This is CS5045!

GCR:ioc7cdl

Unsupervised Learning

“We expect unsupervised learning to become far more important in the longer term. Human and animal learning is largely unsupervised: we discover the structure of the world by observing it, not by being told the name of every object.” – LeCun, Bengio, Hinton, Nature 2015

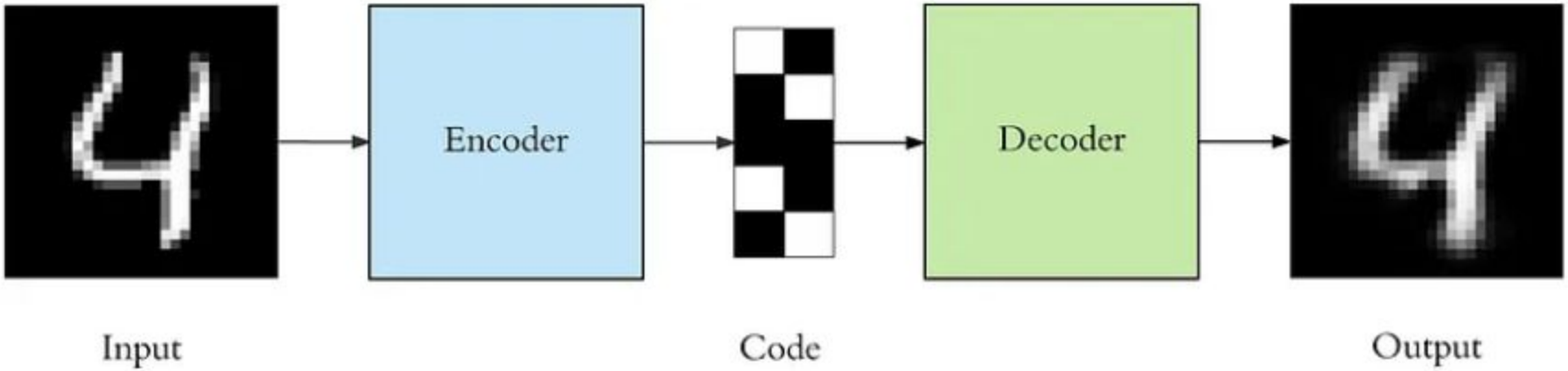
If intelligence was a cake, unsupervised learning would be the cake, supervised learning would be the icing on the cake, and reinforcement learning would be the cherry on the cake. We know how to make the icing and the cherry, but we don't know how to make the cake. – Yann LeCun, March 14, 2016 (Facebook)

AutoEncoders

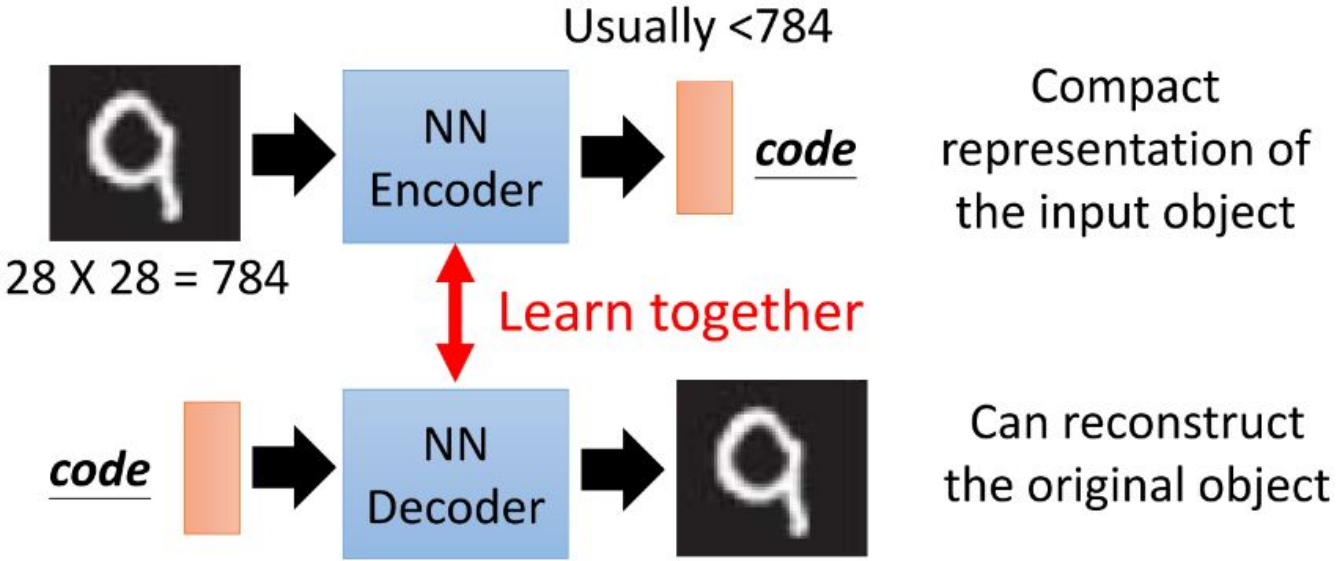
Autoencoders are a specific type of feedforward neural networks where the input is the same as the output.

An autoencoder consists of 3 components: encoder, code and decoder.

Autoencoders are mainly a dimensionality reduction (or compression) algorithm.

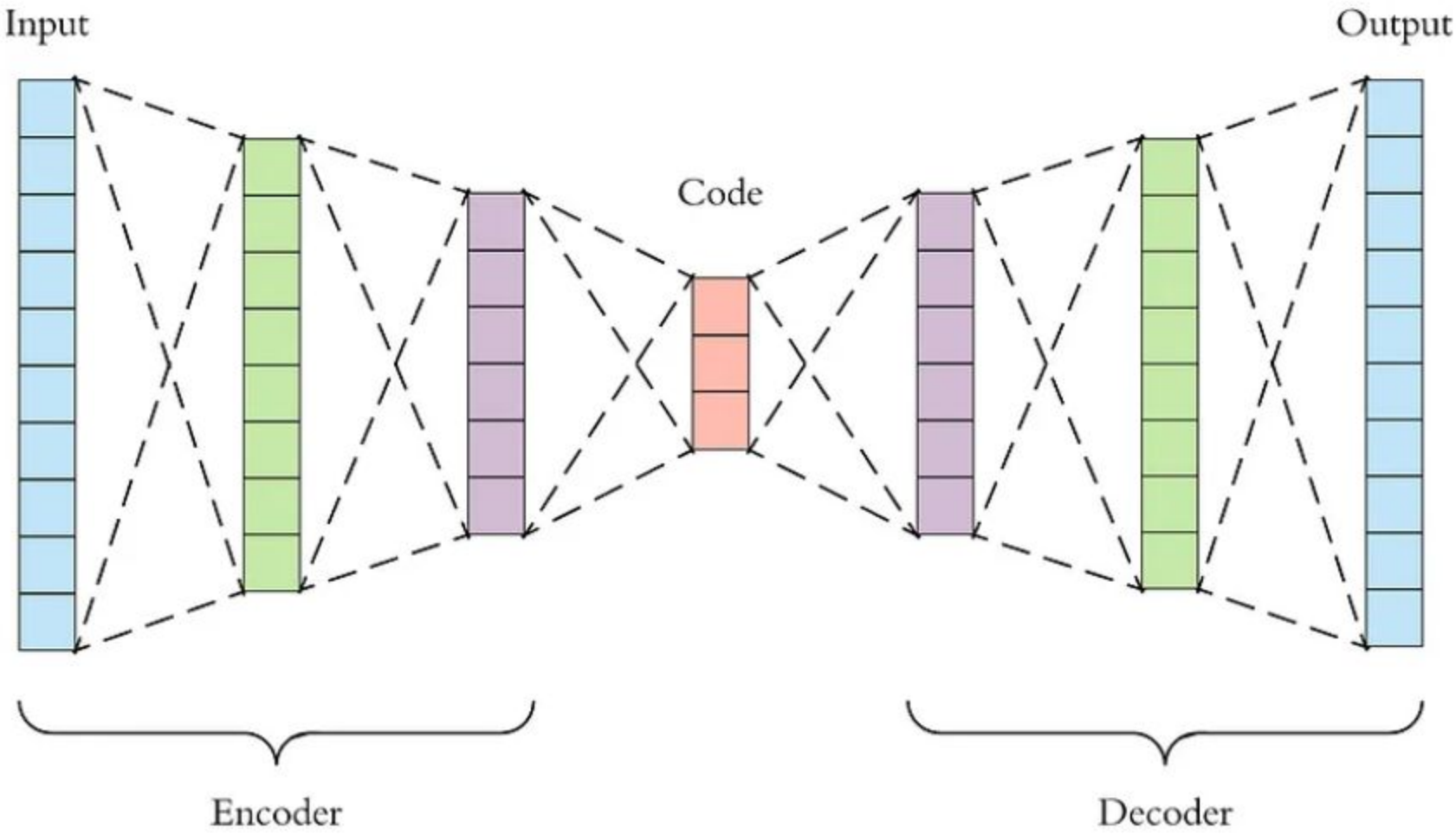

Encoder
Decoder
Input
Code
Output

AutoEncoders



Unsupervised????

