# SMATE: Semi-Supervised Spatio-Temporal Representation Learning on Multivariate Time Series

23.04.24

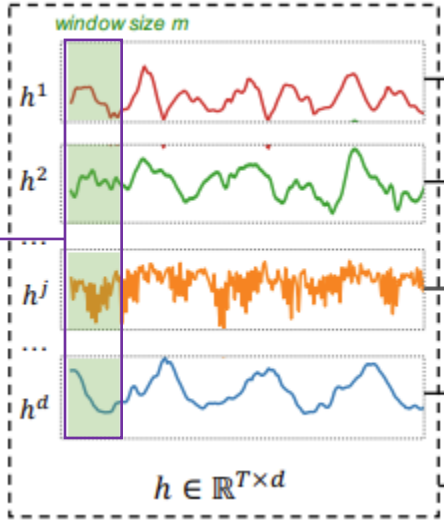
이정민

# 연구 배경

## ❖ 기존 연구들의 한계점(Multivariate Time Series)

- **Sub-sequence level**에서의 **local spatial interactions** 무시**(Spatial dynamics)**
- Supervised loss에만 치중하면 unlabeled 데이터가 실제 features에서 벗어나게 되어 성능 저하를 야기할 수 있음
- 학습된 representation에 대한 해석을 제공할 수 없음

**Local spatial interactions**




Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 기여점

❖ **SMATE(Semi-supervised spatio-temporal representation learning on Multivariate Time sEries)**

- 시계열 특징 뿐만 아니라 features의 공간적 특징도 반영(**Sptaio-Temporal dynamic features**)
- Semi-supervised 기반의 three-step Regularization Process를 통해 class-sepecific한 representation 학습 가능
- Embedding 공간에서 visual interpretability 제공

# 방법론

## ❖ Framework(Asymmetric auto-encoder structure)

- Spatio-Temporal dynamic encoder
- Sequential decoder
- Semi-supervised three-step regularization

