Sydney group update

Australian ATLAS Meeting: August 19, 2021

Introduction: Four Tops Analysis

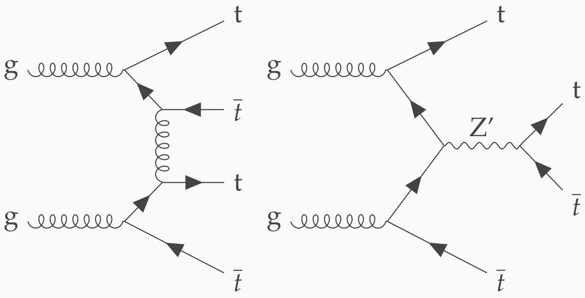


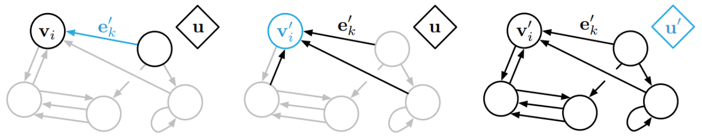
Figure 1: $t\bar{t}t\bar{t}$ production Feynman diagrams for left) Standard Model right) BSM Top-Philic model

- Within the SM, the 4-top production is extremely rare ($\sigma = 12.6^{+5.6}_{-5.2}$fb) and occurs via gluon fusion.
- Some BSM physics models predict a boosting of this cross-section from modified top quark couplings or heavy resonances (Figure 1).

Introduction: Four Tops Analysis

- Products of resonance tops are expected to be largely boosted and produce fat-jets.
- These jet types can be reclustered into so called RC-jets in single lepton analyses.
- Graph Neural Networks (GNNs) could potentially assist in identifying jets originating from resonance tops.
- Although the data science technique has been around since 2009, it only recently gained mainstream and HEPP attention.
- A similar problem was partially solved using GNNs to group jets to common parents in the ttH production at Berkeley.

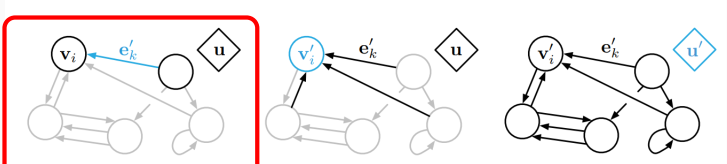
What is a Graph Neural Network?



(a) Edge update (b) Node update (c) Global update

- A Graph Neural Network is a generalized deep learning technique similar to a conventional Neural Network (Deep Layers, Aggregation, Convolution, Pooling etc.)
- What makes a GNN unique is that, non-euclidean sampled data can be encoded on graph data structures where in the context of HEPP;
  - Nodes - Some object (Particle, Jets) that has attributes (η, ϕ, p_T, ...)
  - Edges - Some relation between objects; ΔR, Inv Mass, Δ(*).
  - Graph - Some global properties of the graph; Collision Energy, Missing p_T, ϕ...

What is a Graph Neural Network?

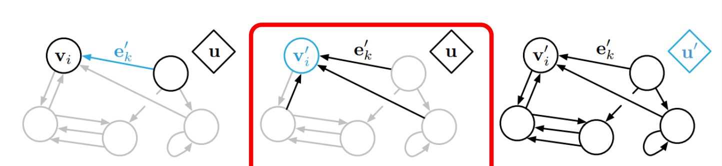


(a) Edge update (b) Node update (c) Global update

Given some graph data structure, with edge and node features, an example computation would look something like this:

- Trainable edge weights are first updated via a multilayer-perceptron (MLP).
- The inputs of the MLP are the current edge state, attributes from *sender* and *receiver* nodes, and some global value.
- Edges are finally updated through a permutation invariant function; summation, averaging, max, min, ...
- This allows for edges to be mapped appropriately to nodes.

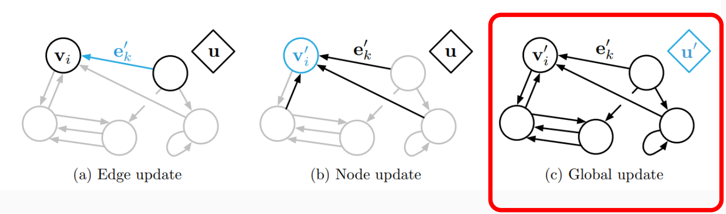
What is a Graph Neural Network?



(a) Edge update (b) Node update (c) Global update

- Nodes are updated by applying an MLP to the node features and updated incoming edge attributes.
- Using the updated edges and nodes of the graph, a permutation invariant function is again used to map to a global value or attribute.

What is a Graph Neural Network?