Autoencoders are considered an unsupervised learning technique since they don’t need explicit labels to train on. But to be more precise they are self-supervised because they generate their own labels from the training data.


Input
Output
Code
Encoder
Decoder

There are 4 hyperparameters that we need to set before training an autoencoder:

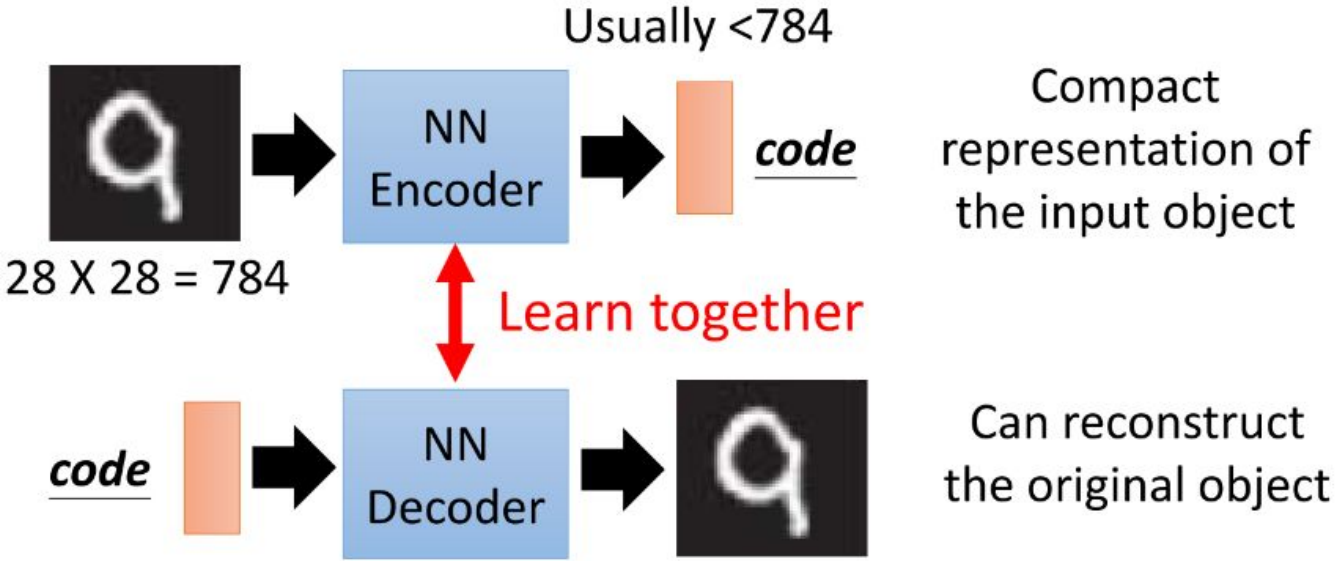
Code size

Number of layers

Number of nodes per layer

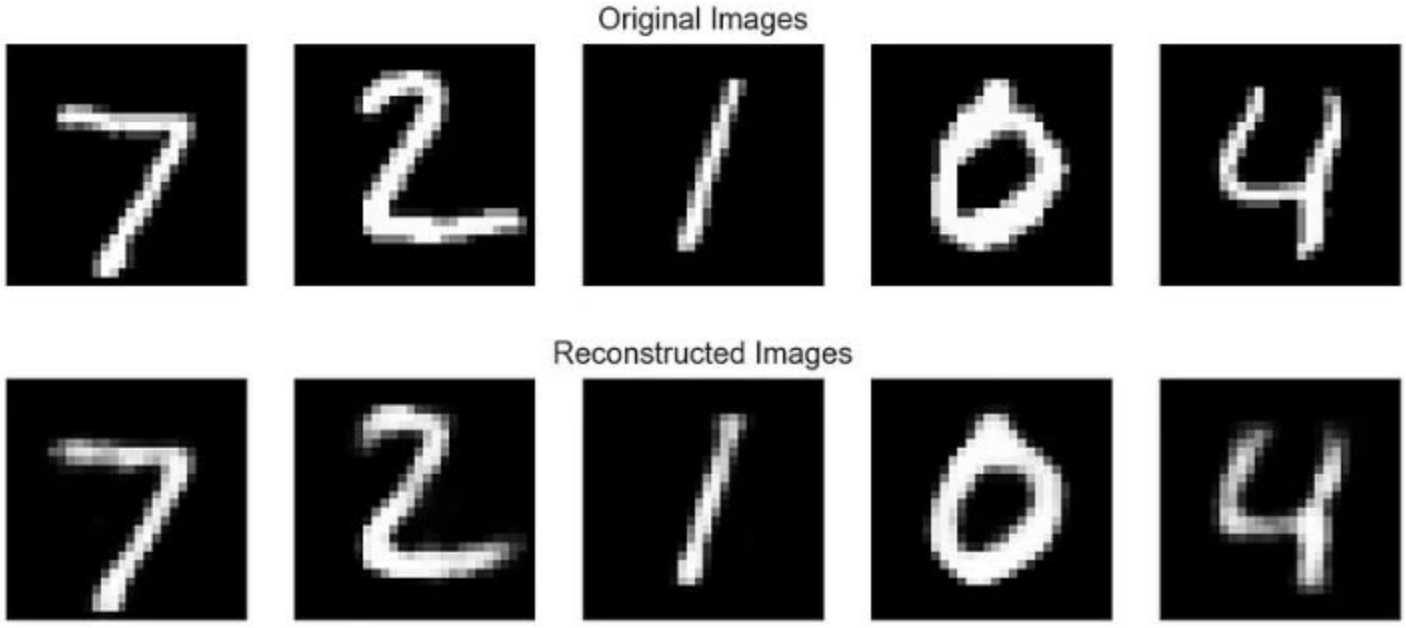
Loss function

AutoEncoders



Implementation

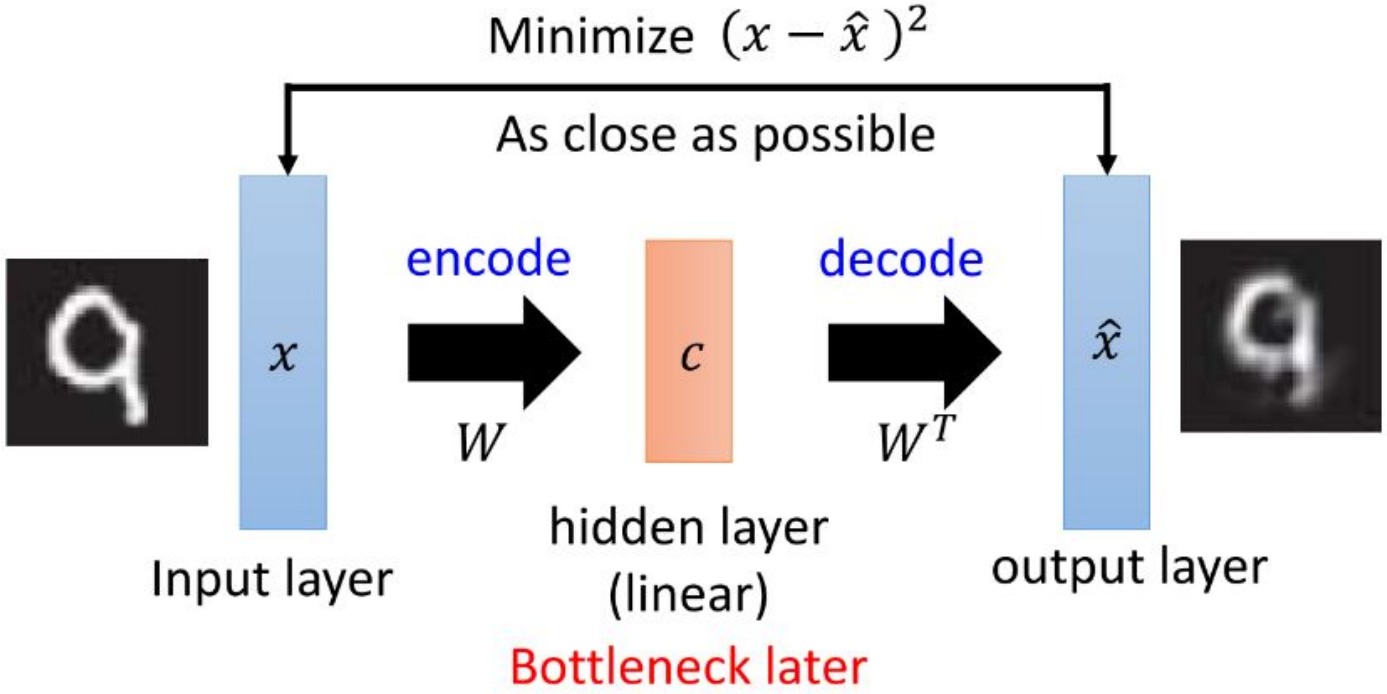
```
input_size = 784
hidden_size = 128
code_size = 32

input_img = Input(shape=(input_size,))
hidden_1 = Dense(hidden_size, activation='relu')(input_img)
code = Dense(code_size, activation='relu')(hidden_1)
hidden_2 = Dense(hidden_size, activation='relu')(code)
output_img = Dense(input_size, activation='sigmoid')(hidden_2)

autoencoder = Model(input_img, output_img)
