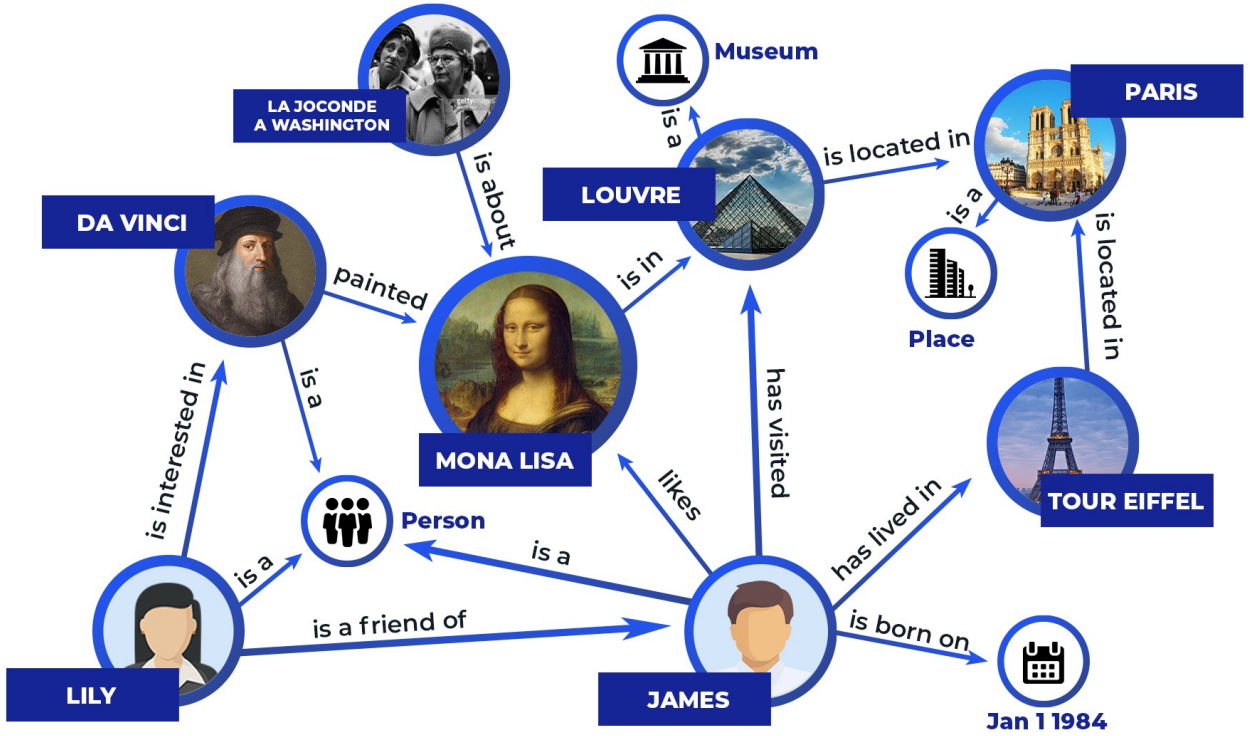
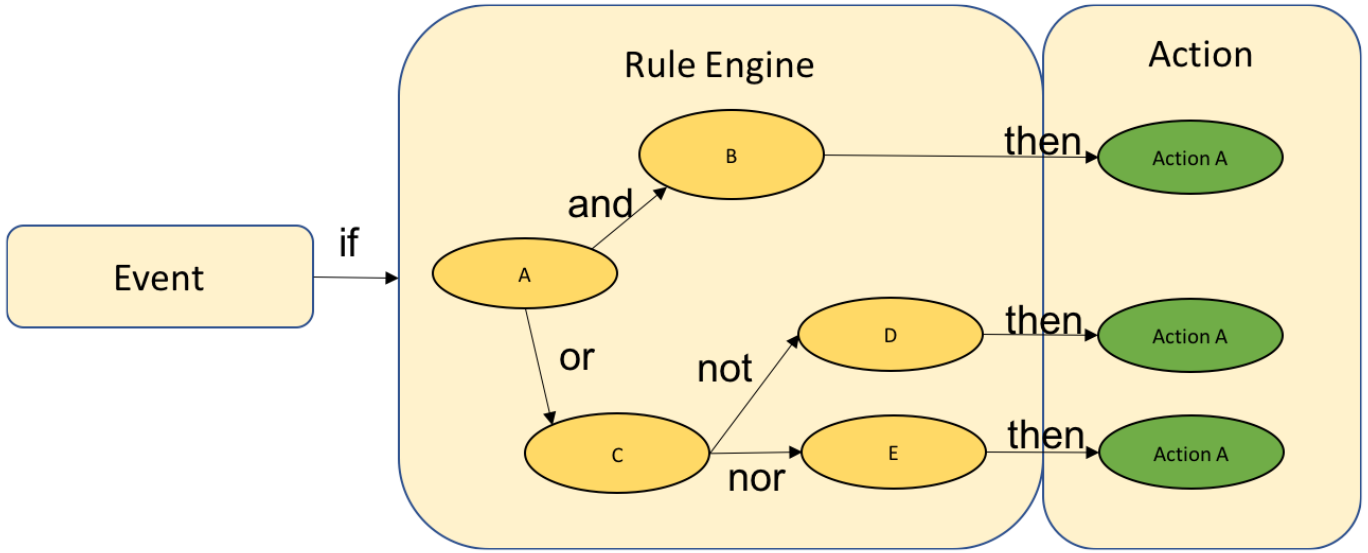
Generative Modeling: Introduction & Overview

Artificial Intelligence

- The field dealing with enabling computer-based systems to perform sophisticated tasks, such as automated reasoning, language translation, or visual perception.

- Siri, Alexa.
  Amazon/Netflix recommendations.
  Knowledge Graphs.
  Rules engines.





