



DeepTreeGAN



Fast Generation of High Dimensional Point Clouds for Calorimeter Simulation

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IML, 02.02.24

*Funded by Helmholtz AI – grant number: ZT-I-PF-5-3

Speedup with Generative Model?

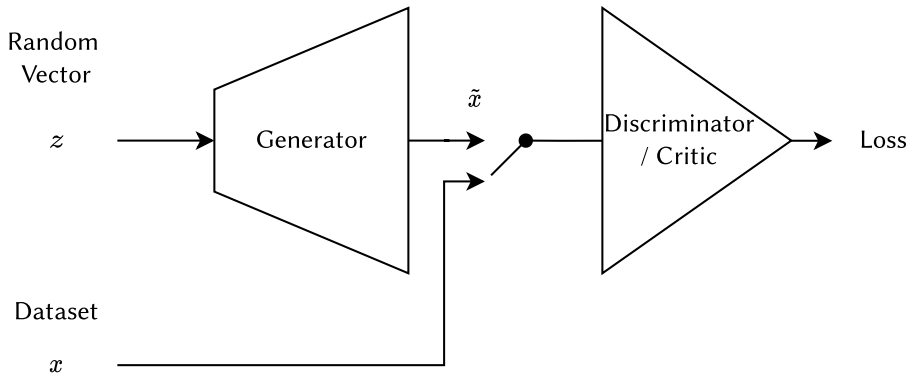
Goal:

»Provide a generative model for the particle showers in the highly granular calorimeters«

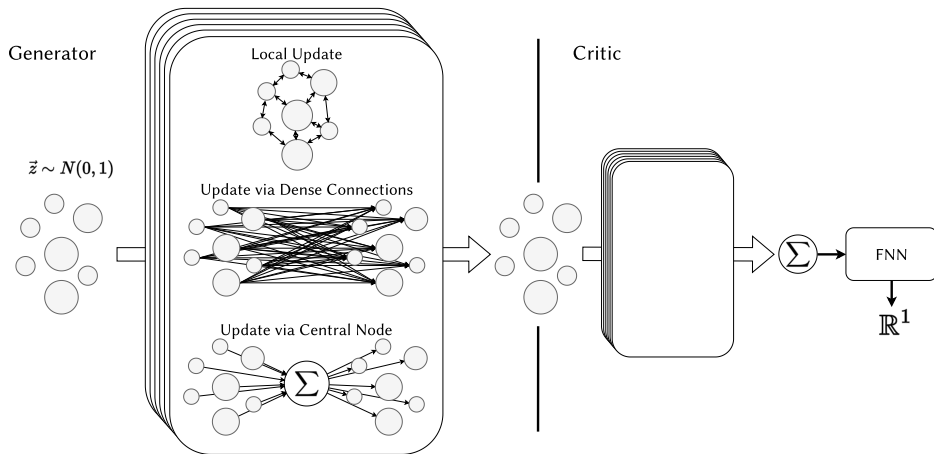
Challenges:

- > Irregular geometry
 - > Number of channels
 - > Sparsity
- ⇒ No ML model powerful enough yet
 - ⇒ Data structure: Point Clouds (PCs)
 - Model architecture independent of calorimeter geometry

Generative Adversarial Networks



Most Common Approach for PC GANs



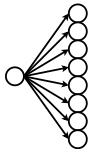
Generator

Core challenge: Upsampling Point Clouds

Same for GAN/VAE/Diffusion+UNet

Naive approach:

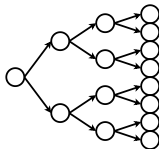
(with feedforward neural networks (FFNs))



- > Latent Vector \rightarrow FFN \rightarrow PCs
- \Rightarrow Number of parameters explodes
- \Rightarrow Not trainable