autoencoder.compile(optimizer='adam', loss='binary_crossentropy')
autoencoder.fit(x_train, x_train, epochs=5)
```


Original Images
Reconstructed Images

A bit of Advice

We should be careful to not make it too powerful. Otherwise the autoencoder will simply learn to copy its inputs to the output, without learning any meaningful representation. It will just mimic the identity function. The autoencoder will reconstruct the training data perfectly, but it will be overfitting without being able to generalize to new instances, which is not what we want.

Recap: PCA

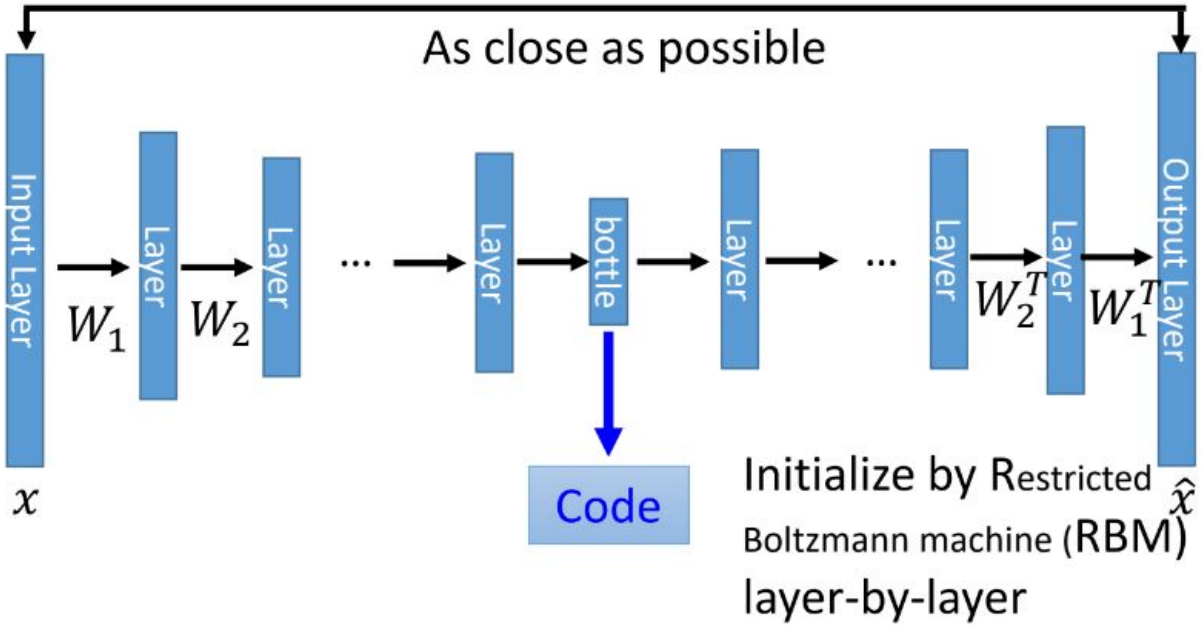


Output of the hidden layer is the code

Deep Auto-encoder

Symmetric is not necessary.

- Of course, the auto-encoder can be deep



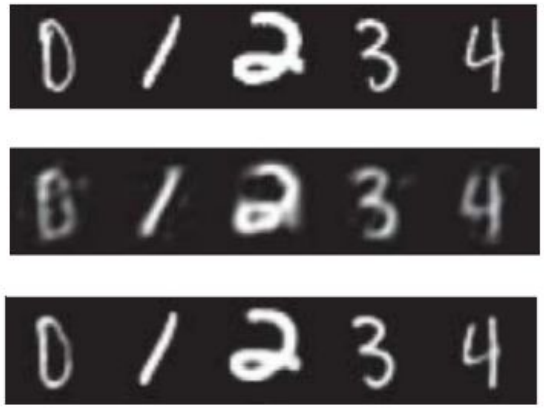
Reference: Hinton, Geoffrey E., and Ruslan R. Salakhutdinov. "Reducing the dimensionality of data with neural networks." *Science* 313.5786 (2006): 504-507

