Supervised vs unsupervised learning

Supervised Learning

Data: (x, y)
x is data, y is label

Goal: Learn function to map
$x \rightarrow y$

Examples: Classification, regression, object detection, semantic segmentation, etc.

Unsupervised Learning

Data: x
x is data, no labels!

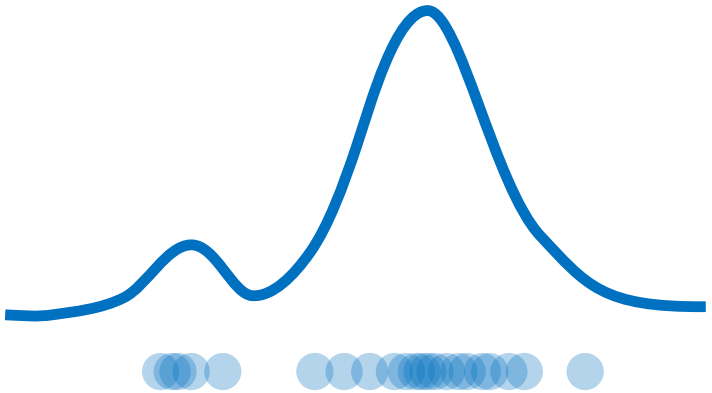
Goal: Learn some *hidden* or *underlying structure* of the data

Examples: Clustering, feature or dimensionality reduction, etc.

Generative modeling

Goal: Take as input training samples from some distribution and learn a model that represents that distribution

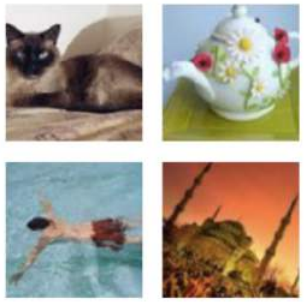
Density Estimation



Sample Generation

Input samples

Training data ~ $P_{data}(x)$



Generated samples

Generated ~ $P_{model}(x)$

How can we learn $P_{model}(x)$ similar to $P_{data}(x)$?

Why generative models? Debiasing

Capable of uncovering **underlying latent variables** in a dataset

Homogeneous skin color, pose

VS

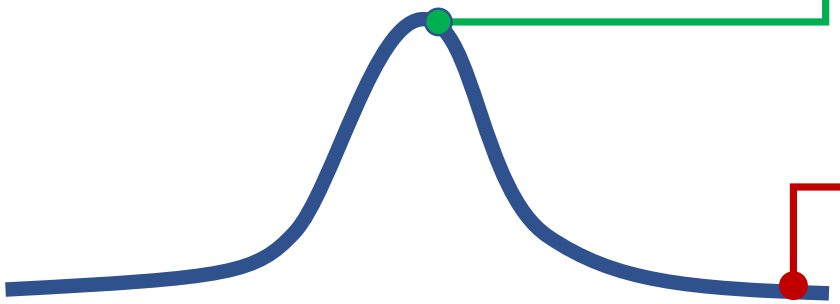
Diverse skin color, pose, illumination

How can we use latent distributions to create fair and representative datasets?

Why generative models? Outlier detection

- **Problem:** How can we detect when we encounter something new or rare?
- **Strategy:** Leverage generative models, detect outliers in the distribution
- Use outliers during training to improve even more!

95% of Driving Data:
(1) sunny, (2) highway, (3) straight road



Detect outliers to avoid unpredictable behavior when training

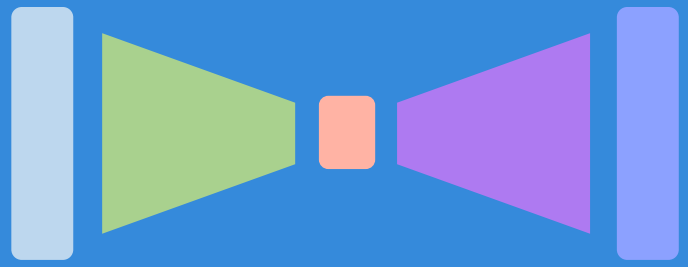
Edge Cases

Harsh Weather

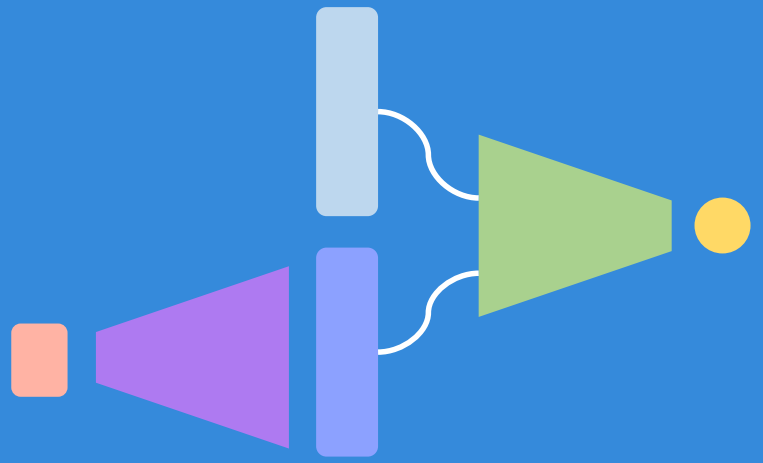
Pedestrians

Latent variable models

Autoencoders and Variational Autoencoders (VAEs)



Generative Adversarial Networks (GANs)



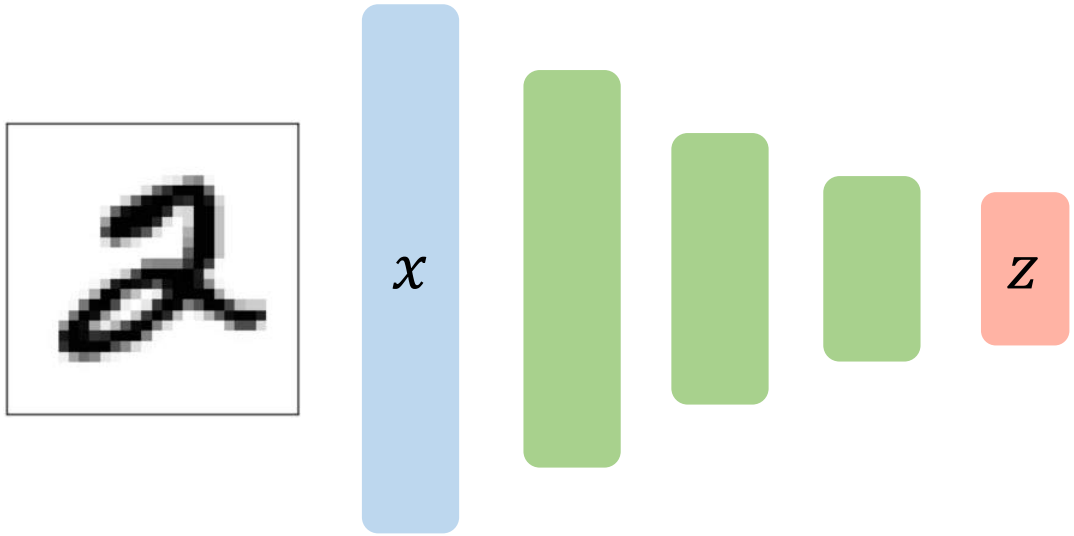
Generative models

Latent variable?

True explanatory factor – learnt only from observed data

Autoencoders: background

Unsupervised approach for learning a **lower-dimensional** feature representation from unlabeled training data

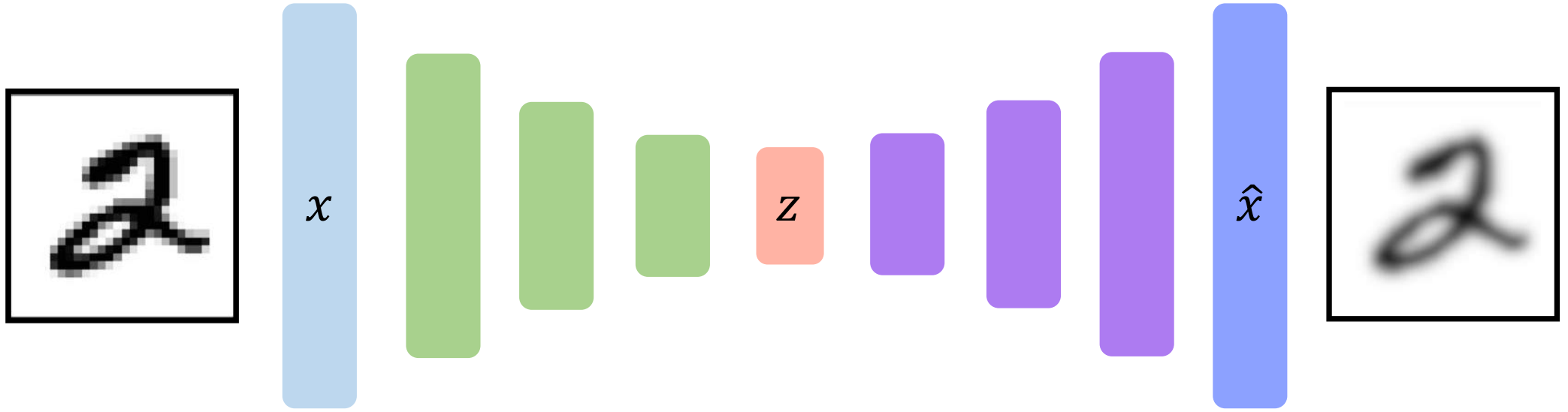


Why do we care about a low-dimensional z?

"Encoder" learns mapping from the data, x, to a low-dimensional latent space, z

Autoencoders: background

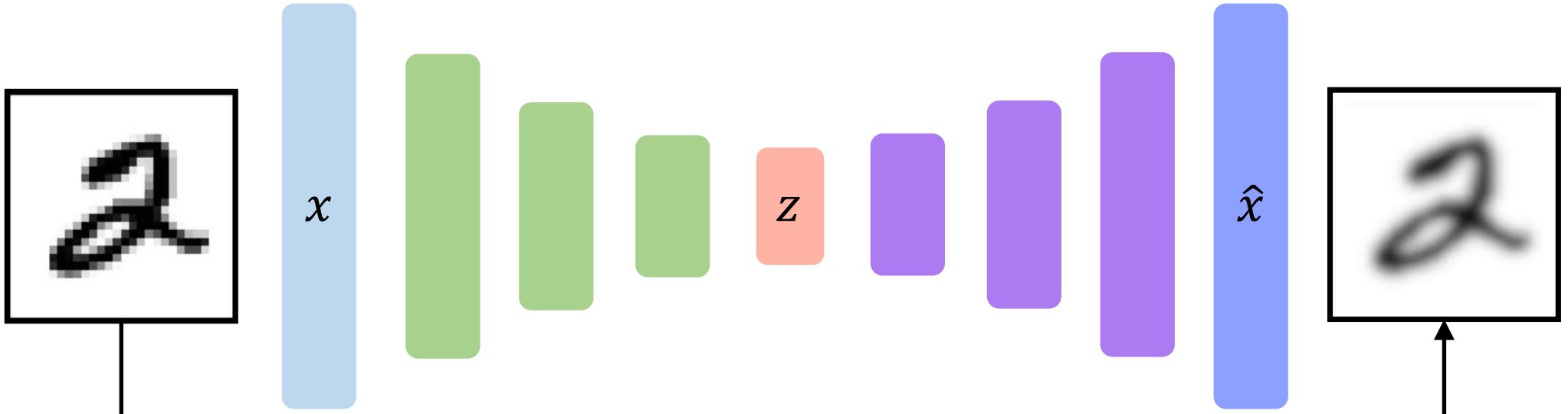
How can we learn this latent space?
Train the model to use these features to **reconstruct the original data**



"Decoder" learns mapping back from latent, z, to a reconstructed observation, $\hat{x}$

Autoencoders: background

How can we learn this latent space?
Train the model to use these features to **reconstruct the original data**

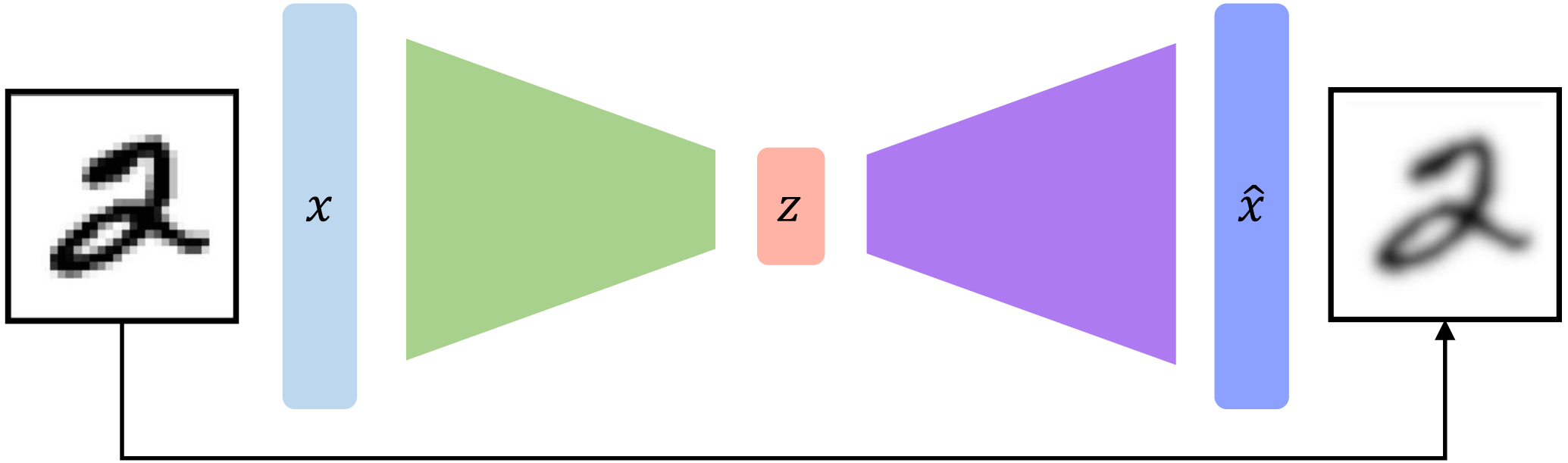


$$\mathcal{L}(x, \hat{x}) = \|x - \hat{x}\|^2$$

Loss function doesn't use any labels!!

Autoencoders: background

How can we learn this latent space?
Train the model to use these features to **reconstruct the original data**



$$\mathcal{L}(x, \hat{x}) = \|x - \hat{x}\|^2$$

Loss function doesn't use any labels!!