(a) Edge update (b) Node update (c) Global update

- Finally, a global attribute update is performed with the global attribute value and updated edge and node vectors.
- The described sequence is **not** necessarily enforced, but can be adjusted arbitrarily, adding to the flexibility of GNNs.
- This flexibility has opened many new architectures; Auto-encoding, Node/Edge predictions, Graph Convolution Neural Networks, Multi-Block models, ...

My Current Progress in Implementing GNNs

- I have been writing most of the infrastructure code;
  - Reading multiple ROOT files (containing resonance events)
  - Converting particle objects; jets, electrons, muons, truth particles, tops, ... into python objects for matching
  - Matching truth particles to truth jets and matching truth jets to detector jets using a ΔR matching technique.
  - Integrated a very basic working GNN into the code using pytorch-geometric.
- But there are still some issues that need resolving:
  - Truth jet and truth particle matching using ΔR is not very unreliable (likely due to gluons and any quarks below charm given a flavor value of 0).
  - Jet and truth jet matching is also experiencing the same issue.
- Next things to work on:
  - Exploring more GNN architectures and comparing their performance on the truth children (perfectly matching tops).
  - Understanding how to properly match jets and truth jets to truth children.

My Current Progress in Implementing GNNs

```
>>>>>>>========== New Event ==========
>>>>>>>========== DetectorMatchingEngine ==========
    --- All Particles ---
Type:  jet  FL:  5 -- FLE:  55 --- TruthParton:  5
Type:  jet  FL:  15 -- FLE:  15 --- TruthParton:  1
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  21
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  21
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  2
Type:  jet  FL:  5 -- FLE:  5 --- TruthParton:  5
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  2
Type:  jet  FL:  4 -- FLE:  4 --- TruthParton:  4
Type:  jet  FL:  5 -- FLE:  5 --- TruthParton:  5
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  21
Type:  jet  FL:  0 -- FLE:  0 --- TruthParton:  21
Type:  mu  TruTyp:  6  TruOri:  10  Prompt:  1  C:  -1.0
Type:  truthjet  FL:  5  FLE:  55  nCHad:  1  nBHad:  2  Index:  0
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  1
Type:  truthjet  FL:  0  FLE:  0  nCHad:  1  nBHad:  0  Index:  2
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  3
Type:  truthjet  FL:  5  FLE:  5  nCHad:  1  nBHad:  1  Index:  4
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  5
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  6
Type:  truthjet  FL:  4  FLE:  4  nCHad:  1  nBHad:  0  Index:  7
Type:  truthjet  FL:  5  FLE:  5  nCHad:  0  nBHad:  1  Index:  8
Type:  truthjet  FL:  15  FLE:  15  nCHad:  0  nBHad:  0  Index:  9
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  10
Type:  truthjet  FL:  0  FLE:  0  nCHad:  0  nBHad:  0  Index:  11

####### dR ########
TJet Flavour:  0  Extended:  0  nChad 0  nBhad 0  Index:  3 Jet Flavour:  0  Extended:  0  Truth Parton:  2  HS:  1  dR:  0.0096
TJet Flavour:  5  Extended:  55  nChad 1  nBhad 2  Index:  0 Jet Flavour:  5  Extended:  55  Truth Parton:  5  HS:  1  dR:  0.0108
TJet Flavour:  0  Extended:  0  nChad 1  nBhad 0  Index:  2 Jet Flavour:  0  Extended:  0  Truth Parton:  21  HS:  1  dR:  0.013
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TJet Flavour:  5  Extended:  5  nChad 0  nBhad 1  Index:  8 Jet Flavour:  5  Extended:  5  Truth Parton:  5  HS:  1  dR:  0.0167
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```

Fin

Thanks for Listening!

Peter W. Battaglia et al. “Relational inductive biases, deep learning, and graph networks”. In: *CoRR* abs/1806.01261 (2018). arXiv: 1806.01261. URL: http://arxiv.org/abs/1806.01261 A. M. Sirunyan et al. “Search for production of four top quarks in final states with same-sign or multiple leptons in proton–proton collisions at $\sqrt{s} = 13$ TeV”. In: *The European Physical Journal C* 80.2 (2020). ISSN: 1434-6052. DOI: 10.1140/epjc/s10052-019-7593-7. URL: http://dx.doi.org/10.1140/epjc/s10052-019-7593-7 Jeong Han Kim et al. “Probing TeV scale top-philic resonances with boosted top-tagging at the high luminosity LHC”. In: *Physical Review D* 94.3 (2016). ISSN: 2470-0029. DOI: 10.1103/physrevd.94.035023. URL: http://dx.doi.org/10.1103/PhysRevD.94.035023