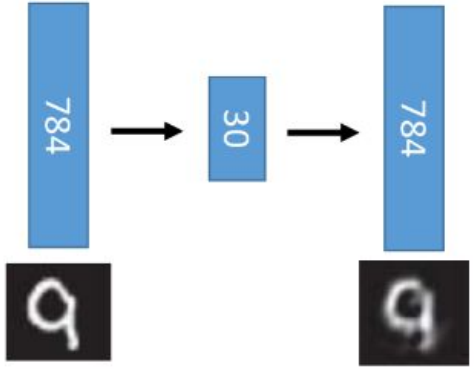
Deep Auto-encoder

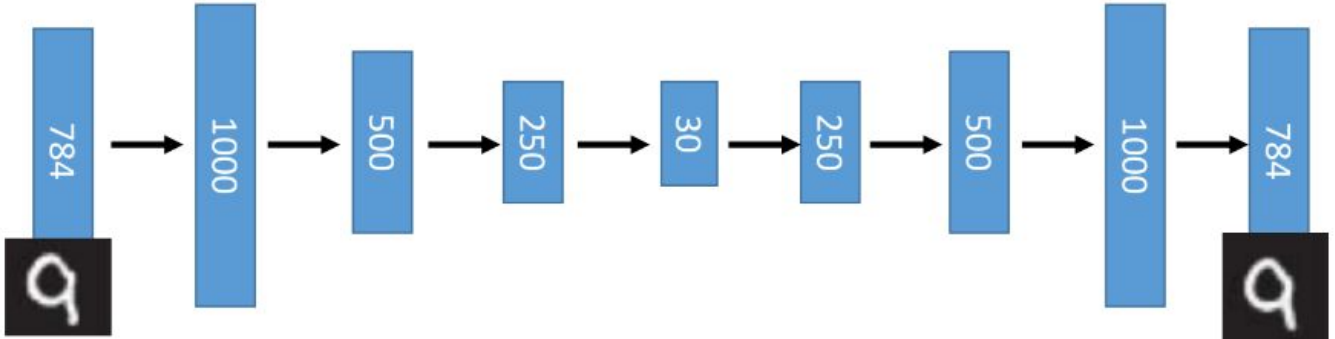
Original Image

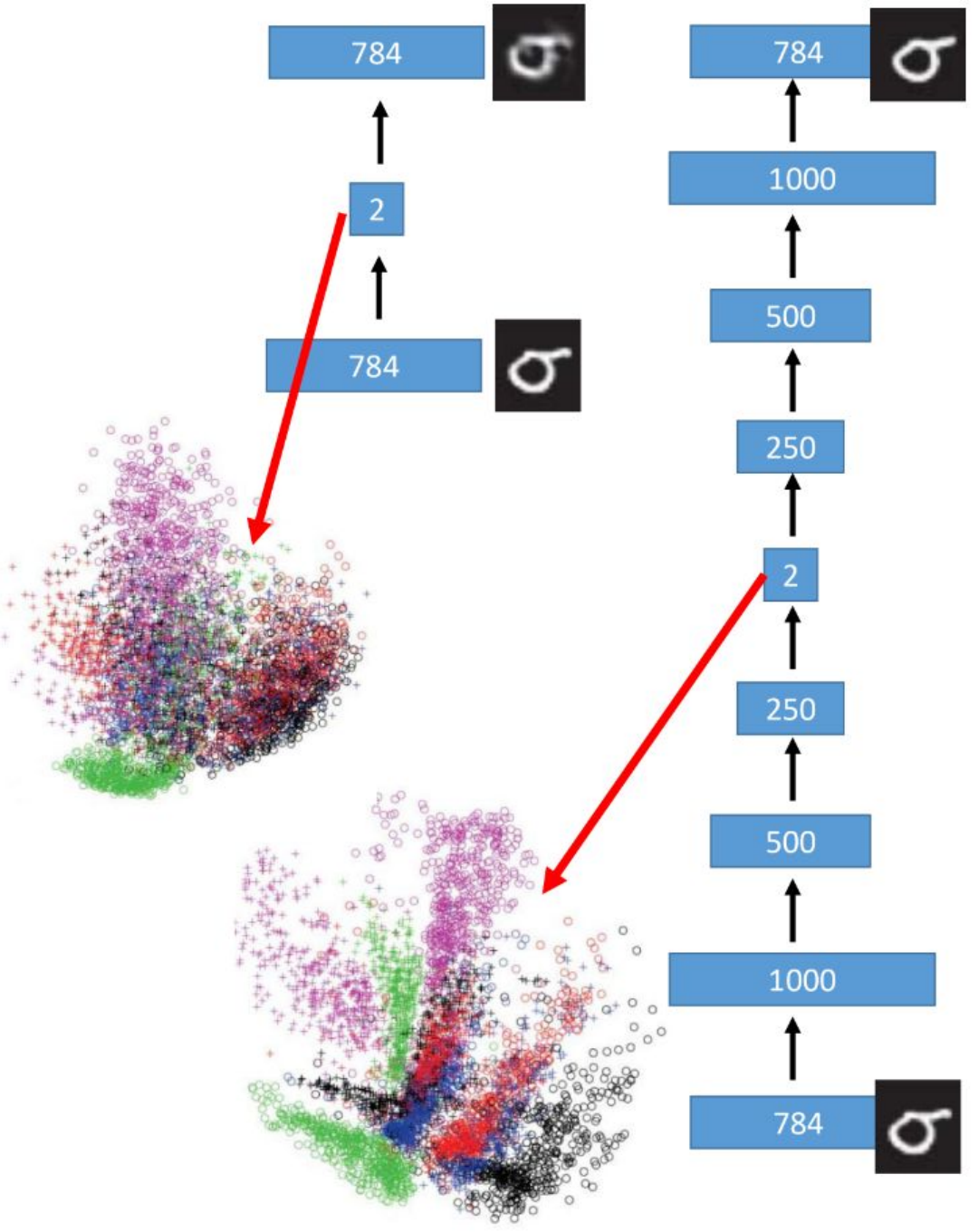
PCA

Deep Auto-encoder







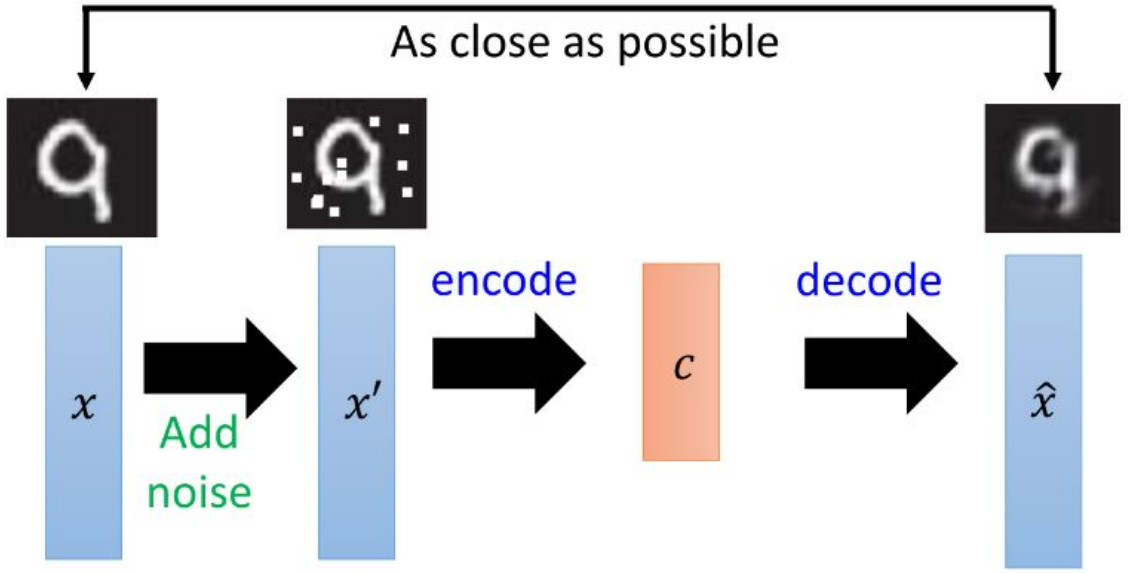

784
2
784
784
1000
500
250
2
250
500
1000
784

Auto-encoder

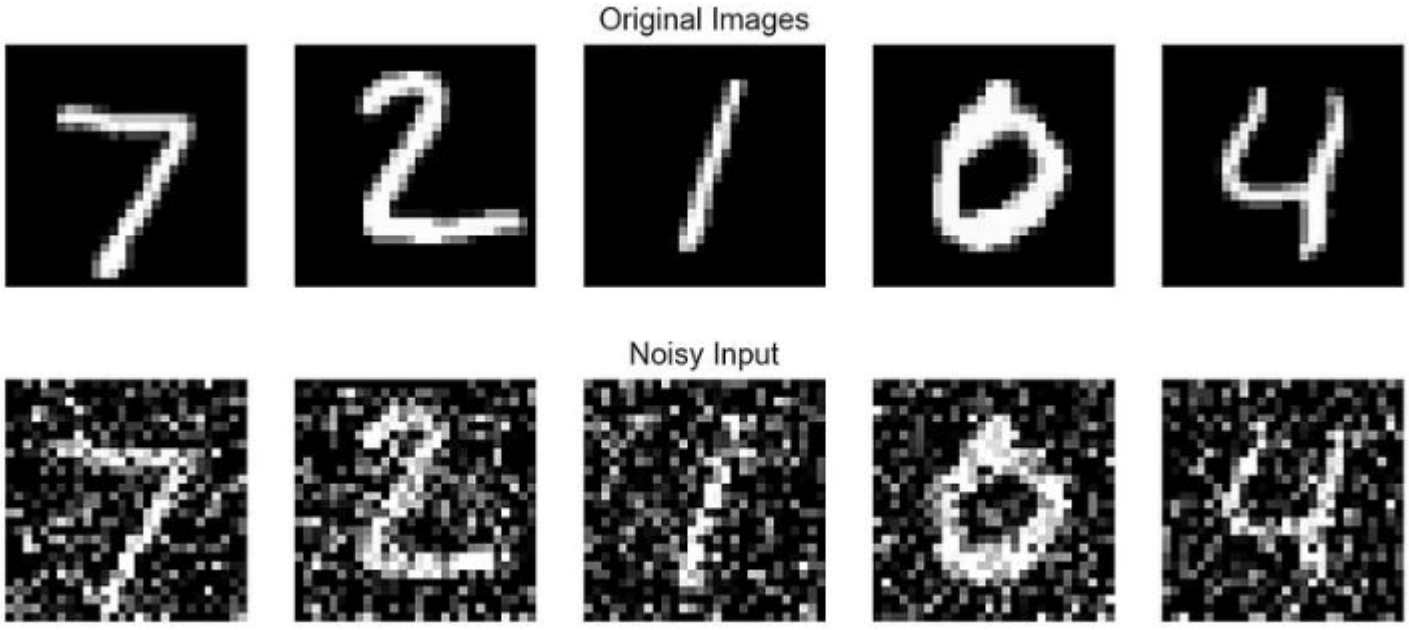
More: Contractive auto-encoder

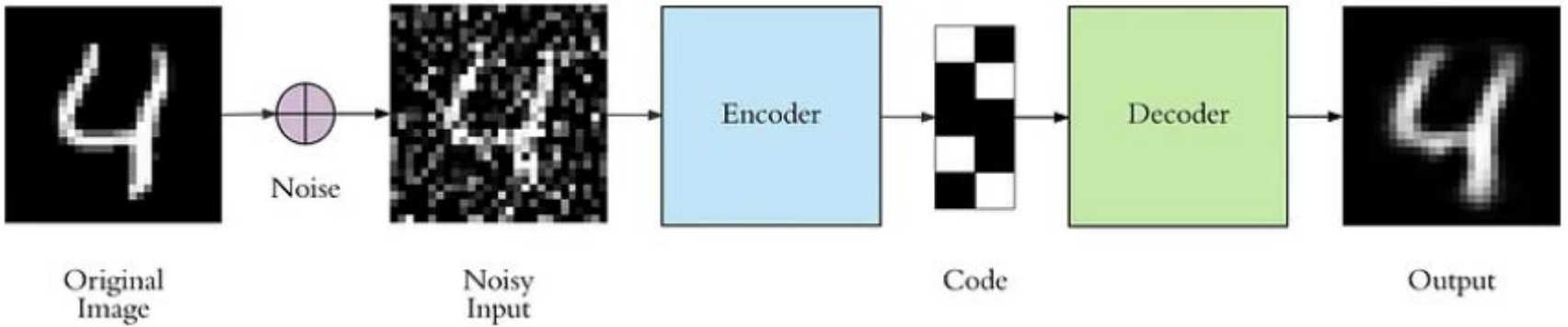
Ref: Rifai, Salah, et al. "Contractive auto-encoders: Explicit invariance during feature extraction." *Proceedings of the 28th International Conference on Machine Learning (ICML-11)*. 2011.