Dimensionality of latent space → reconstruction quality

Autoencoding is a form of compression!
Smaller latent space will force a larger training bottleneck

2D latent space

5D latent space

Ground Truth

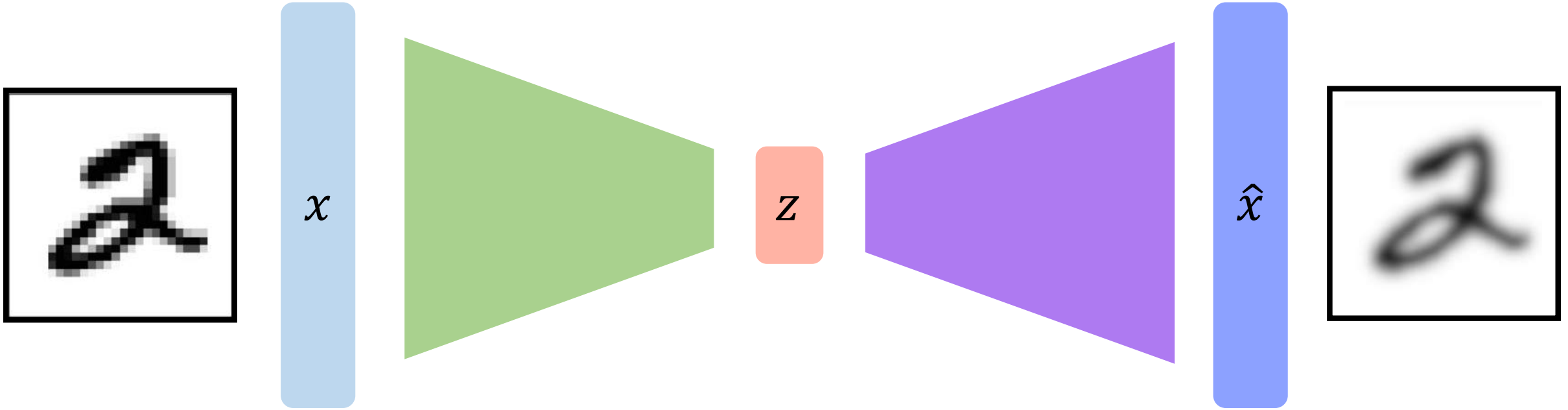
Autoencoders for representation learning

Bottleneck hidden layer forces network to learn a compressed latent representation

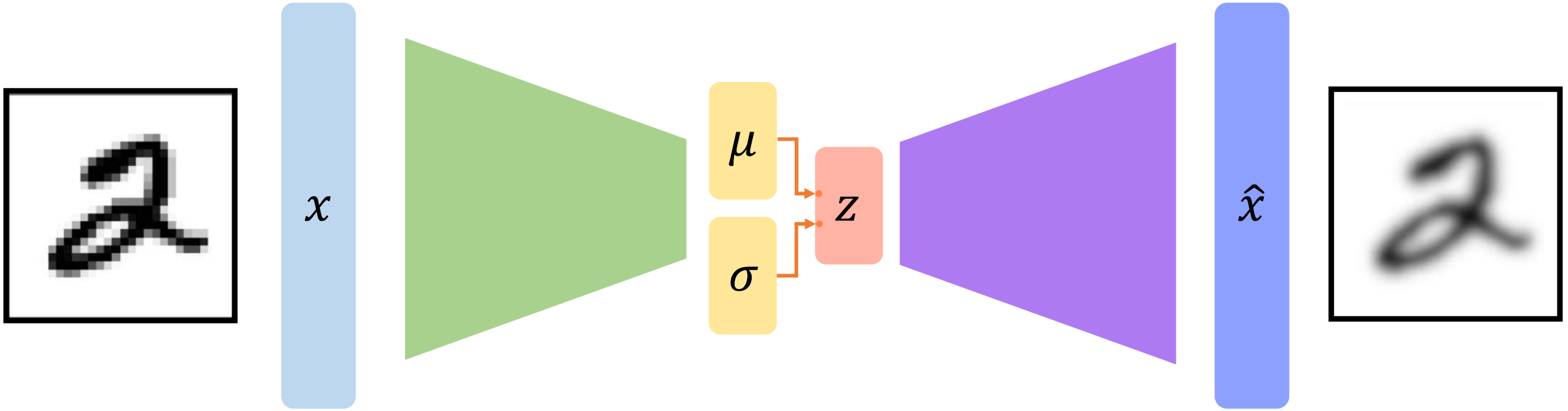
Reconstruction loss forces the latent representation to capture (or encode) as much "information" about the data as possible

Autoencoding = **Auto**matically **encoding** data

VAEs: key difference with traditional autoencoder



VAEs: key difference with traditional autoencoder



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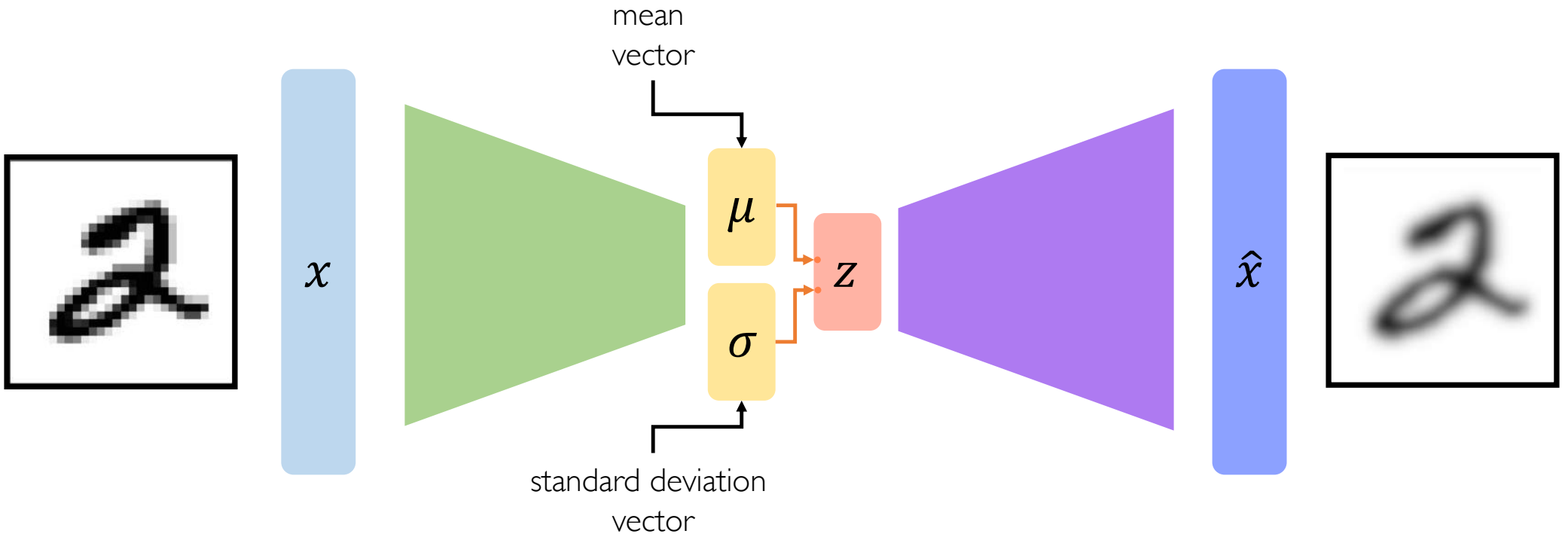
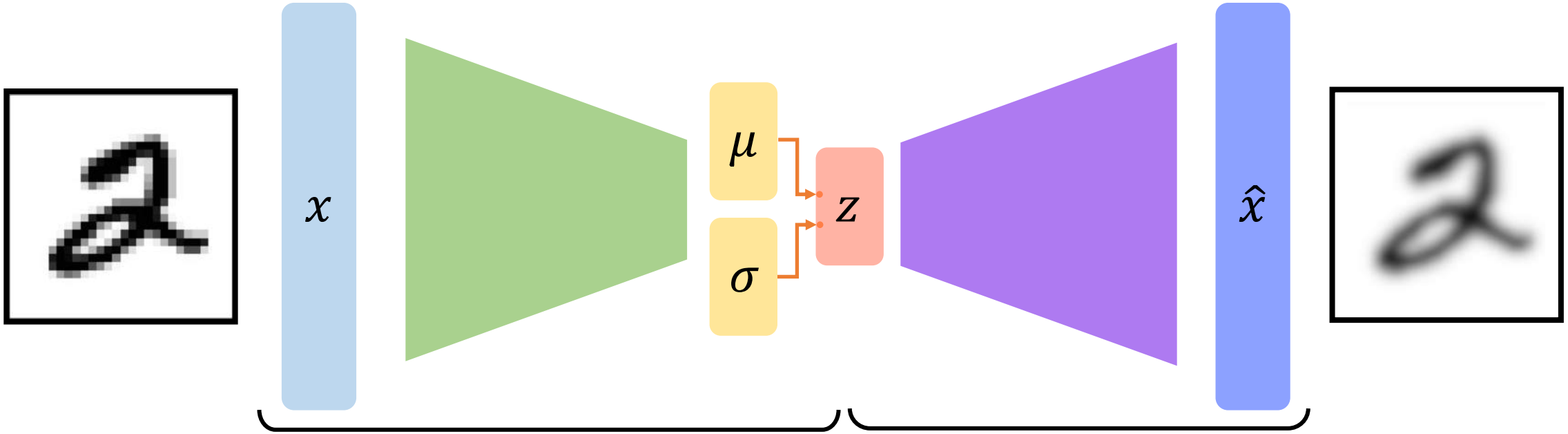


Variational autoencoders are a probabilistic twist on autoencoders!

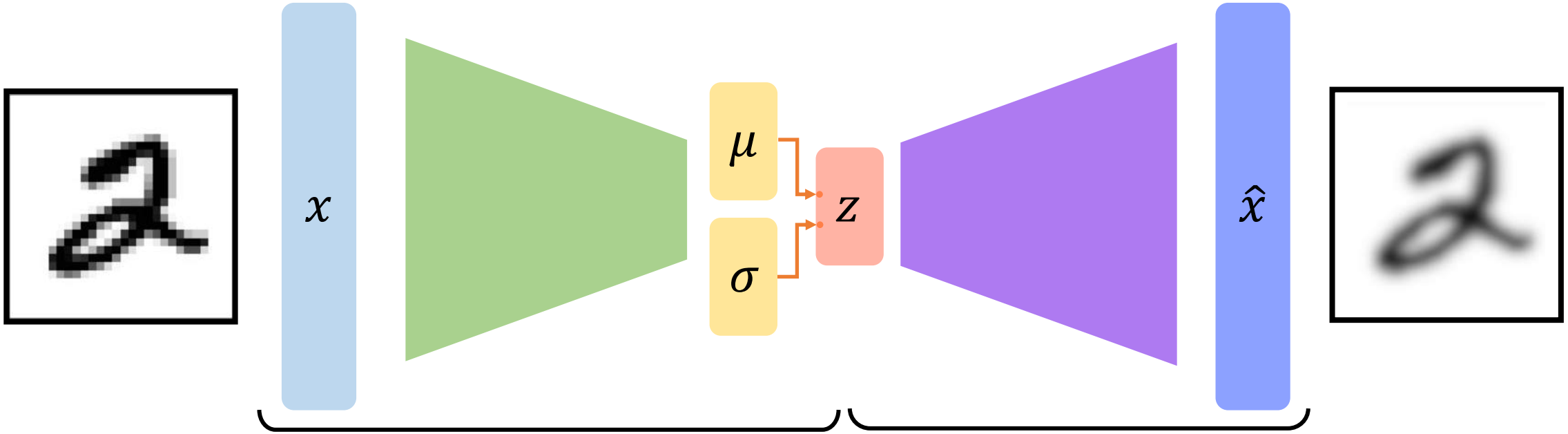
Sample from the mean and standard dev. to compute latent sample

VAE optimization



Encoder computes: $p_\phi(\mathrm{z}|x)$ Decoder computes: $q_\theta(\mathrm{x}|z)$

VAE optimization



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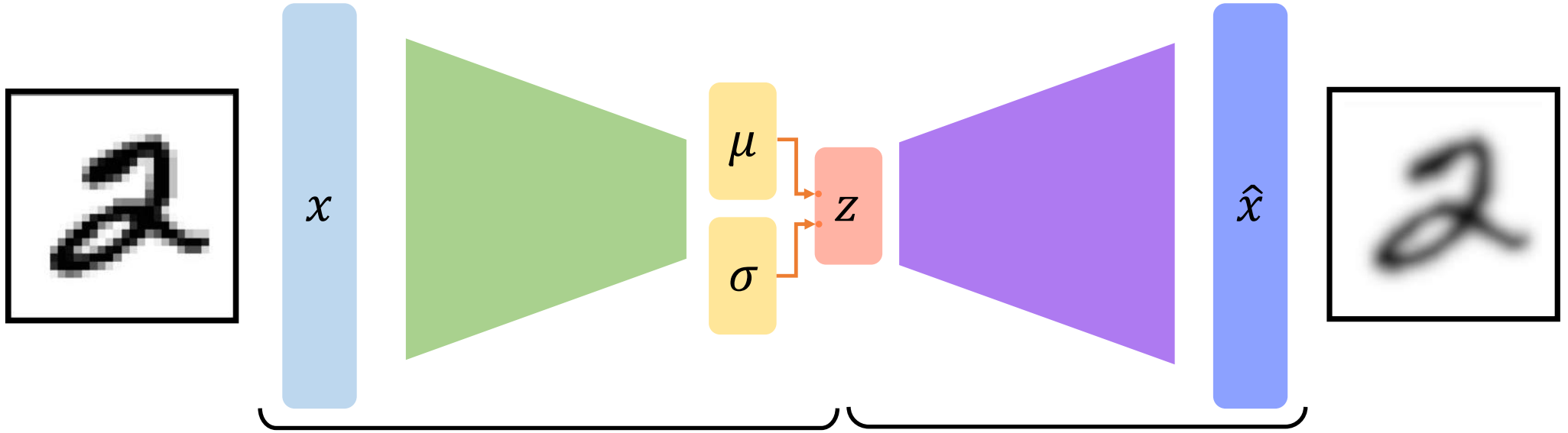
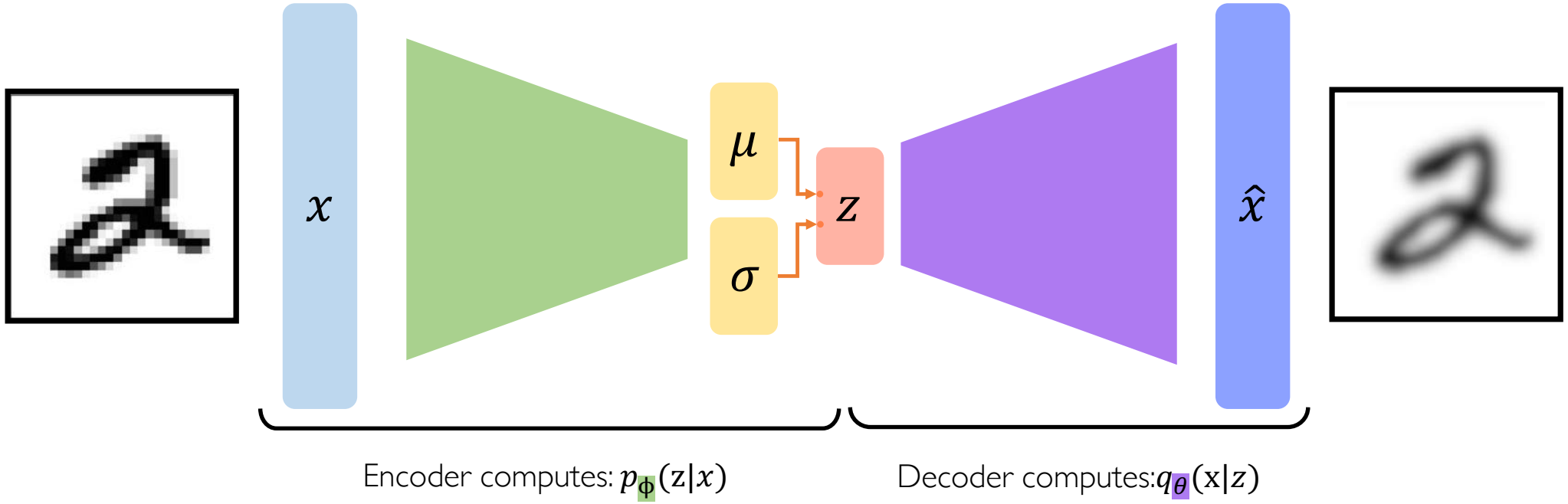