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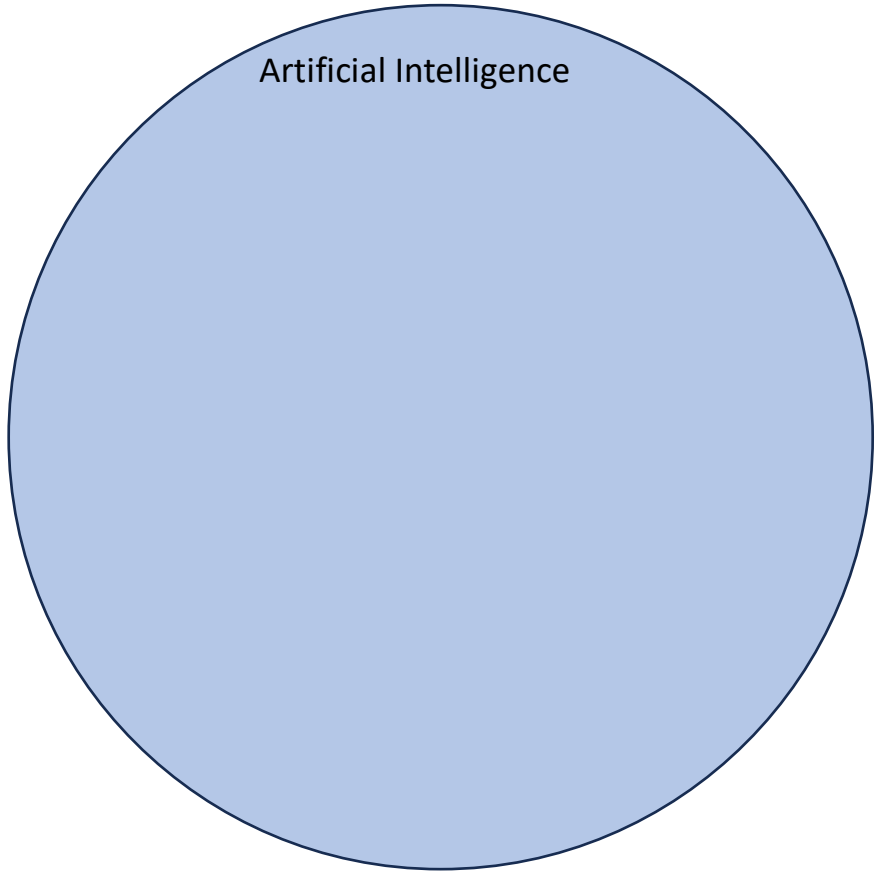
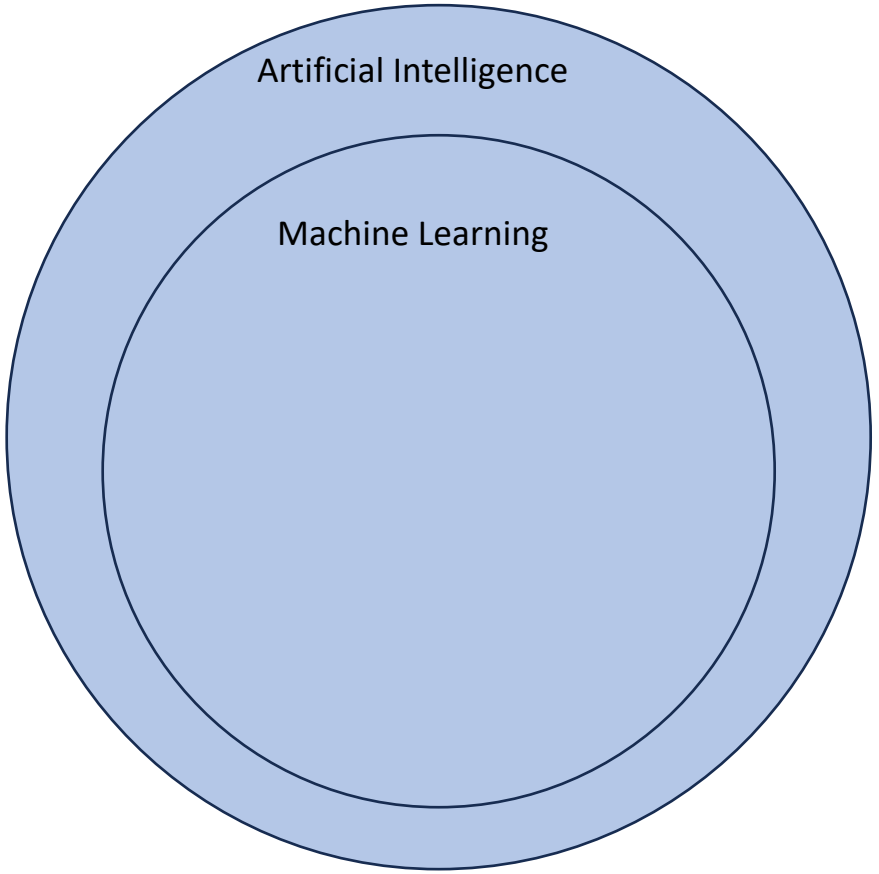


Machine Learning

- A branch of AI that specifically focuses on enabling computer-based systems to infer models from data. The ``learning'' expresses the ability of an algorithm to progressively improve its performance by processing data and information.

- Siri, Alexa (?).
  Amazon/Netflix recommendations.
  ~~Knowledge Graphs.~~
  ~~Rules Engines~~.



