Latent Space Topology of Several Machine Learning Algorithms

CSIC 5011 — Topological and Geometric Data Reduction and Visualisation

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Low Dimensional Representation

- How many dimensions are required to store important information?
- Low-dimensional representation of...
  - **Raw** data.
  - Data after Robust PCA (**RPCA**).
  - Latent space of Variational Autoencoder (**VAE**)
  - Latent space of Bi-directional Generative Adversarial Network (**BiGAN**)

MNIST Fashion Dataset

- Images of fashionables
- Training set of 60,000 samples
- Test set of 10,000 samples
- 28x28 grayscale images
- 10 labels
- Reshaped into 784*60000

2D Representation

- Linear Discriminant Analysis and t-SNE perform the best
- Trouser and dress categories are most distinct
- Shirt and coat categories are difficult to distinguish.

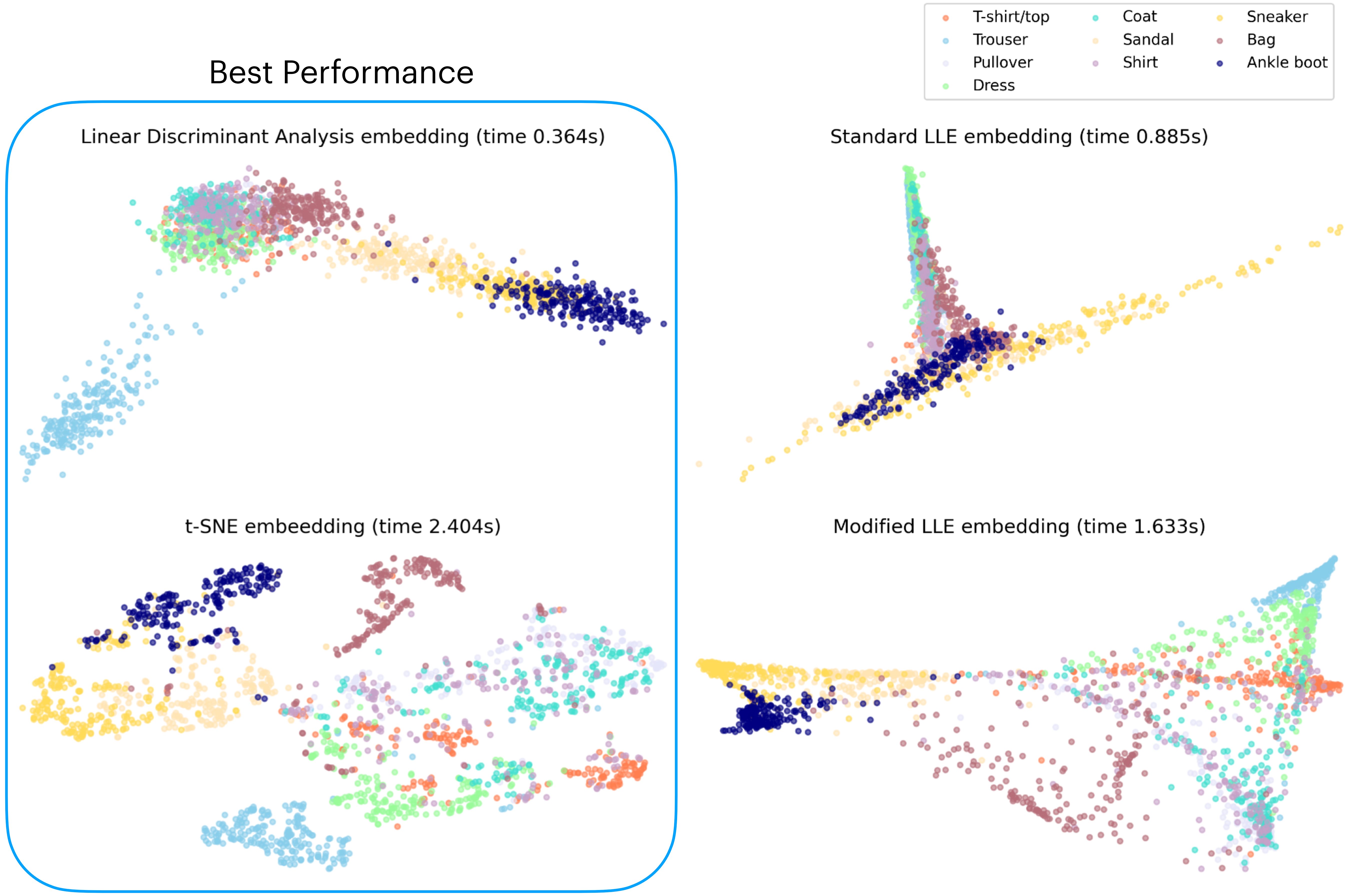
Robust PCA

- RPCA to compute minimum rank and separate image
- Dimension reduction on the low-rank matrix
- Low rank image = background, high rank image = decoration

