# AutoEncoders

Rowel Atienza, Ph.D.
University of the Philippines
github.com/roatienza
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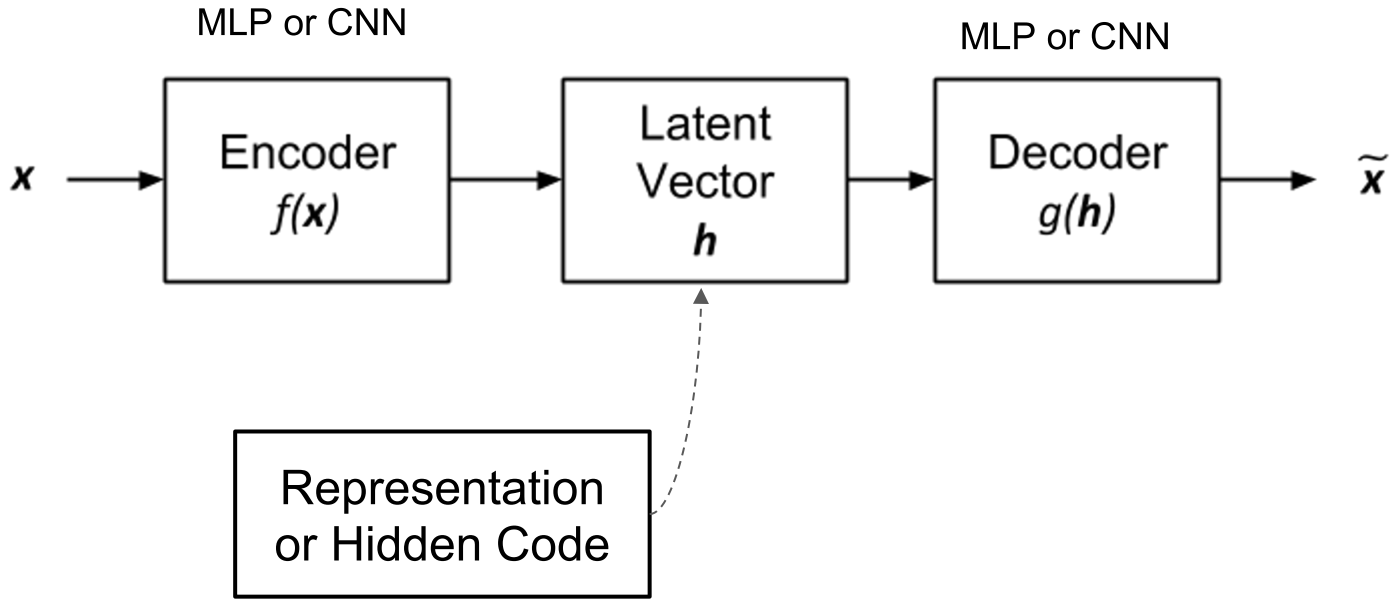
# Exercise

Draw an image of a 100-peso bill
Draw from what you can remember only
Do not look and copy a 100-peso bill

