DeepTreeGAN

Fast Generation of High Dimensional Point Clouds for Calorimeter Simulation

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The DeGeSim Project

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DESY.

Speedup with Generative Model?

Goal:

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

Challenges:

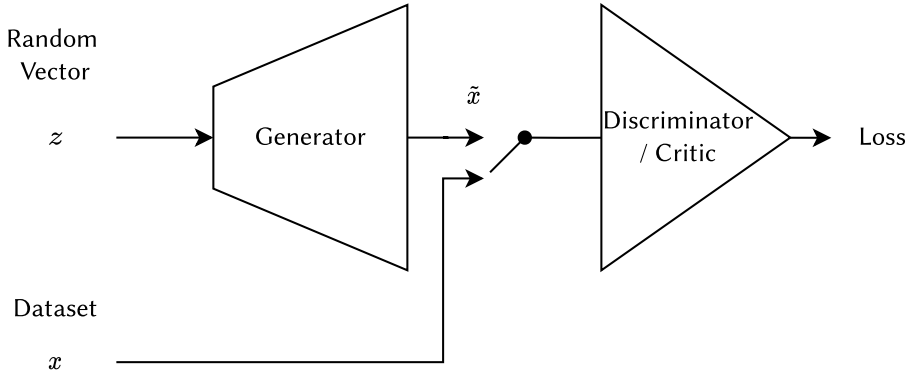
- Irregular geometry
- Number of channels
- Sparsity

⇒ No ML powerful enough model yet

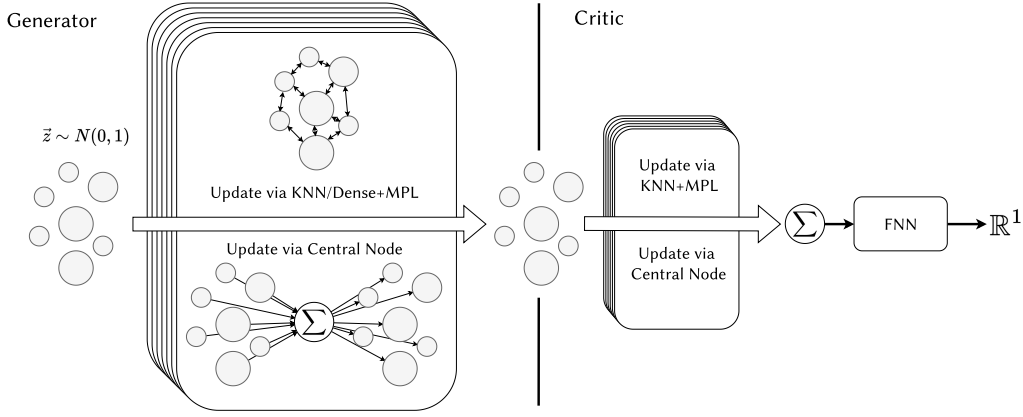
⇒ Data structure: Point Clouds (PCs)

- Model architecture independent of calorimeter geometry

Generative Adversarial Networks



Most Common Approach for PC GANs

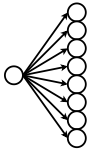


Generator

Core challenge: Upsampling Point Clouds

Same for GAN/VAE/Diffusion+UNet

Naive approach:
(with feedforward neural networks (FNNs))

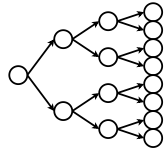


> Latent Vector ⟶ FFN ⟶ PCs

⇒ Number of parameters explodes

⇒ Not trainable

DeepTreeGAN:
(Inspired by TreeGAN ARXIV:1905.06292)