Computed rank = 432

Low Rank

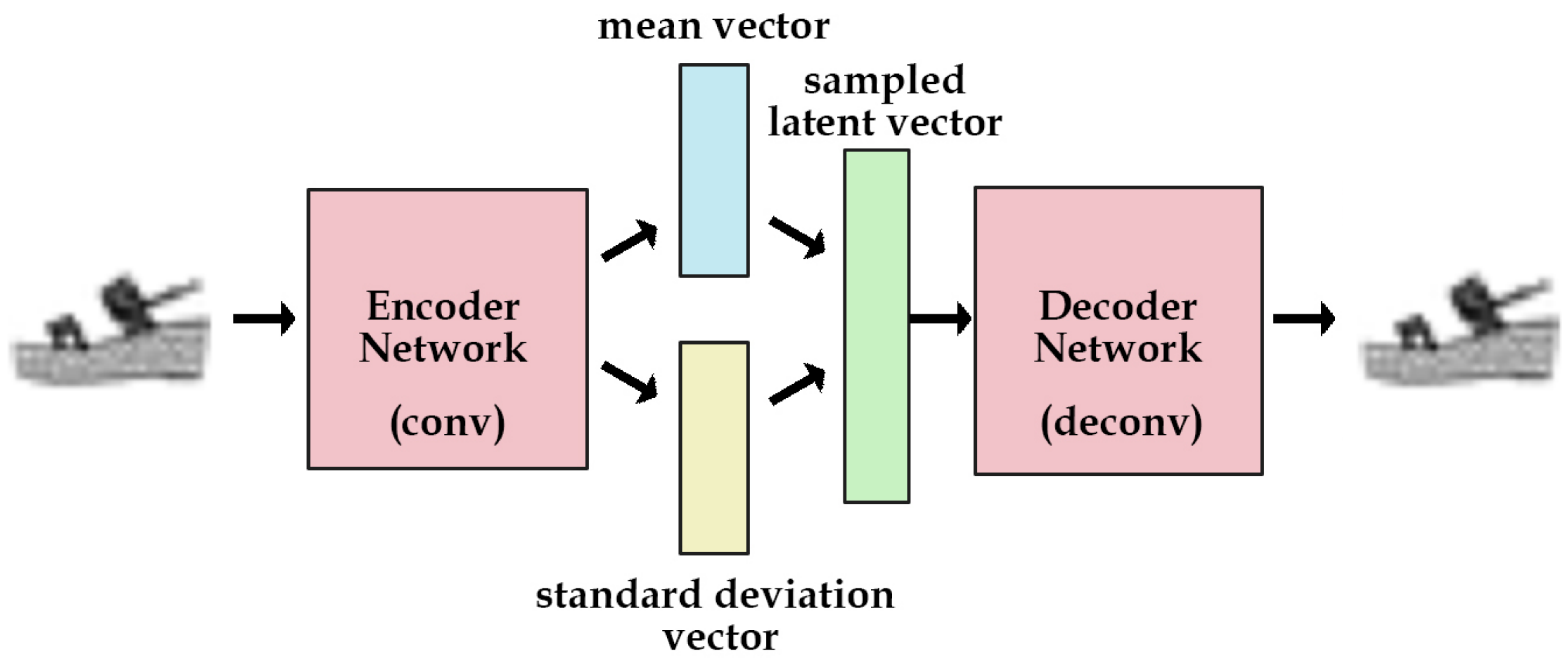
High Rank

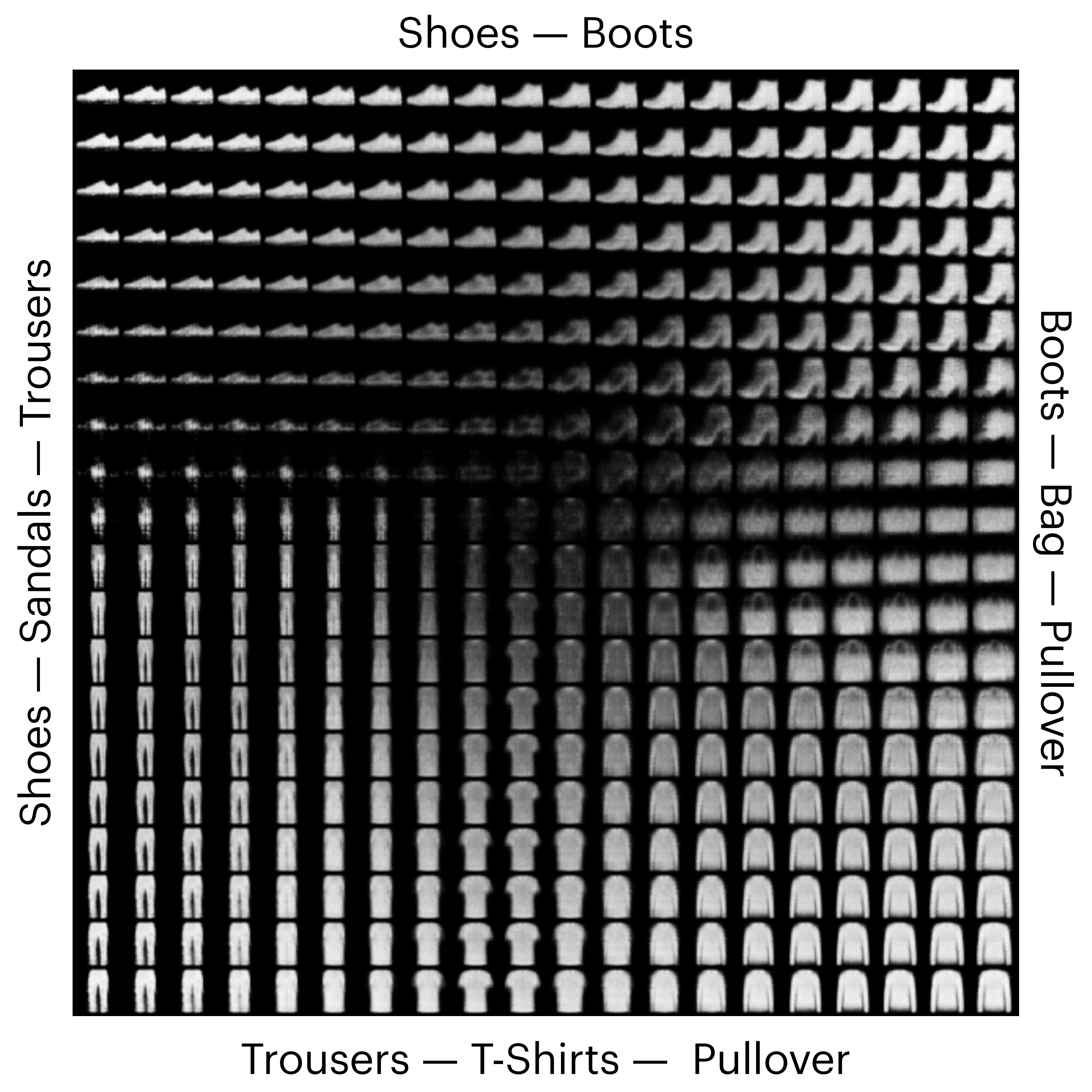


Candès, E. J., Li, X., Ma, Y., & Wright, J. (2011). *Robust principal component analysis?*. Journal of the ACM (JACM), 58(3), 1-37.

Variational Autoencoder (VAE)

- Use VAE to encode image into latent space
- Dimension reduction on the latent space