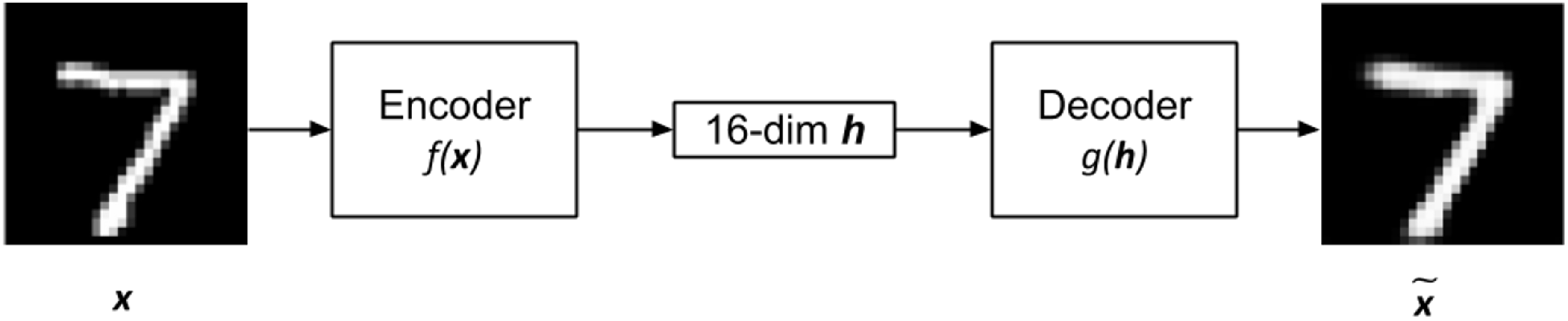

# AutoEncoder

- A self-supervised/unsupervised network
  - Supply it with data, it will figure out the mapping from input to output
- A neural network that attempts to copy its input to its output
  - In doing so, it learns a hidden code, $\boldsymbol{h}$, that represents its input
- The network has 2 parts
  - An encoder: $\boldsymbol{h} = f(\boldsymbol{x})$
  - A decoder: $\boldsymbol{r} = g(\boldsymbol{h})$

# AutoEncoder



# AutoEncoder



# AutoEncoder

Autoencoder must not learn: $g(\boldsymbol{h}) = g(f(\boldsymbol{x})) = \boldsymbol{x}$

Instead it must learn to approximate $\boldsymbol{x}$ only;

In doing so, it learns special properties of $\boldsymbol{x}$

Roughly, our brain compresses (lossy) information about what it senses


# AutoEncoder

For example in MNIST, properties could be writing style, tilt, thickness, roundness of stroke, etc.

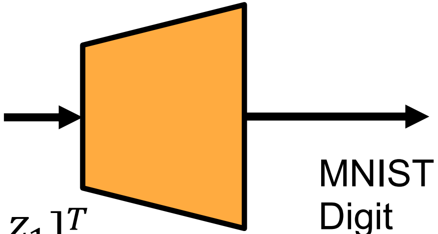
All properties needed to represent digits 0 to 9.

Autoencoder is not an identity function

# AutoEncoder Decoder as a Generative Model

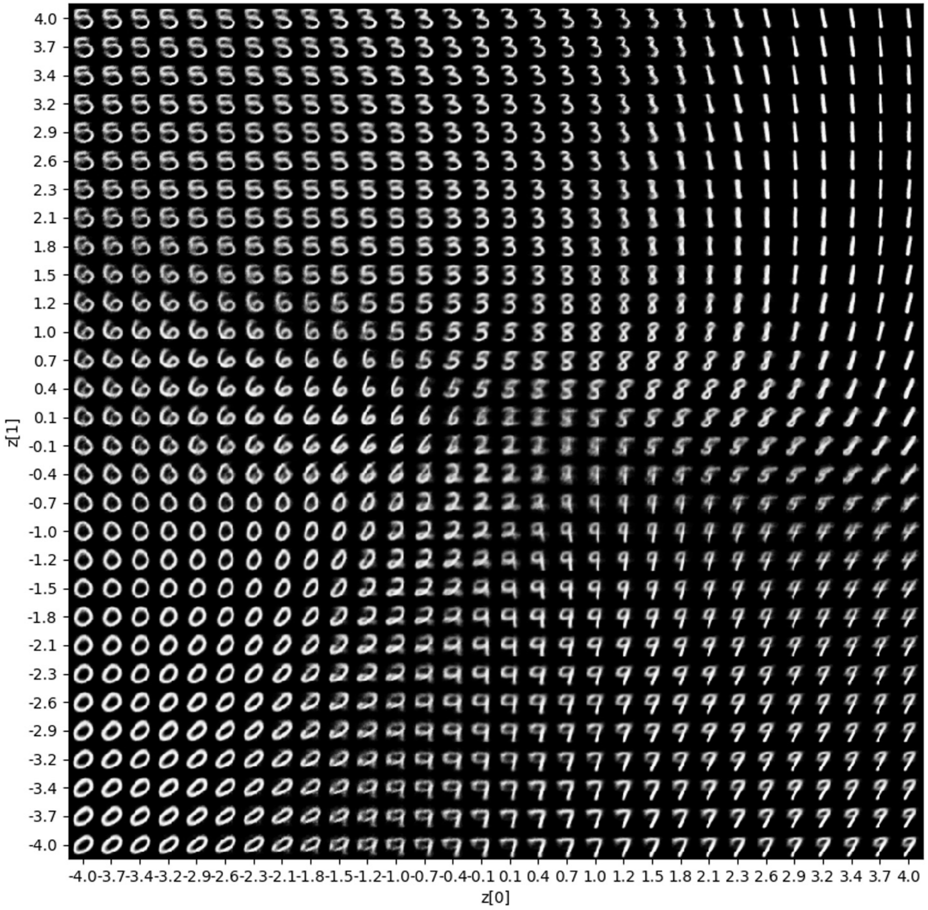
# Digits over latent code (2-dim)