- De-noising auto-encoder



Vincent, Pascal, et al. "Extracting and composing robust features with denoising autoencoders." *ICML,* 2008.


Original Images
Noisy Input



Denoising autoencoder is trained as:

```
autoencoder.fit(x_train_noisy, x_train)
```

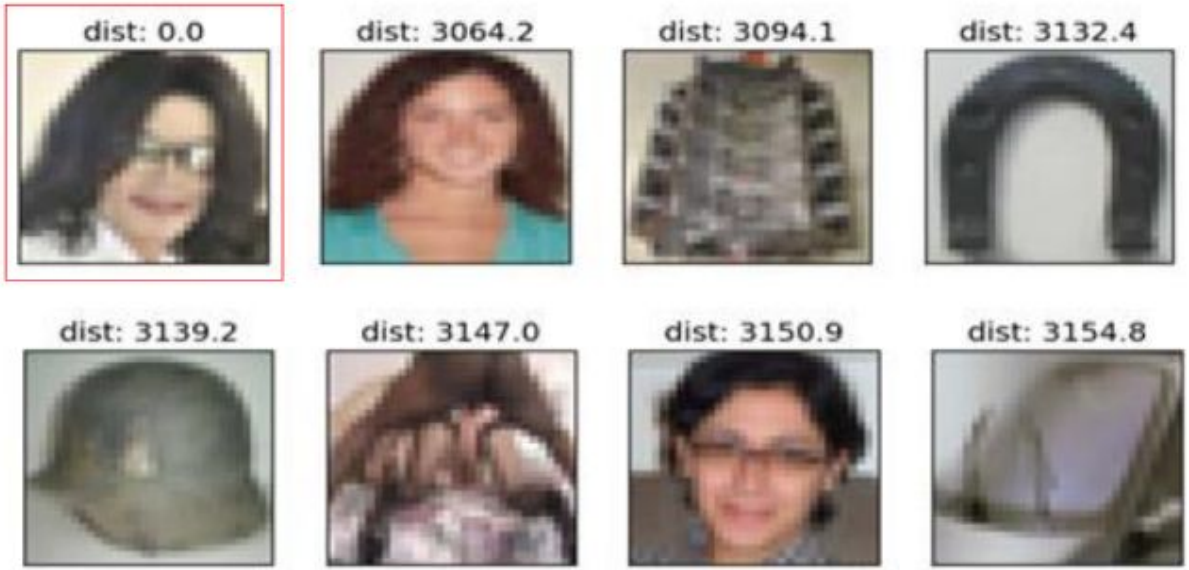
Auto-encoder – Similar Image Search

Retrieved using Euclidean distance in pixel intensity space

(Images from Hinton's slides on Coursera)

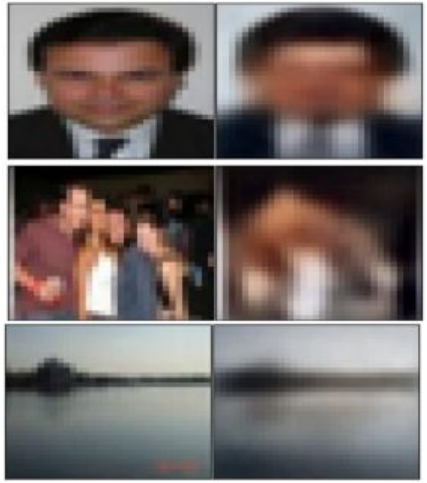
Reference: Krizhevsky, Alex, and Geoffrey E. Hinton. "Using very deep autoencoders for content-based image retrieval." *ESANN*. 2011.