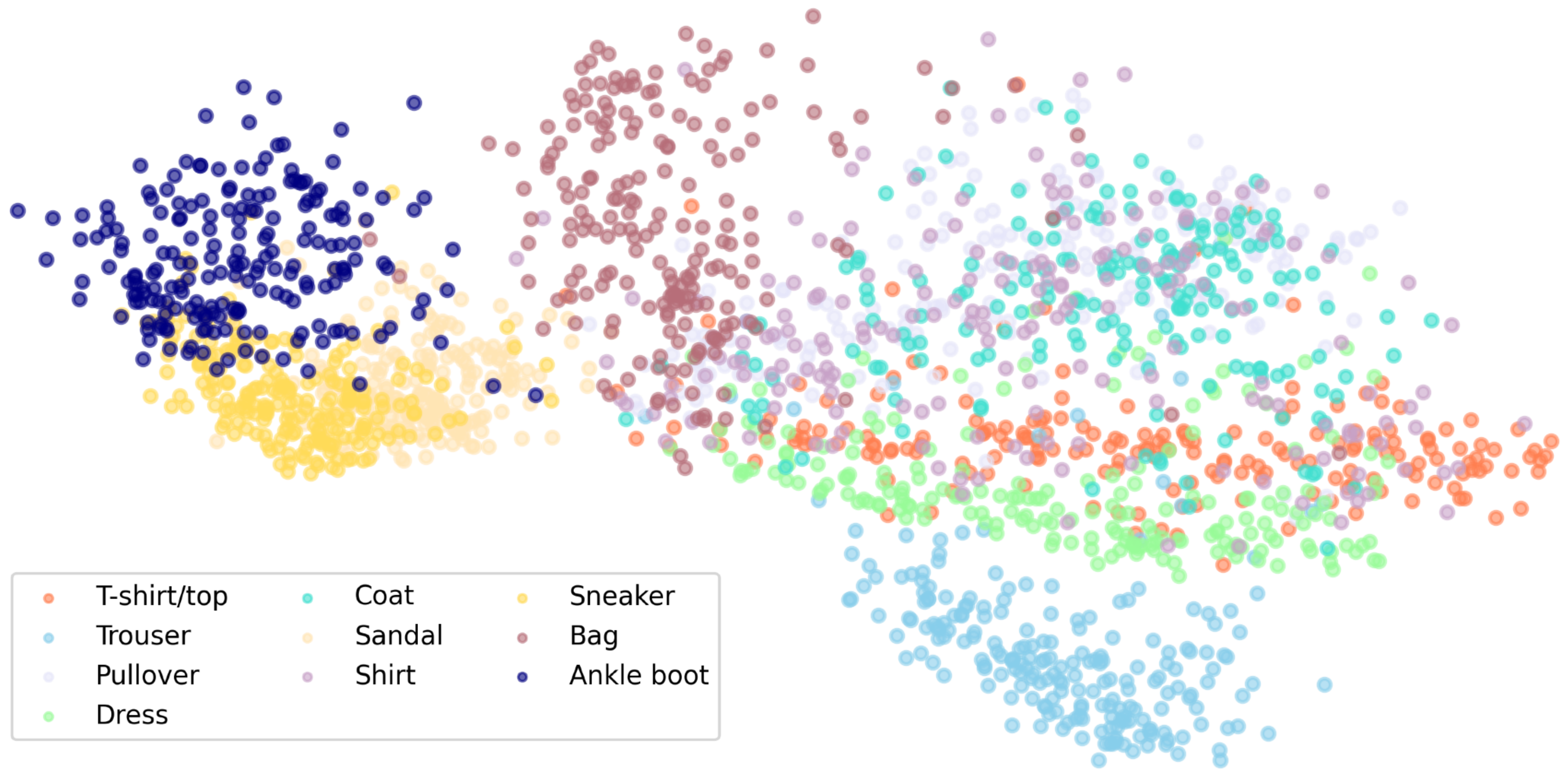


Kingma, D. P., & Welling, M. (2013). *Auto-encoding variational bayes*. arXiv preprint arXiv:1312.6114.