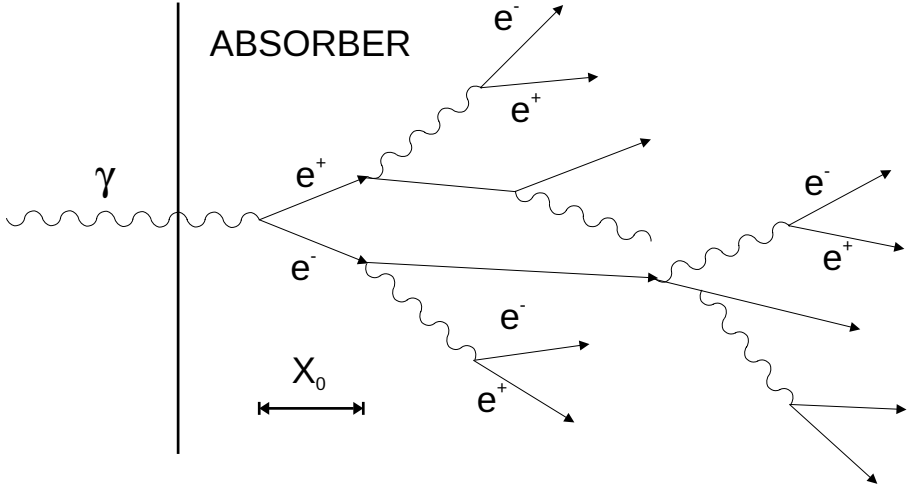


> FFN projects one particle to multiple particles, repeat to grow a tree

⇒ Small output space for each FFN

⇒ Small number of parameters

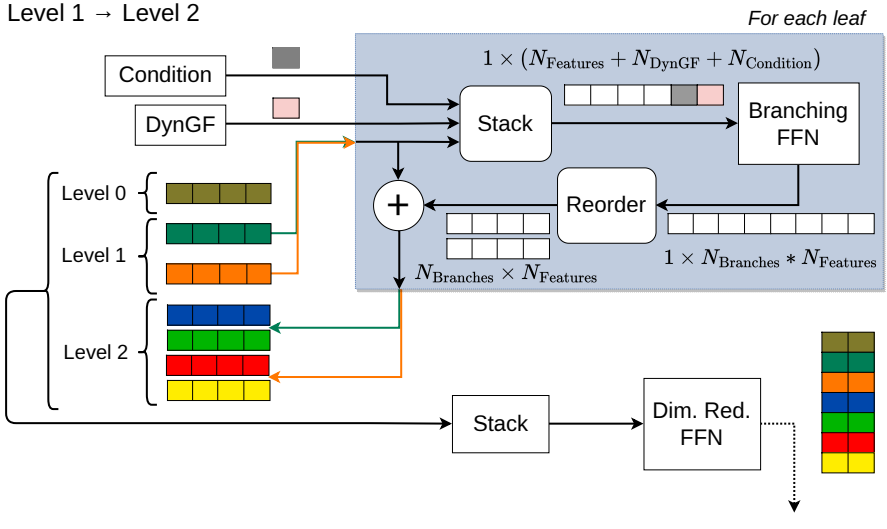
Physics inspired!



