



Semantic Communication Research Presentation

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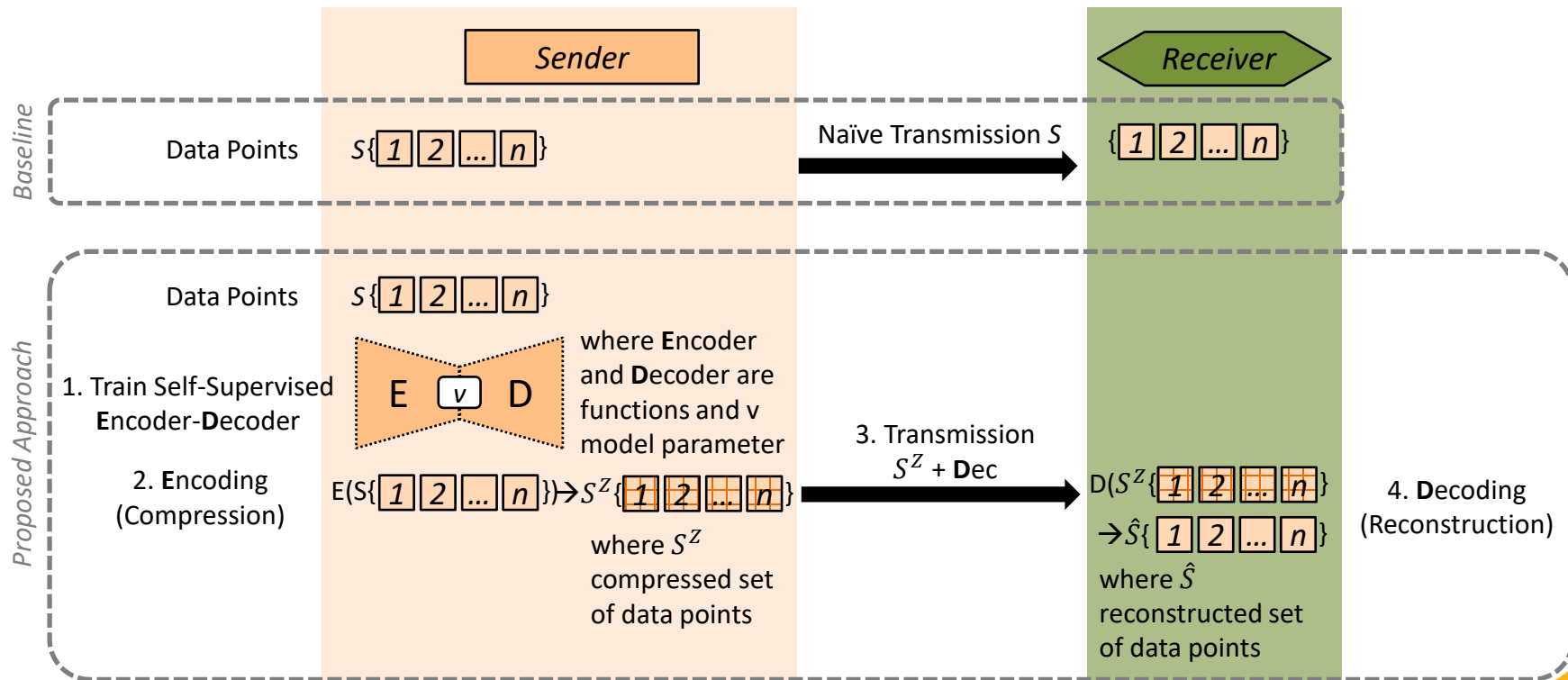
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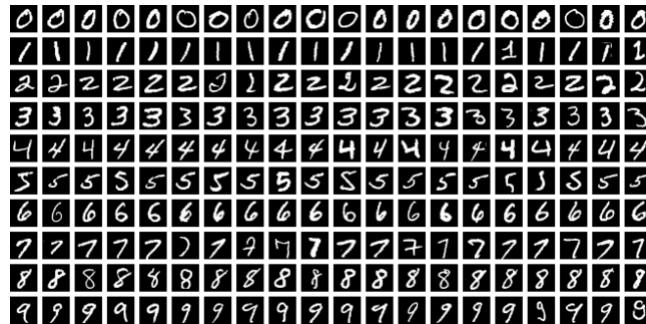
Prof. Dr. Ioannis Barbounakis