Smooth transitions from one obj into another

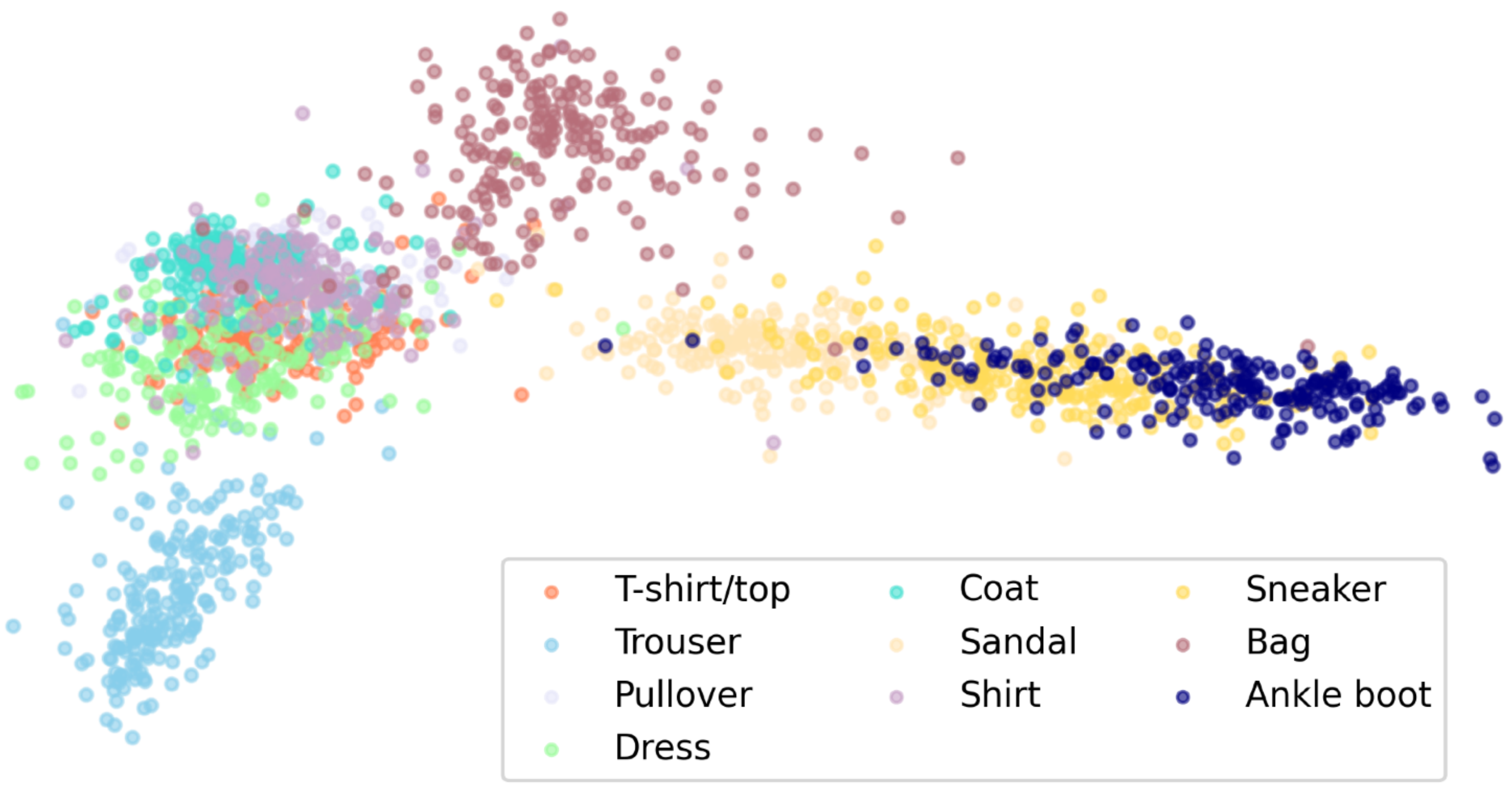
Variational Autoencoder (VAE)