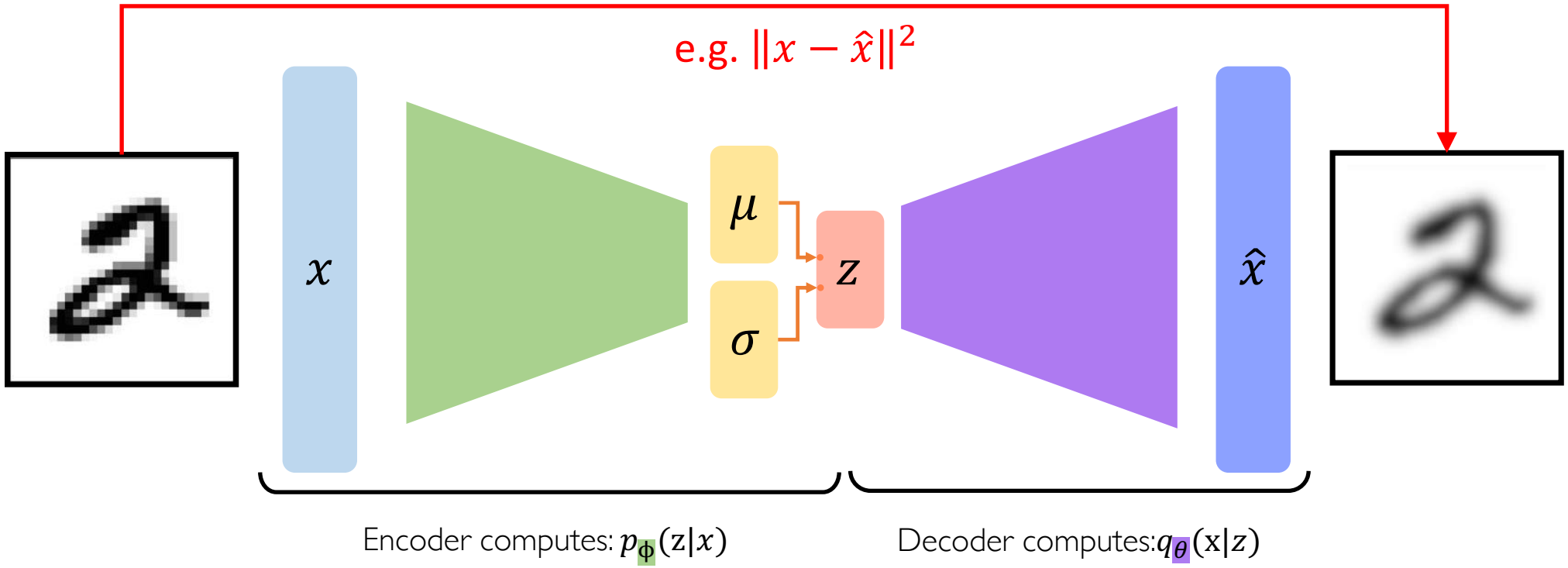
$\mathcal{L}(\phi, \theta)$ = (reconstruction loss) + (regularization term)

VAE optimization



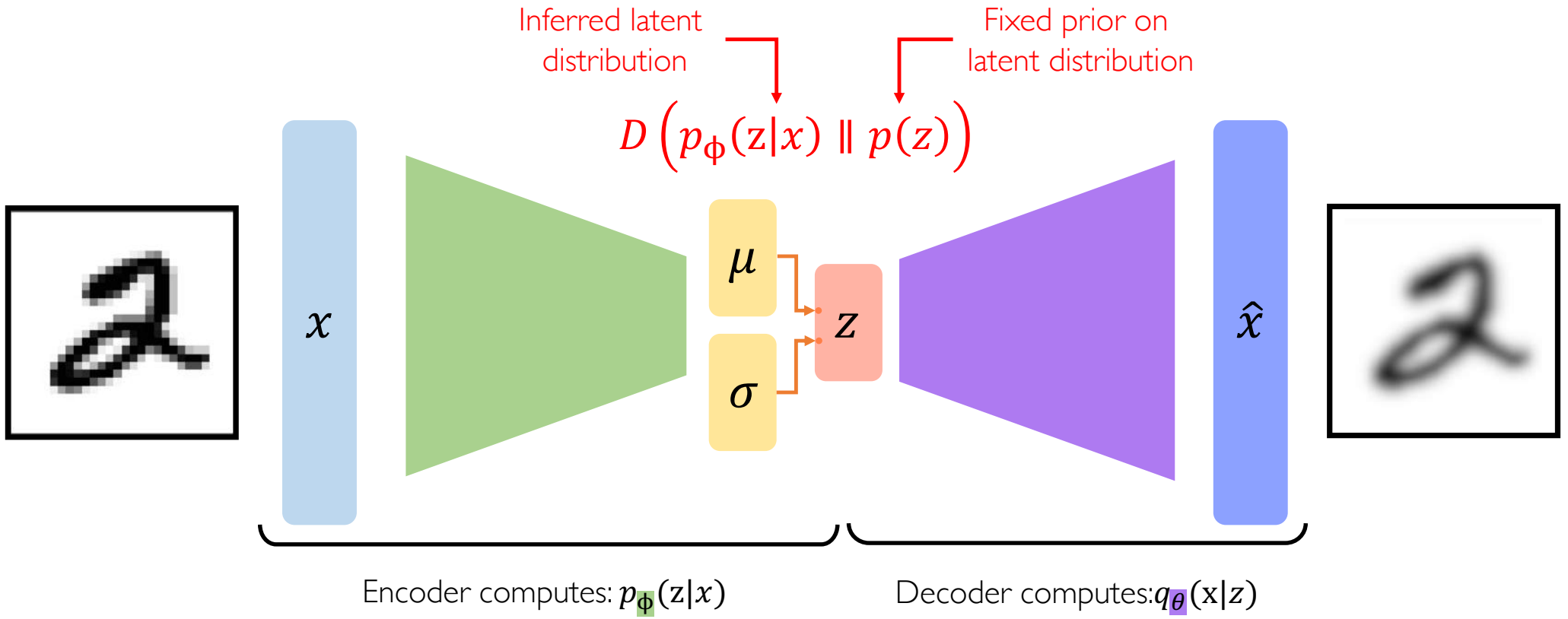
$$\mathcal{L}(\phi, \theta, x) = \text{(reconstruction loss)} + \text{(regularization term)}$$

VAE optimization



$$\mathcal{L}(\phi, \theta, x) = \boxed{\text{(reconstruction loss)}} + \text{(regularization term)}$$

VAE optimization



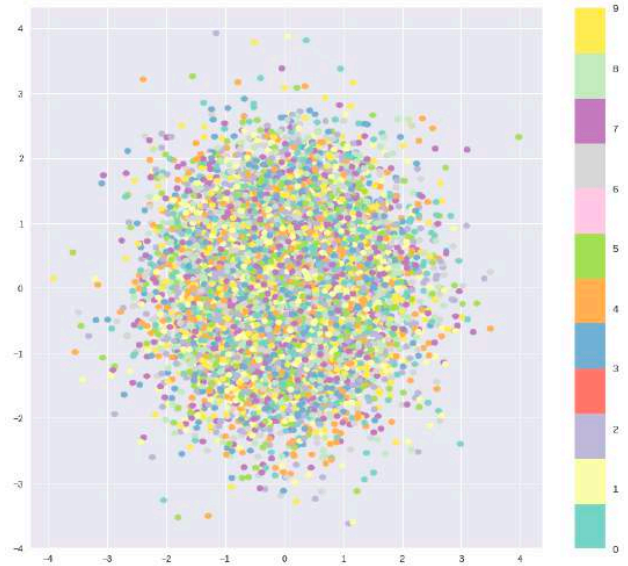
$$\mathcal{L}(\phi, \theta, x) = \text{(reconstruction loss)} + \boxed{\text{(regularization term)}}$$

Priors on the latent distribution

$$D\left(p_\phi(\mathrm{z}|x) \parallel p(z)\right)$$

Inferred latent distribution

Fixed prior on latent distribution



Common choice of prior:

$$p(z) = \mathcal{N}(\mu = 0, \sigma^2 = 1)$$

- Encourages encodings to distribute encodings evenly around the center of the latent space
- Penalize the network when it tries to "cheat" by clustering points in specific regions (ie. memorizing the data)

Priors on the latent distribution

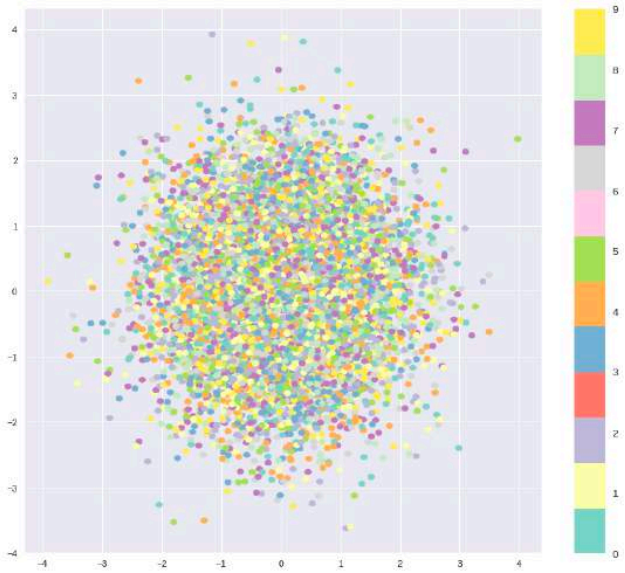
$$D_{\mathrm{KL}}(P \parallel Q) = -\sum_{x \in \mathcal{X}} P(x) \log\left(\frac{Q(x)}{P(x)}\right).$$

Kullback-Leibler

$$D\left(p_\phi(\mathrm{z}|x) \parallel p(z)\right)$$

$$= -\frac{1}{2}\sum_{j=0}^{k-1}\left(\sigma_j + \mu_j^2 - 1 - \log\sigma_j\right)$$

KL-divergence between the two distributions



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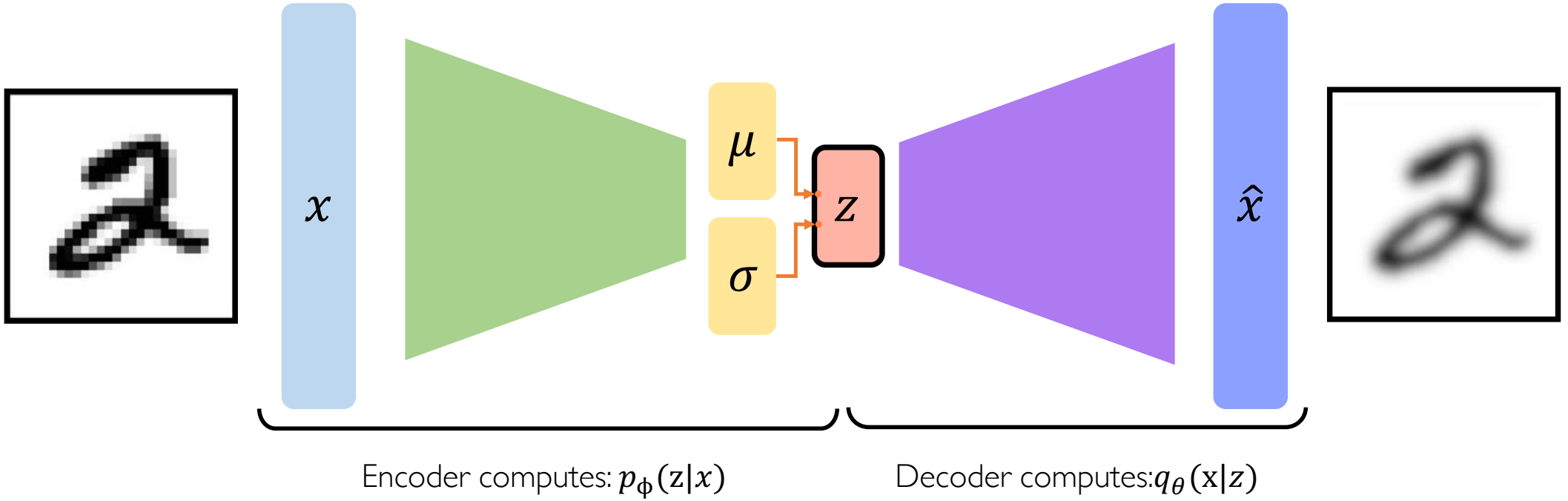
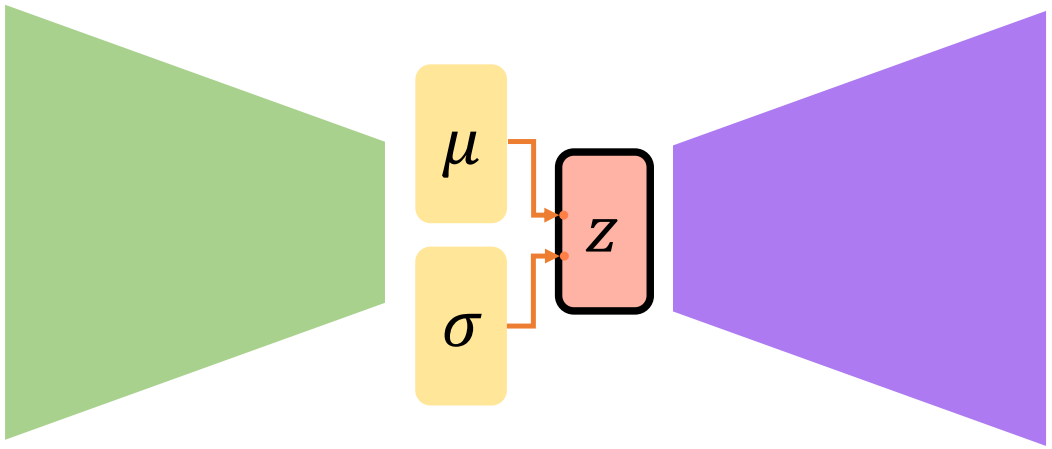
VAEs computation graph