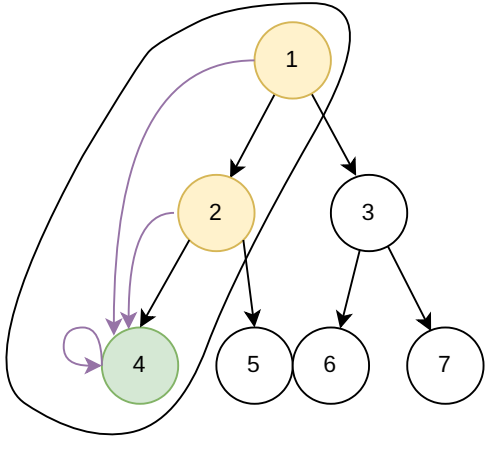
https://cds.cern.ch/record/1388922

DeepTreeGAN

Branching



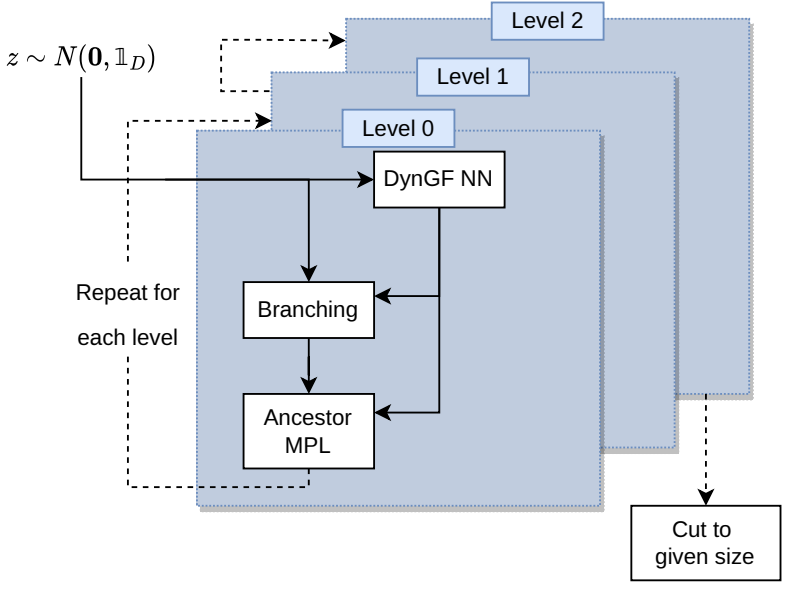
Ancestor Message Passing Layer



Update Node 4 (w/ Neighbors, Messages)