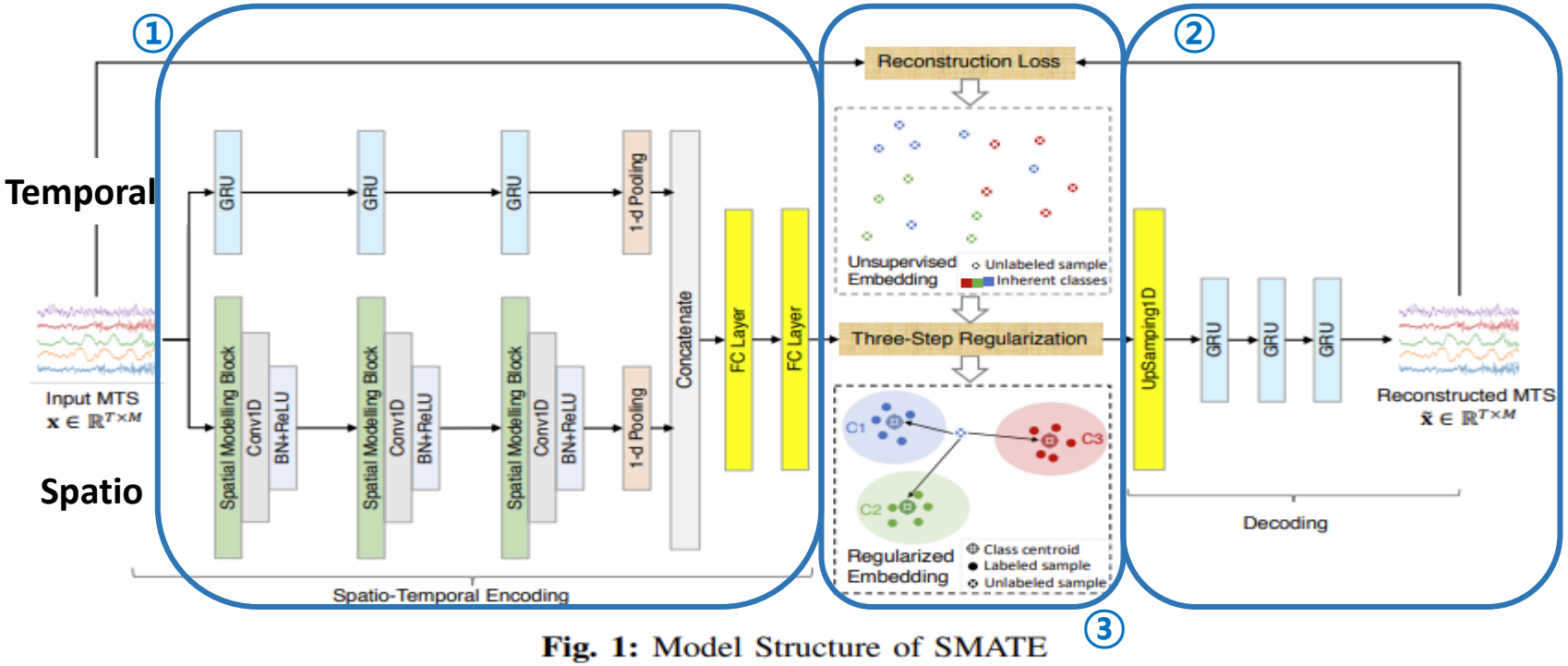



**Fig. 1:** Model Structure of SMATE

Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

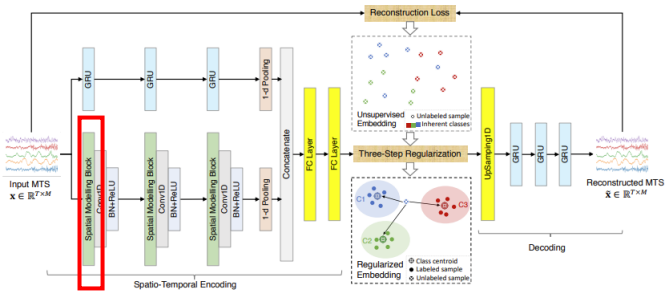



**Fig. 1:** Model Structure of SMATE

① Spatio-Temporal dynamic encoder

## ❖ Spatial Modeling Block(SMB)

- $T$: Window 수, 첫 번째 block에서는 $d = M$
- Pooling
  - ➢ $s_H(i) = avg([h_{i-\frac{m}{2}}: h_{i+\frac{m}{2}}]),\ i: time\ stick$

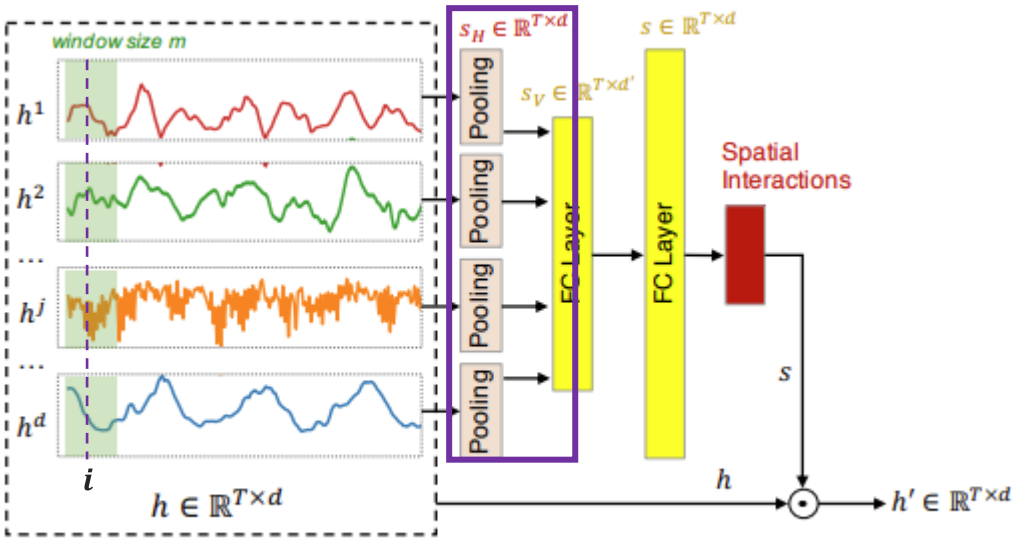



**Fig. 2:** The Spatial Modeling Block (SMB)

Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

① Spatio-Temporal dynamic encoder

## ❖ Spatial Modeling Block(SMB)

- FC Layer
  - ➢ $s_H$를 vertical 방향으로 압축하여 **h간의 interactions**이 반영된 $s_V$ 생성
  - ➢ $s_V$를 초기 차원에 맞게 $s$로 remapping