Retrieved using Euclidean distance in pixel intensity space



retrieved using 256 codes

Auto-encoder – Similar Image Search



32x32

8192

4096

2048

1024

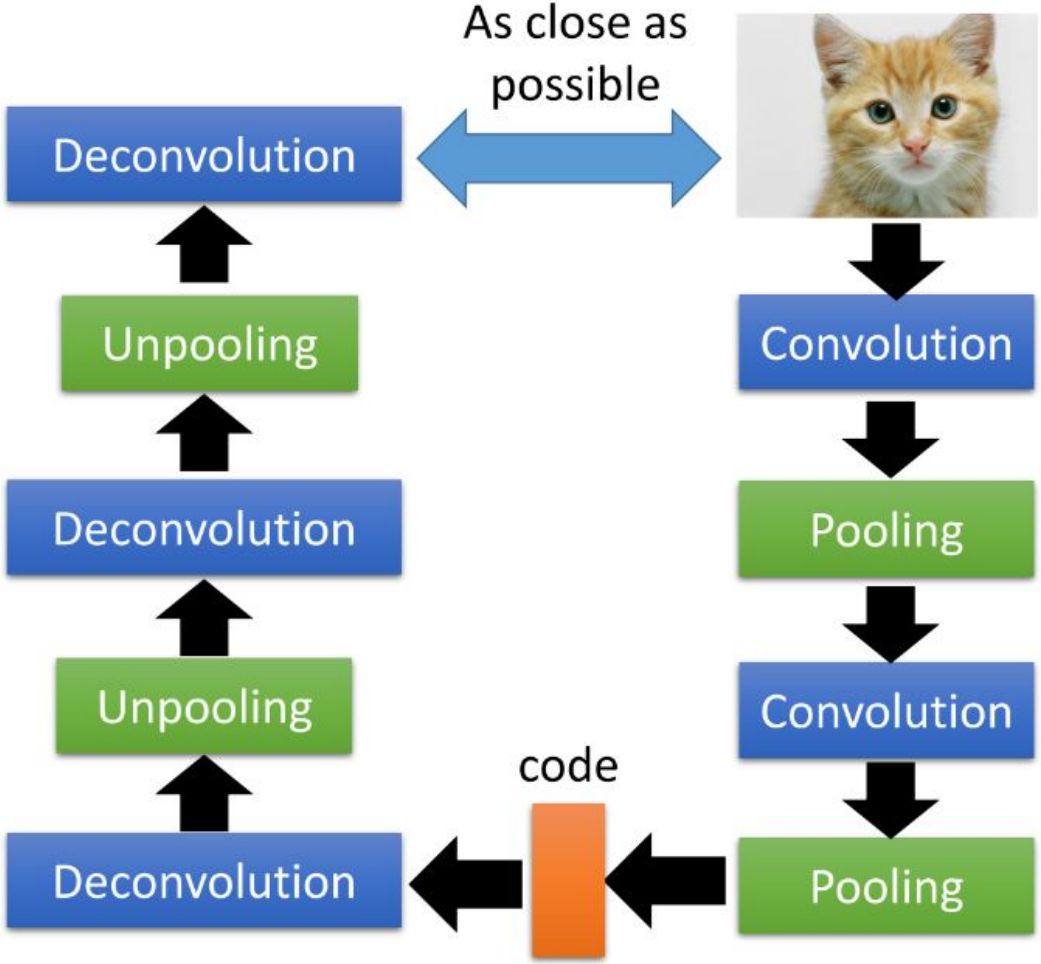
512

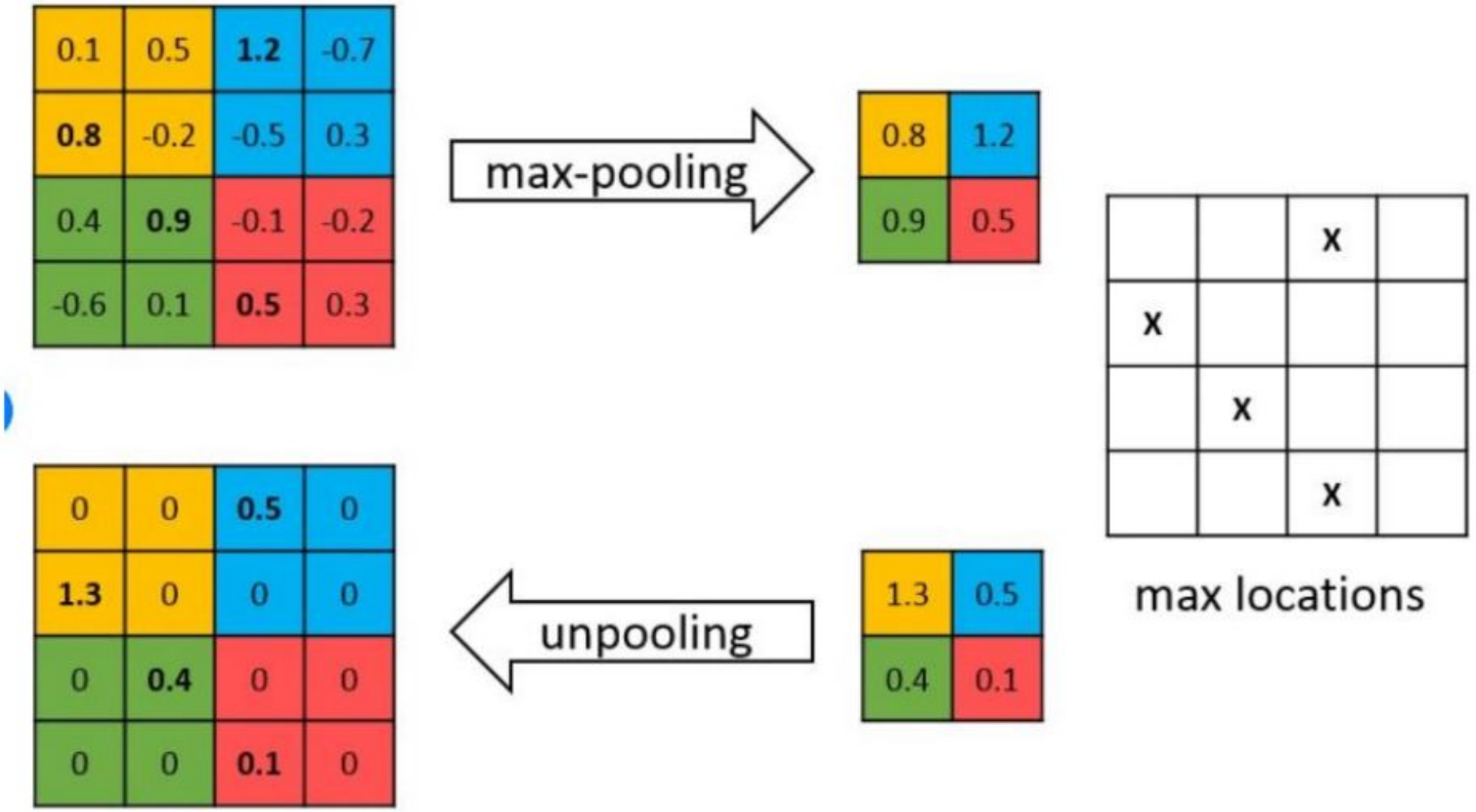
code

256

(crawl millions of images from the Internet)