Problem: We cannot backpropagate gradients through sampling layers!



$$\mathcal{L}(\phi, \theta, x) = \text{(reconstruction loss)} + \text{(regularization term)}$$

Reparametrizing the sampling layer



Key Idea:

~~$z \sim \mathcal{N}(\mu, \sigma^2)$~~

Consider the sampled latent vector as a sum of

- a fixed μ vector,
- and fixed σ vector, scaled by random constants drawn from the prior distribution

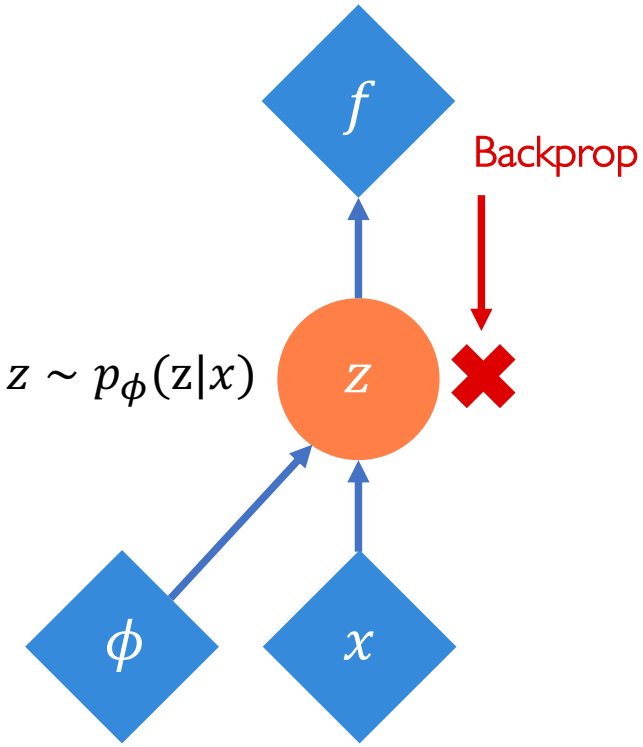
$$\Rightarrow z = \mu + \sigma \odot \varepsilon$$

where $\varepsilon \sim \mathcal{N}(0,1)$

Reparametrizing the sampling layer

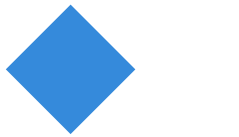
Deterministic node

Stochastic node



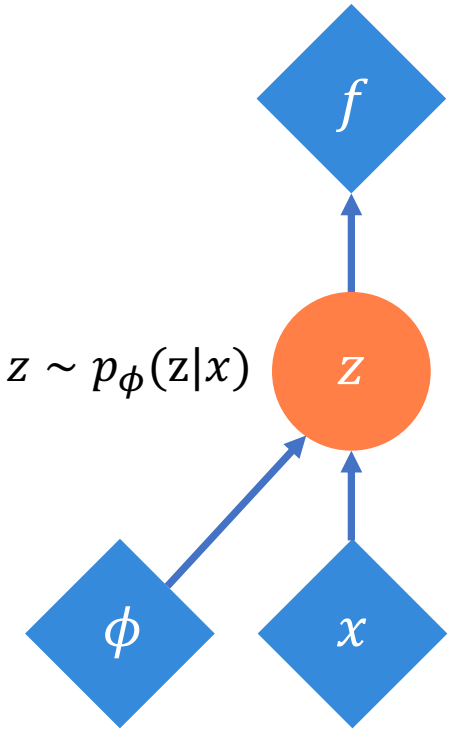
Original form

Reparametrizing the sampling layer

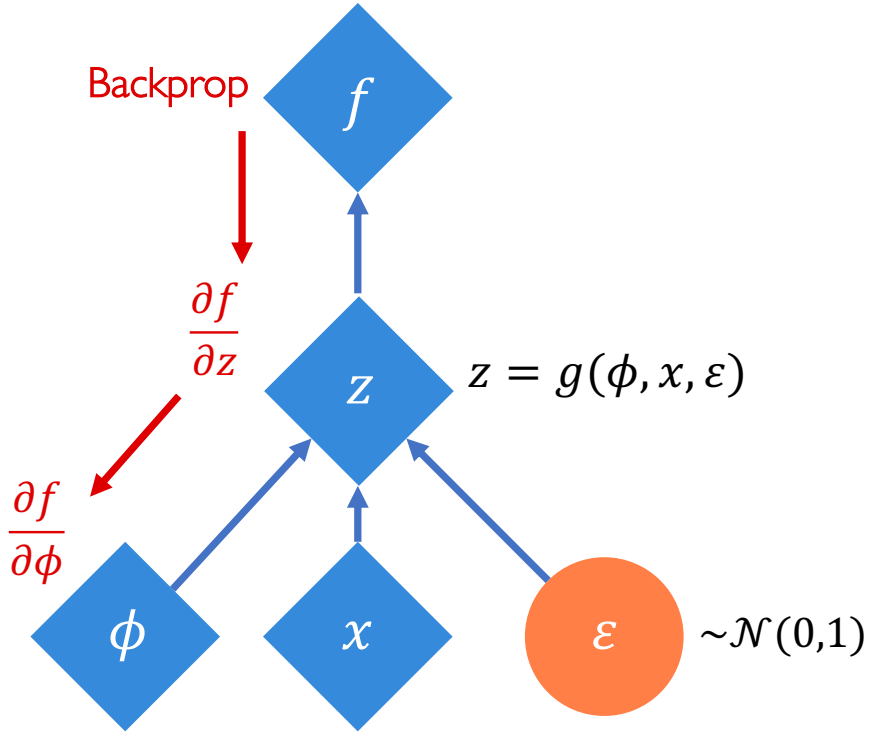


Deterministic node

Stochastic node



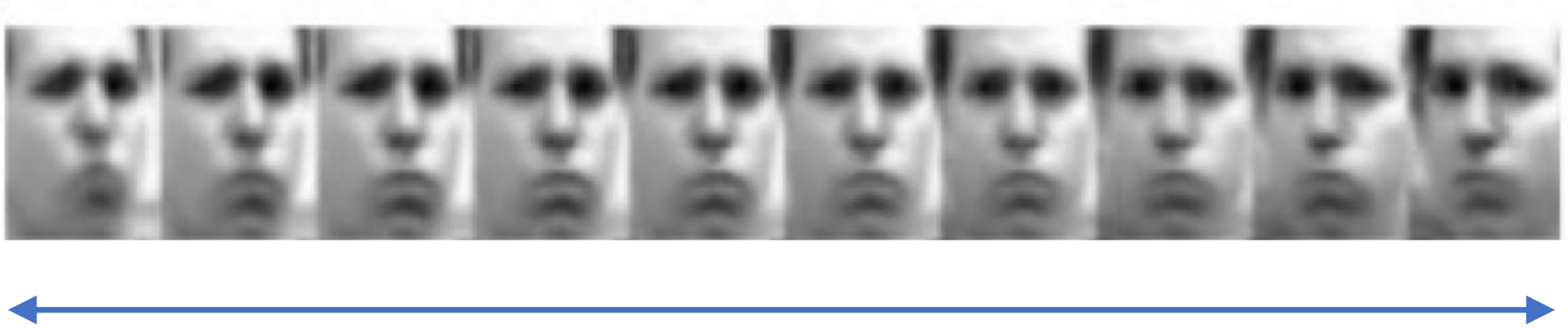
Original form



Reparametrized form

VAEs: Latent perturbation

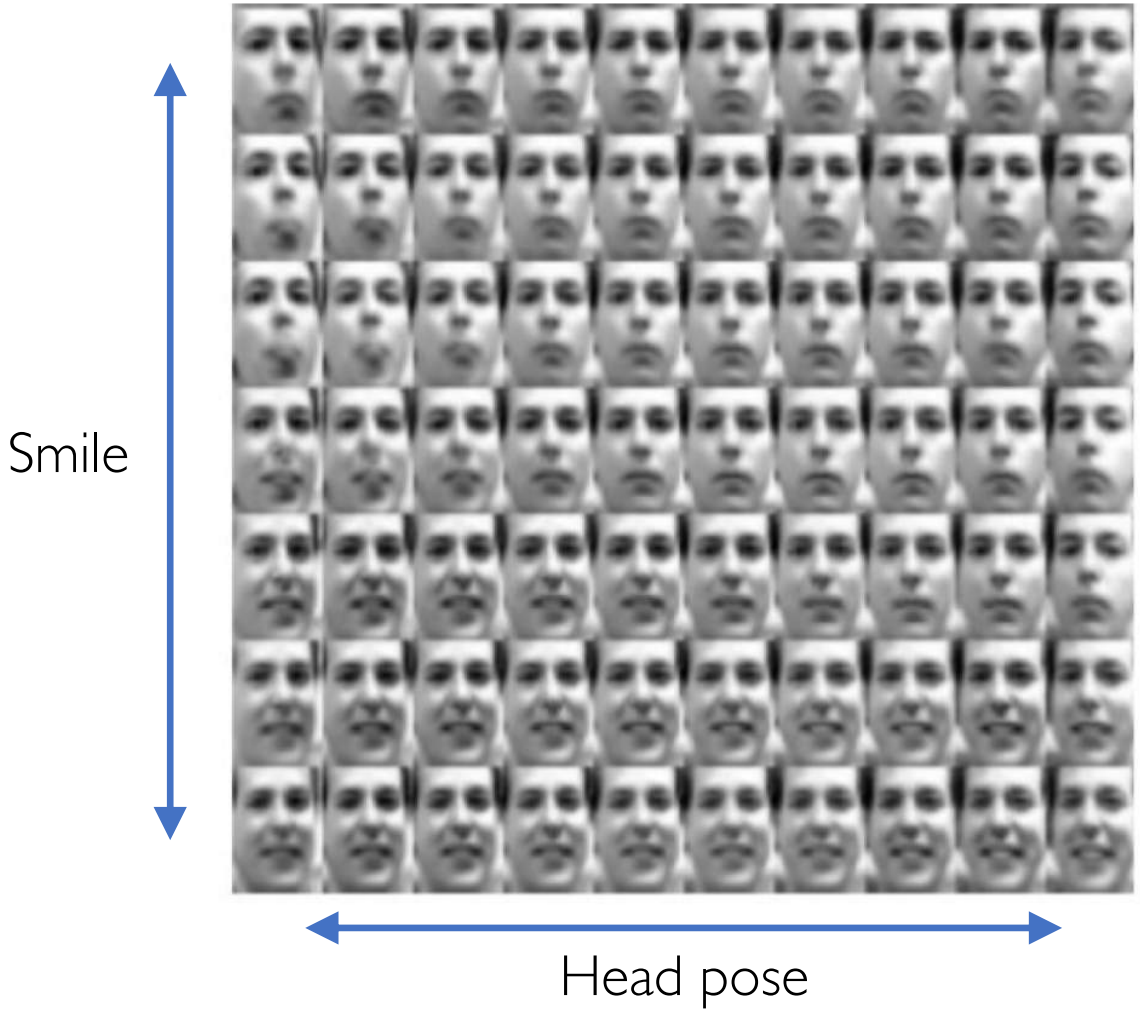
Slowly increase or decrease a **single latent variable**
Keep all other variables fixed