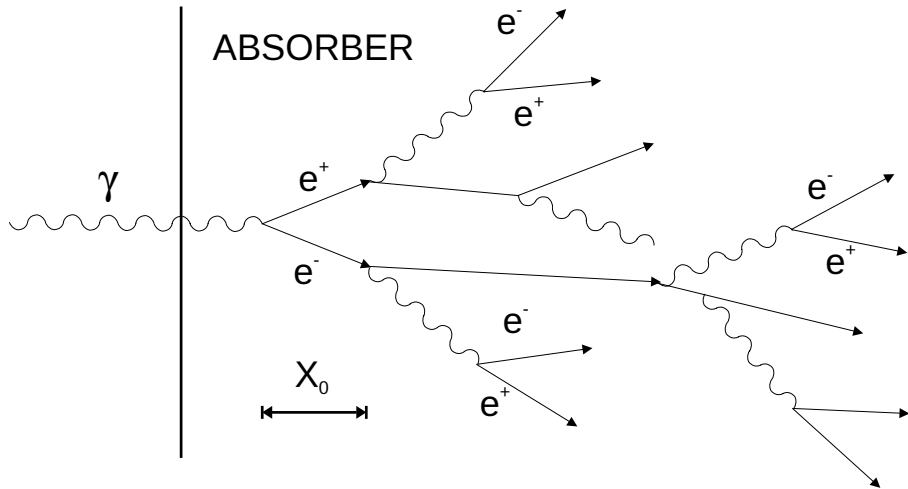
DeepTreeGAN:

(Inspired by TreeGAN ARXiv:1905.06292)



- > FFN projects one particle to multiple particles, repeat to grow a tree
- \Rightarrow Small output space for each FFN
- \Rightarrow Small number of parameters

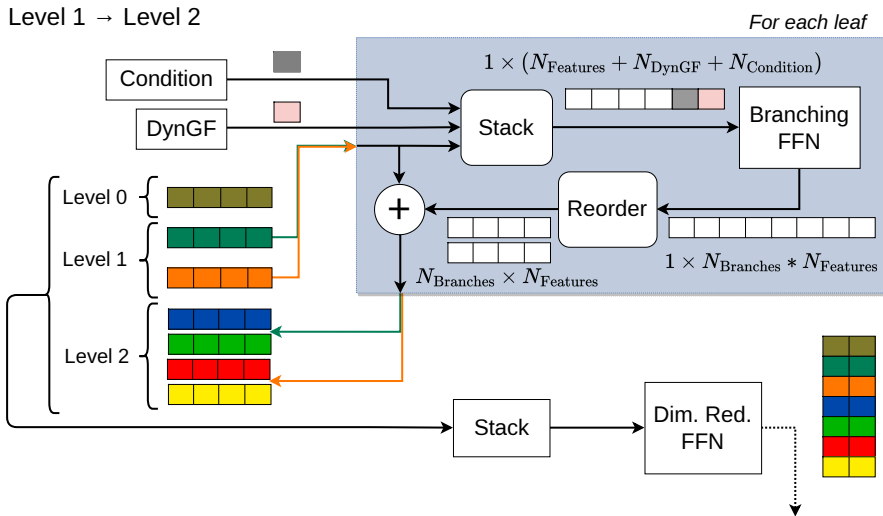
Physics inspired!