Auto-encoder for CNN

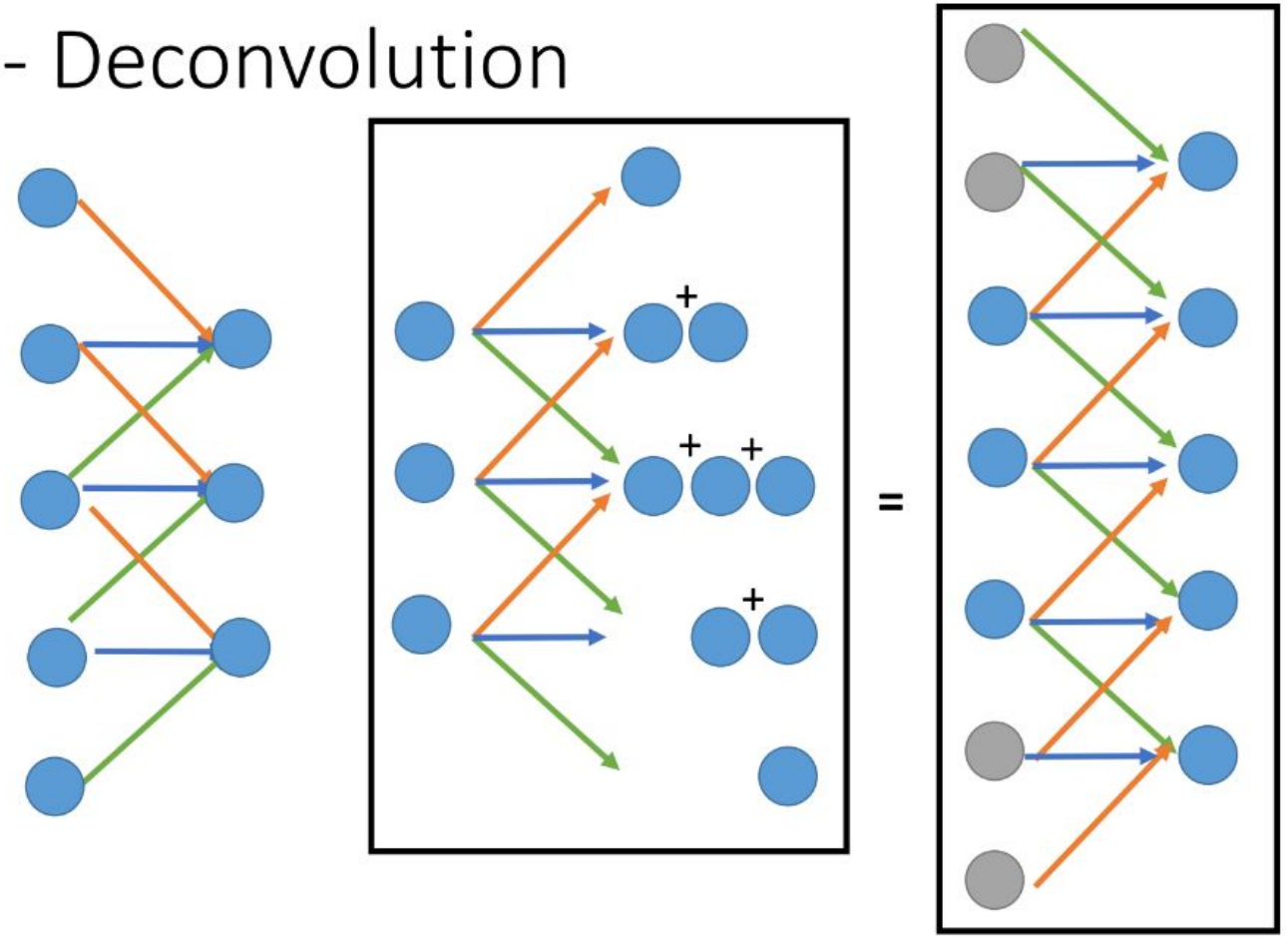




Pooling and unpooling layers. For each pooling layer, the max locations are stored. These locations are then used in unpooling layer.

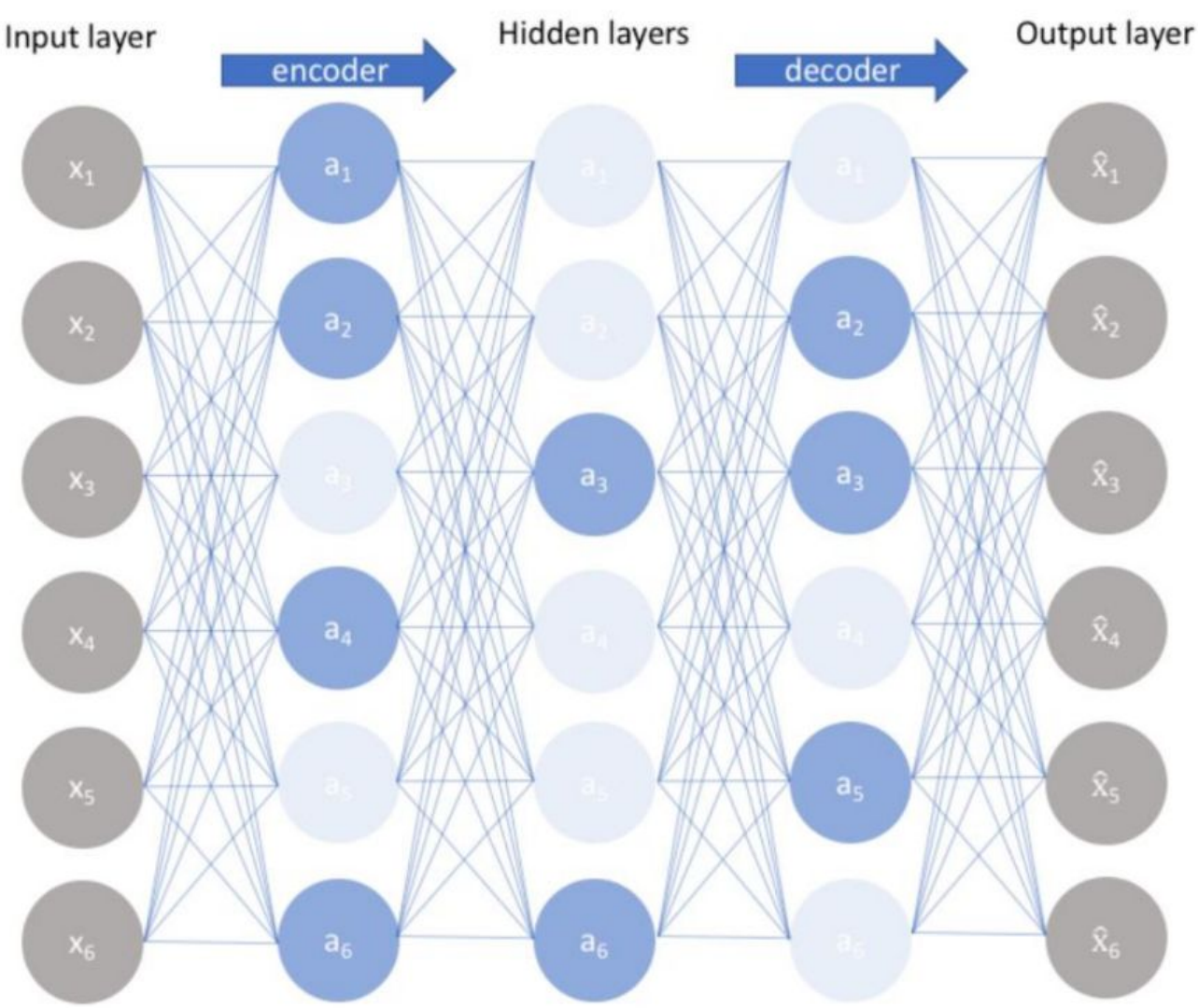
CNN
- Deconvolution

Actually, deconvolution is convolution.

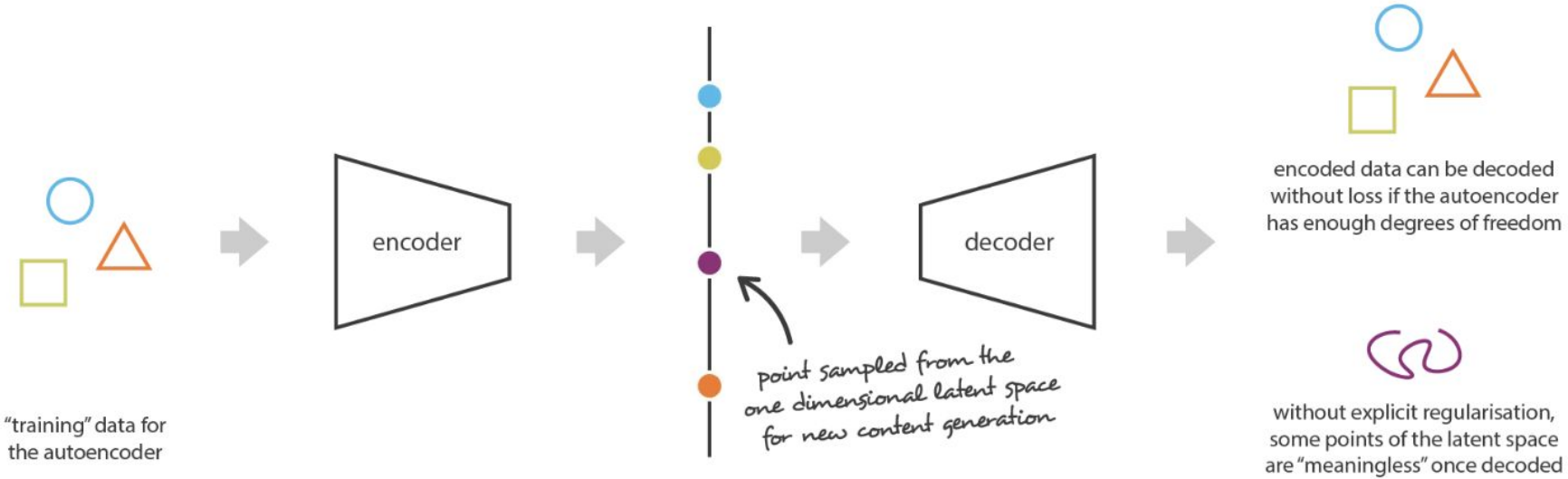


Sparse AutoEncoder

- Use of Regularization (For better generalization)
- Introducing sparsity constraint such that only a fraction of the nodes would have nonzero values called active nodes
- Add a penalty term to the loss function such that only a fraction of nodes become active
- This forces the autoencoder to represent each input as a combination of small number of nodes and demands to discover interesting structure in the data