Head pose

Different dimensions of z encodes **different interpretable latent features**

VAEs: Latent perturbation

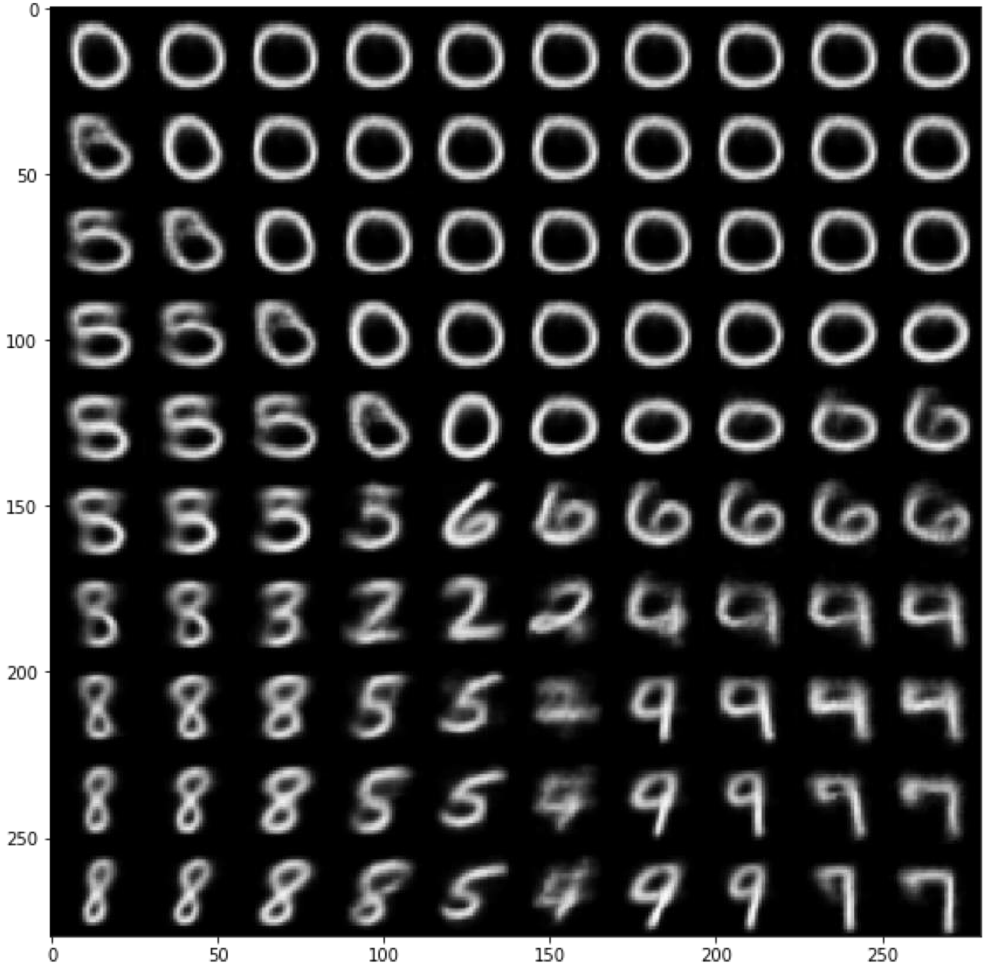


Ideally, we want latent variables that are uncorrelated with each other

Enforce diagonal prior on the latent variables to encourage independence

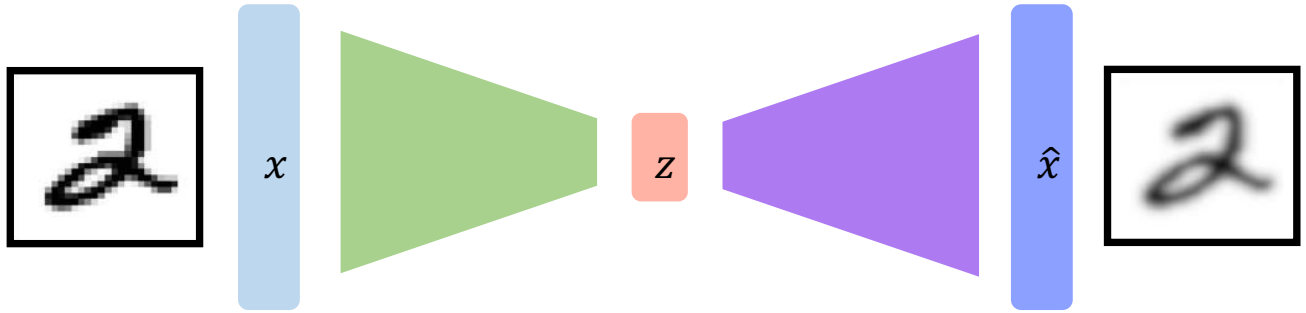
Disentanglement

VAEs: Latent perturbation



VAE summary

1. Compress representation of world to something we can use to learn
2. Reconstruction allows for unsupervised learning (no labels!)
3. Reparameterization trick to train end-to-end
4. Interpret hidden latent variables using perturbation
5. Generating new examples

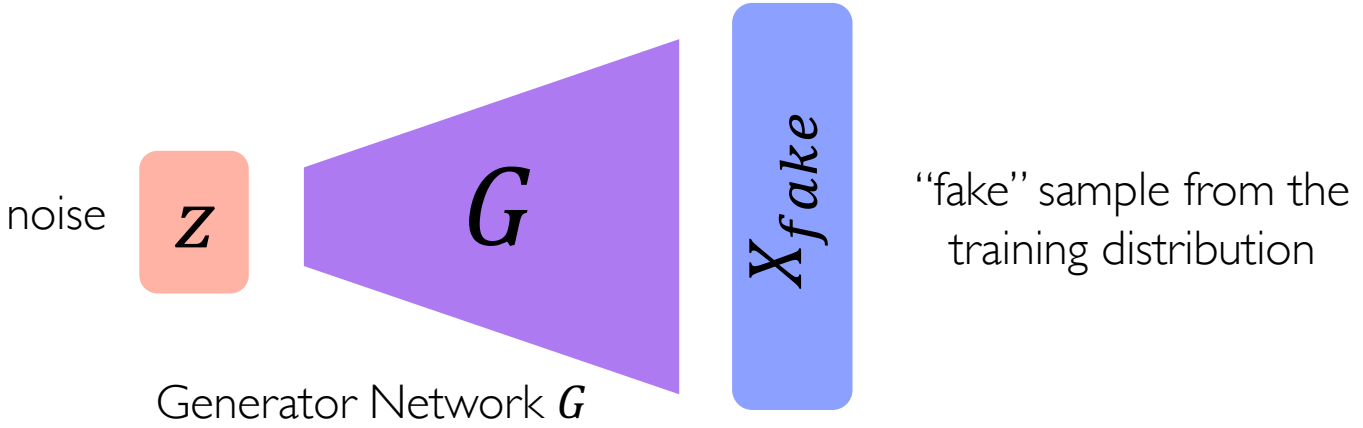


What if we just want to sample?

Idea: don't explicitly model density, and instead just sample to generate new instances.

Problem: want to sample from complex distribution – can't do this directly!

Solution: sample from something simple (noise), learn a transformation to the training distribution.

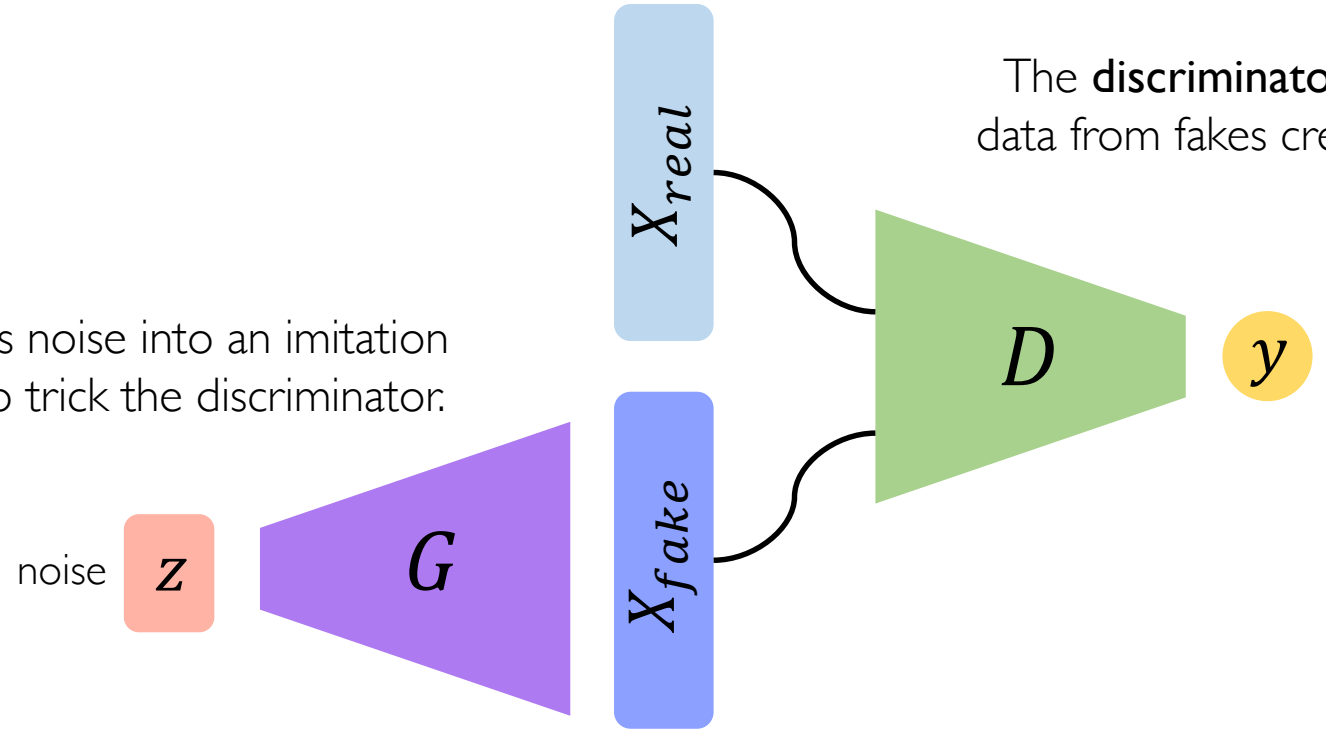


Generative Adversarial Networks (GANs)

Generative Adversarial Networks (GANs) are a way to make a generative model by having two neural networks compete with each other.

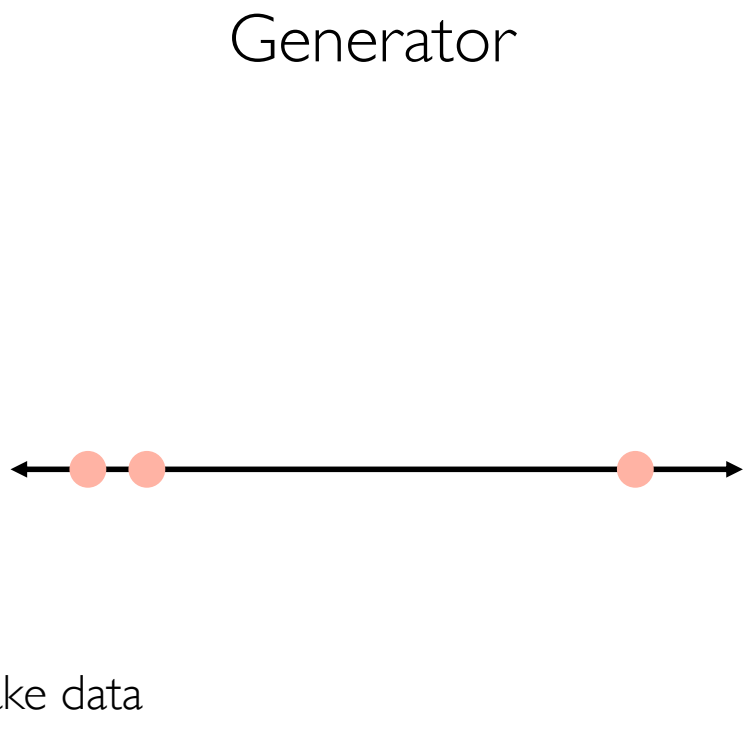
The **discriminator** tries to identify real data from fakes created by the generator.

The **generator** turns noise into an imitation of the data to try to trick the discriminator.



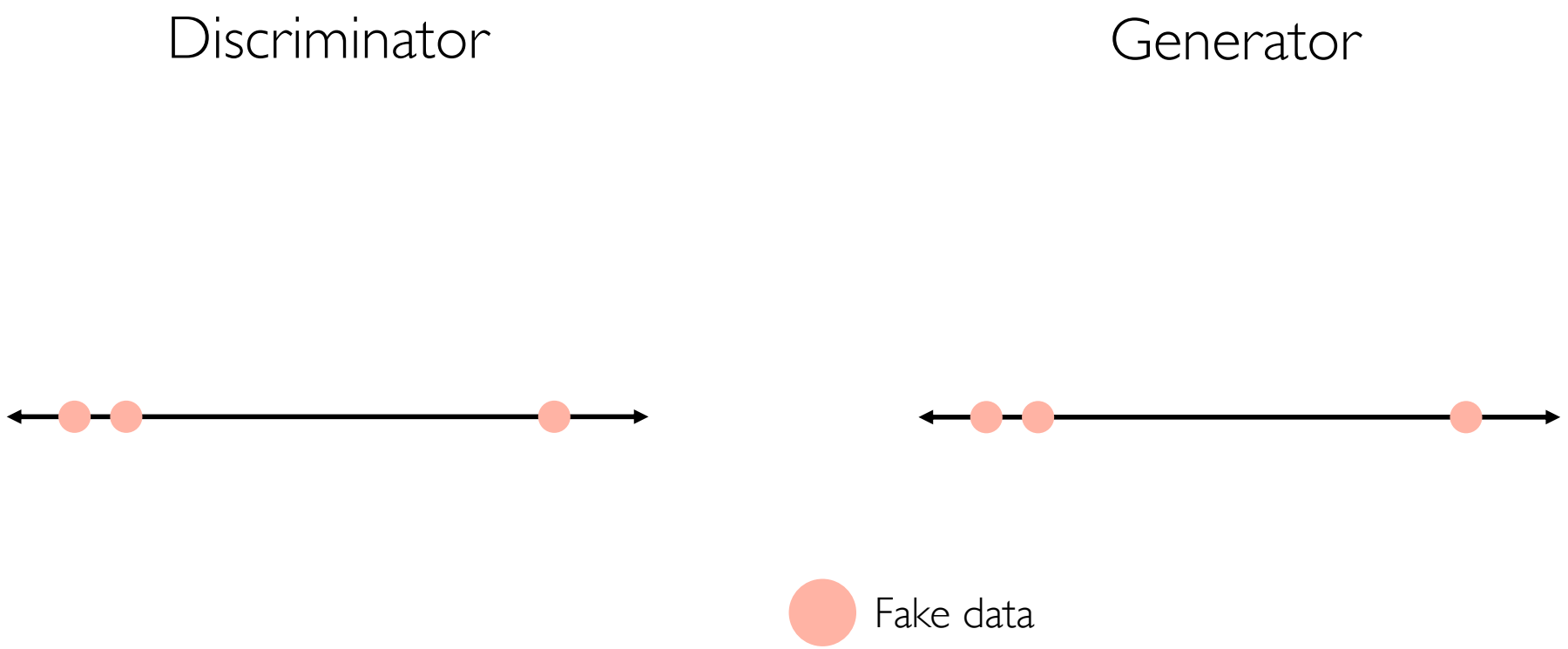
Intuition behind GANs

Generator starts from noise to try to create an imitation of the data.



Intuition behind GANs

Discriminator looks at both real data and fake data created by the generator.



