AUTOENCODERS

AI for Industrial Analytics

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WHY AUTOENCODERS?

- Feedforward Neural Networks
- Unsupervised learning
- Data compression
- Dimensionality reduction
- Data reconstruction
- Data denoising
- Anomaly detection

Healthcare: 

- Drug discovery
- Medical image analysis
- Diagnosis
- Disease progression

Industrial Analytics: 

- Predictive maintenance
- Energy consumption optimization
- Quality control improvement

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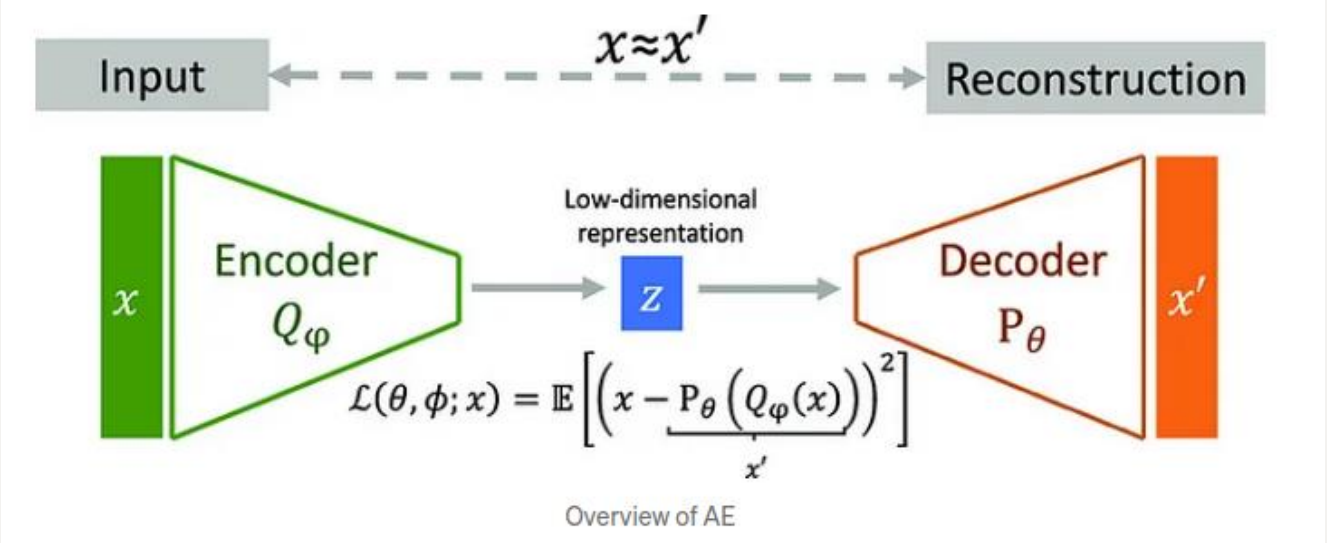
WHAT IS AN AUTOENCODER?

- Decoder: Feature extraction
- Latent space / Bottleneck: compressed knowledge representation
- Encoder: Reconstruction of input data
- Goal in training: minimize the difference between the original input and the reconstructed output



Overview of AE

Hyperparameters to be set:

- Dimensions of latent space
- Number of layers
- Nodes per layer
- Loss function

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APPLICATIONS OF INTEREST OF THE AUTOENCODERS

Convolutional autoencoder for hand-written digit identification:

- MNIST dataset of 28x28 gray scale images
- Train dataset: 48.000 images
- Validation dataset: 12.000 images
- Test dataset: 10.000 images

Goal:

- Build a convolutional autoencoder (Conv2D) with transpose convolution
- Inspect the latent space and reconstruction ability of the model

Time-series anomaly detection:

- Synthetic "normal" signals from a specific distribution

$$y_{\text{normal}} = A_1 \sin(f_1 x) + A_2 \sin(f_2 x) + A_3 \sin(f_3 x)$$

- Synthetic "abnormal" signals
- Train Conv1D autoencoder with Upsampling
- Assess the performance of the classification output

Goal:

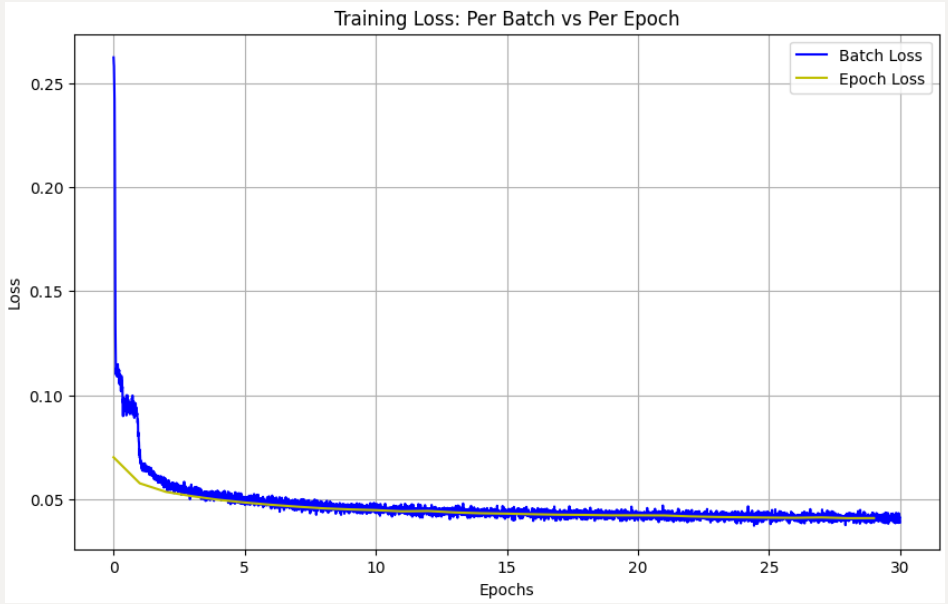
- Hands-on practice in anomaly detection with autoencoders