VAE with a latent space of 2 dimensions

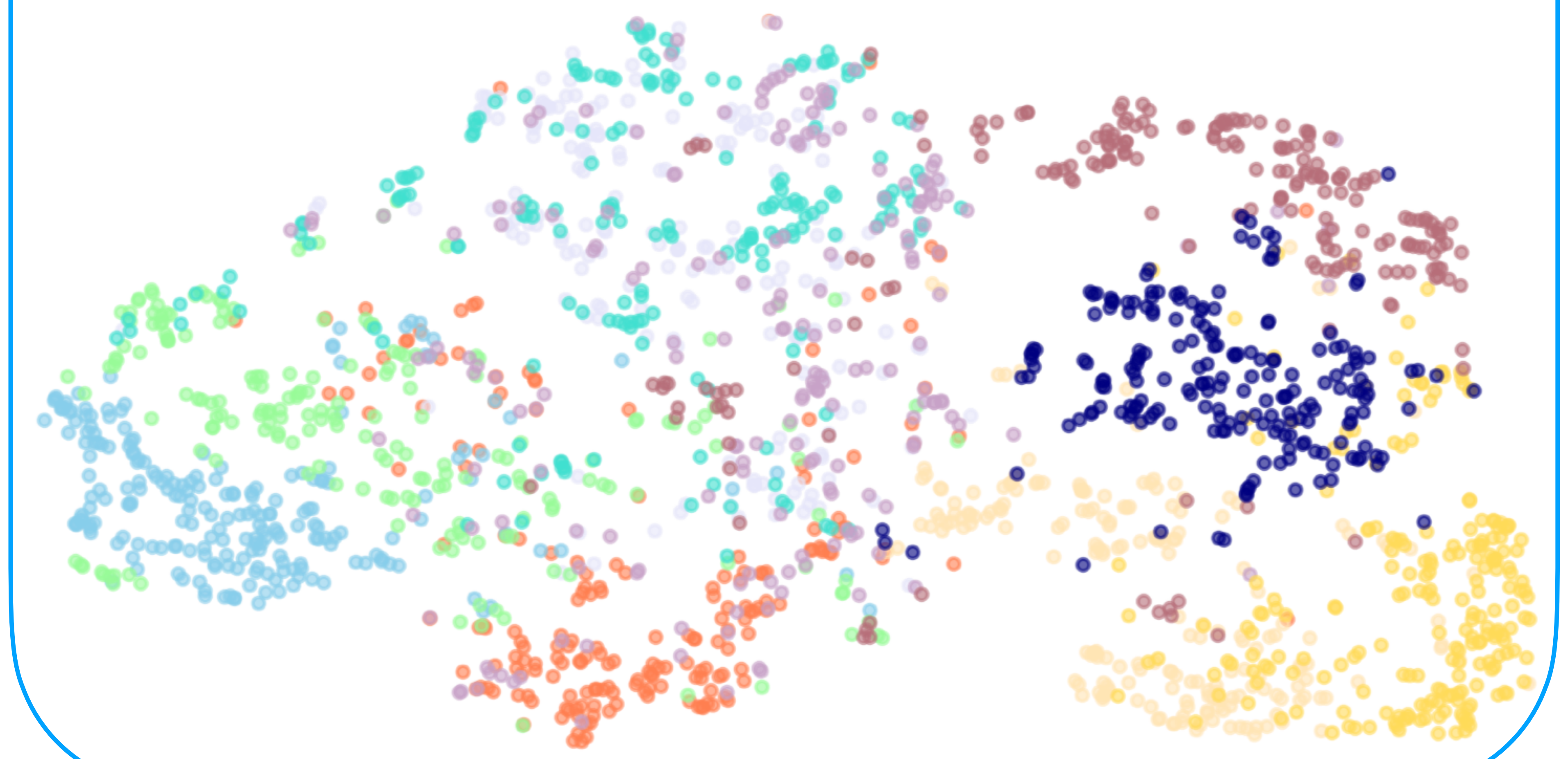


Best Performance Among 11 Methods

Linear Discriminant Analysis embedding (time 0.192s)



t-SNE embeedding (time 2.650s)

