FEDERATED SHIFT-INVARIANT DICTIONARY LEARNING ENABLED DISTRIBUTED USER PROFILING

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UNDERSTANDING USER BEHAVIOR IS A KEY ENABLER

- Active distribution network is crucial to the operation of a power grid with high penetration of renewable energies.

- And understanding user behaviors is a key enabler of active distribution network.

- How to understand user behaviors?
- What are the practical challenges?

Source: https://www.varonis.com/blog/what-is-user-behavior-analytics

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CONVENTIONAL WISDOM

- The conventional wisdom is to conduct user profiling (i.e., clustering).

- Though effective, it faces several practical obstacles.

- Clustering requires massive data and each single data holder may not have enough data to understand all kinds of users.
- Also, data are the crucial assets for each data holder. Hence, data holders may not want to directly exchange the data with each other.

Source Up Inc.

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OUR IDEA

- Distributed User Profiling Based on Federated Learning & Dictionary Learning

- Our idea is based on a simple observation:
  - Each user's data are the energy consumption aggregation of all its appliances.
  - Hence, the energy consumption patterns of those appliances can serve as the dictionary, which is used to construct the user's energy consumption data.
  - If the dictionary is rich, then the user profiling can be done more accurately.

- Hence, we propose that each data holder first conducts the dictionary learning based on its own data, and then exchange the dictionary with each other based on the federated learning framework.

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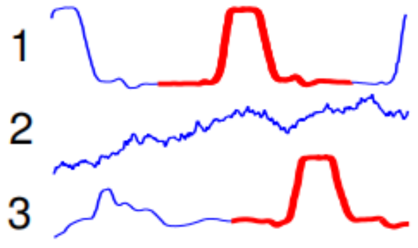
STEP 1:
SHIFT-INVARIANT DICTIONARY LEARNING FOR USER PROFILING

Learn dictionary based on end users' load series

Cluster the derived pattern matrices D

Intuitive Idea



Time Warp

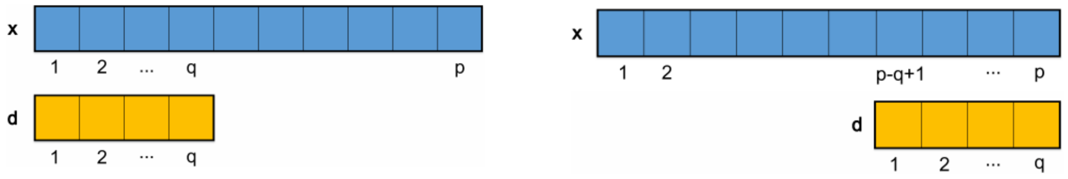
Making basis vector shift-invariant

Shifting Operator

$$\Psi(d_k,[\beta]_k)=\begin{cases}[d_k]_{t-[\beta]_k}, if\ 1\le t-[\beta]_k\le q\\ 0, otherwise\end{cases}$$

Shift-Invariant Dictionary Learning

$$\min_{D,\alpha_j,[\beta_j]_k}\sum_{j=1}^{J}\frac{1}{2}\left\|x_j-\sum_{k=1}^{K}[\alpha_j]_k\Psi\left(d_k,[\beta_j]_k\right)\right\|_2^2+\lambda\sum_{j=1}^{J}\left\|\alpha_j\right\|_1$$



The same basis with different shifts

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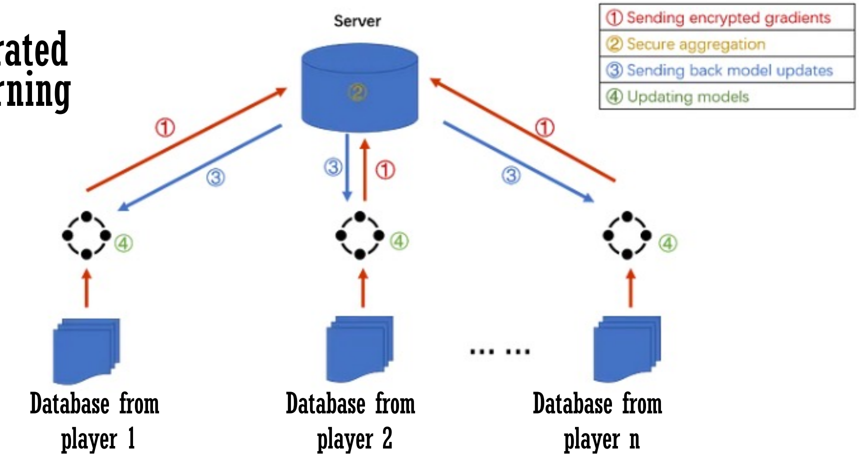
STEP 2:
FEDERATED SHIFT-INVARIANT DICTIONARY LEARNING CLUSTERING

- **Incorporate federated learning**
- **Enable distributed user profiling without exchanging the datasets with each other**

Federated Learning



Solution Procedure:

1. Local user dictionary learning

$$\min_{m^* \in [1,\cdots,M], \alpha_j} \sum_{x_j \in P_u} \frac{1}{2} \left\| x_j - \sum_{k=1}^{K} [\alpha_j]_k \Psi\left(d_k^{m^*}, [\beta_j]_k\right) \right\|_2^2 + \lambda \left\| \alpha_j \right\|_1$$

2. Local dictionary updating

$$\min_{d_k^{m^*}} \sum_{x_j \in P_u} \frac{1}{2} \left\| x_j - \sum_{k=1}^{K} [\alpha_j]_k \Psi\left(d_k^{m^*}, [\beta_j]_k\right) \right\|_2^2$$

3. Dictionary aggregation (federated averaging)

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NUMERICAL EVALUATION

Dictionary learning helps

TABLE I: Clustering Performance Comparison.

Evaluation	SIDL-clustering	K-means	GMM	K-shape	SC
h-score	0.9203	0.8714	0.7253	0.8942	0.8906
c-score	0.9453	0.9053	0.7451	0.9070	0.8934
v-measure	0.9322	0.8876	0.7349	0.9004	0.8920

- Dictionary learning better reveals the load series patterns.

Distributed implementation comes with a cost.

TABLE II: Performance Comparison between Centralized SIDL Clustering and Federated SIDL Clustering.

Method	*v-measure*	h-score	c-score	Comp. Time
Central	0.9322	0.9203	0.9453	264min
Federated	0.9115	0.8972	0.9269	52min

- The federated framework significantly improves the computation efficiency at the cost of slightly reduced v-measure, h-score and c-score.

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