Anywhere we navigate the latent space, there is a corresponding decodable MNIST digit-like image.




$$\boldsymbol{h} = \boldsymbol{z} = [z_0 \quad z_1]^T$$

2nd dim

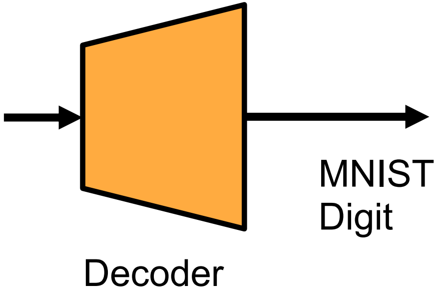



1st dim

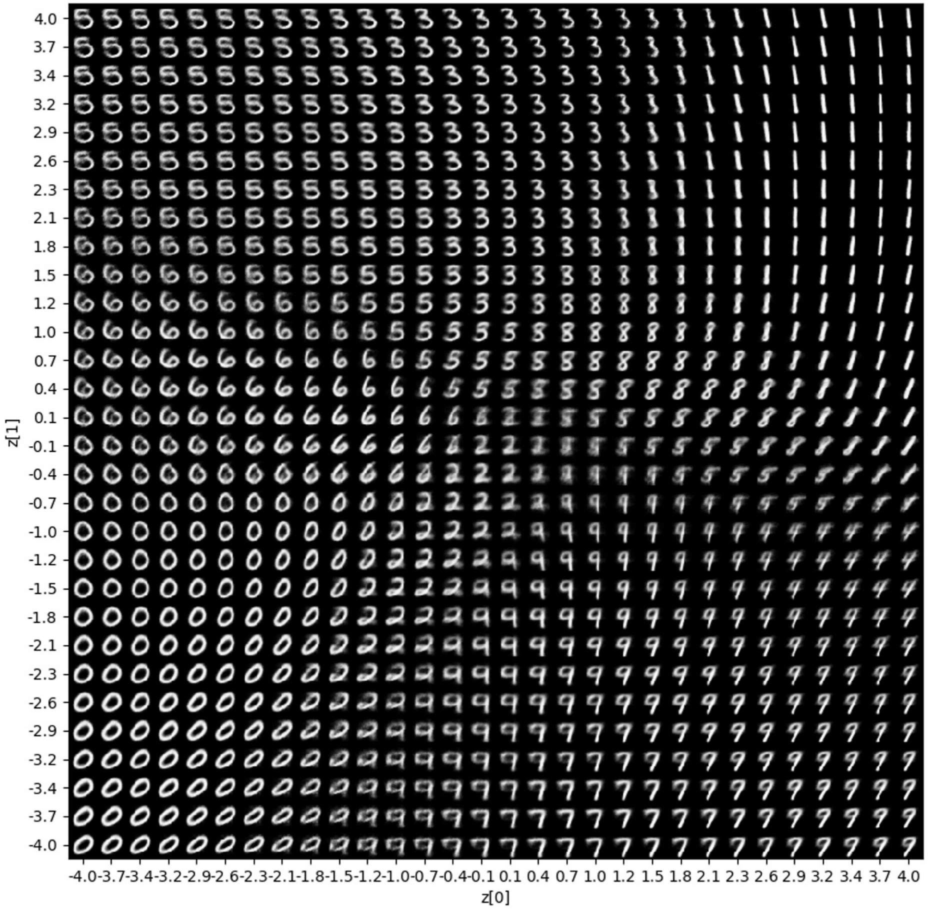
# Application

The decoder is a generative model

$$\boldsymbol{z} = \begin{bmatrix} z_0 & z_1 \end{bmatrix}^T$$