Machine Learning

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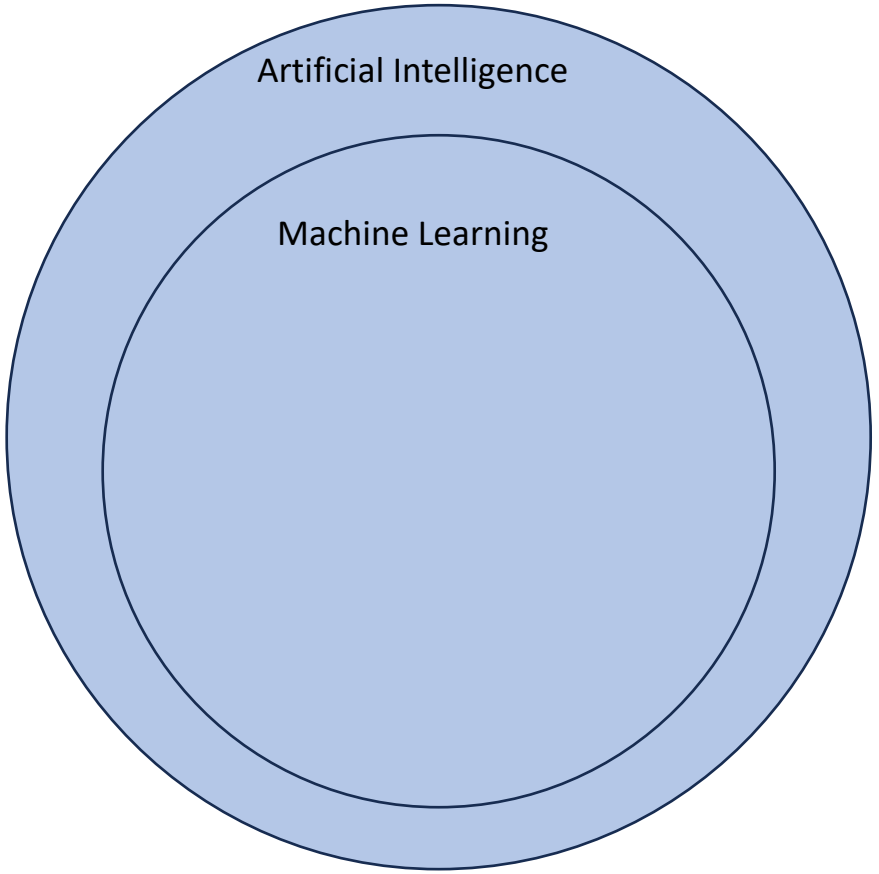
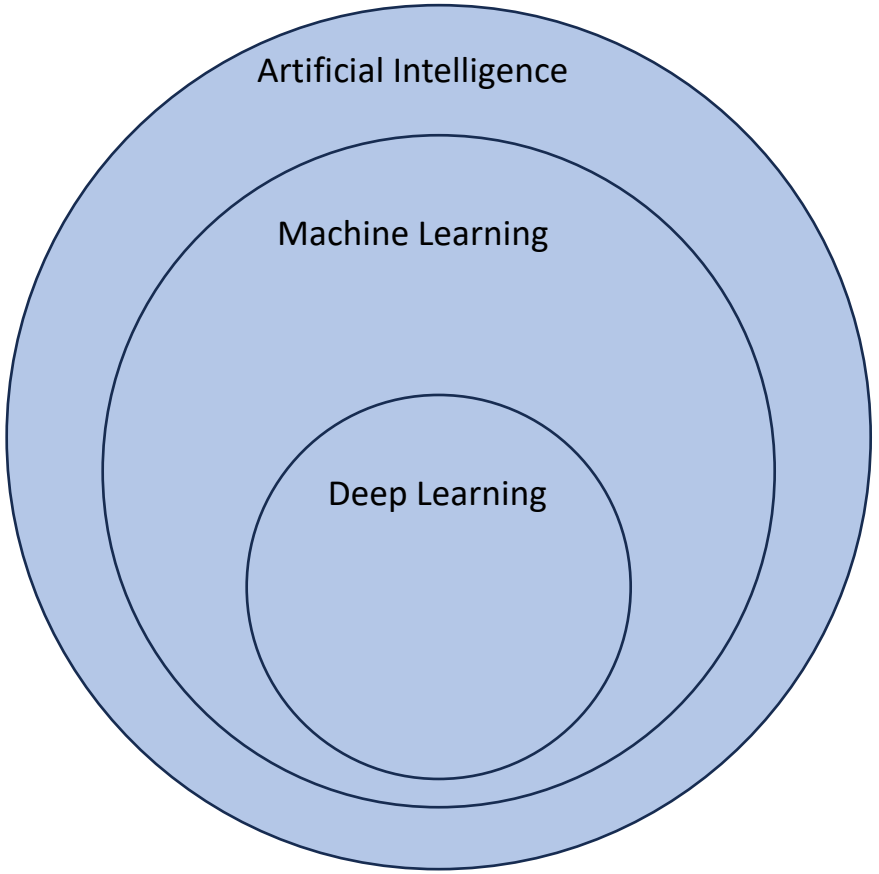
- Random Forests, Gradient Boosted Trees, PGMs, Neural Networks.



Deep Learning

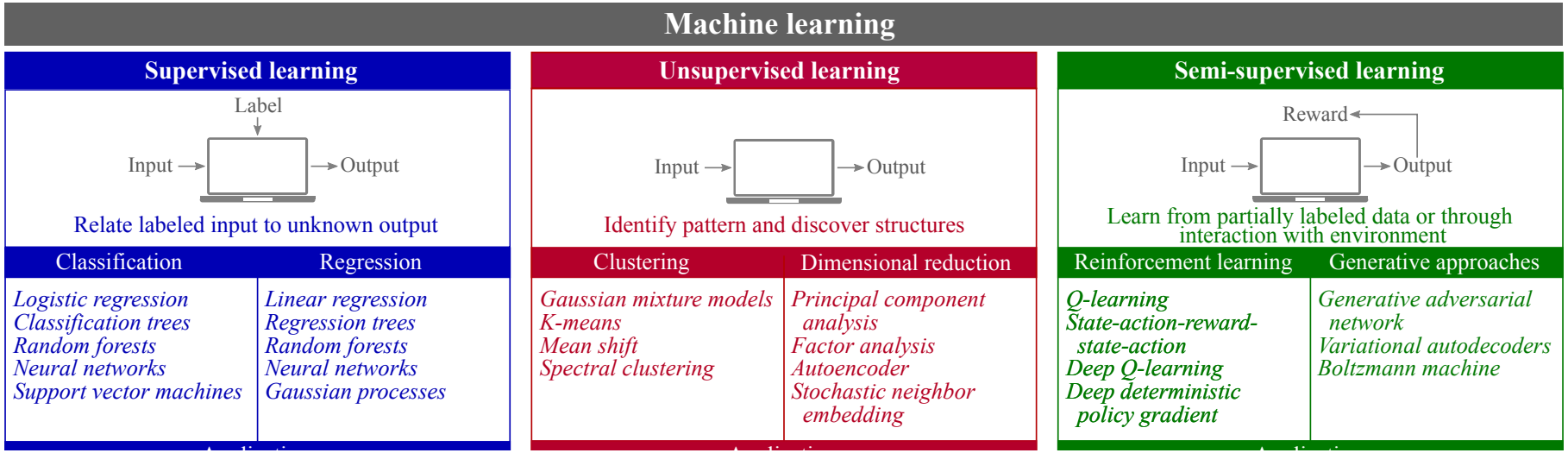
- Deep learning is a class of ML in which multilayer representations are utilized to extract hierarchical features from a complex input.

- Common deep learning models are based on neural network architectures and include CNNs, RNNs, deep belief networks, etc.



Machine Learning: Types of learning

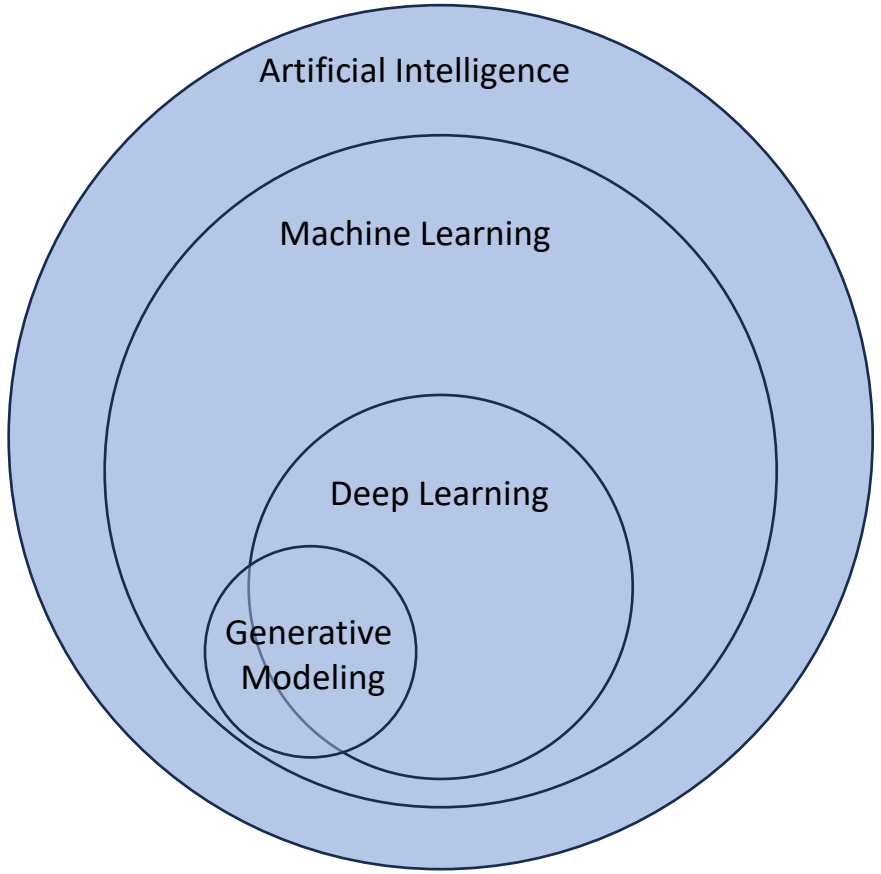
- Supervised.
- Unsupervised.
- Semi-supervised/Weak supervision.
- Reinforcement learning.



