Semantic Communication

Research Presentation

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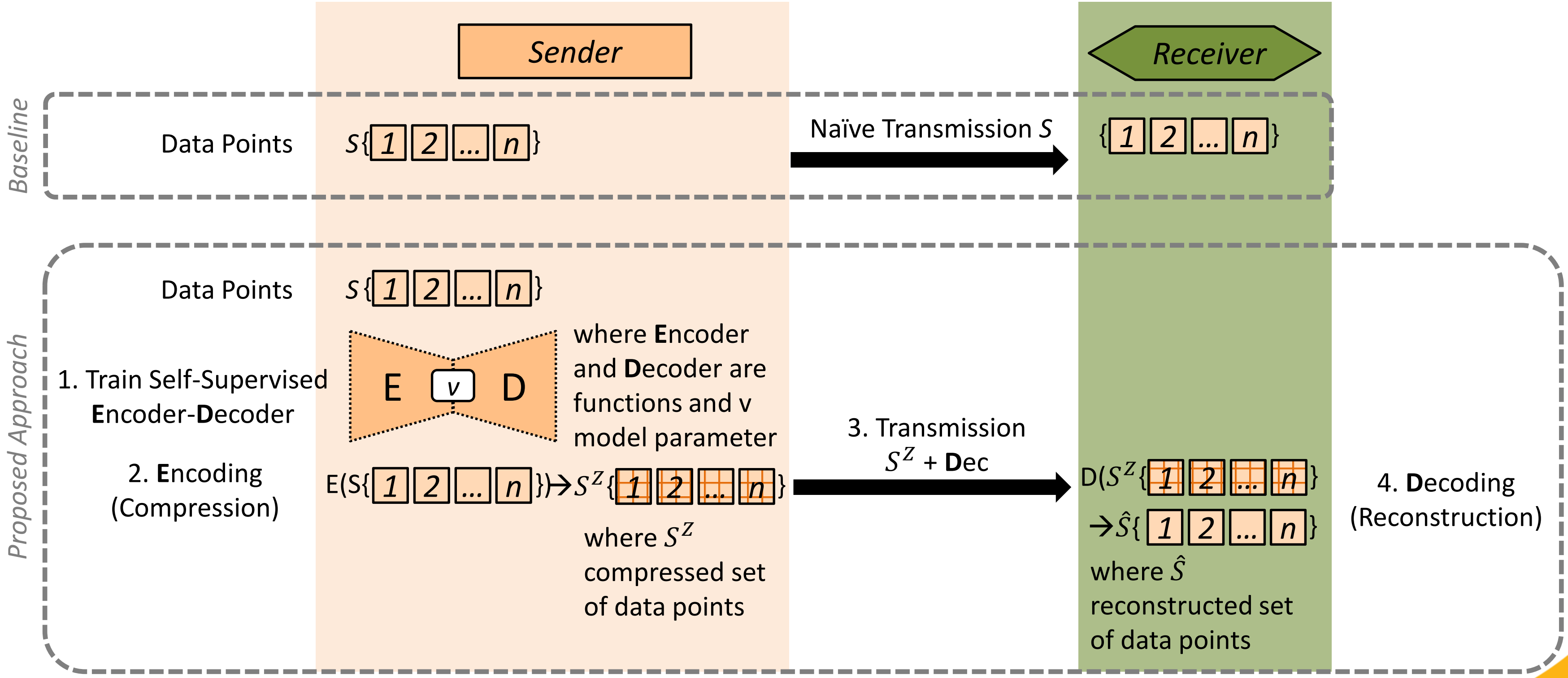
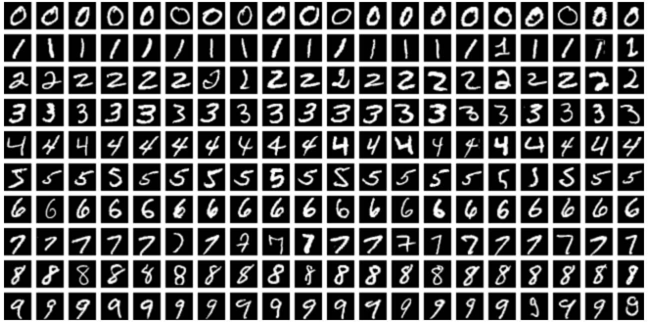
Communication



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. Train Self-Supervised Encoder-Decoder

```
mean, pca = method_pca_variance(X=S, v=0.8)
```

✓ 7.6s

2. Encoding (Compression)

```
S_z = pca_encode(S, mean, pca)
```

✓ 0.1s

```
#compressed second digit
S_z[1]
```

✓ 0.0s

```
array([1010.494   , -289.9636  , -576.1207  , -485.08362 ,
        841.47833 , -145.46716 ,  -48.333355 ,  102.231064 ,
        -34.786186 , -151.26501 , -282.70004 , -110.107765 ,
        329.9303   ,  -97.00281 , -226.4773  , -156.05844 ,
        -49.416885 ,  -37.92279 ,   63.192932 ,  113.47844 ,
        202.56096 ,  -94.196815 ,  -12.712128 ,  -29.628128 ,
        233.85992 ,  196.91718 ,   18.939308 ,  -28.379498 ,
        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 + **Dec**

3. Transmission