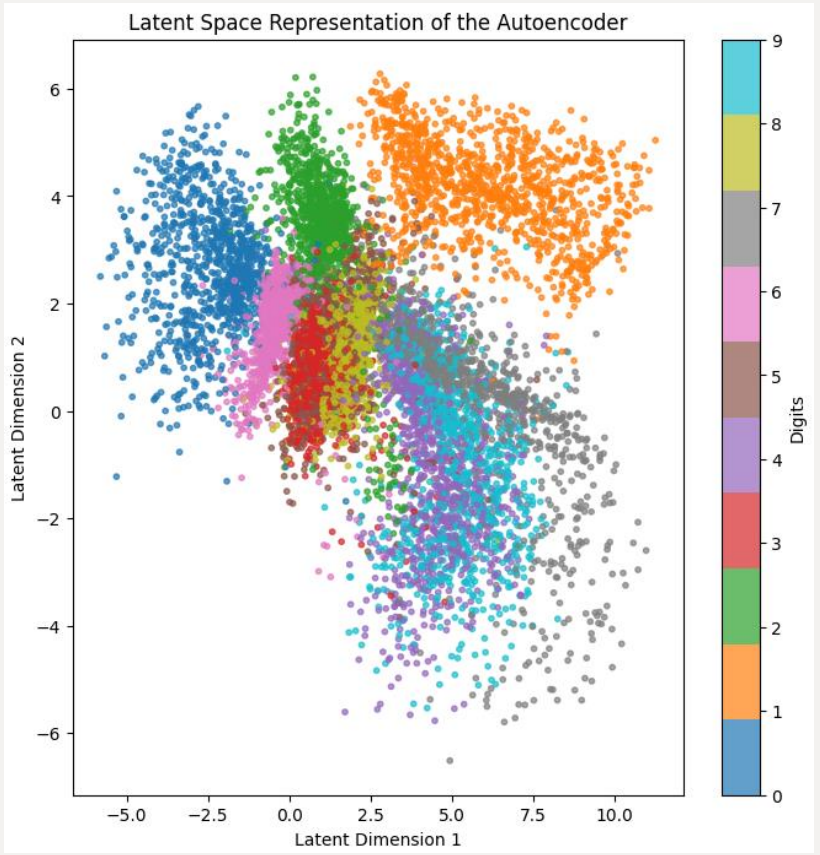
RESULTS OF CONVOLUTIONAL AYTOENCODERS

Layer (type)	Output Shape	Param #
Conv2d-1	[-1, 32, 28, 28]	320
LeakyReLU-2	[-1, 32, 28, 28]	0
Conv2d-3	[-1, 64, 14, 14]	18,496
LeakyReLU-4	[-1, 64, 14, 14]	0
Conv2d-5	[-1, 64, 7, 7]	36,928
LeakyReLU-6	[-1, 64, 7, 7]	0
Conv2d-7	[-1, 64, 7, 7]	36,928
Flatten-8	[-1, 3136]	0
Linear-9	[-1, 2]	6,274
Linear-10	[-1, 3136]	9,408
Reshape-11	[-1, 64, 7, 7]	0
ConvTranspose2d-12	[-1, 64, 7, 7]	36,928
LeakyReLU-13	[-1, 64, 7, 7]	0
ConvTranspose2d-14	[-1, 64, 13, 13]	36,928
LeakyReLU-15	[-1, 64, 13, 13]	0
ConvTranspose2d-16	[-1, 32, 27, 27]	18,464
LeakyReLU-17	[-1, 32, 27, 27]	0
ConvTranspose2d-18	[-1, 1, 55, 55]	289
Trim-19	[-1, 1, 28, 28]	0
Sigmoid-20	[-1, 1, 28, 28]	0

Total params: 200,963
Trainable params: 200,963
Non-trainable params: 0

Bottleneck





- Input images

- Reconstructed images

RESULTS OF TIME-SERIES ANALYSIS WITH AUTOENCODERS

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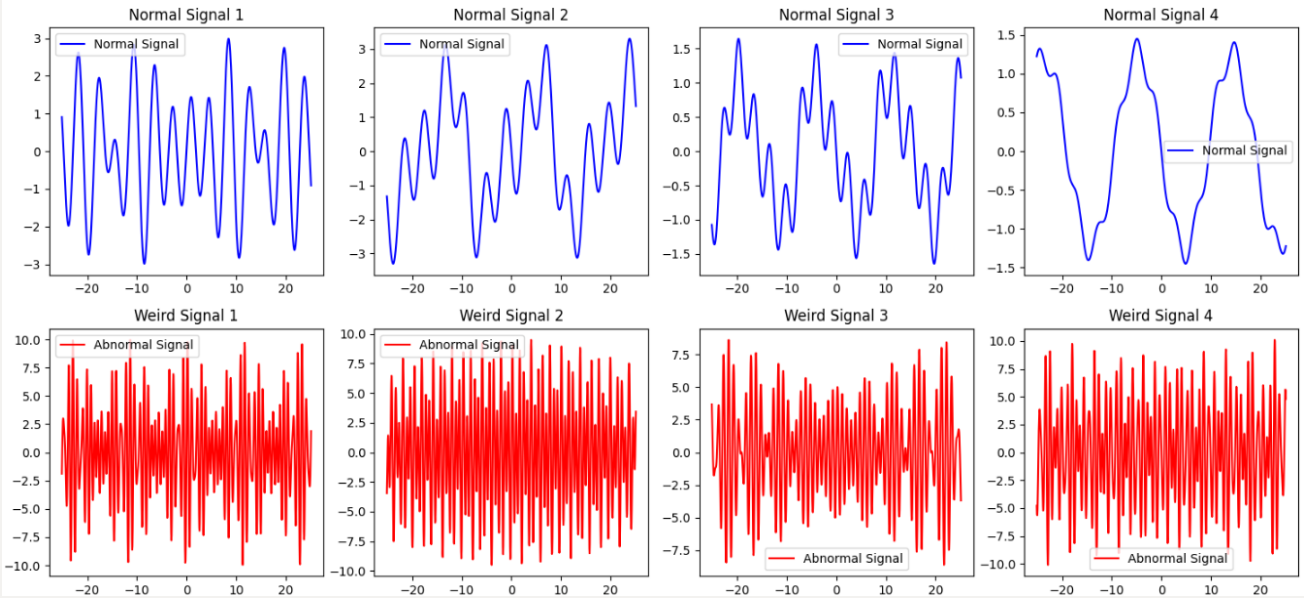
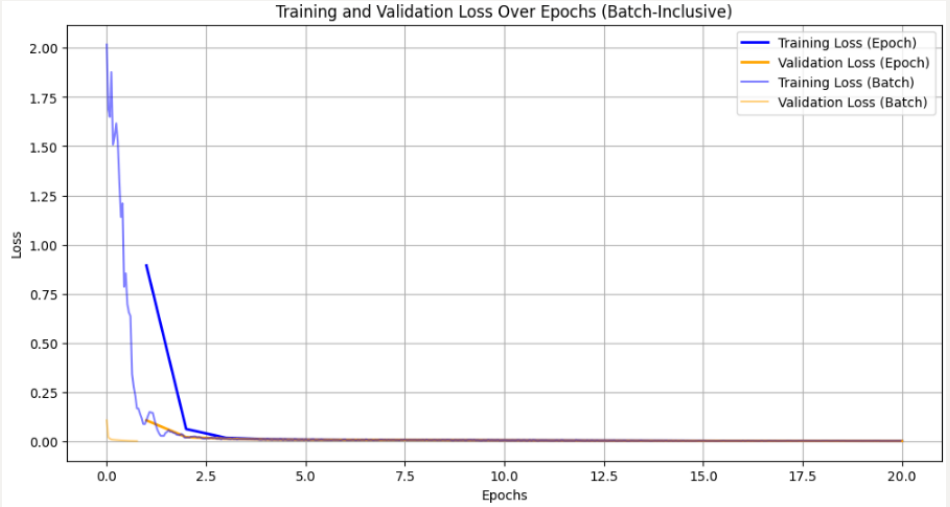
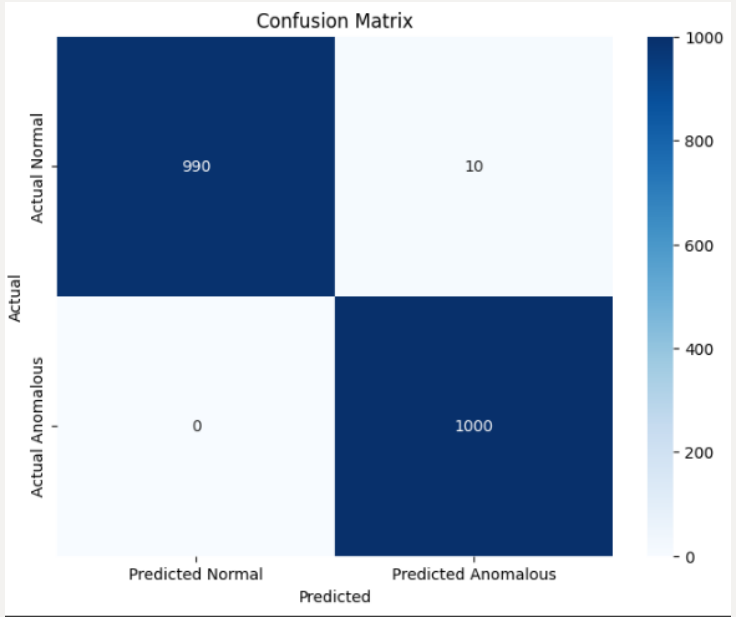