Generative Modeling

- Focus on not prediction/classification of samples, but creation of new samples or refinement of extant samples.

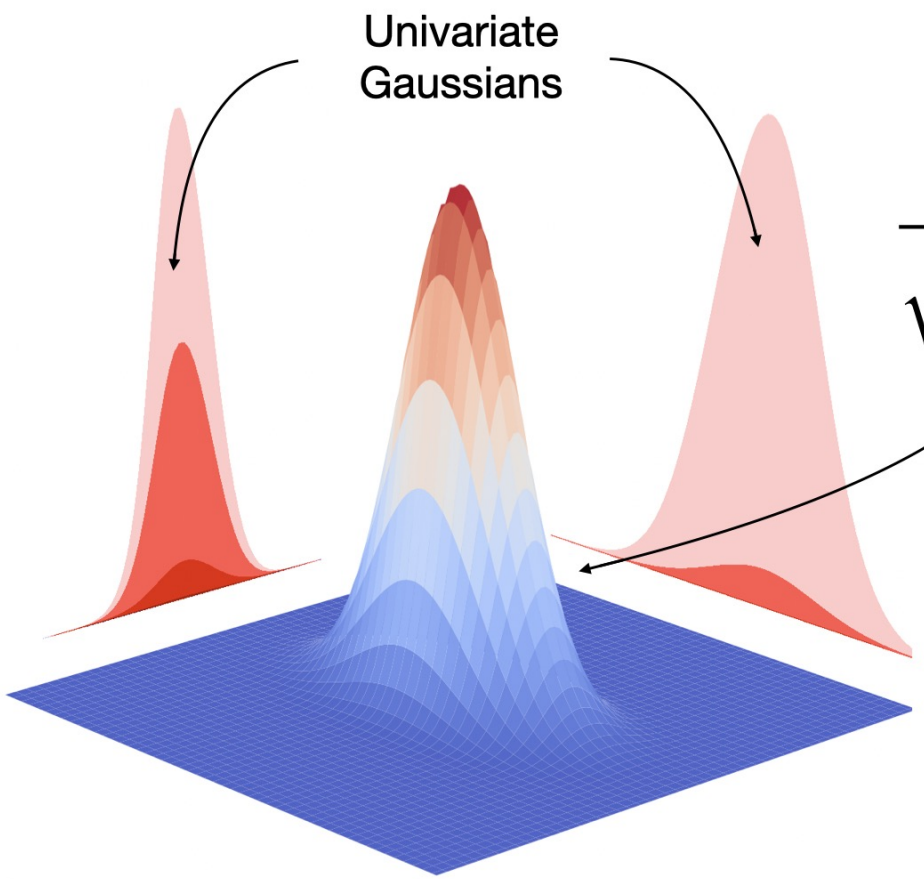
- LLMs (Large Language Models),
  GANs (Generative Adversarial Networks),
  Normalizing Flows,
  Variational Auto-Encoders (VAEs),
  Diffusion Models,
  Autoregressive Models….



Discriminative Versus Generative Modeling

	Discriminative Models	Generative Models
Objective	Used to *predict or classify* samples. (Regression/Classification)	Used to *create* samples inspired by training data.
Learning	Learn conditional distribution of target/label, given the input: P(y|x)	Learn joint distribution of input and output: P(x,y)
Example Application	Given an image, predict its class.	Given a class, generate an image form this class.
Example Algorithm	Logistic Regression	GAN