Input layer
encoder
Hidden layers
decoder
Output layer
x_1
x_2
x_3
x_4
x_5
x_6
a_1
a_2
a_3
a_4
a_5
a_6
a_1
a_2
a_3
a_4
a_5
a_6
a_1
a_2
a_3
a_4
a_5
a_6
$\hat{x}_1$
$\hat{x}_2$
$\hat{x}_3$
$\hat{x}_4$
$\hat{x}_5$
$\hat{x}_6$

VAE



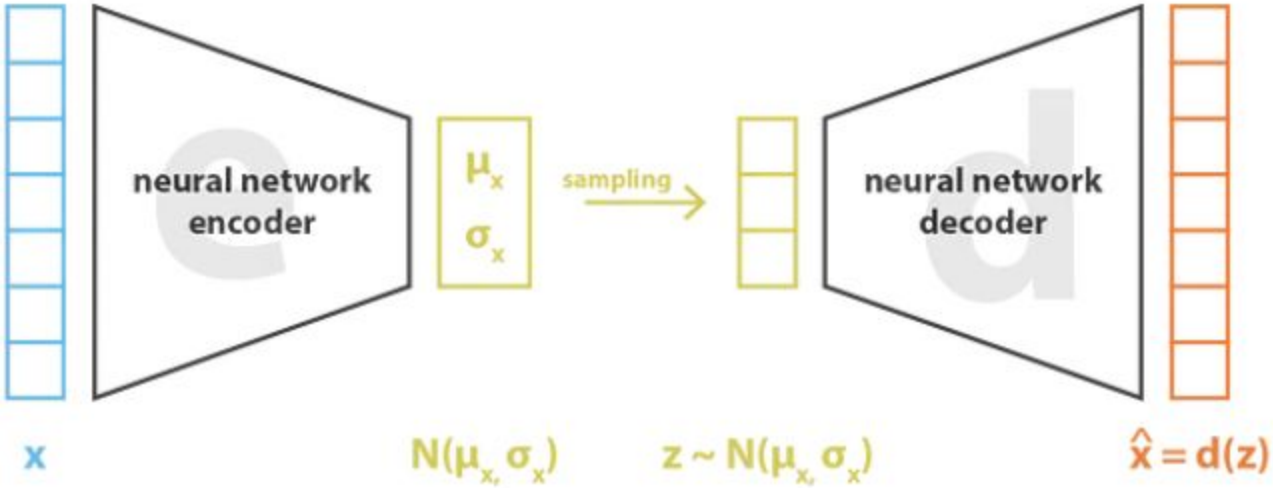
Irregular latent space prevent us from using autoencoder for new content generation.

VARIATIONAL AUTOENCODER

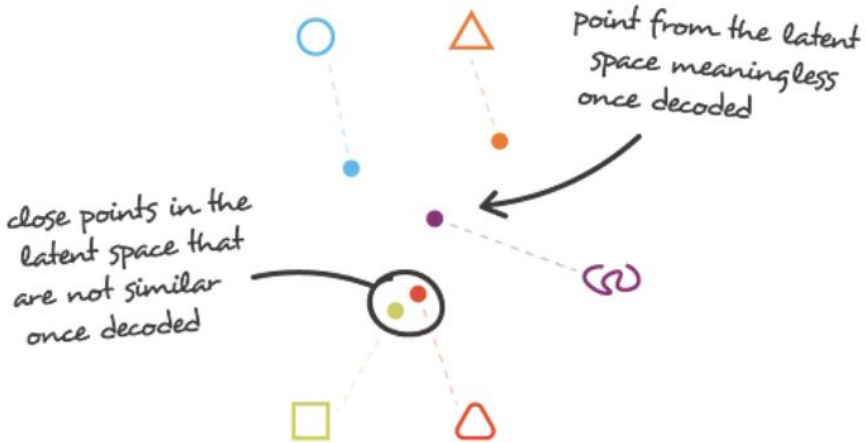
A variational autoencoder can be defined as being an autoencoder whose training is regularised to avoid overfitting and ensure that the latent space has good properties that enable generative process.


simple autoencoders
input
x
encoding
latent representation
z = e(x)
decoding
input reconstruction
d(z)

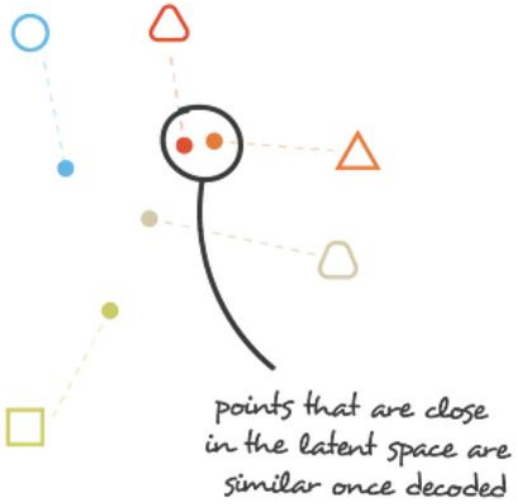

variational autoencoders
input
x
encoding
latent distribution
p(z|x)
sampling
sampled latent representation
z ~ p(z|x)
decoding
input reconstruction
d(z)



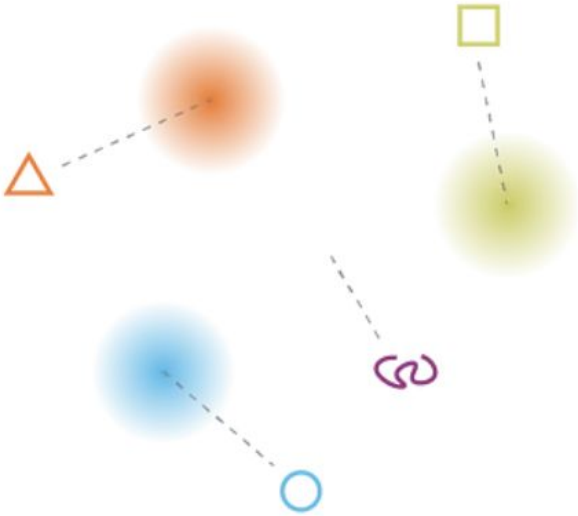
$$\text{loss} = \|x - \hat{x}\|^2 + KL[N(\mu_x, \sigma_x), N(0, I)] = \|x - d(z)\|^2 + KL[N(\mu_x, \sigma_x), N(0, I)]$$



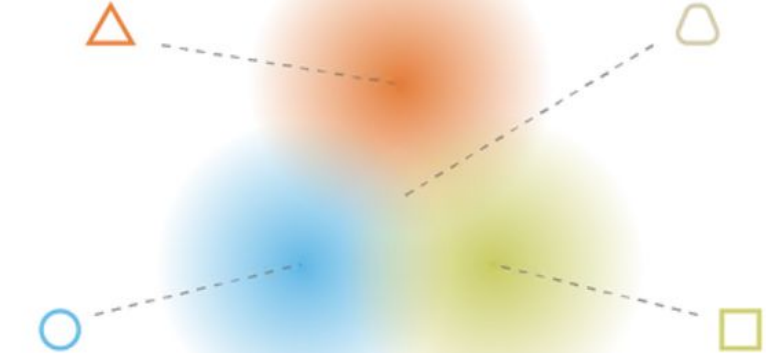
irregular latent space



regular latent space



what can happen without regularisation



what we want to obtain with regularisation

The returned distributions of VAEs have to be regularised to obtain a latent space with good properties.

References

https://towardsdatascience.com/applied-deep-learning-part-3-autoencoders-1c083af4d798

https://towardsdatascience.com/understanding-variational-autoencoders-vaes-f70510919f73