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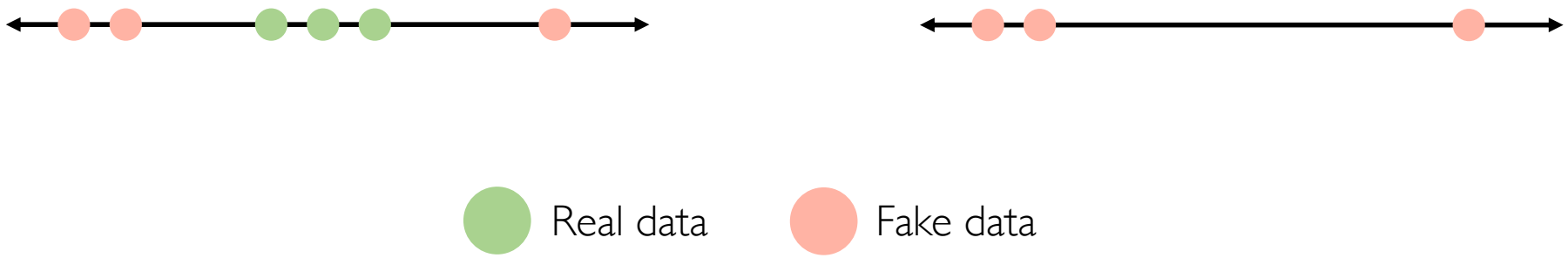
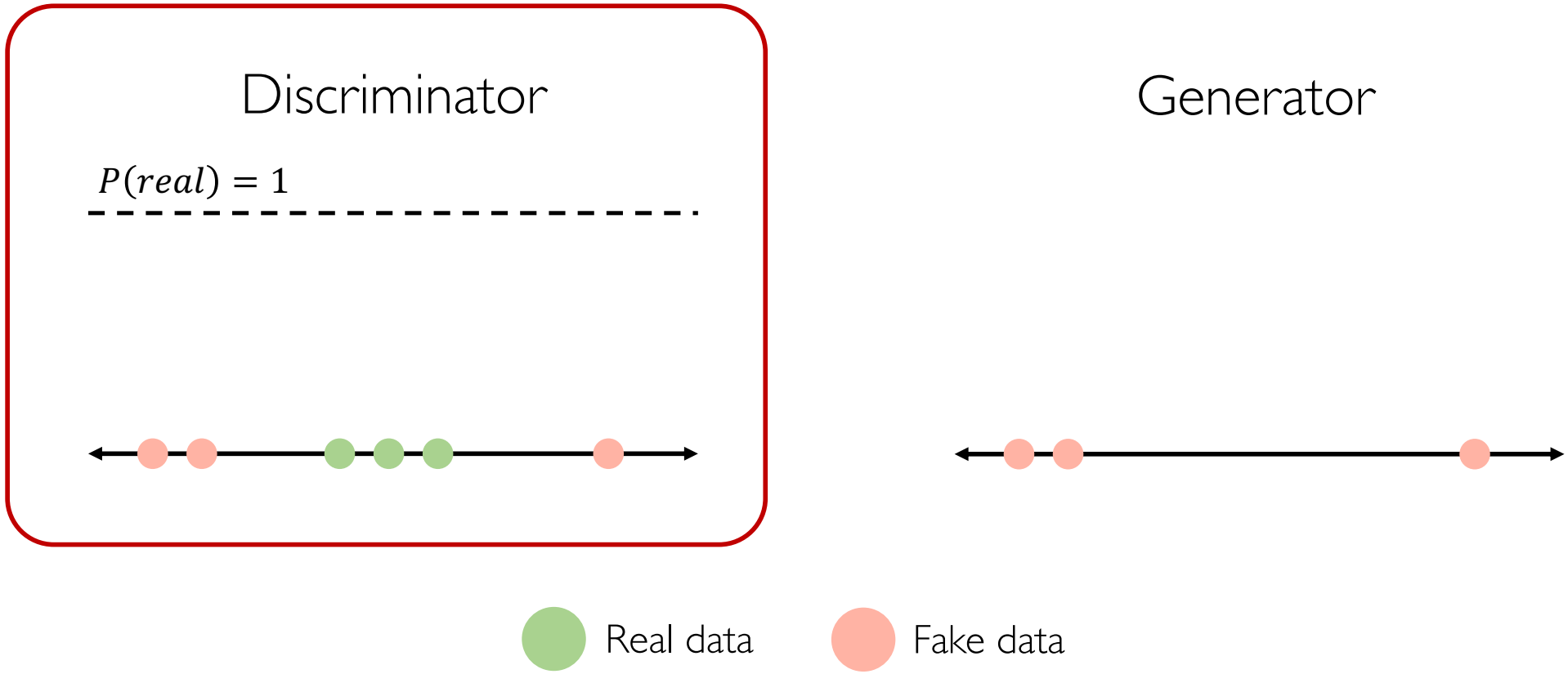
Discriminator

Generator



Intuition behind GANs

Discriminator tries to predict what's real and what's fake.



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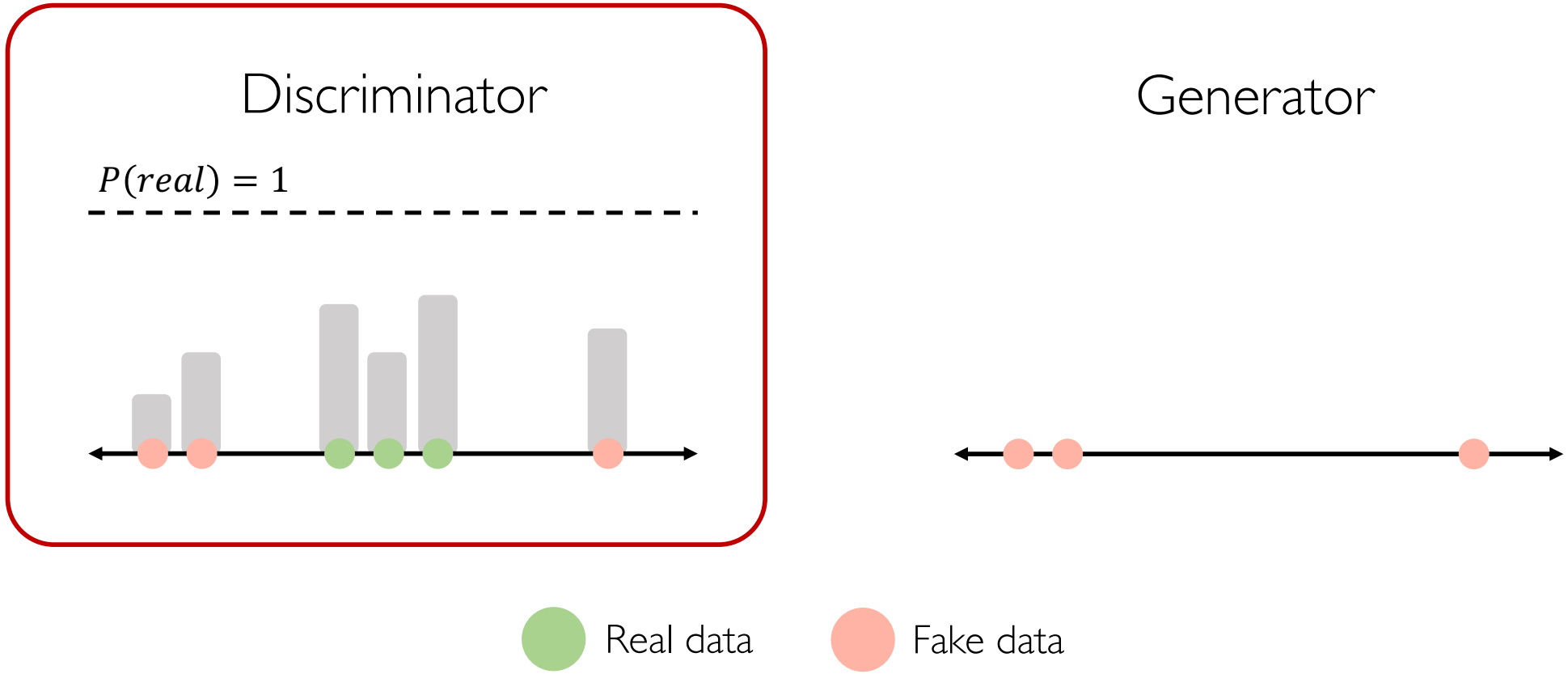

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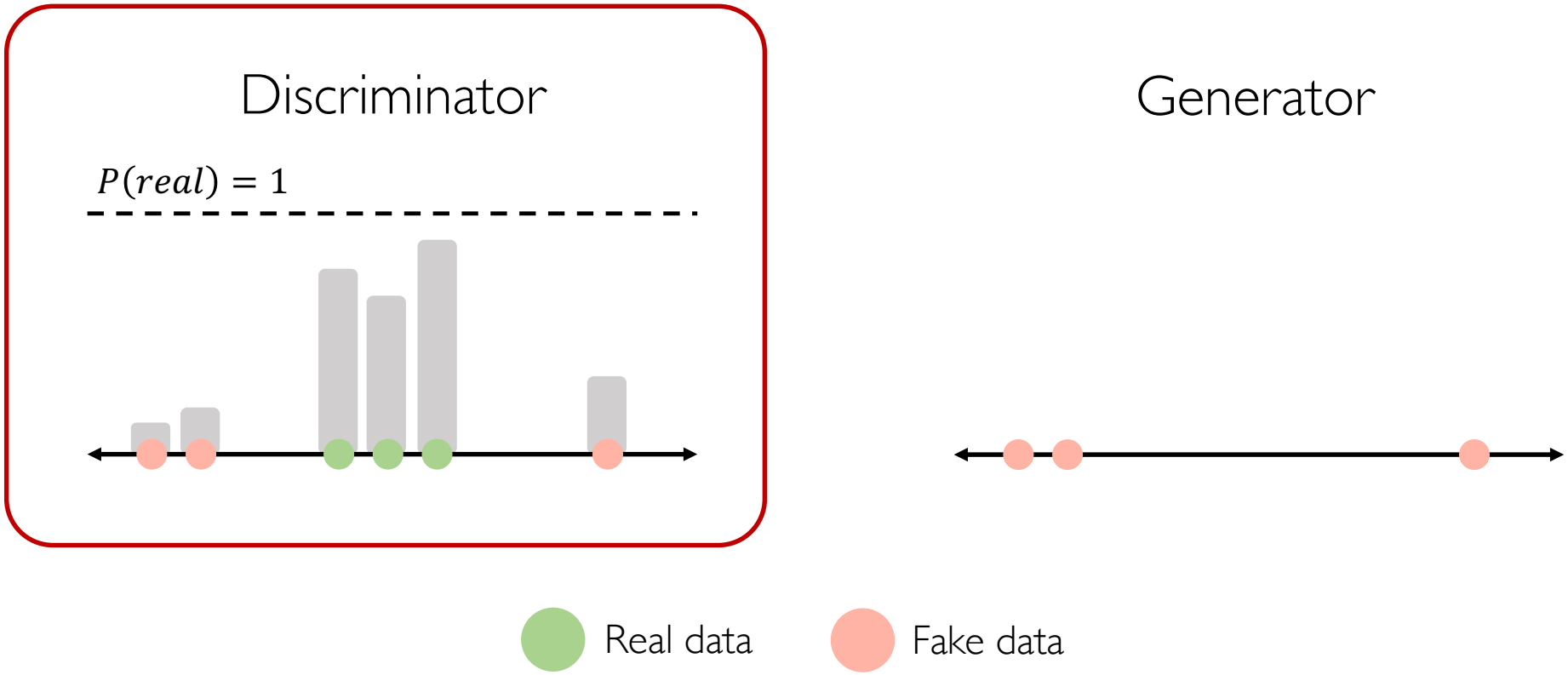

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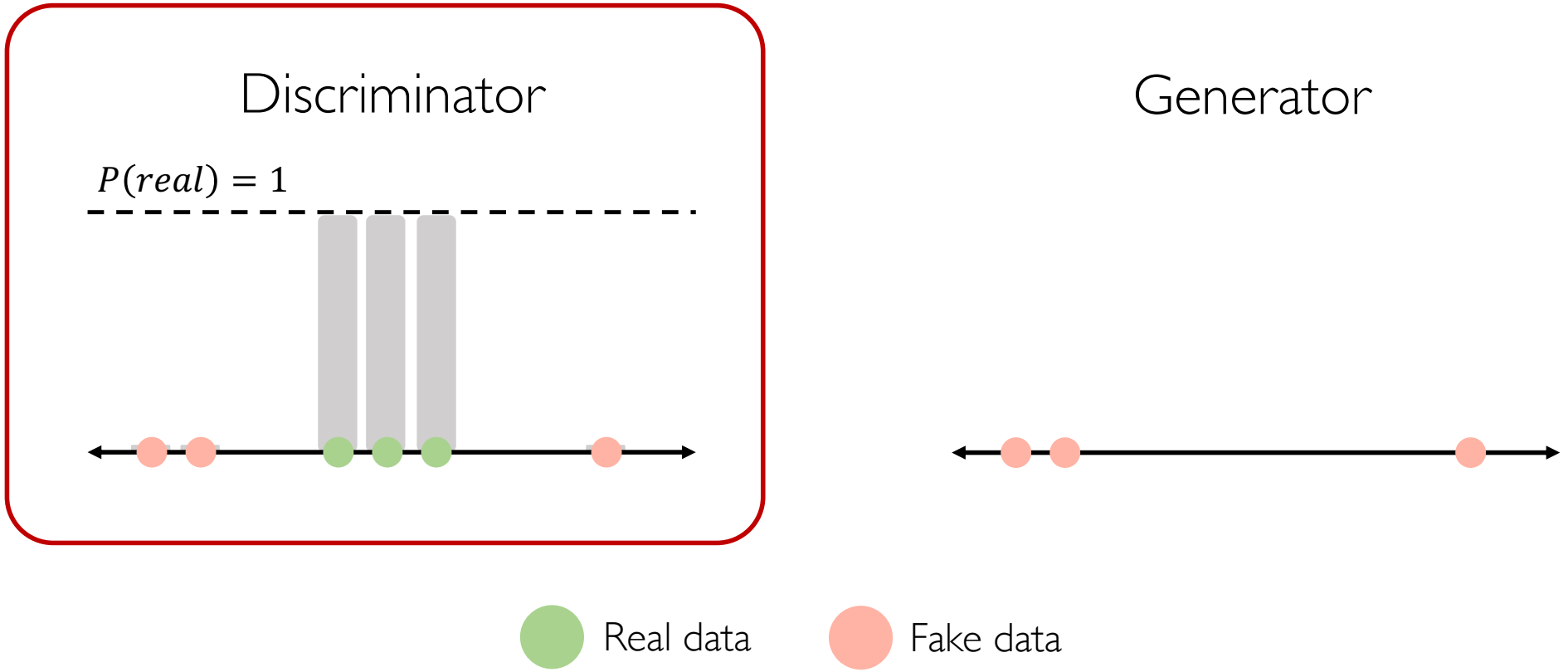
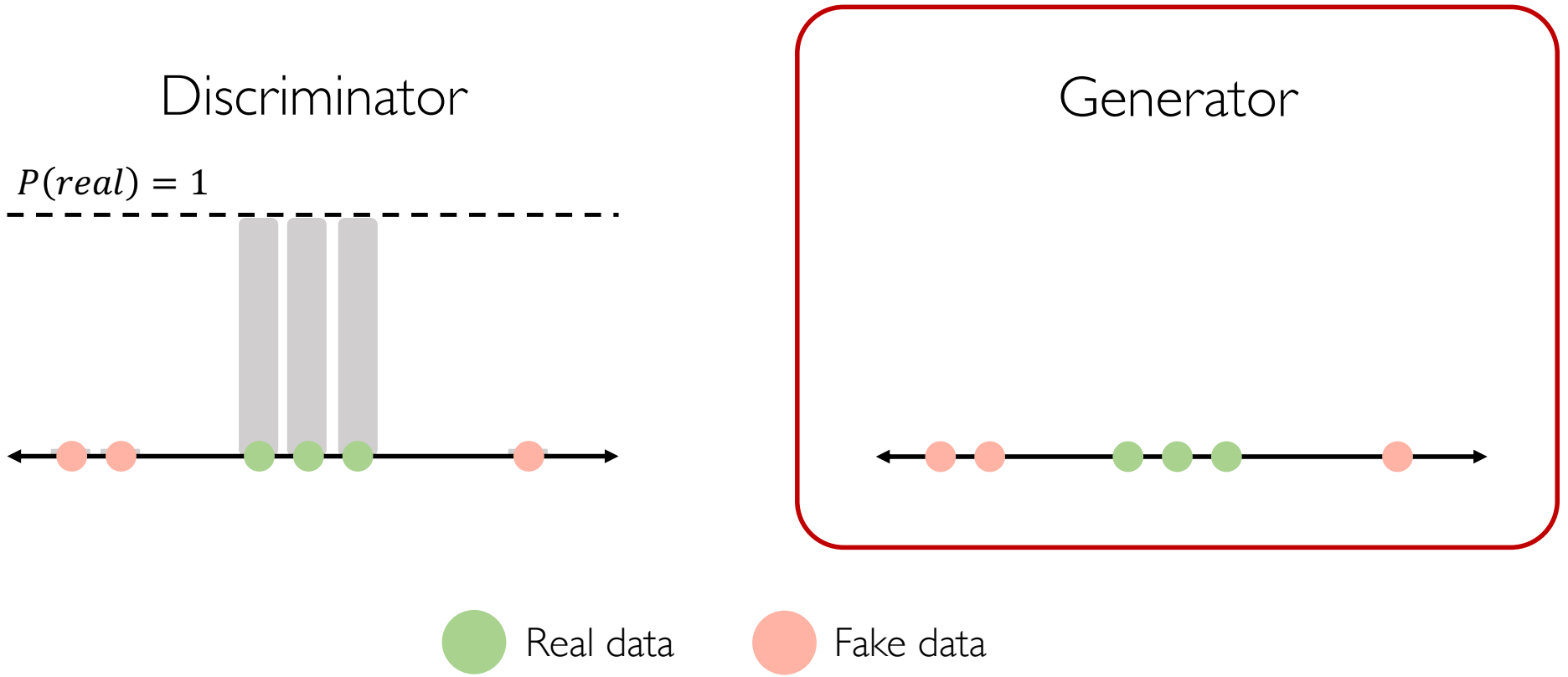