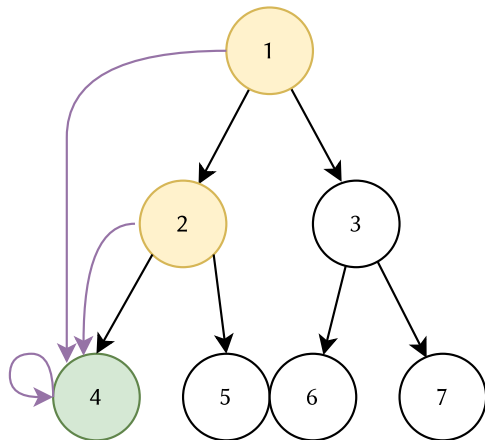
<https://cds.cern.ch/record/1388922>

DeepTreeGAN

Branching



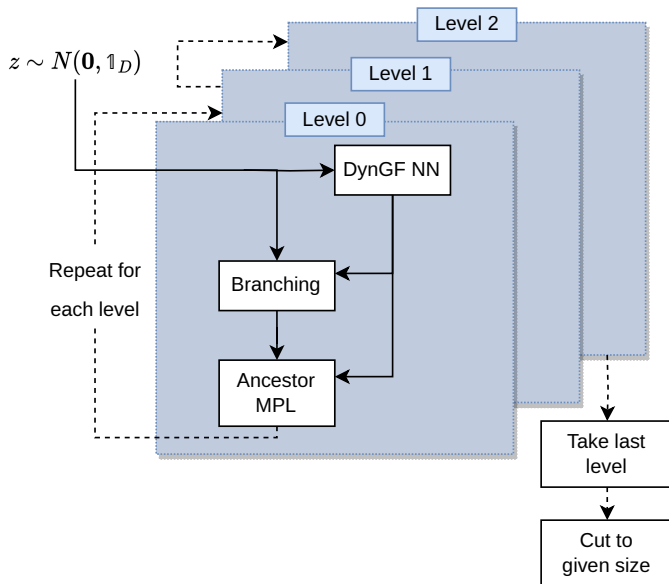
Ancestor Message Passing Layer



Update Node 4 (w/ Neighbors, Messages)

DeepTreeGAN

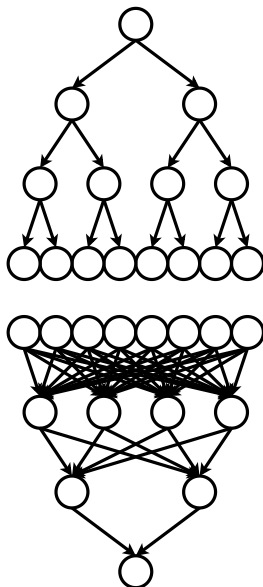
Architecture



Critic



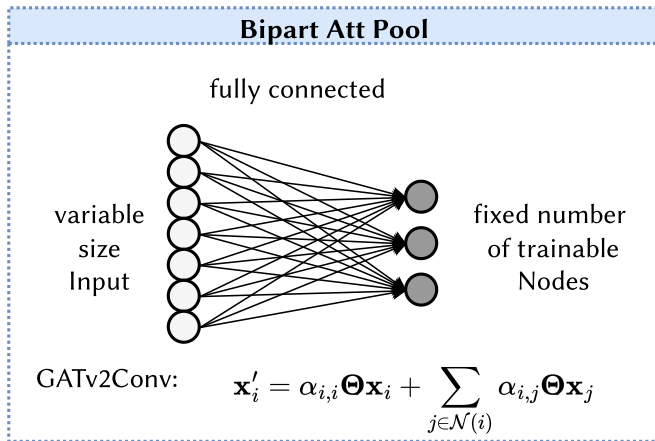
- > Idea:
Iteratively reduce the number of points
- > Pooling requirements:
 - Differentiable
 - Arbitrary input size
 - Adjustable output size
 - Permutation invariant