2nd dim

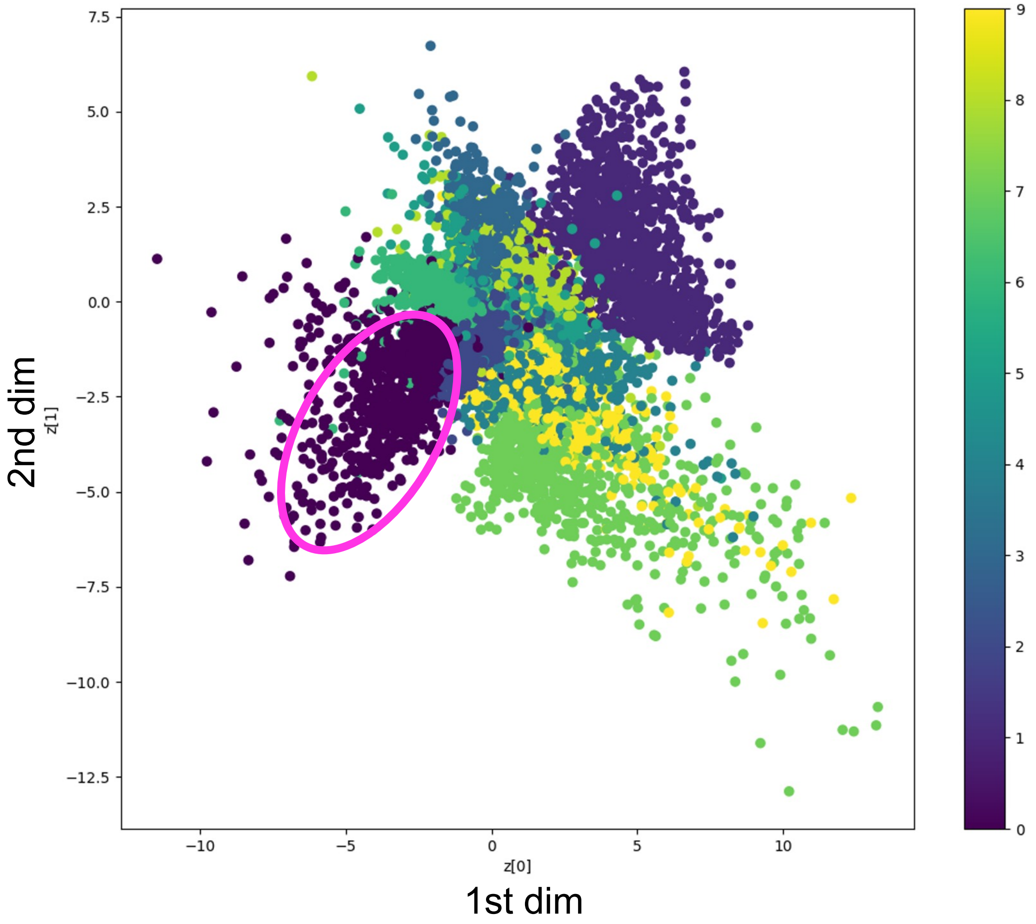



1st dim

# AutoEncoder Encoder as a Clustering Network

# Digits over latent code (2-dim)

Similar digits appear to cluster in one region.

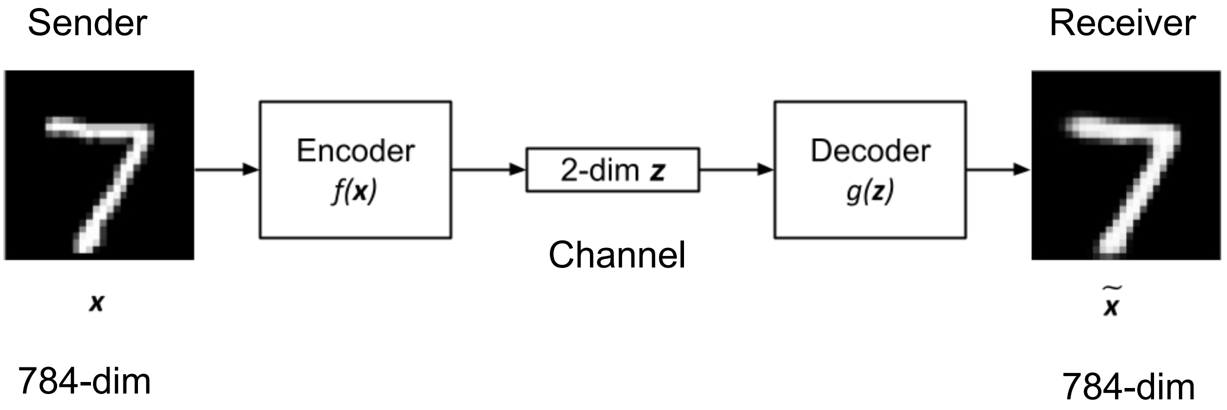


# Other Applications

Dimensionality reduction (compression)

Feature learning

Many more...