DeepTreeGAN

Architecture

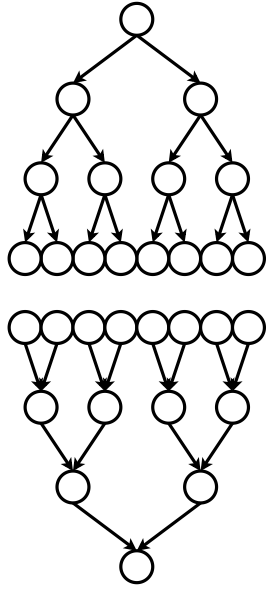


Critic

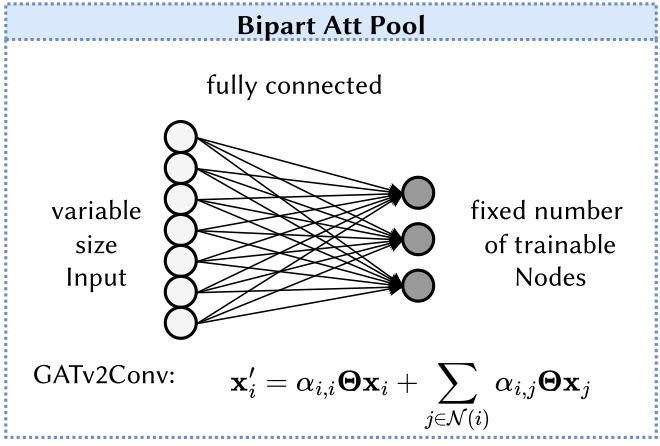
Critic

vs

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

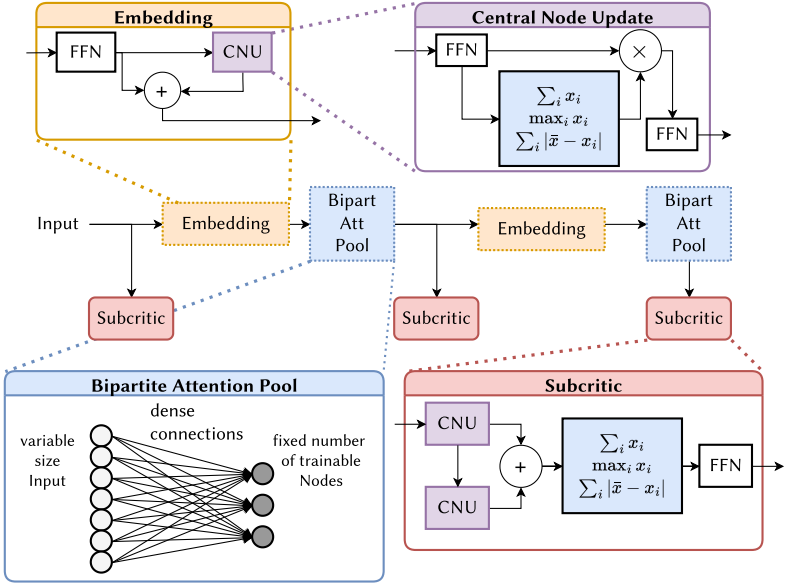


Bipartite Attention Pool



arXiv:2105.14491

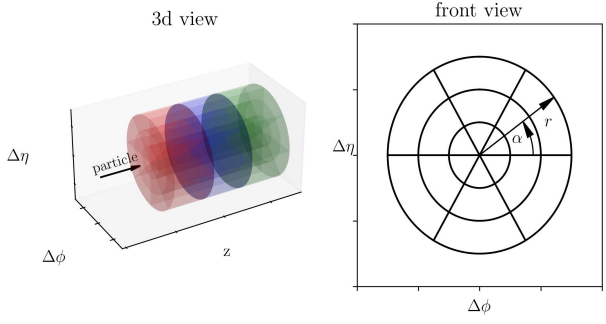
DeepTree Critic



Benchmark on Calochallange

CaloChallange

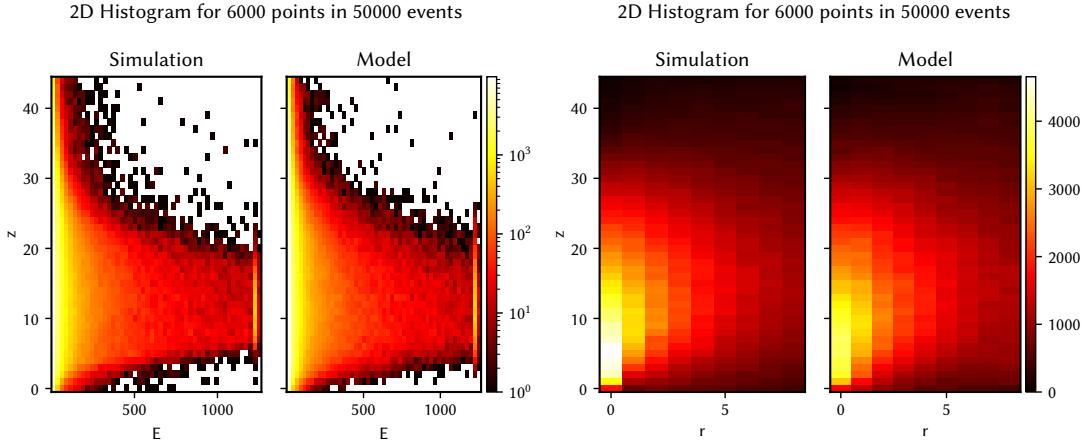
- Public dataset: DOI 10.5281/ `calochallenge.github.io/homepage/`
- 100k GEANT4-simulated electrons showers for training/testing
- Energies with log-uniform distribution [1 GeV,1 TeV]
- Concentric cylinder detector geometry
- 45 layers(z) x 9 radial segments (r) x 16 angular segments (α) = 6480 voxels



CaloChallange

- 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 (`caloutils` talk # 102)
  - Rotate generated showers by a random shift in α

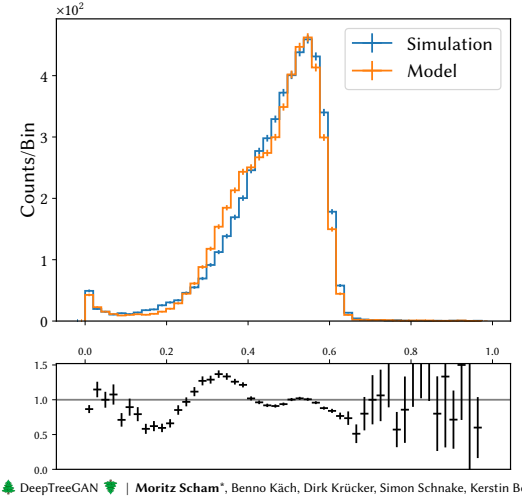
2D – Number of Hits



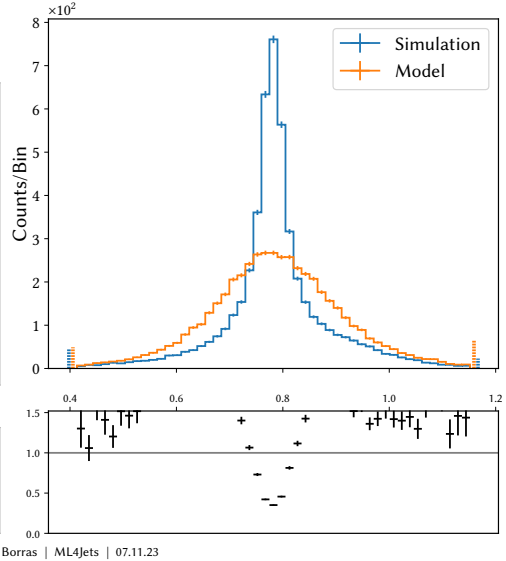
⇒ Looks good!