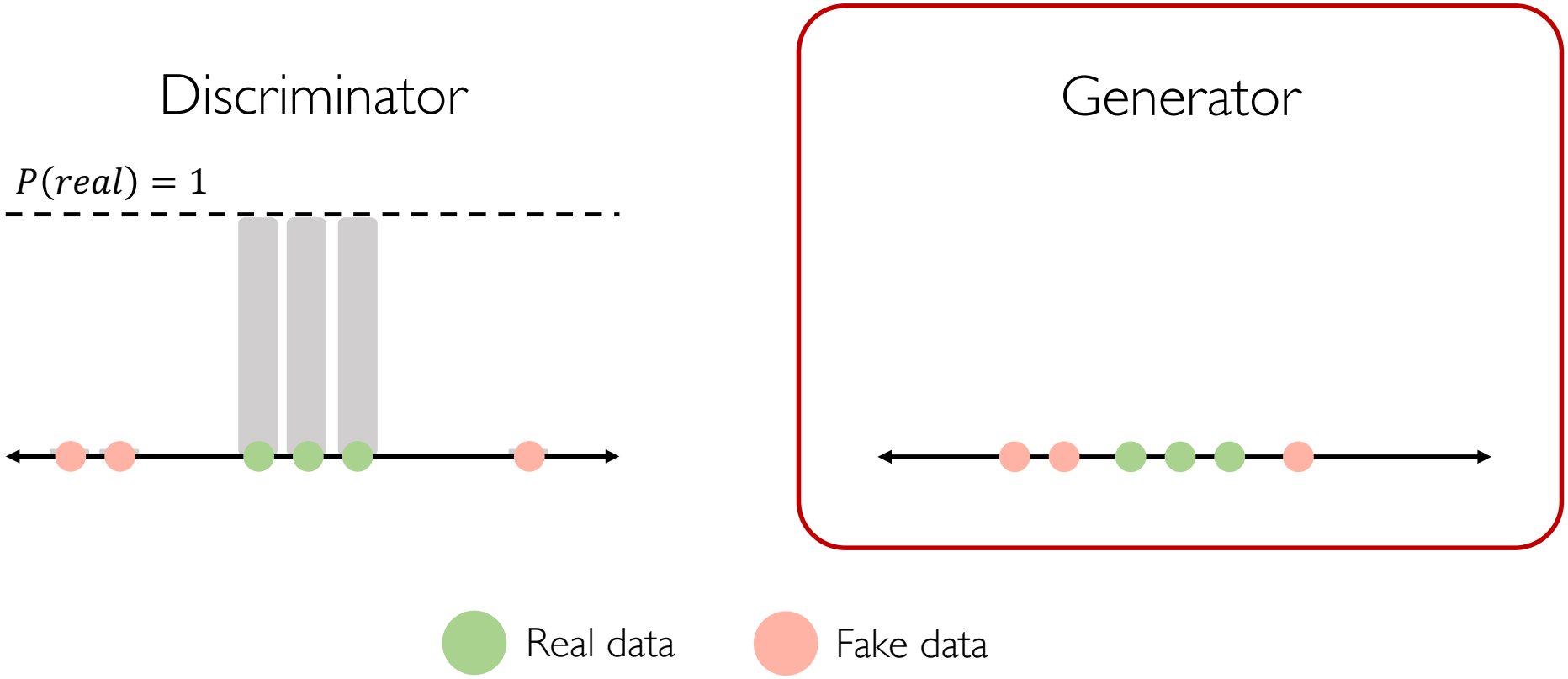
Intuition behind GANs

Generator tries to improve its imitation of the data.



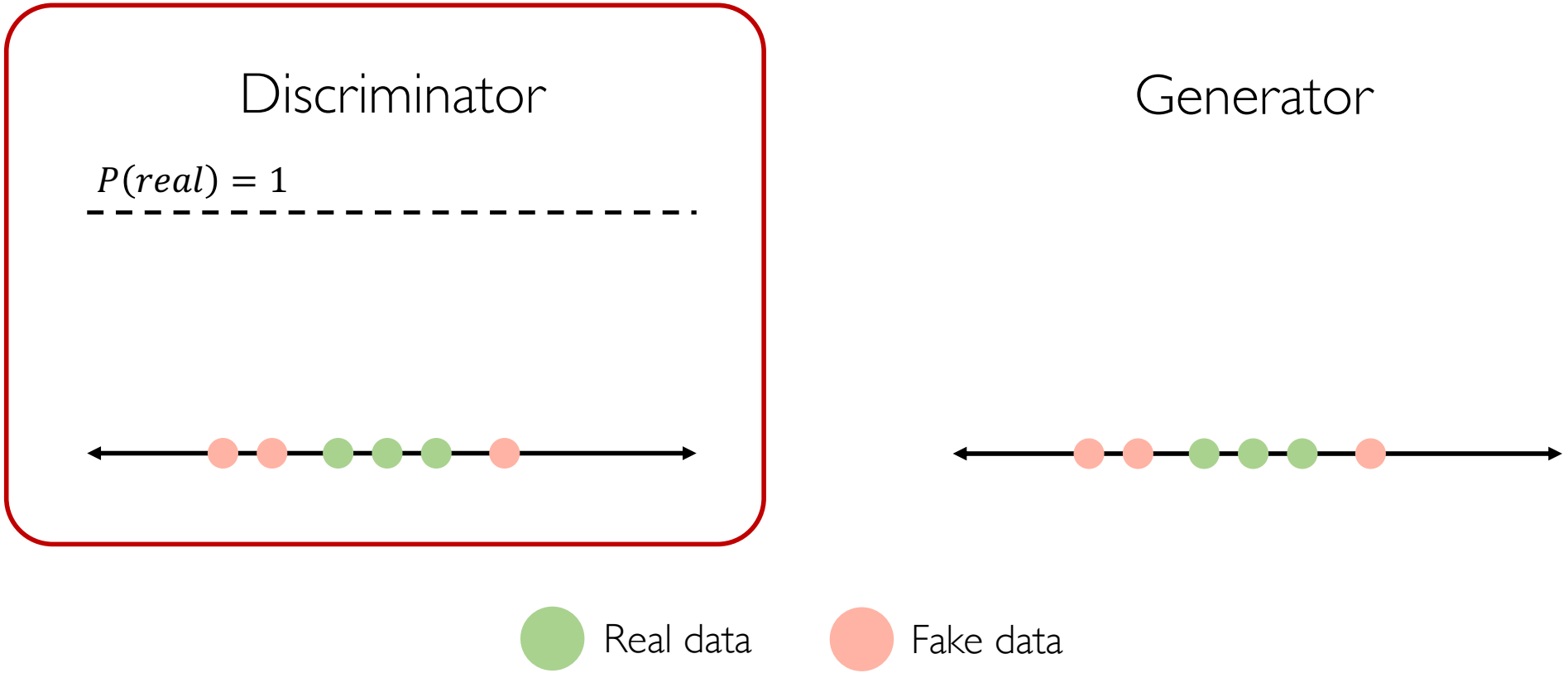
Intuition behind GANs

Generator tries to improve its imitation of the data.



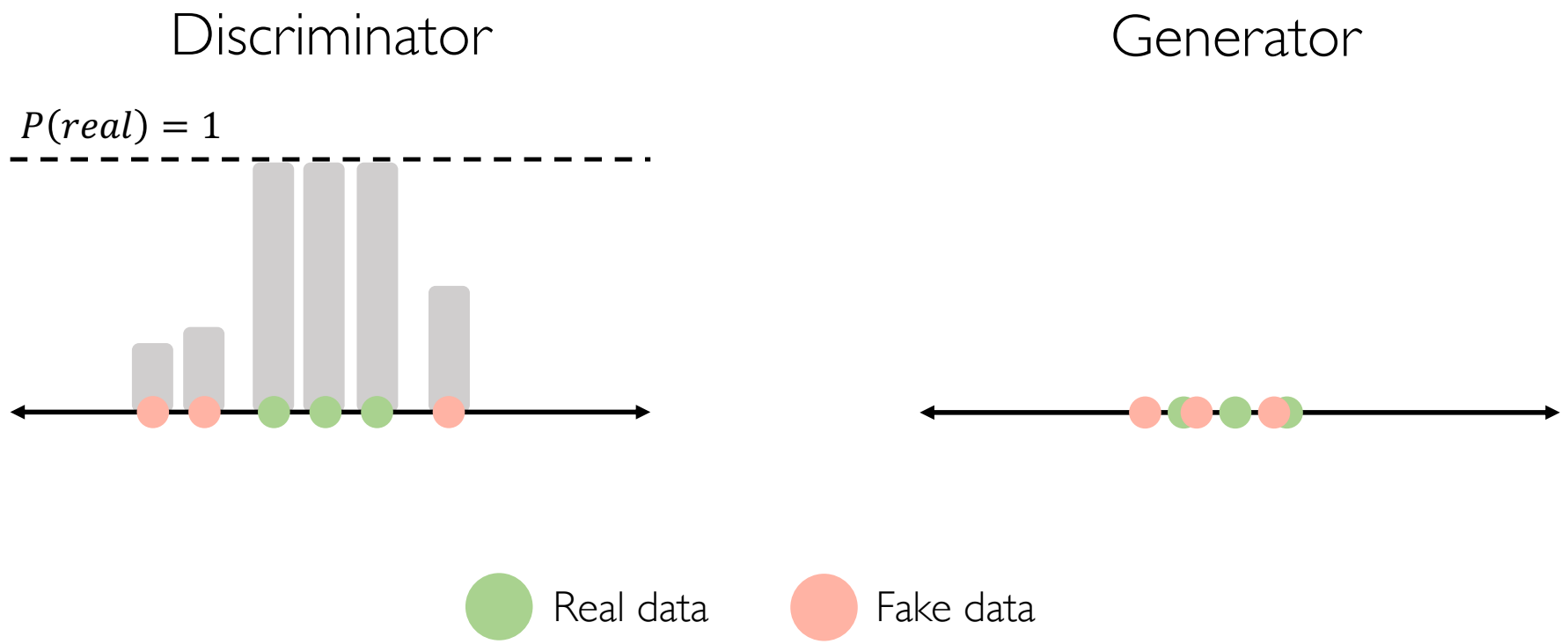
Intuition behind GANs

Discriminator tries to predict what's real and what's fake.



Intuition behind GANs

Discriminator tries to identify real data from fakes created by the generator.
Generator tries to create imitations of data to trick the discriminator.



Training GANs

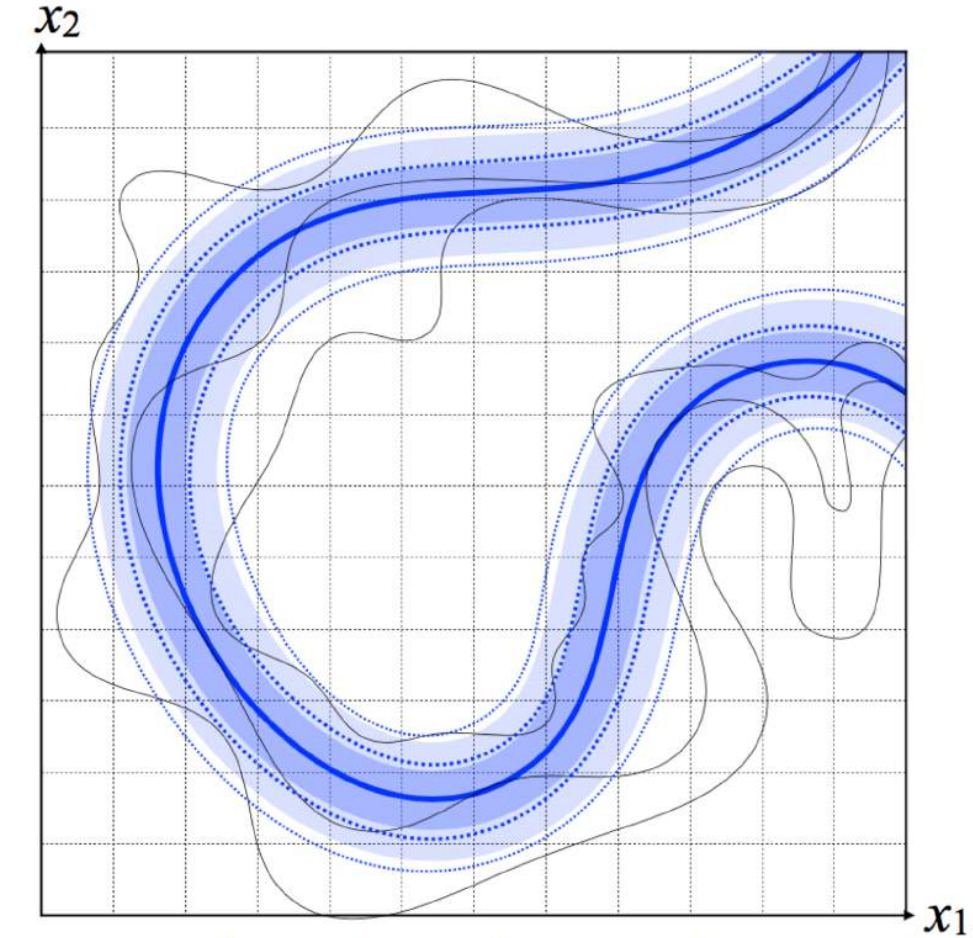
Discriminator tries to identify real data from fakes created by the generator.
Generator tries to create imitations of data to trick the discriminator.

