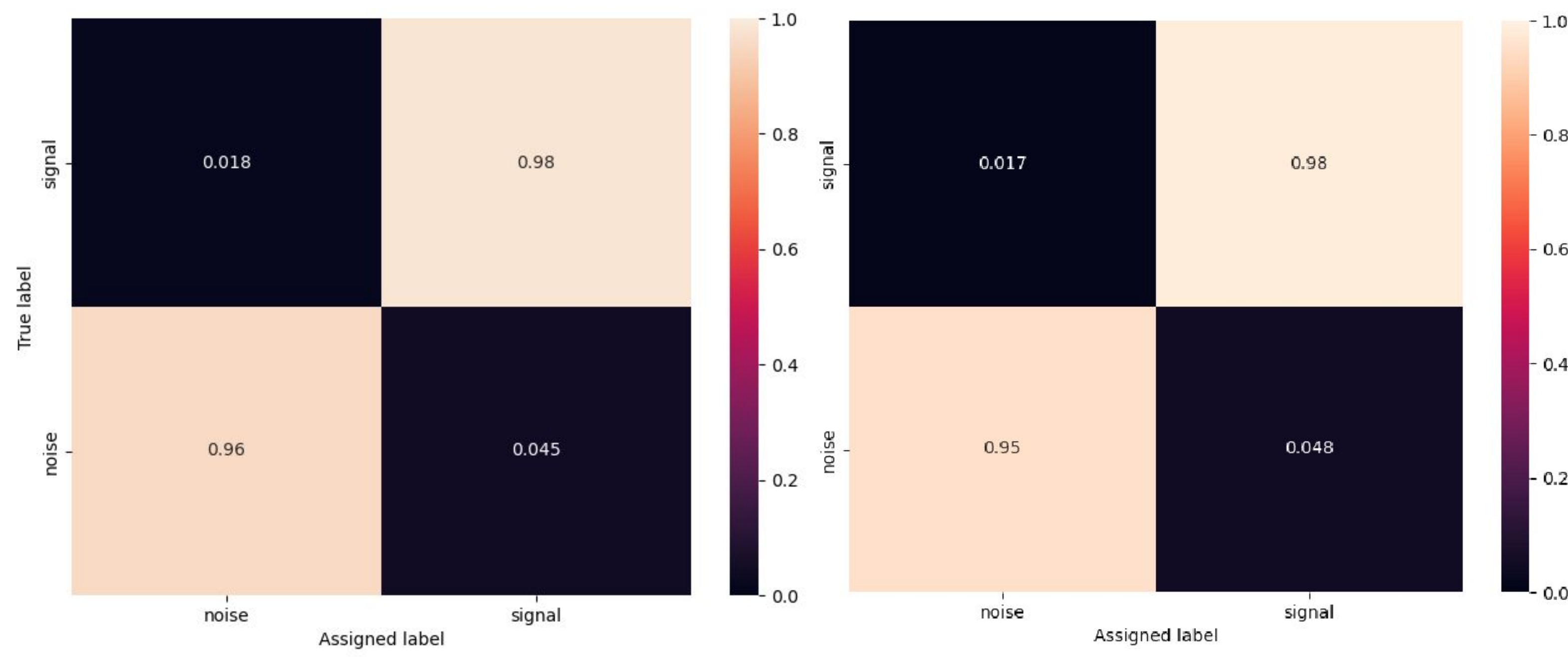

Figure 5. Comparing the Filter Recall (Efficiency). The plot to the right is with the optical data, and the one to the left is without it.

Next Steps

- Create a hierarchical approach that encapsulates a comprehensive interpretation of data at different levels, ranging from TPC hits at the low level to particle clusters and overall neutrino identification at the high level.
- Experiment with more types of graph architectures to compare performance.
- Evaluate models with varied decoders to see if performance is affected by overall feature space.

References

[1] Hewes, V., Aurisano, A., Cerati, G., Kowalkowski, J., Lee, C., Liao, W., Grzenda, D., Gumpula, K., & Zhang, X. (2024). *NuGraph2: A Graph Neural Network for Neutrino Physics Event Reconstruction.* arXiv. https://arxiv.org/abs/2403.11872
[2] Fermi National Accelerator Laboratory. (n.d.). *Public datasets.* Retrieved July 22, 2024, from https://microboone.fnal.gov/documents-publications/public-datasets/