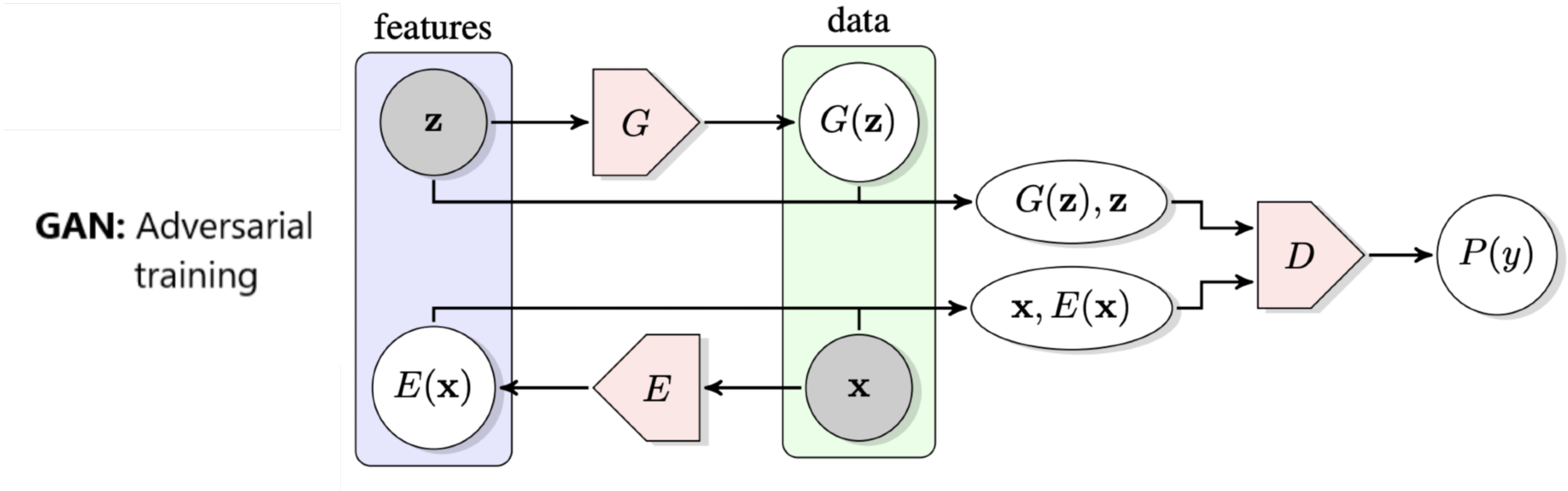


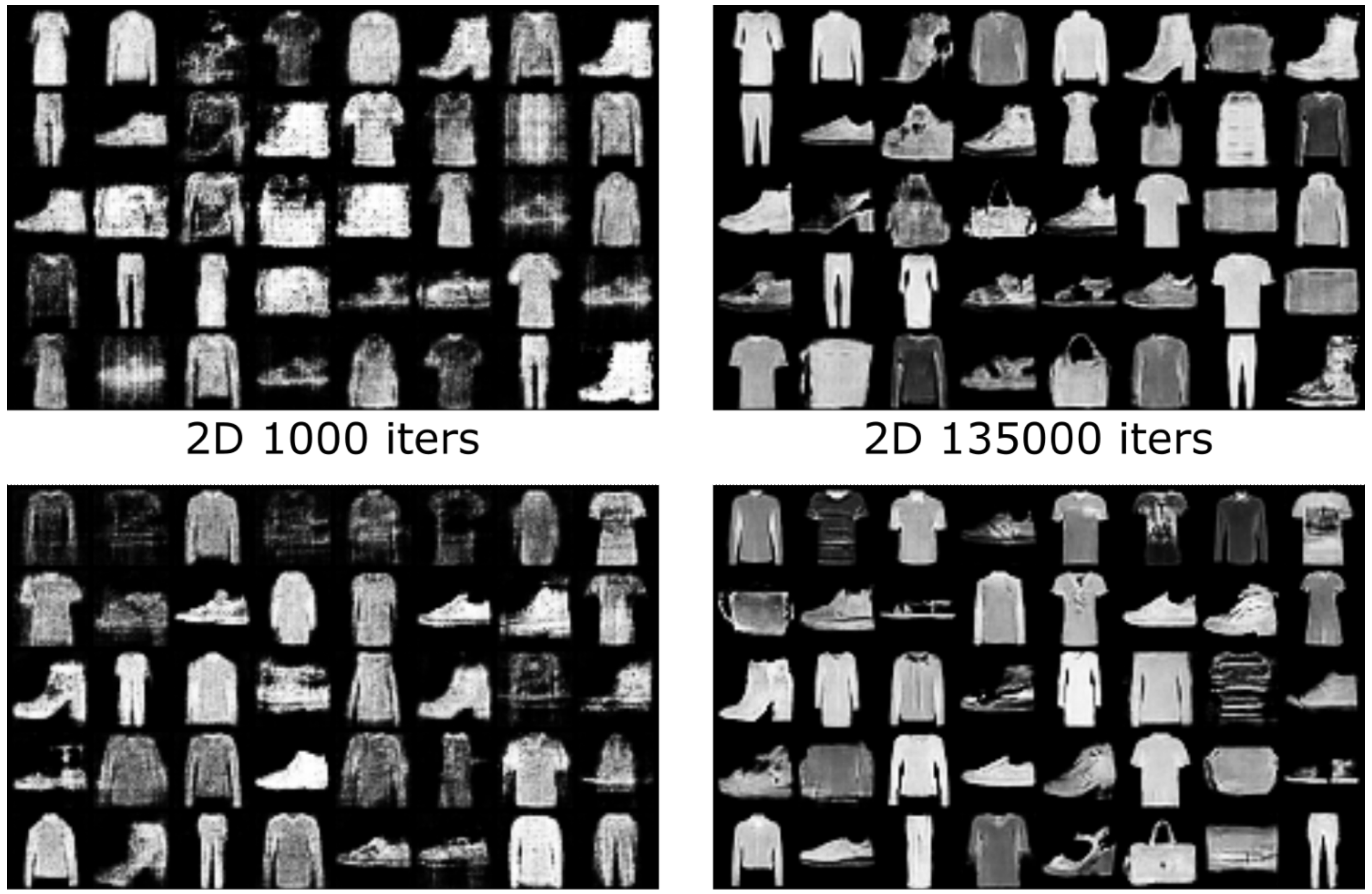
Observations

- VAE itself can encode high-dimensional data into low dimensions
- It has same good performance as the two non-ML algorithms
- Latent space of VAE has a clear structure

Bi-directional Generative Adversarial Network (BiGAN)

- Use GAN to encode image into latent space
- Dimension reduction on the latent space
- Generate realistic (but fake) images





2D 1000 iters