Example: A (naïve) Generative model

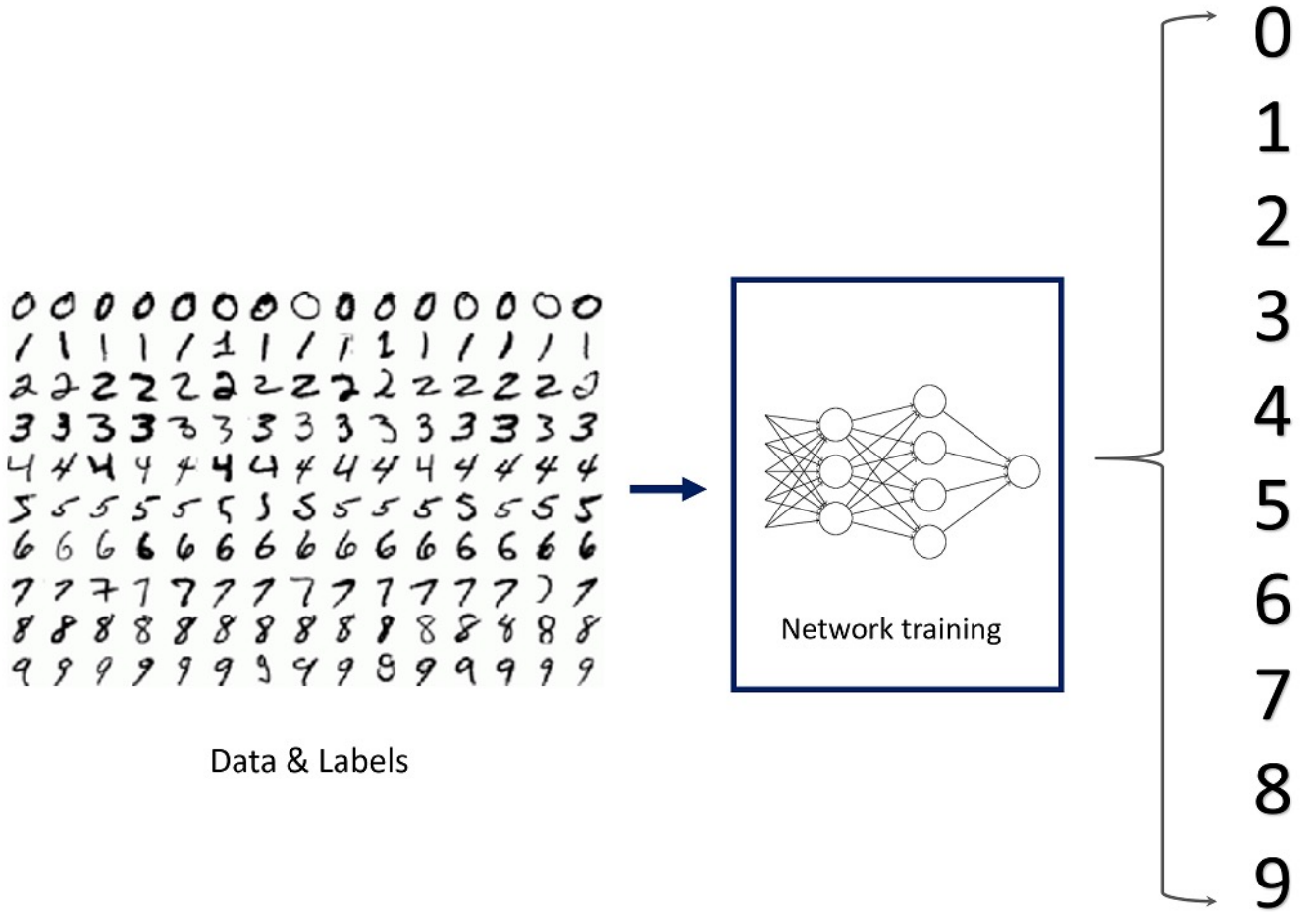


Multivariate
Gaussian

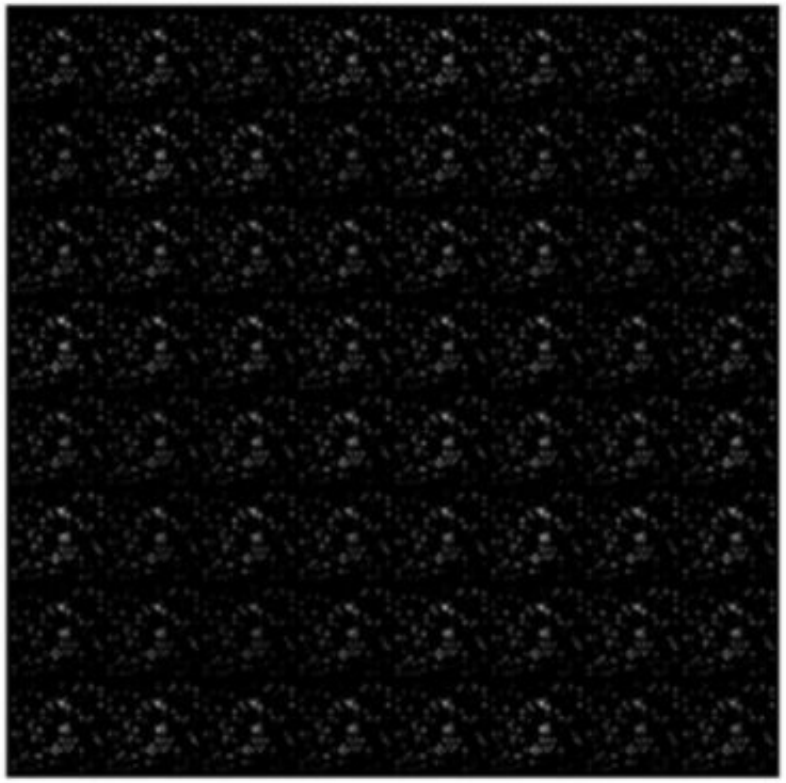
$$\frac{1}{\sqrt{(2\pi)^2\,|\hat{\Sigma}|}} e^{-\frac{1}{2}(\vec{r}-\vec{\mu})^T\hat{\Sigma}^{-1}(\vec{r}-\vec{\mu})}$$

$$\hat{\Sigma} = \begin{pmatrix} \sigma_x^2 & cov(x,y) \\ cov(y,x) & \sigma_y^2 \end{pmatrix}$$

Contrast Example: MNIST Discriminative



Contrast Example: MNIST Generative



Epoch 1

Epoch 100

Epoch 200

How to “Spot” Generative Models?

- Output is a new object from the same space as the training samples. Example 1.
- Output dimensionality is higher than input significantly. Eg images, videos, audio.

Examples of Generative Model Applications

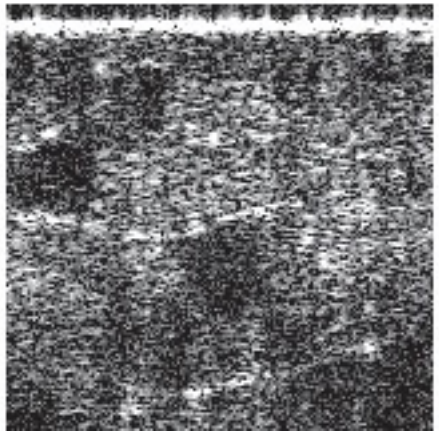
Input	Output
Low resolution Image	High resolution image (Super Resolution)
Image with missing sections	Completed Image (Image completion/Inpainting)
Noisy Image	Clean Image (Denoising)
Image (Black & White)	Image (Eastman Color)
Image	Description (Captioning)
Image	Animation (Sequencing)
Text	Image (Image Generation)