# The hidden code, $\boldsymbol{h}$

Dimensionality is much less than $\boldsymbol{x}$

For example, MNIST $\boldsymbol{x}$ could be 28 x 28 = 784 but $\boldsymbol{h}$ could be 2 or 4

The small dimension of $\boldsymbol{h}$ forces the neural network to learn only the most important features of $\boldsymbol{x}$

# How to train an autoencoder

The learning process is described by minimizing a loss function

$$L(\boldsymbol{x}, g(f(\boldsymbol{x})))$$

$L$ penalizes $g$ as being dissimilar from $\boldsymbol{x}$

Such as mean squared error (MSE)

# AutoEncoder vs PCA

Principal Component Analysis (PCA) or SVD can only learn linear feature representation

Autoencoder can learn both linear and non-linear feature representations

# Stochastic Encoder and Decoder

In AutoEncoder, the input is also the output

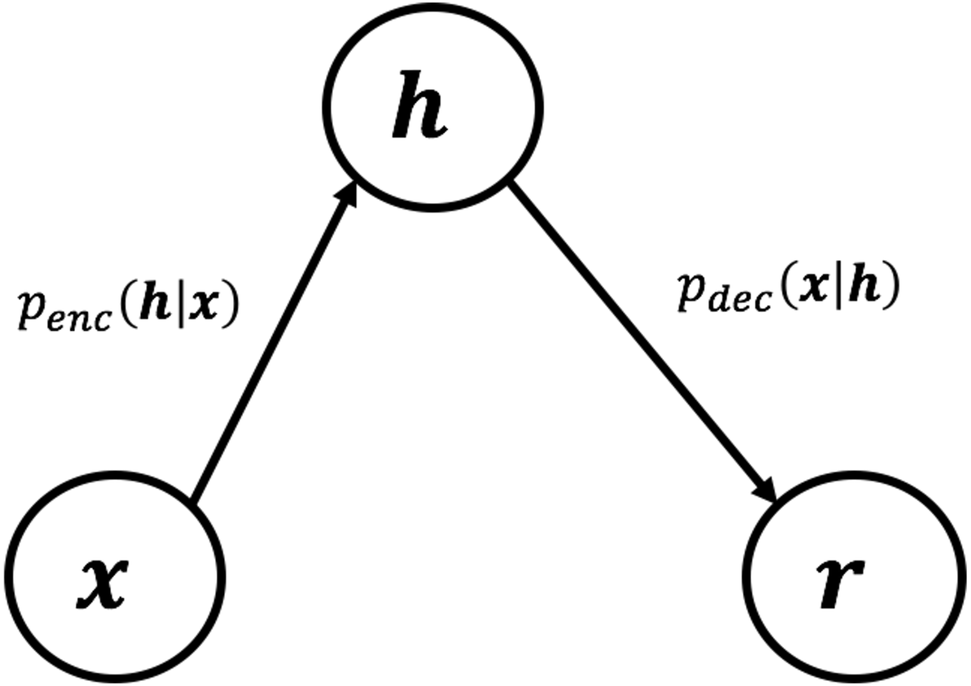
Encoder: $p_{enc}\left(\boldsymbol{h}\middle|\,\boldsymbol{x}\right)$