```
print("Original size of a digit:")
print(len(S[0]))
print("Compressed size of a digit:")
print(len(S_z[0]))
print("Reduction:")
print(f"{1 - (len(S_z[0])/len(S[0])):.2%}")

print("-------")
print("Original size of a digit times dataset size:")
print(str(len(S[0])) + " x " + str(len(S)) + " = " + str(len(S[0])*len(S)))
print("Compressed size of a digit times dataset size:")
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

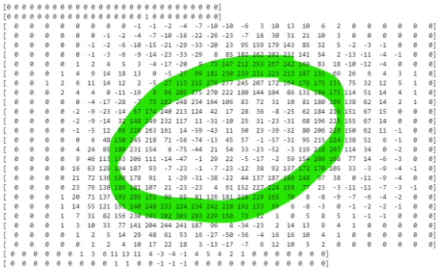
4. Decoding (Reconstruction)

```
S_hat = pca_decode(S_z, mean, pca)
```

✓ 0.2s

```
print_digit_array(np.array([round(pixel) for pixel in S_hat[1]]))
```

✓ 0.0s



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 → Receiver S: 100%
  - Sender E(S) = S^Z → 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

Irrelevant Lines

Alg.1: 14,15

Alg.2: 7-12

Algorithms

Algorithm 1 Local Self-Supervised Models

Input: S_k local schema, T^a, T^t 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: $S_k^t \leftarrow (e_{k_j}^t \leftarrow T^a(a_{k_j}) | a_{k_j} \in t_{k_i} \in S_k) \cup$
$(e_{k_i}^t \leftarrow T^t(t_{k_i}) | t_{k_i} \in S_k)$ `//Local serialization.`

2: $S_k^{\vec{v}} \leftarrow (e_{k_i}^{\vec{v}} \leftarrow E(e_{k_i}^t) | e_{k_i}^t \in S_k^t))$ `//Local signatures.`

3: $\mu_k = \text{mean}(S_k^{\vec{v}})$ `//Compute local signatures mean.`

4: $X_{origin} = S_k^{\vec{v}} - \mu_k$ `//Project signatures onto origin.`

5: $SV = \{sv_1, sv_2, \ldots\}, PC = \{pc_1, pc_2, \ldots\} = SVD(X_{origin})$ `//Compute full Singular Value Decomposition and return Singular Values and Principal Components.`

6: $EV^{sum} = \sum_{j=1}^{SV} sv_j^2$ `//Compute the sum of the squared SV for Explained Variance.`

7: $EV \leftarrow (ev_i = \frac{sv_i^2}{EV^{sum}} | \forall sv_i \in SV)$ `//Compute EV per PC.`

8: $CEV = (ev_1, ev_1 + ev_2, \ldots) \leftarrow \text{CumulativeSum}(EV)$ `//Cumulate EV for each added PC.`

9: $n_{comp} \leftarrow \text{GetIndex}(CEV, v) + 1$ `//Find PC number needed to locally explain the global variance so that` $> v$.

10: $PC_k \leftarrow \{pc_1, pc_2, \ldots\}$ with $pc_l \in PC \wedge l < n$ `//Reduce set of all PC to the top-`n.

11: $X^Z = X_{origin} \cdot PC_k^T$ `//Encode projected signatures.`

12: $\hat{X}_{origin} = X^Z \cdot PC_k$ `//Decode signatures.`

13: $\hat{X} = \hat{X}_{origin} + \mu_k$ `//Reverse projection onto origin.`

14: $S_k^s \leftarrow \{s_{k_i} = MSE(e_{k_i}^{\vec{v}}, \hat{x}_i) | \forall (e_{k_i}^{\vec{v}}, \hat{x}_i) \in (S_k^{\vec{v}}, \hat{X})\}$ `//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: $S_k^{\vec{v}}$ local schema signatures, $M = \{M_1, M_2, \ldots, M_m\} \setminus \{M_k\}$ models of all other local schemas where $M_m = \{\mu_m, PC_m, l_m\}$

Output: Streamlined schema: $S_k' = \{e_{k_1}, e_{k_2}, \ldots, e_{k_i}\}$

1: **for all** $M_m \in M$ **do**

2: $\quad X_{origin} = S_k^{\vec{v}} - \mu_m$

3: $\quad X^Z = X_{origin} \cdot PC_m^T$ `//Encode projected signatures.`

4: $\quad \hat{X}_{origin} = X^Z \cdot PC_m$ `//Decode signatures.`

5: $\quad \hat{X} = \hat{X}_{origin} + \mu_m$ `//Reverse projection onto origin.`

6: $\quad S_k^s \leftarrow \{s_{k_i} = MSE(e_{k_i}^{\vec{v}}, \hat{x}_i) | \forall (e_{k_i}^{\vec{v}}, \hat{x}_i) \in (S_k^{\vec{v}}, \hat{X})\}$ `//Compute mean reconstruction error score of original and encoded-decoded signatures.`

7: $\quad$ **for all** $s_{k_i} \in S_k^s$ **do**

8: $\quad\quad$ **if** $s_{k_i} \leq l_m$ **then**

9: $\quad\quad\quad S_k' \leftarrow Append(S_k', e_{k_i})$ `//Append linkable table or attribute signature` $e_{k_i} \in S_k$ `to streamlined schema` S_k'.

10: $\quad\quad$ **end if**

11: $\quad$ **end for**

12: **end for**

13: **return** S_k'

Corresponding paper in review