Super Resolution

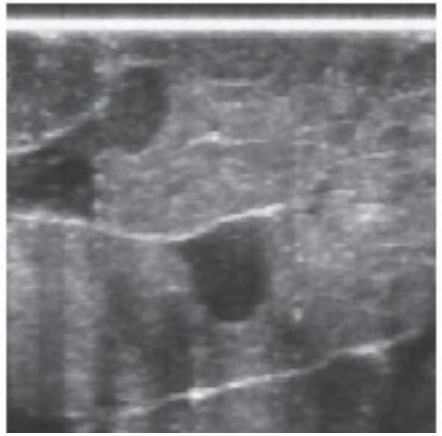
Inpainting

Denoising

Input Image



SM-GAN De-nosing Image



Colorizing


H.RENAUD
TÉLEPHONE
VITTEL
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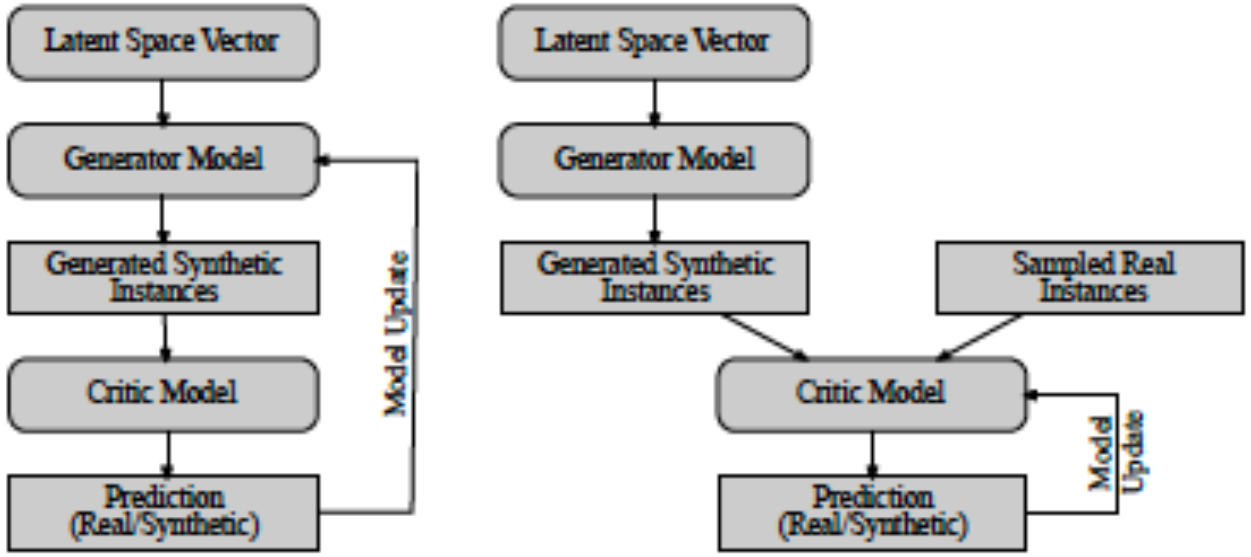
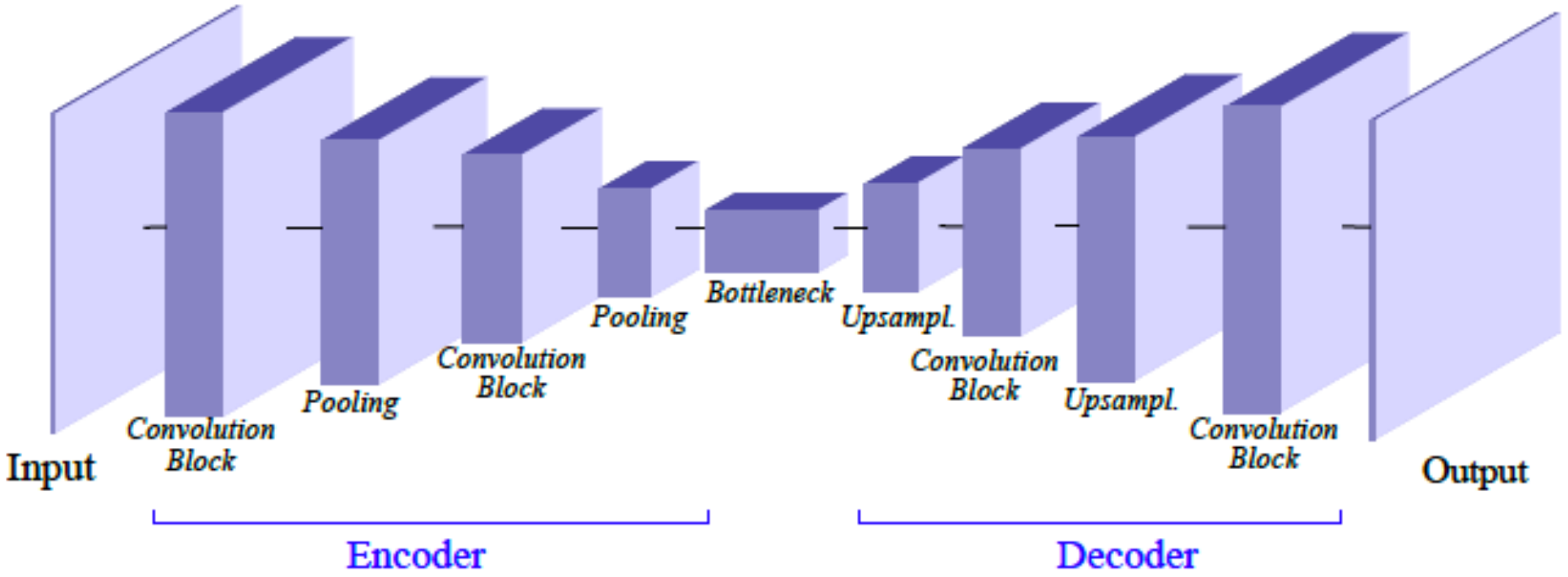
Generative Adversarial Networks



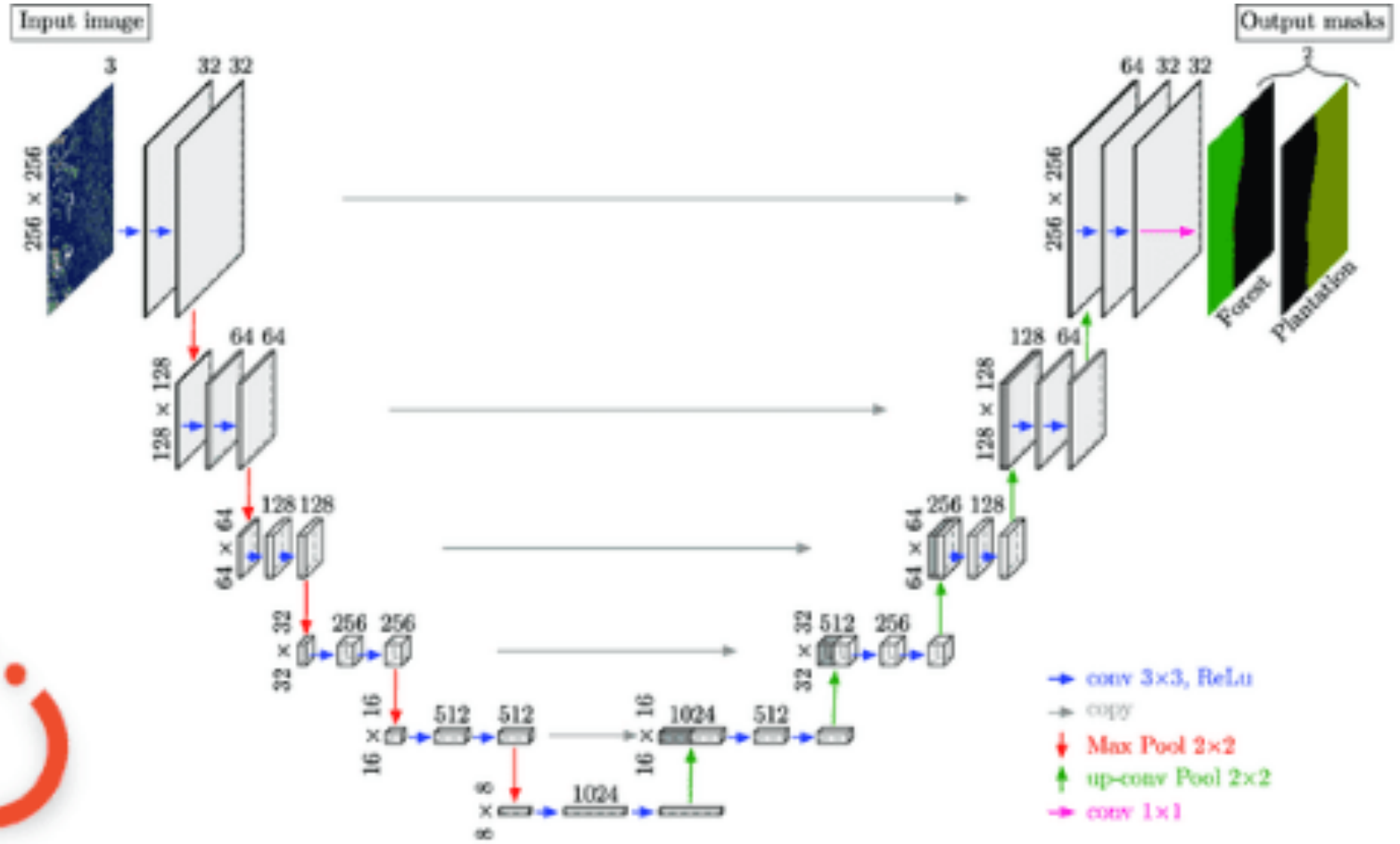
(a) Generator model.