Communication



MNIST dataset

The MNIST database of handwritten digits with 784 features (28x28 pixels)



https://www.openml.org/search?type=data&sort=nr_of_likes&status=active&id=554

Communication Example

Sender

```
1 import matplotlib.pyplot as plt
2 from PIL import Image
3 from sklearn.decomposition import PCA
4 import numpy as np
5
6 # Load the data
7 data = np.loadtxt('data.npy')
8
9 # Split the data into training and testing sets
10 train_data, test_data = data[:10000], data[10000:]
11
12 # Train the PCA model
13 pca = PCA(n_components=100)
14 pca.fit(train_data)
15
16 # Encode the test data
17 S_z = pca.encode(test_data)
```

1. Train Self-Supervised Encoder-Decoder

```
1 mean, pca = method_pca_variance(X=S, v=0.8)
✓ 70s
```

2. Encoding (Compression)

```
1 S_z = pca_encode(S, mean, pca)
✓ 0.1s
```

```
1 #compressed second digit
2 S_z[1]
✓ 0.0s

array([[1010.494 , -289.9636 , -576.1107 , -485.00362 ,
        841.47833 , -145.46716 , -48.33355 , 102.231064 ,
        -34.786186 , -151.26501 , -282.70004 , -110.107765 ,
        329.9303 , -97.00201 , -226.4773 , -156.05044 ,
        -49.416885 , -37.92279 , 63.192932 , 113.47844 ,
        202.50096 , -94.190815 , -12.712128 , -29.628128 ,
        233.85992 , 196.91718 , 18.039308 , -28.378498 ,
        363.63416 , -84.49492 , -7.011917 , -100.57101 ,
        192.7258 , 86.99288 , -137.27632 , -79.502464 ,
        61.11911 , 4.0909624 , -43.707153 , -83.74587 ,
        219.2553 , -64.80328 , 68.30545 ], dtype=float32)
```

3. Transmission
 $S^Z + \text{Dec}$

3. Transmission

```
1 print("Original size of a digit:")
2 print(len(S[0]))
3 print("Compressed size of a digit:")
4 print(len(S_z[0]))
5 print("Reduction:")
6 print(f"1 - (len(S_z[0])/len(S[0])):.2%")
7
8 print("-----")
9 print("Original size of a digit times dataset size:")
10 print(str(len(S[0])) + " x " + str(len(S)) + " = " + str(len(S[0])*len(S)))
11 print("Compressed size of a digit times dataset size:")
12 print(str(len(S_z[0])) + " x " + str(len(S)) + " = " + str(len(S_z[0])*len(S)))
✓ 0.0s
```

Original size of a digit:
784
Compressed size of a digit:
43
Reduction:
94.52%

Original size of a digit times dataset size:
784 x 70000 = 54880000
Compressed size of a digit times dataset size:
43 x 70000 = 3010000