2D 135000 iters

432D 1000 iters

432D 135000 iters

Zhirui Zhang, Shujie Liu, Mu Li, Ming Zhou, and Enhong Chen. 2018. *Bidirectional Generative Adversarial Networks for Neural Machine Translation*. In Proceedings of the 22nd Conference on Computational Natural Language Learning, pages 190–199, Brussels, Belgium.

Bi-directional Generative Adversarial Network (BiGAN)

Yeezy 350?

YSL T-shirt?

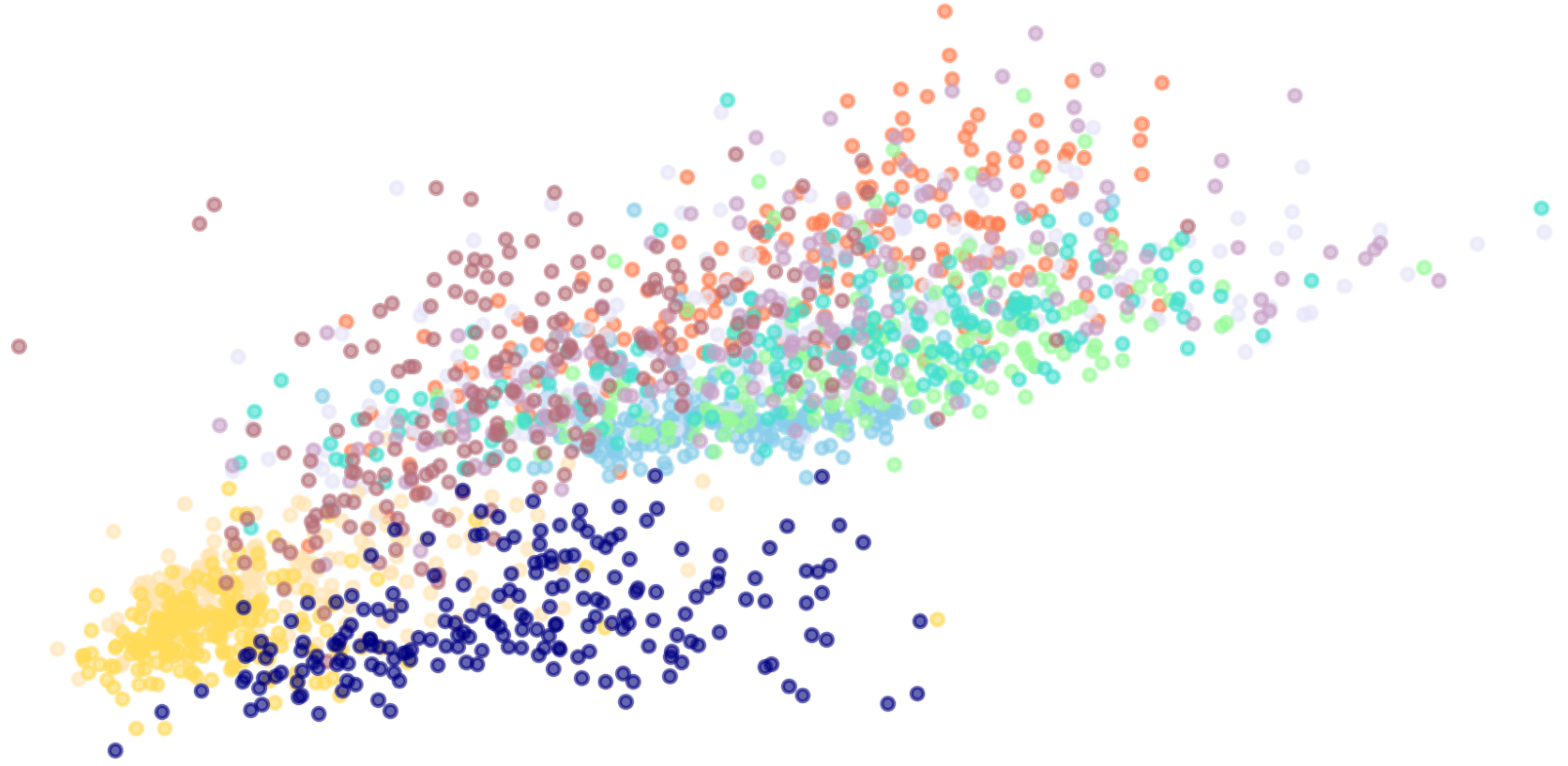
Adidas Trainer?