Shower variables

$$\frac{\sum_i^{\text{Sphere}(\sigma=0.3)} \mathrm{E_i}}{\sum_i^{\text{Sphere}(\sigma=0.8)} \mathrm{E_i}}$$



Response ($E/\sum_i \mathrm{E_i}$)



Benchmarking on JetNet-150

JetNet

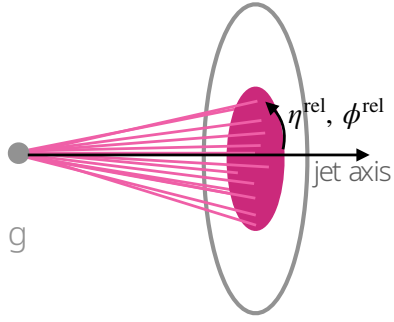
JetNet (arXiv:2106.11535) provides :

> Dataset

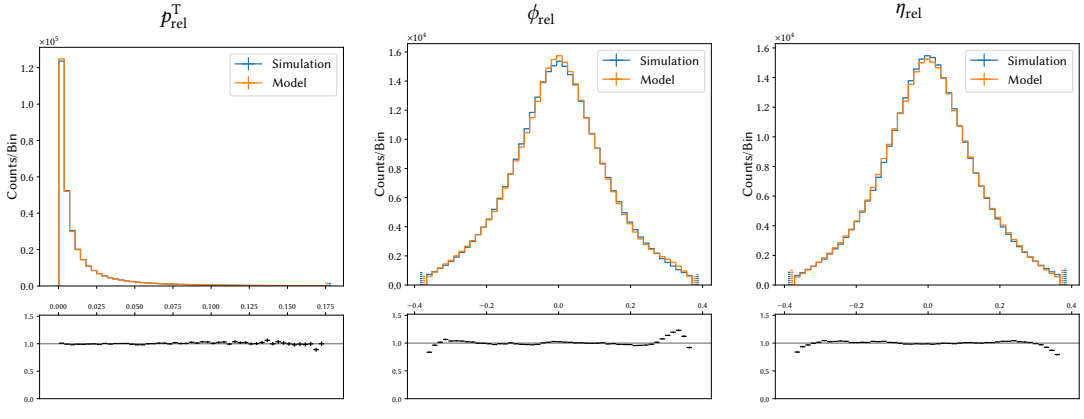
- Public dataset generated with Pythia
- Hadronized jet from pp collisions @ 13 TeV
- Anti-k_T clustered (R=0.8)
- 170k gluon jets, light quark jets and top jets (each)
- Leading 150 constituents by p_T
- Rescaled variables:

$$p_{\mathrm{T}}^{\mathrm{rel}} = \frac{p_{\mathrm{T}}^{\mathrm{particle}}}{p_{\mathrm{T}}^{\mathrm{jet}}}, \quad \eta^{\mathrm{rel}} = \eta^{\mathrm{particle}} - \eta^{\mathrm{jet}}, \quad \varphi^{\mathrm{rel}} = \varphi^{\mathrm{particle}} - \varphi^{\mathrm{jet}}$$

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

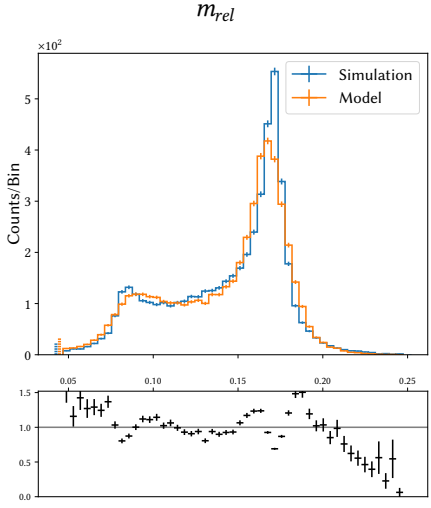


Jet Constituents – Top Jets



⇒ Looks good!

Global Features – Mass



⇒ Not perfect, but promising!

Comparison to EPiC-GAN / MDMA

arXiv:2301.08128 / 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	$\mathbf{0.57 \pm 0.09}$	0.10 ± 0.02	$\mathbf{2.12 \pm 0.64}$	5.3 ± 0.9
DeepTreeGAN	1.49 ± 0.04	0.13 ± 0.02	5.01 ± 0.08	$\mathbf{3.4 \pm 0.7}$

$\Rightarrow$ 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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