(b) Critic model.

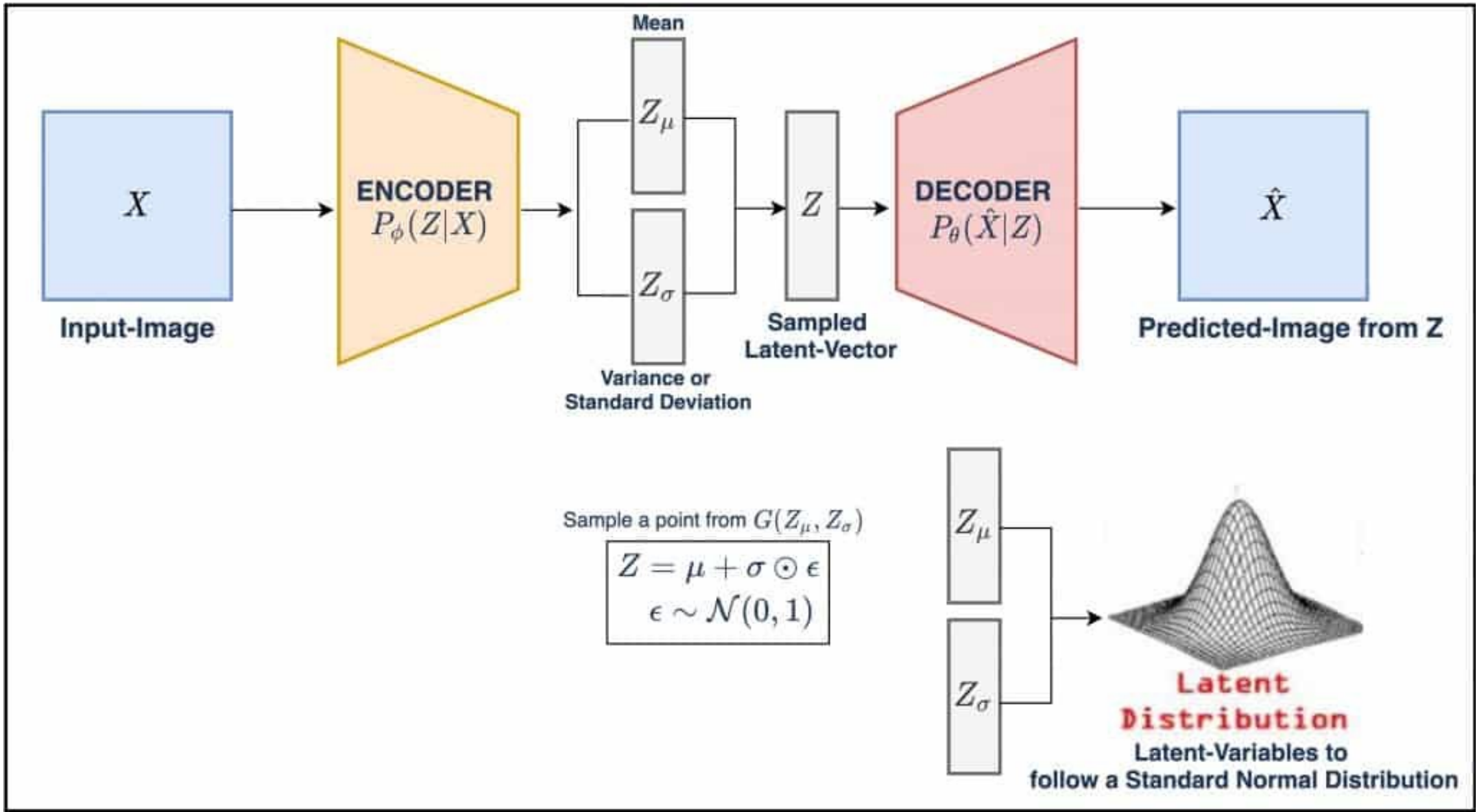
Encoder-Decoder Approaches



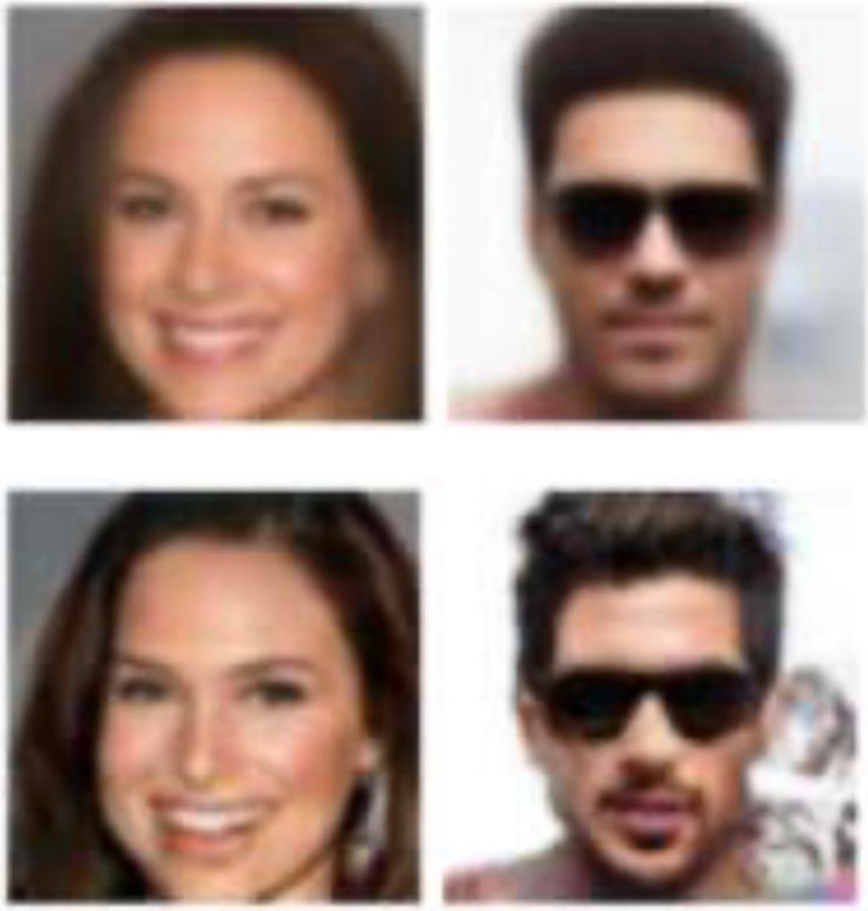
Autoencoders



Variational Auto Encoders



VAEs vs GANs



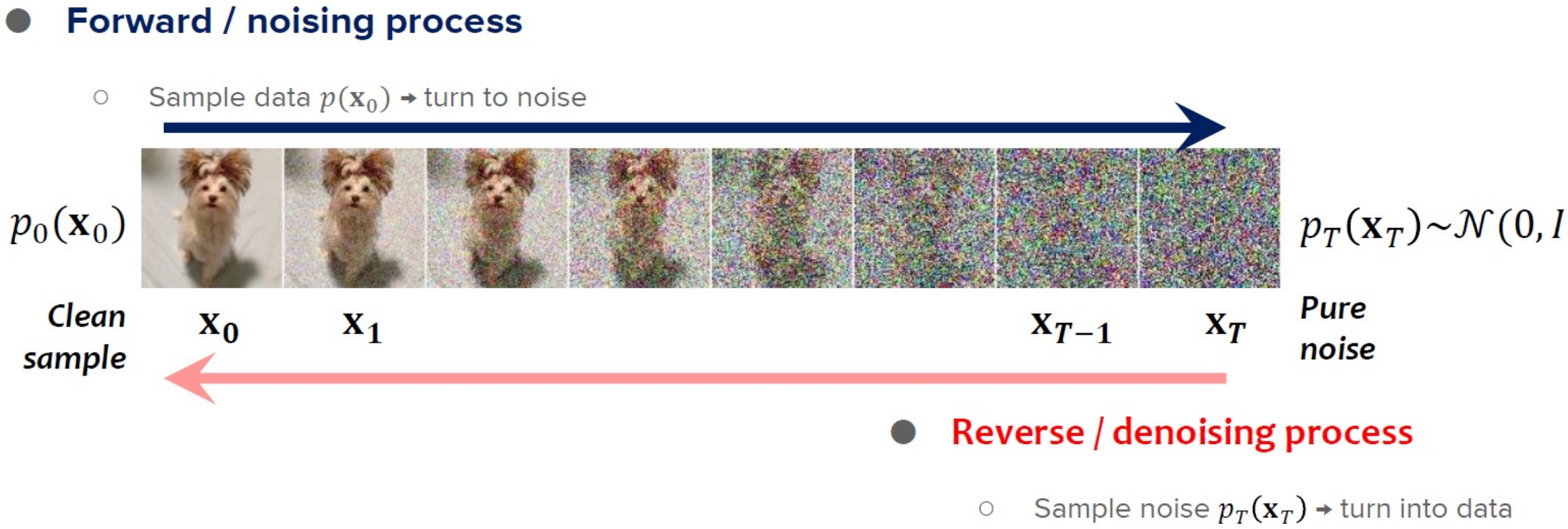
Diffusion Models

- Derive inspiration from physics (thermodynamics).

- Unconditional Generation (image synthesis) or
  Conditioned synthesis (Text to Image: Flying Dog eating Pizza).

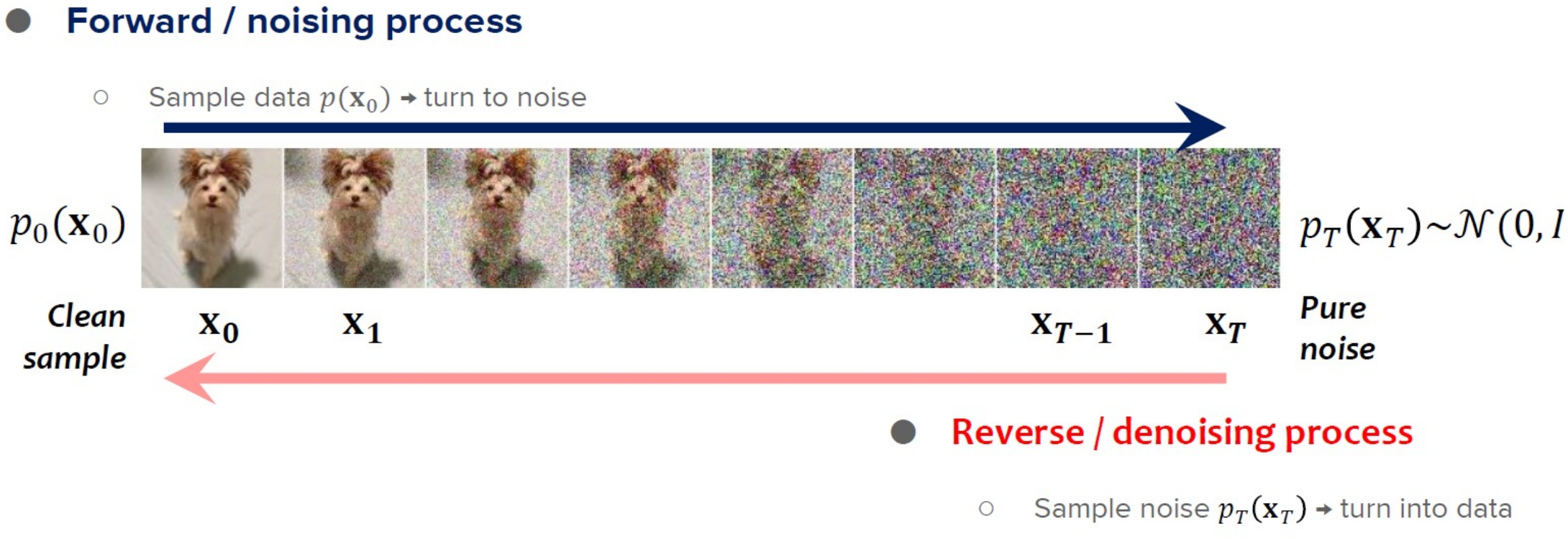
Diffusion Models

- Forward Diffusion: Destroy the structure in image via adding noise, iteratively.
  Reverse Diffusion: Attempt to remove noise, iteratively



Diffusion Models

- Add noise to pristine images. Train model to denoise noisy image to get original images.
- Denoising Diffusion Probabilistic Model (DDPM): Generate images starting from noise/static.
- ~1000 steps of noising and denoising
- Forward: P(xt|xt-1)
  Reverse: P(xt-1|xt)



Questions?