Generated Images
Iter=135000

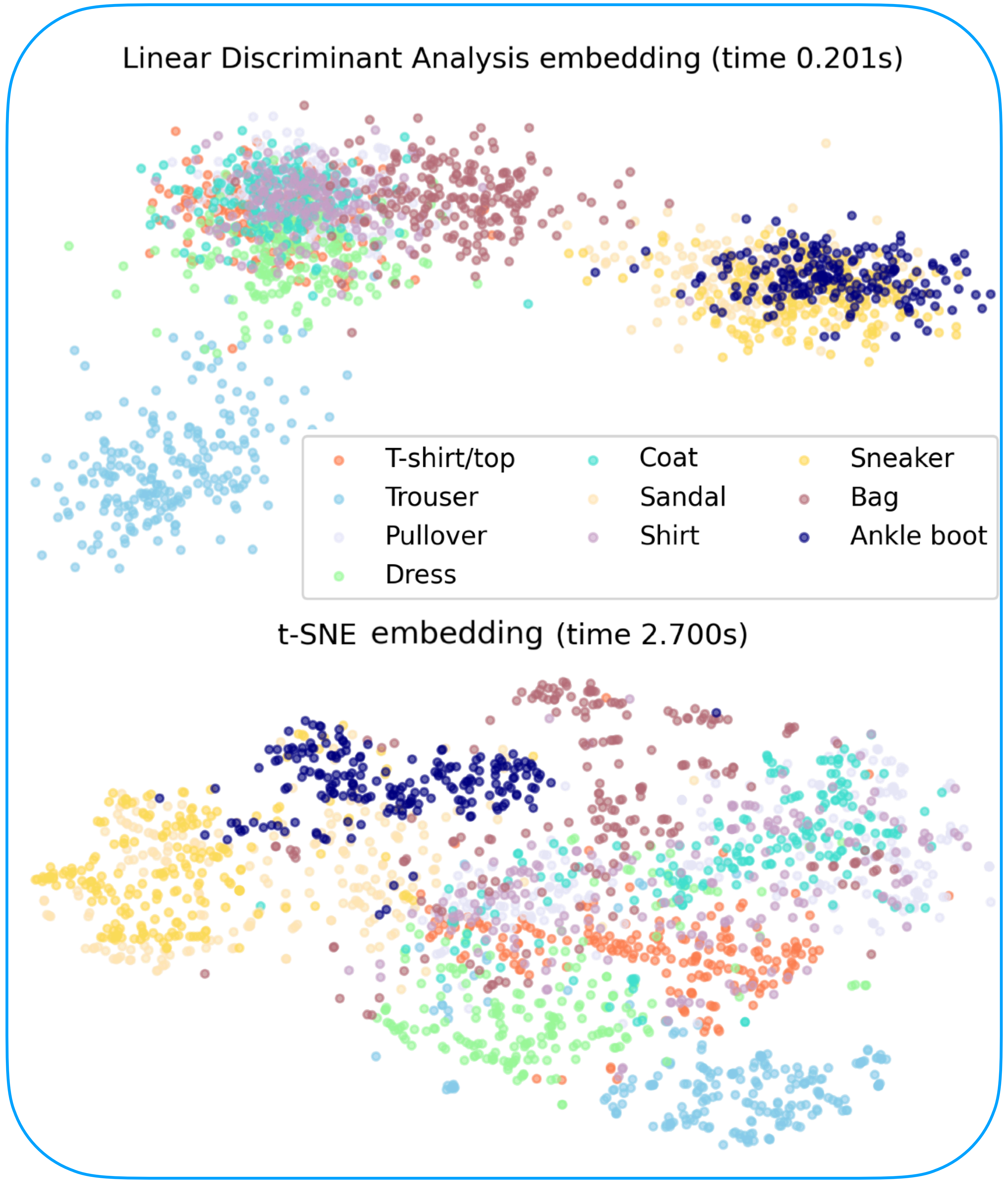
Reconstructed Images
Iter=135000

Bi-directional Generative Adversarial Network (BiGAN)

BiGAN with a latent space of 2 dimensions



Best Performance Among 11 Methods



Observations

- GAN demonstrates proficiency in creating high-quality images.
- GAN exhibits limitations in effectively reducing dimensionality
- Latent space of GAN is not well organised

Conclusion

- High-dimensional images have distinct features even in 2D
- To our surprise, linear methods perform best in dimension reduction
- RPCA can separate layout and decoration patterns
- VAE (as the name suggests) can encode high-D data into low-D but generated image are not detail-rich
- BiGAN (as the name suggests) on the other hand can generate high quality image but cannot encode information in a structured way