Layer (type)	Output Shape	Param #
Conv1d-1	[-1, 32, 1000]	192
ReLU-2	[-1, 32, 1000]	0
MaxPool1d-3	[-1, 32, 500]	0
Conv1d-4	[-1, 16, 500]	1,552
ReLU-5	[-1, 16, 500]	0
MaxPool1d-6	[-1, 16, 250]	0
Conv1d-7	[-1, 16, 250]	784
ReLU-8	[-1, 16, 250]	0
Upsample-9	[-1, 16, 500]	0
Conv1d-10	[-1, 32, 500]	2,592
ReLU-11	[-1, 32, 500]	0
Upsample-12	[-1, 32, 1000]	0
Conv1d-13	[-1, 1, 1000]	97
Identity-14	[-1, 1, 1000]	0

Total params: 5,217
Trainable params: 5,217
Non-trainable params: 0



REFLECTION ON AUTOENCODERS

- Specific to the distribution of training data. Deterministic not easy to generalize.
- Prone to Overfitting.
- Require careful construction and parameter selection to avoid reconstruction of the identical input data.

- Variational autoencoders
- GANs
- Denoising autoencoders
- Sparse autoencoders

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THANK YOU!

References:

- Syed Hasan, 2024, AutoEncoders: Theory + PyTorch Implementation
- Piero Paialunga, 2024, Hands-on Time Series Anomaly Detection using Autoencoders, with Python