Generator

Critic

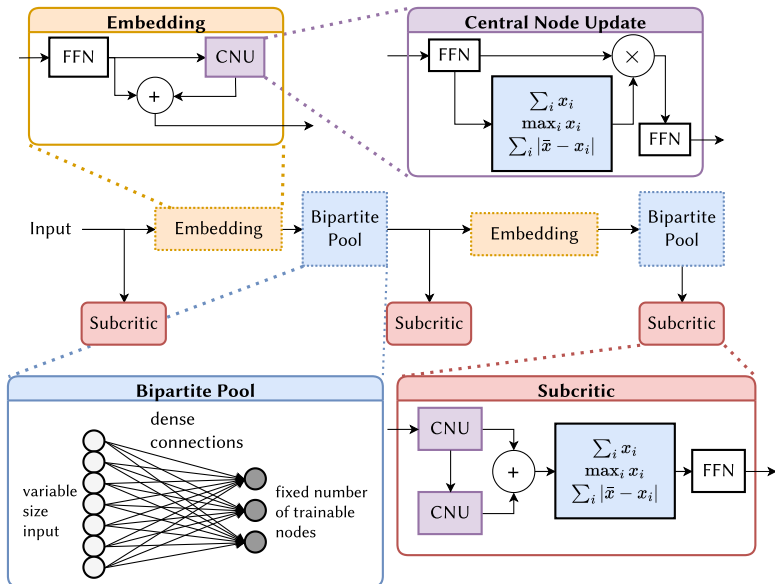
Bipartite Attention Pool



GATConv:ARXIV:2105.14491

Similar approach: PMA blocks from set transformer ARXIV:1810.00825

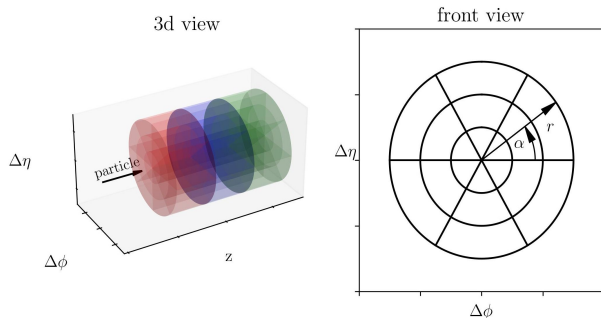
DeepTree Critic



Benchmark on Calochallenge

CaloChallenge

- > Public dataset: DOI 10.5281/ calochallenge .github.io/homepage/
- > 100k GEANT4-simulated electrons showers for training/testing
- > Energies with log-uniform distribution [1 GeV,1 TeV]
- > Concentric cylinder detector geometry
- > 45 layers(z) x 9 radial segments (r) x 16 angular segments (α) = 6480 voxels

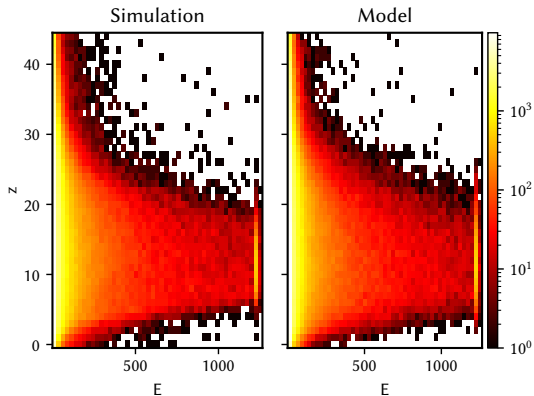


CaloChallenge

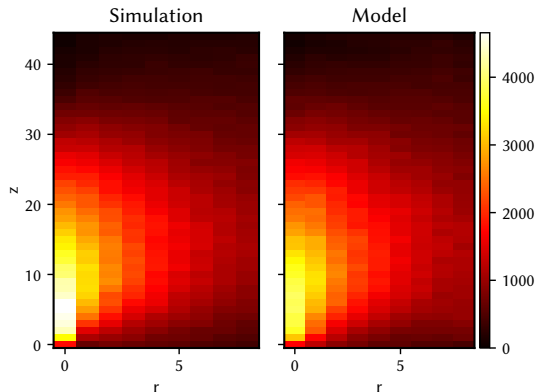
- > Generator needs the number of hits from simulation
- > Condition on generator + critic on $\sum_i E_i, \frac{1}{n} \sum_i E_i, n$
- > Postprocessing:
 - Hit collision shifted to neighboring cells (<https://caloutils.readthedocs.io>)
 - Rotate generated showers by a random shift in α

2D – Number of Hits

2D Histogram for 6000 points in 50000 events



2D Histogram for 6000 points in 50000 events



⇒ Looks good!

Benchmarking on JetNet-150

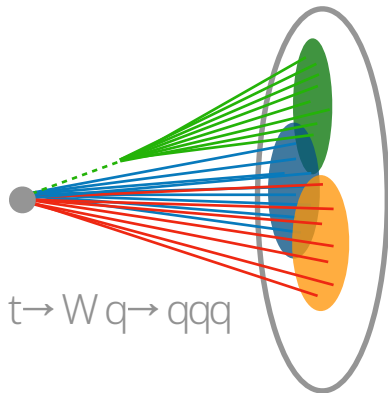
JetNet (ARXIV:2106.11535) provides:

> Dataset

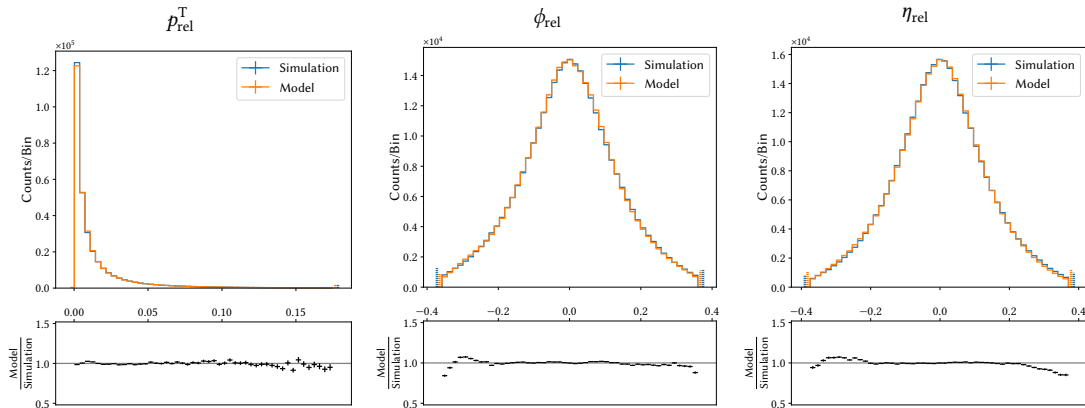
- Public dataset generated with Pythia
- Hadronized jet from pp collisions @ 13 TeV
- Anti- k_T clustered (R=0.8)
- used here: 170k top jets (each)
- Leading 150 constituents by p_T
- Rescaled variables:

$$p_T^{rel} = \frac{p_T^{particle}}{p_T^{jet}}, \quad \eta^{rel} = \eta^{particle} - \eta^{jet}, \quad \varphi^{rel} = \varphi^{particle} - \varphi^{jet}$$

- $\sum p_T^{rel} = 1 \Rightarrow$ rescale model output to 1
- Properties of the constituents relative to the jet

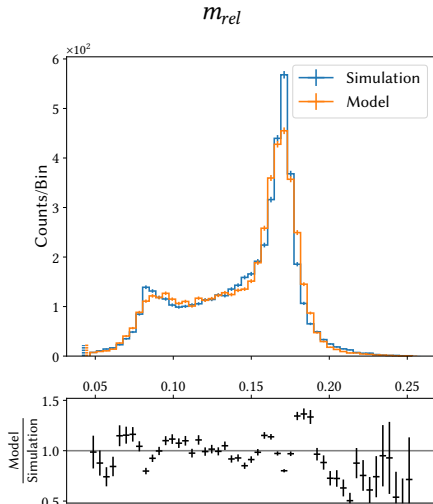


Jet Constituents – Top Jets



⇒ Looks good!

Global Features – Mass



⇒ Not perfect, but pretty good!

Comparison to PC-GANs

EPiC-GAN [arXiv:2301.08128](#) / MDMA [arXiv:2305.15254](#)

- > Metrics from the JETNET library / [arXiv:2211.10295](#)
- > 25k event hold-out sample
- > ‘Limit’ row gives the measured in-sample distance by bootstrapping the hold-out dataset.
- > Lower is better, best in bold

Model	$W_1^M(\times 10^3)$	$W_1^P(\times 10^3)$	$W_1^{EFP}(\times 10^5)$	$FPD(\times 10^4)$
Limit	0.42 ± 0.09	0.12 ± 0.04	1.22 ± 0.32	1.2 ± 0.6
EPiC-GAN	0.69 ± 0.08	0.65 ± 0.03	2.67 ± 0.39	22 ± 1
MDMA	0.57 ± 0.09	0.10 ± 0.02	2.12 ± 0.64	5.3 ± 0.9
DeepTree**	0.77 ± 0.06	0.17 ± 0.02	3.46 ± 0.10	2.5 ± 0.4

⇒ Competitive Results

Conclusion

- > Almost identical architecture for jets and calorimeter showers
- > New, differentiable up/downscaling methods for point clouds
- > Promising approach for scaling to even larger PCs (e.g. HGCal)



Thank you!

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