Symmetries, Safety, and Self-Supervision

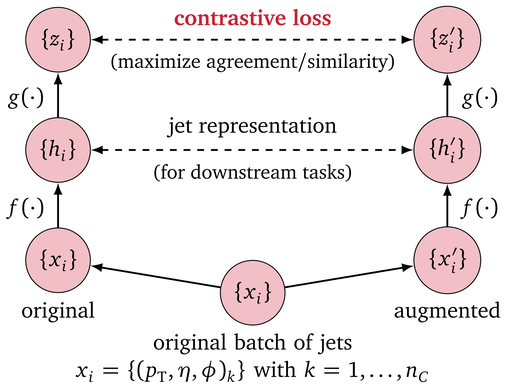
Barry M. Dillon[1], Gregor Kasieczka[2], Hans Olischläger[1], Tilman Plehn[1], Peter Sorrenson[1,3], **Lorenz Vogel**[1]

[1]*Institut für Theoretische Physik, Universität Heidelberg, Germany* [2]*Institut für Experimentalphysik, Universität Hamburg, Germany* [3]*Heidelberg Collaboratory for Image Processing, Universität Heidelberg, Germany*

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

JetCLR: contrastive learning of jet representations

Mapping $f : \mathcal{J} \to \mathcal{R}$ from low-level jet-constituent data ($\mathcal{J}$) to optimized observables ($\mathcal{R}$) through self-supervised contrastive learning



- augmentations: create an augmented version x_i' of each jet x_i in the original batch $\{x_i\}$ – two different but correlated views of the same jet
  - positive pairs: $\{(x_i, x_i')\}$
  - negative pairs: $\{(x_i, x_j)\} \cup \{(x_i, x_j')\}$ with $i \neq j$
- pass both batches through the network
- latent space $z = g(h) = g(f(x)) \in \mathbb{R}^{\dim(z)}$
- representation space $\mathcal{R}$: $h = f(x) \in \mathcal{S}^{\dim(z)-1}$ (unit hypersphere, before head network)

contrastive loss function: map symmetry-related pairs closer together and all other pairs further apart (alignment and uniformity)

$$\mathcal{L}_i = -\log\left\{\frac{e^{s(z_i,z_i')/\tau}}{\sum_{i\neq j\in\text{batch}}\left(e^{s(z_i,z_j)/\tau} + e^{s(z_i,z_j')/\tau}\right)}\right\}$$

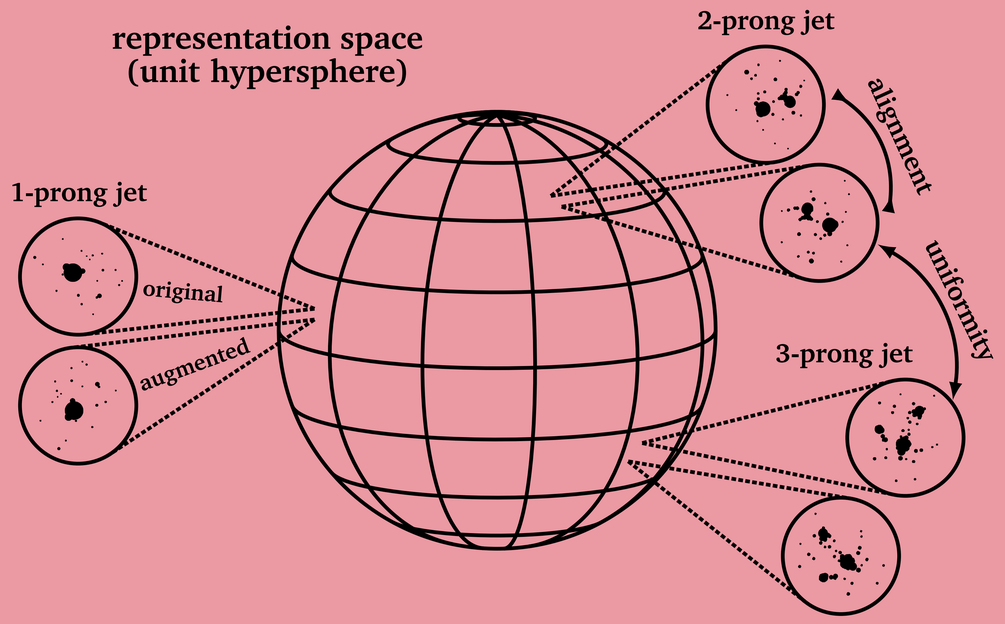
with cosine-similarity measure:

$$s(z_i, z_j) := \frac{z_i \cdot z_j}{|z_i||z_j|} = \cos\theta_{ij} \in [-1, 1]$$

Symmetry-inspired augmentations

- rotations and translations in the η–ϕ plane
- collinear splitting and IR-smearing (IRC safety)

Contrastive learning is an excellent framework for incorporating knowledge about **symmetries and invariances** into modern machine-learning models

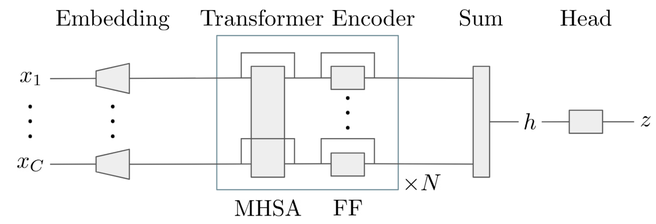




Take a picture to
download the full paper
SciPost Phys. 12, 188 (2022)

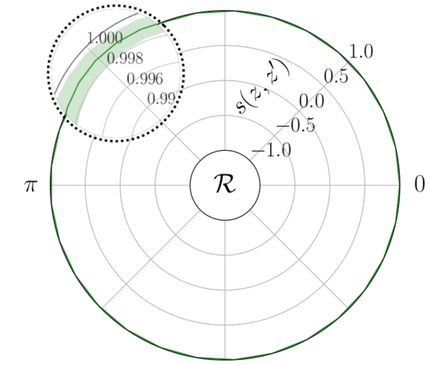
Dataset and network

Data representation for top and QCD jets using a permutation-invariant transformer-encoder model

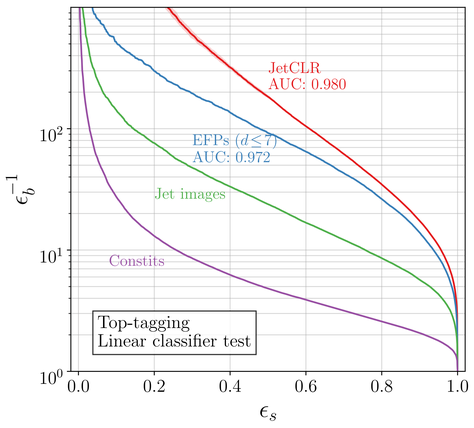


Results

Similarity is maintained under rotations:



JetCLR ROC curve performance in a simple linear classifier test (top-tagging):



References

[1] B. M. Dillon et al., SciPost Phys. 12, 188 (2022), arXiv:2108.04253.
[2] T. Chen et al., PMLR 119, 1597 (2020), arXiv:2002.05709.
[3] A. Butter et al., SciPost Phys. 5, 028 (2018), arXiv:1707.08966.
[4] P. T. Komiske et al., JHEP 04, 013 (2018), arXiv:1712.07124.