Decoder: $p_{dec}\left(\boldsymbol{x}\middle|\,\boldsymbol{h}\right)$

Similar to other networks, the goal of stochastic autoencoder is to minimize

$$-\log p_{dec}(\boldsymbol{x}|\boldsymbol{h})$$

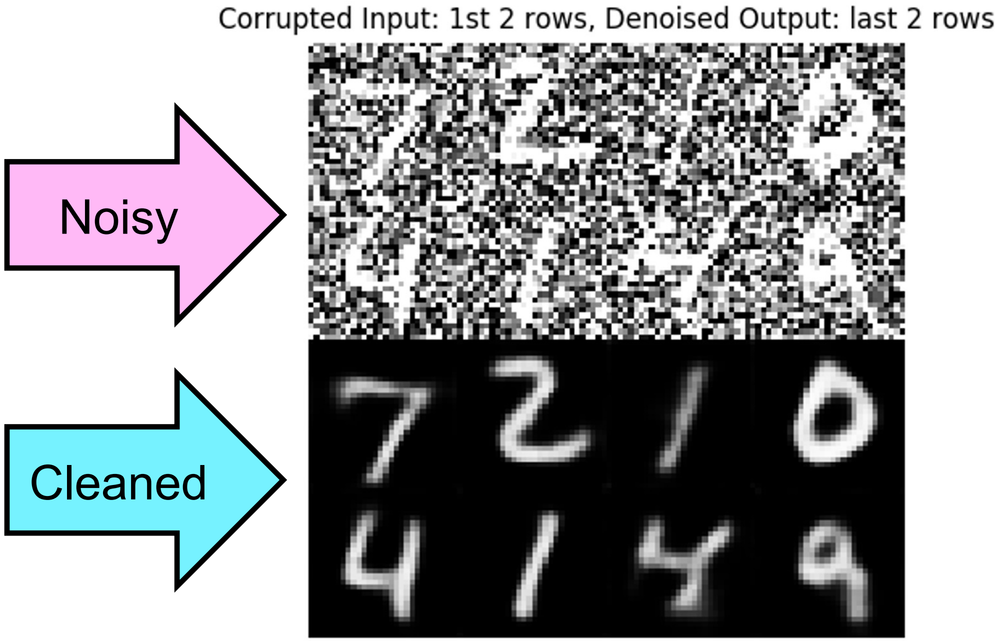
# Encoding/Decoding Distribution Graphical Model



# Applications

# Denoising AutoEncoder

Can we recover clean data given noised data?



# Denoising AutoEncoder

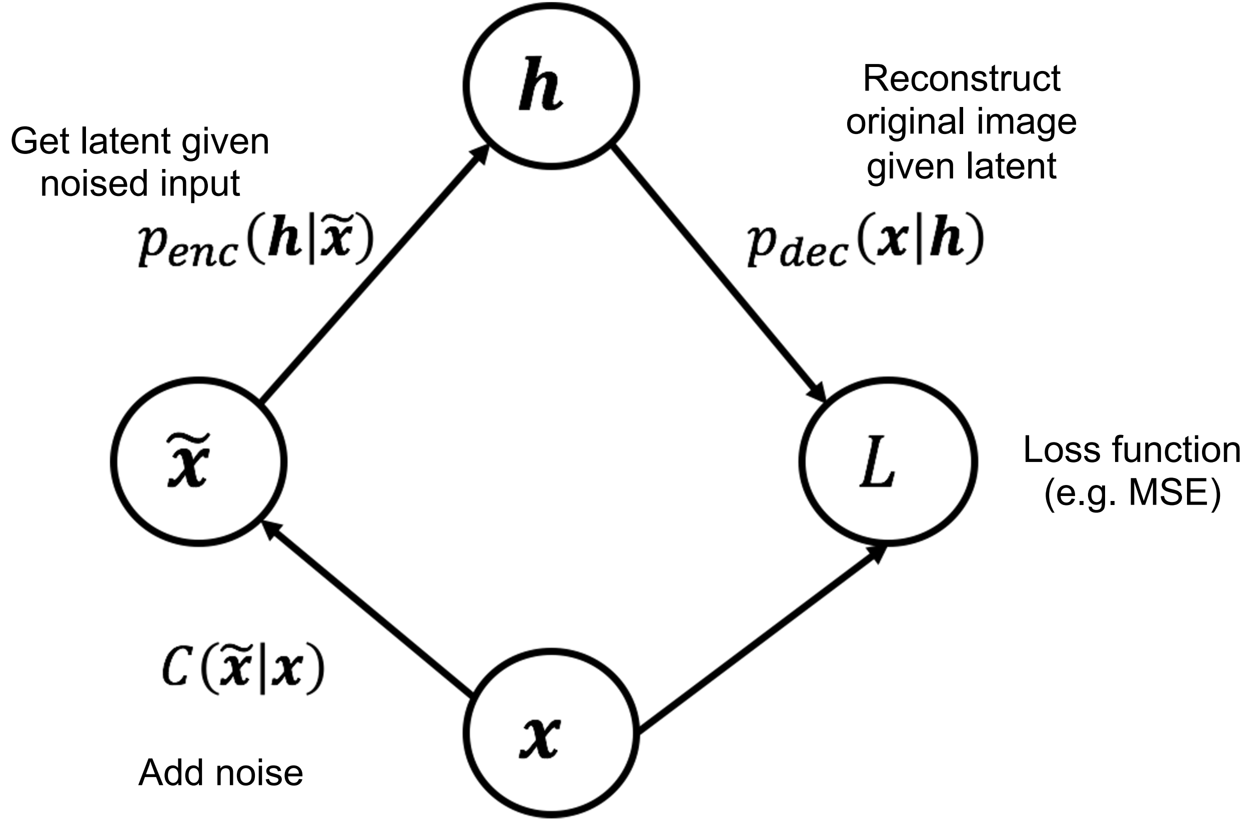
The idea is to recover the true distribution from a corrupted input:

$$L\left(\boldsymbol{x}, g\left(f\left(\widetilde{\boldsymbol{x}}\right)\right)\right)$$

$\widetilde{\boldsymbol{x}}$ is the corrupted version of $\boldsymbol{x}$

The network receives a corrupted input and generates a clean output (clean or uncorrupted version of input)

# Denoising AutoEncoder Graphical Model



# Denoising AutoEncoder

Sample a training example $\boldsymbol{x}$ from training data
Sample a corrupted version of $\boldsymbol{x}$ using corruption process

$$C(\widetilde{\boldsymbol{x}}|\boldsymbol{x})$$

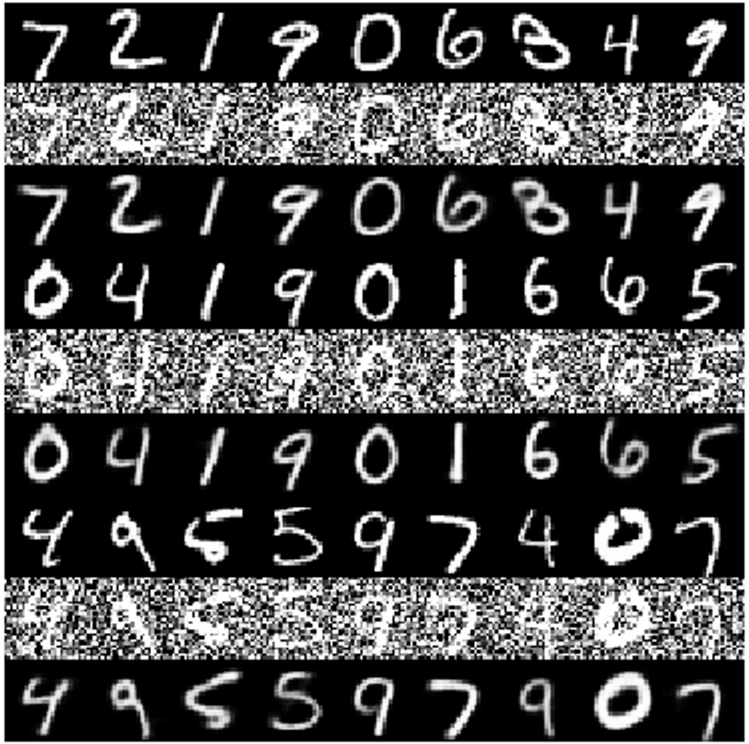
Use data points $(\widetilde{\boldsymbol{x}}, \boldsymbol{x})$to train the network to estimate autoencoder reconstruction distribution

$$p_{recon}(\boldsymbol{x}|\widetilde{\boldsymbol{x}}) = p_{dec}(\boldsymbol{x}|\boldsymbol{h})$$

where $\boldsymbol{h}$ is the output of the encoder $\boldsymbol{h} = f(\widetilde{\boldsymbol{x}})$