Train GAN jointly via **minimax** game:

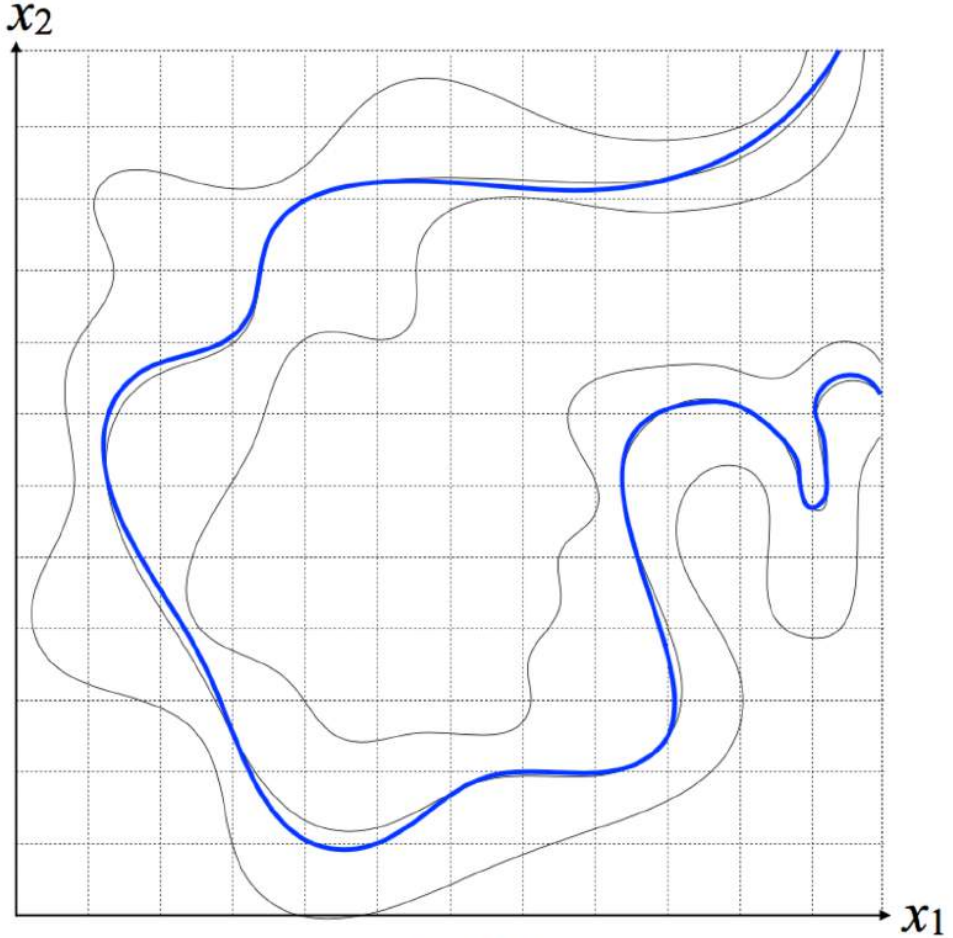
$$\min_{\theta_g} \max_{\theta_d} \left[\mathbb{E}_{x \sim p_{data}} \log D_{\theta_d}(x) + \mathbb{E}_{z \sim p(z)} \log \left(1 - D_{\theta_d} \left(G_{\theta_g}(z) \right) \right) \right]$$

Discriminator wants to maximize objective s.t. $D(x)$ close to 1, $D(G(z))$ close to 0.
Generator wants to minimize objective s.t. $D(G(z))$ close to 1.

Why GANs?



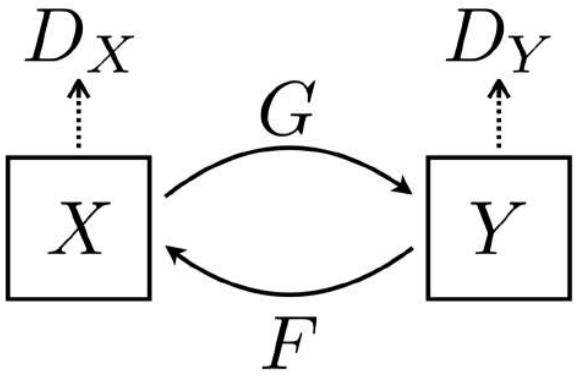
more traditional max-likelihood approach



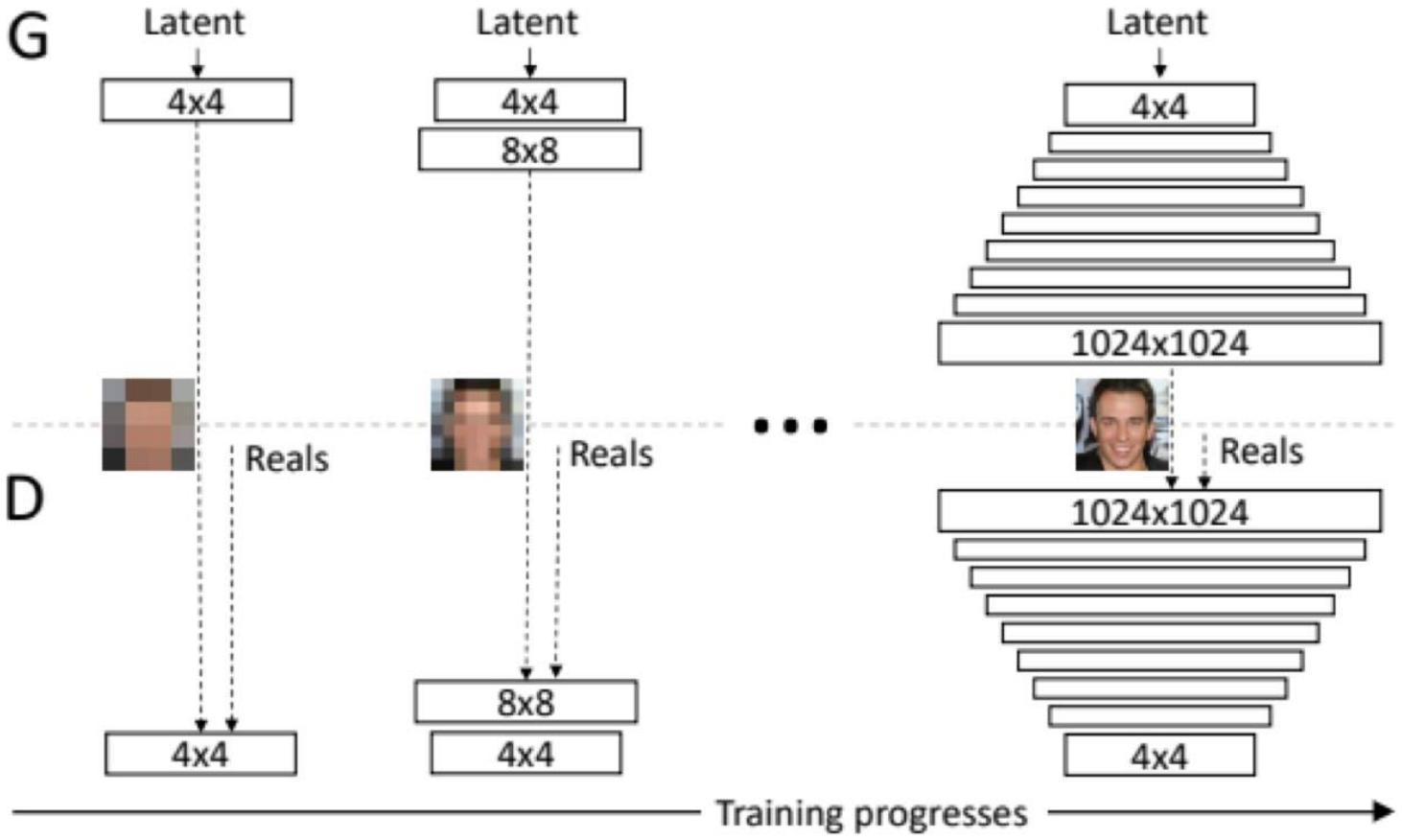
GAN

CycleGAN: domain transformation

CycleGAN learns transformations across domains with unpaired data.

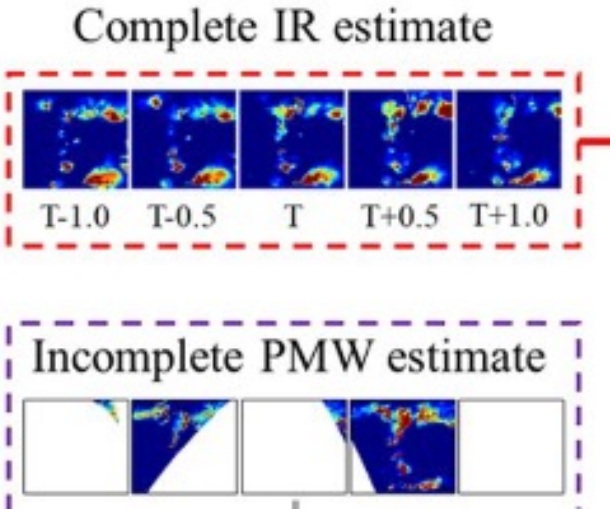


Progressive growing of GANs (NVIDIA)



Karras et al., ICLR 2018.

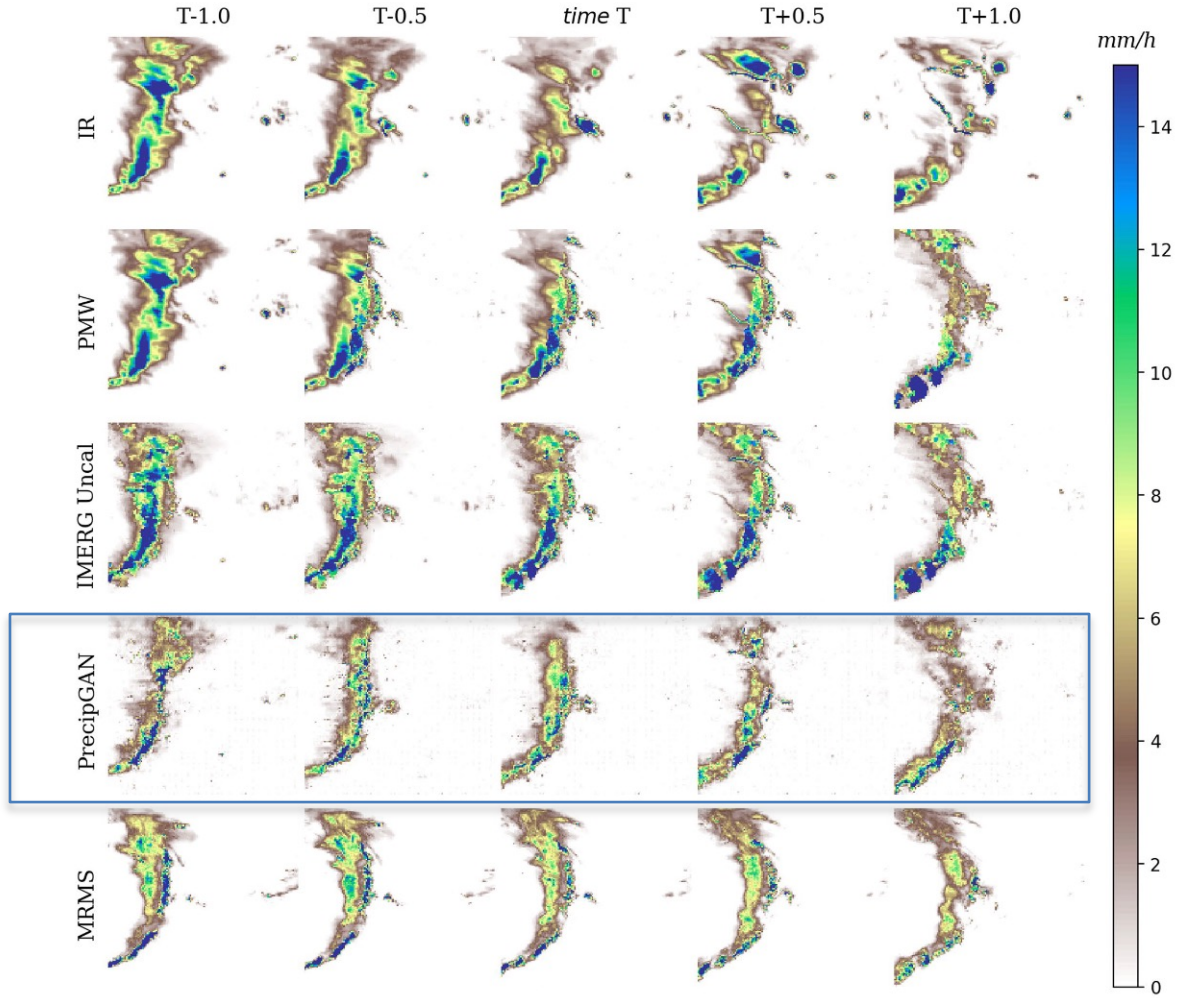
GANs applications



Method:
Generative models (cGANs)
Resolution: 1km

cGAN

Radar



PrecipGAN: Merging Microwave and Infrared Data for Satellite Precipitation Estimation Using Generative Adversarial Network

Cunguang Wang[1,2], Guoqiang Tang[3,4], and Pierre Gentine[2]