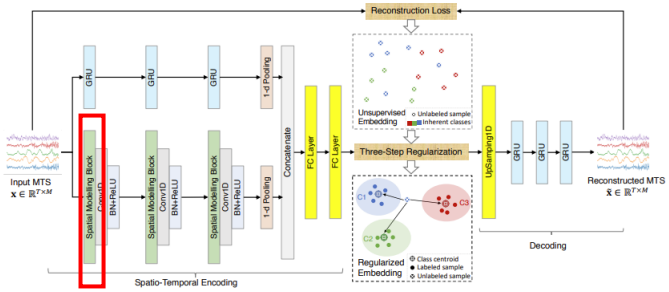



**Fig. 1:** Model Structure of SMATE

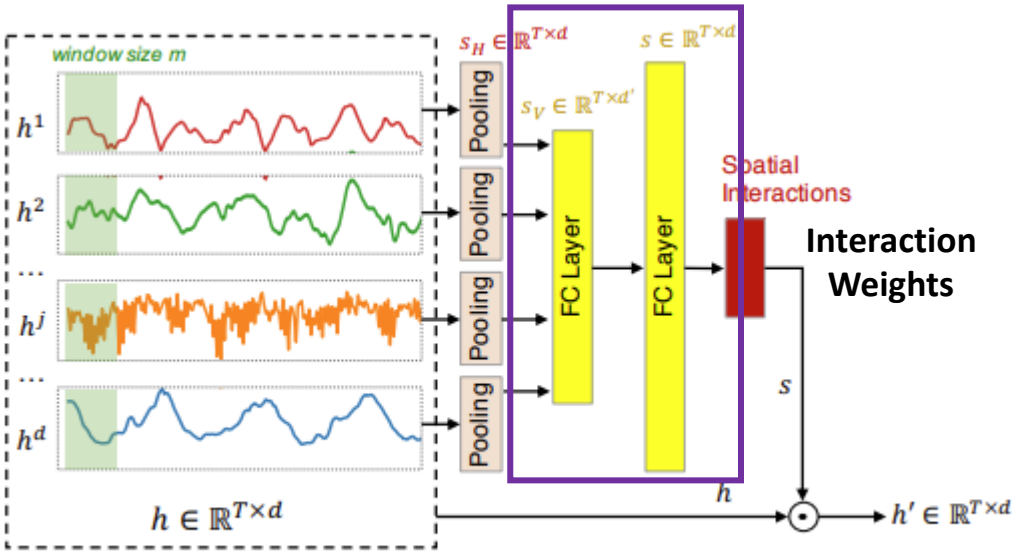



**Fig. 2:** The Spatial Modeling Block (SMB)

Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

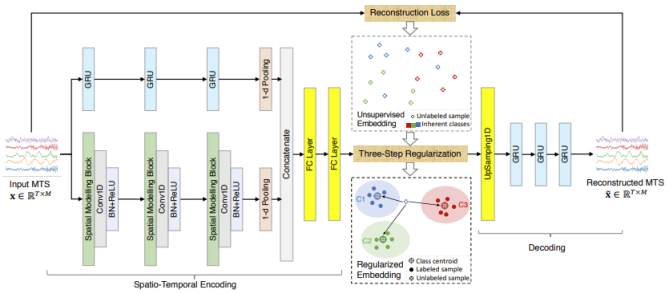



**Fig. 1:** Model Structure of SMATE

① Spatio-Temporal dynamic encoder

## ❖ Temporal channel(GRU based)

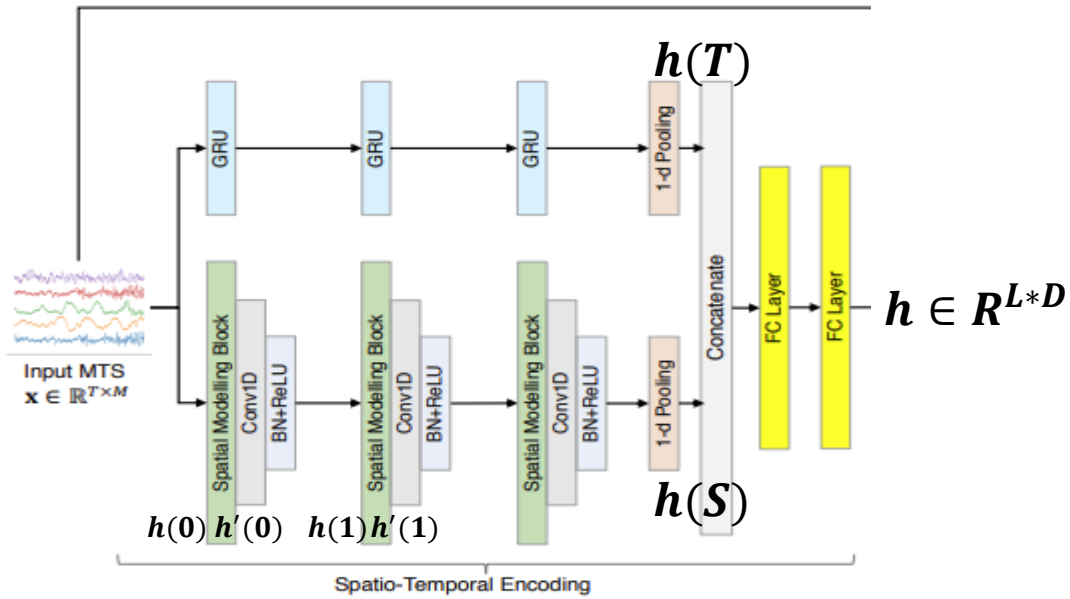