Receiver

4. Decoding (Reconstruction)

```
1 S_hat = pca_decode(S_z, mean, pca)
✓ 0.0s

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Remarks and Questions

R1: The size of the compressed set of data points S^Z and the decoder function D depends on the parameter v (generalizability of the model). The higher v , the larger the size of S^Z and the decoder function D and the more accurate the reconstruction.

R2: There must be a trade-off in transmitting the data points from Sender to Receiver naively S versus with the proposed approach $S^Z + D$. Performance metrics:

- Volume of transmission: $S > S^Z + D$
- Data Accuracy:
 - Sender $S \rightarrow$ Receiver S : 100%
 - Sender $E(S) = S^Z \rightarrow$ Receiver $D(S^Z) = \hat{S}$: Reconstruction Error(S, \hat{S})

Q1: What baseline compression methods exist?

Q2: When is the volume of the transmission indeed lower than the baseline while maintaining accurate data interpretation at receiver's end?

Back-Up

Algorithms

Algorithm 1 Local Self-Supervised Models

Input: S_k local schema, T^a, T^l global textual serialization, E global language model encoder, $v \in (1..0)$ global variance

Output: Local model: $M_k = \{\mu_k$ local signature mean, PC_k local principal components, l_k local linkability range}

- 1: $S_k^t \leftarrow (e_{k_j}^t \leftarrow T^a(a_{k_j}) | a_{k_j} \in t_{k_i} \in S_k) \cup (e_{k_i}^t \leftarrow T^l(t_{k_i}) | t_{k_i} \in S_k)$ //Local serialization.
- 2: $S_k^{\bar{t}} \leftarrow (e_{k_i}^{\bar{t}} \leftarrow E(e_{k_i}^t) | e_{k_i}^t \in S_k^t)$ //Local signatures.
- 3: $\mu_k = \text{mean}(S_k^{\bar{t}})$ //Compute local signatures mean.
- 4: $X_{\text{origin}} = S_k^{\bar{t}} - \mu_k$ //Project signatures onto origin.
- 5: $SV = \{sv_1, sv_2, \dots\}, PC = \{pc_1, pc_2, \dots\} = \text{SVD}(X_{\text{origin}})$ //Compute full Singular Value Decomposition and return Singular Values and Principal Components.
- 6: $EV^{\text{sum}} = \sum_{j=1}^{SV} sv_j^2$ //Compute the sum of the squared SV for Explained Variance.
- 7: $EV \leftarrow (ev_i \leftarrow \frac{sv_i^2}{EV^{\text{sum}}} | \forall sv_i \in SV)$ //Compute EV per PC.
- 8: $CEV = (ev_1, ev_1 + ev_2, \dots) \leftarrow \text{CumulativeSum}(EV)$ //Cumulate EV for each added PC.
- 9: $n_{\text{comp}} \leftarrow \text{GetIndex}(CEV, v) + 1$ //Find PC number needed to locally explain the global variance so that $> v$.
- 10: $PC_k \leftarrow \{pc_1, pc_2, \dots\}$ with $pc_l \in PC \wedge l < n$ //Reduce set of all PC to the top- n .
- 11: $X^Z = X_{\text{origin}} \cdot PC_k^T$ //Encode projected signatures.
- 12: $\hat{X}_{\text{origin}} = X^Z \cdot PC_k$ //Decode signatures.
- 13: $\hat{X} = \hat{X}_{\text{origin}} + \mu_k$ //Reverse projection onto origin.
- 14: $S_k^s \leftarrow \{s_{k_i} = \text{MSE}(e_{k_i}^{\bar{t}}, \hat{x}_i) | \forall (e_{k_i}^{\bar{t}}, \hat{x}_i) \in (S_k^{\bar{t}}, \hat{X})\}$ //Compute mean reconstruction error score of original and encoded-decoded signatures.
- 15: $l_k \leftarrow \max(s_{k_i} \in S_k^s)$ //Select maximum outlier score as local linkability range.
- 16: **return** $M_k = \{\mu_k, PC_k, l_k\}$ //Local model components.

Corresponding paper in review

Algorithm 2 Local Linkability Assessment

Input: $S_k^{\bar{t}}$ local schema signatures, $M = \{M_1, M_2, \dots, M_m\} \setminus \{M_k\}$ models of all other local schemas where $M_m = \{\mu_m, PC_m, l_m\}$

Output: Streamlined schema: $S'_k = \{e_{k_1}, e_{k_2}, \dots, e_{k_l}\}$

- 1: **for all** $M_m \in M$ **do**
- 2: $X_{\text{origin}} = S_k^{\bar{t}} - \mu_m$
- 3: $X^Z = X_{\text{origin}} \cdot PC_m^T$ //Encode projected signatures.
- 4: $\hat{X}_{\text{origin}} = X^Z \cdot PC_m$ //Decode signatures.
- 5: $\hat{X} = \hat{X}_{\text{origin}} + \mu_m$ //Reverse projection onto origin.
- 6: $S_k^s \leftarrow \{s_{k_i} = \text{MSE}(e_{k_i}^{\bar{t}}, \hat{x}_i) | \forall (e_{k_i}^{\bar{t}}, \hat{x}_i) \in (S_k^{\bar{t}}, \hat{X})\}$ //Compute mean reconstruction error score of original and encoded-decoded signatures.
- 7: **for all** $s_{k_i} \in S_k^s$ **do**
- 8: **if** $s_{k_i} \leq l_m$ **then**
- 9: $S'_k \leftarrow \text{Append}(S'_k, e_{k_i})$ //Append linkable table or attribute signature $e_{k_i} \in S_k$ to streamlined schema S'_k .
- 10: **end if**
- 11: **end for**
- 12: **end for**
- 13: **return** S'_k

Corresponding paper in review