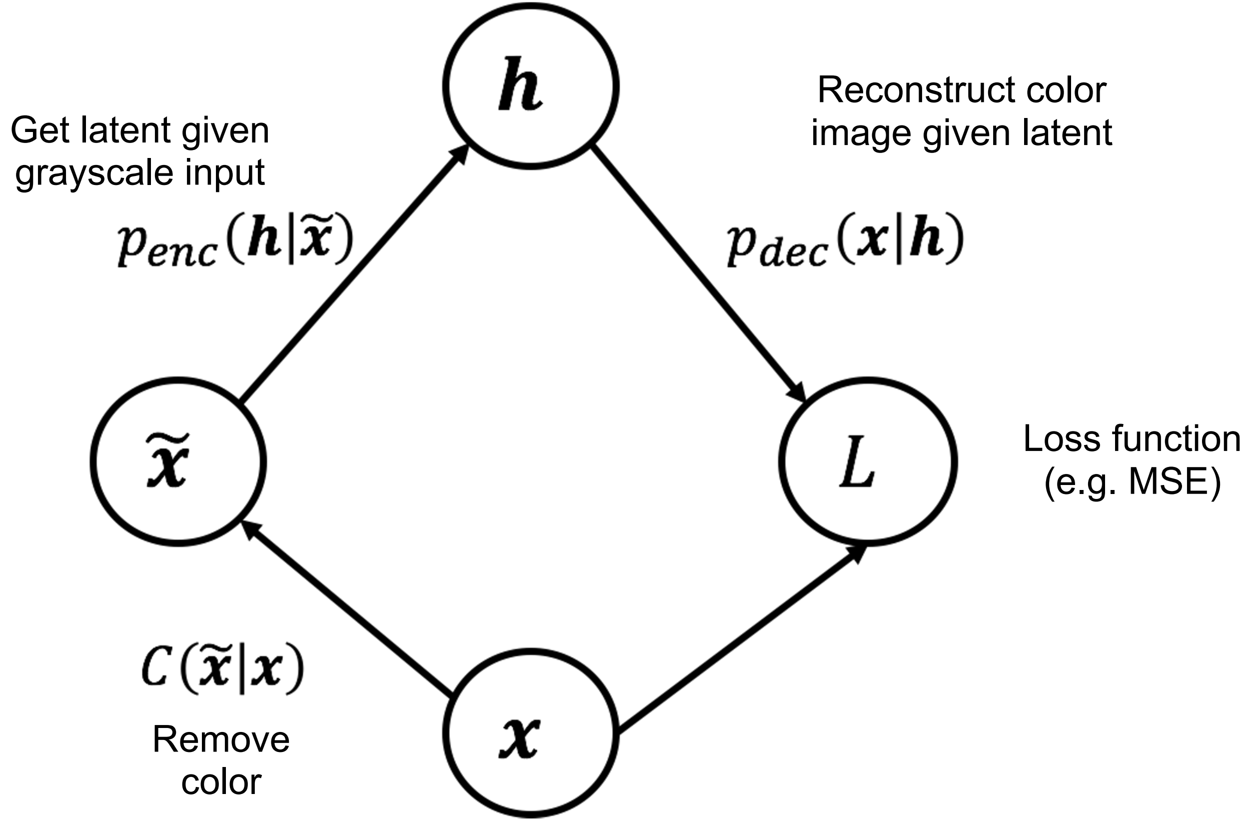
# Denoising AutoEncoder on MNIST

Original images: top rows, Corrupted Input: middle rows, Denoised Input:  third rows

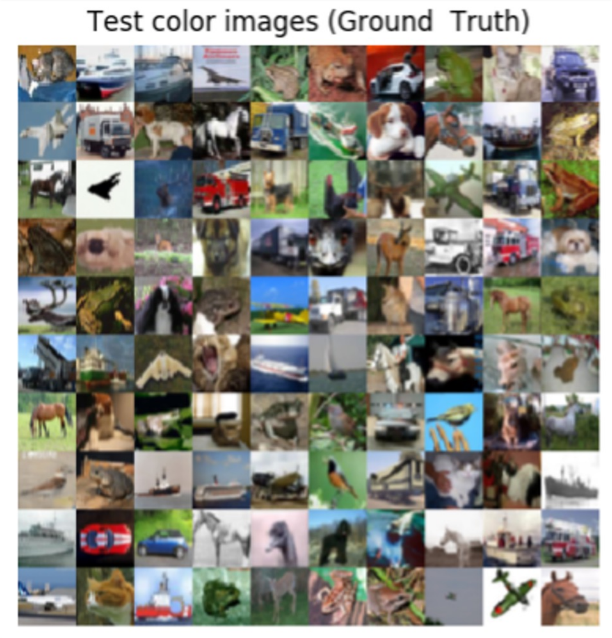


# Colorization

# Colorization AutoEncoder



# Colorization AutoEncoder on CIFAR10





Code demo is next