- $h(T) \in R^{L*d_g}, L = \frac{T}{P}, P: pool\ sampleing\ size$

## ❖ Spatial channel

- $h'(l) = SMB\big(h(l)\big),\ h(l+1) = ReLU(BN(W \otimes h'(l) + b)$

  1-D convolutional kernel

- $h(S) \in R^{L*d_c}$




Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

③ Semi-supervised three-step regularization

## ❖ Joint Model Optimization

- Class-Specific한 특징을 더 잘 반영하기 위함

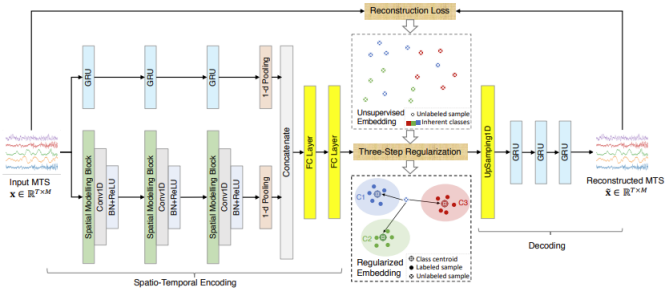
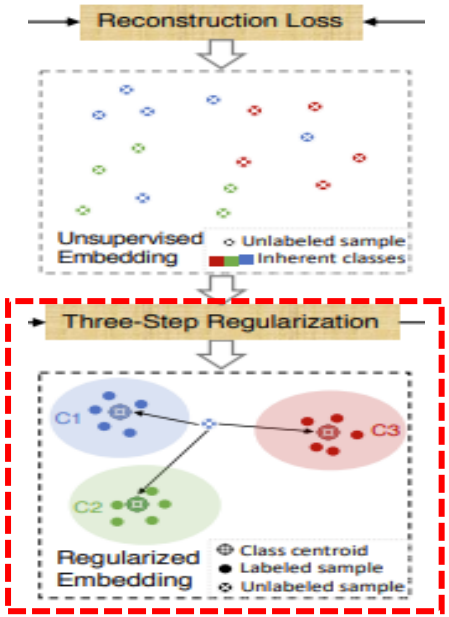



**Fig. 1:** Model Structure of SMATE




Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

③ Semi-supervised three-step regularization

## ❖ Joint Model Optimization(Class-specific)

1. Supervised Centroids Initialization
2. Supervised Centroids Adjustment
3. Unsupervised Centroids Adjustment

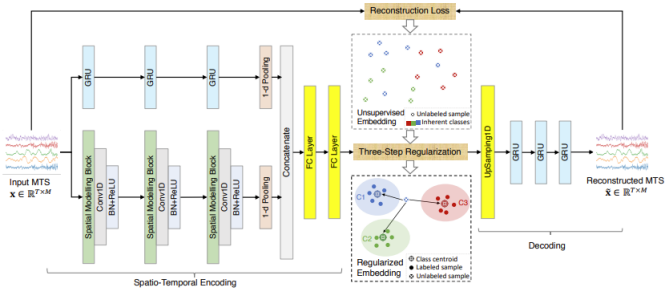
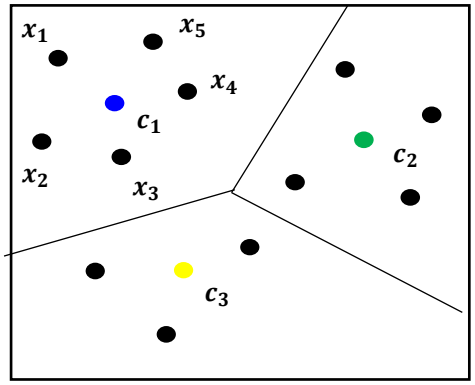



**Fig. 1:** Model Structure of SMATE




**< Labeled dataset >**

- ✓ Labeled set으로 초기 centroids($c_k$) 구축
- ✓ $H^k = f_\theta(X^k)$
- ✓ $c_k = mean(H^k)$

Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

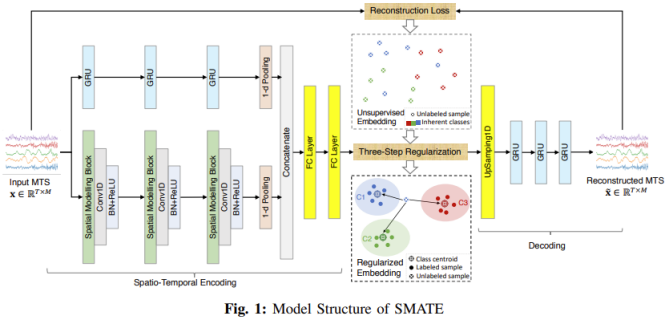
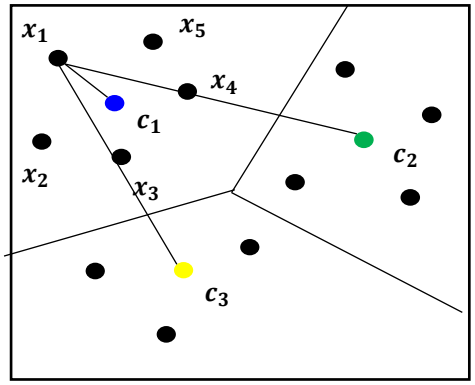



**Fig. 1:** Model Structure of SMATE

③ Semi-supervised three-step regularization

❖ **Joint Model Optimization(Class-specific)**

1. Supervised Centroids Initialization
2. Supervised Centroids Adjustment
3. Unsupervised Centroids Adjustment




**< Labeled dataset >**

- ✓ Euclidean Distance로 $h_i^k, c_k$간의 weight 설정
- ✓ 설정된 weight로 새로운 centroids 형성
- ✓ $W_{k,i} = 1 - \frac{ED\left(h_i^k, c_k\right)}{\sum_{j=1}^{K} ED(h_i^k, c_j)}$
- ✓ $c_k = \sum_{i=1}^{N_K} W_{k,i} h_i^k$

Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

③ Semi-supervised three-step regularization

## ❖ Joint Model Optimization(Class-specific)

1. Supervised Centroids Initialization
2. Supervised Centroids Adjustment
3. Unsupervised Centroids Adjustment

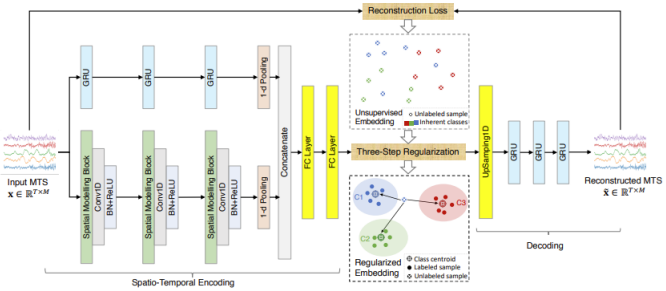
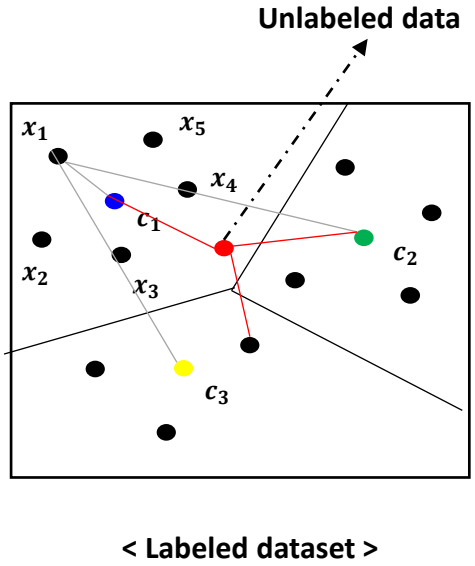



**Fig. 1:** Model Structure of SMATE




**< Labeled dataset >**

- ✓ ED로 unlabeled data에 대한 클래스별 확률 값 계산
- ✓ $\widehat{p_\theta}(y = k|\widehat{x_i}) = 1 - \frac{ED(f_\theta(\widehat{x_i}), c_k)}{\sum_{j=1}^{K} ED(f_\theta(\widehat{x_i}), c_j)}$
- ✓ Labeled data와 unlabeled data를 같이 이용하여 새로운 centroids 설정

$$\mathbf{c}_k = \frac{N_k}{N_k + \hat{N}_k} \sum_{i=1}^{N_k} W_{k,i} \cdot \mathbf{h}_i^k + \frac{\hat{N}_k}{N_k + \hat{N}_k} \sum_{i=1}^{\hat{N}_k} \hat{p}_{k,i} \cdot \hat{\mathbf{h}}_i^k$$


Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.

# 방법론

## Training Loss

### ❖ Total Loss

- Reconstruction Loss($L_R$)
- Regularization Loss ($L_{Reg}$)

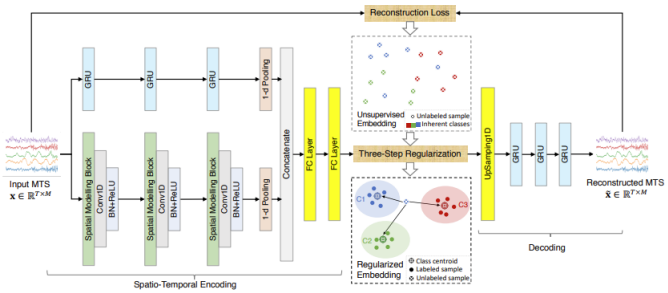



**Fig. 1:** Model Structure of SMATE

**Total dataset**

$$L_R = \sum_t \left|\left|x_t - \tilde{x_t}\right|\right|_2$$

**Labeled dataset**

$$L_{Reg} = -\sum_k logW_\theta(y = k|x)$$

$$\min_{\theta} \boldsymbol{L_R + \lambda L_{Reg}}$$


Zuo, J., Zeitouni, K., & Taher, Y. (2021, December). Smate: Semi-supervised spatio-temporal representation learning on multivariate time series. In *2021 IEEE International Conference on Data Mining (ICDM)* (pp. 1565-1570). IEEE.