Energy Disaggregation with Discriminative Sparse Coding

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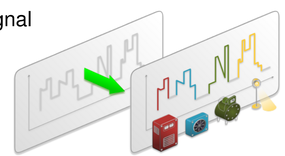
RiskEcon® Lab for Decision Metrics @ NYU Courant Institute of Mathematical Sciences

Energy Disaggregation

Definition: task of taking a whole-home energy signal and separating it into its component appliances.



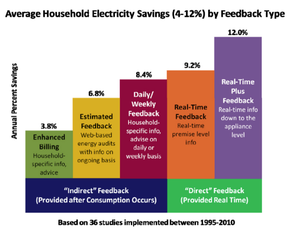
Why it matters?

customers:

- understand bill and plan monthly budget
- identify/repair/replace energy hogs
- make financial decision when to use device

utilities:

- identify/verify appliance in Demand Response
- understand customer behavior
- improve capacity planning



Sparse Coding Pre-training

Goal: find basis functions (or *dictionary*) $\mathbf{B}_i \in \mathbb{R}^{T\times n}$ and *activations* $\mathbf{A}_i \in \mathbb{R}^{n\times m}$ of each individual class $\mathbf{X}_i$ using $\mathbf{X}_i \approx \mathbf{B}_i\mathbf{A}_i$

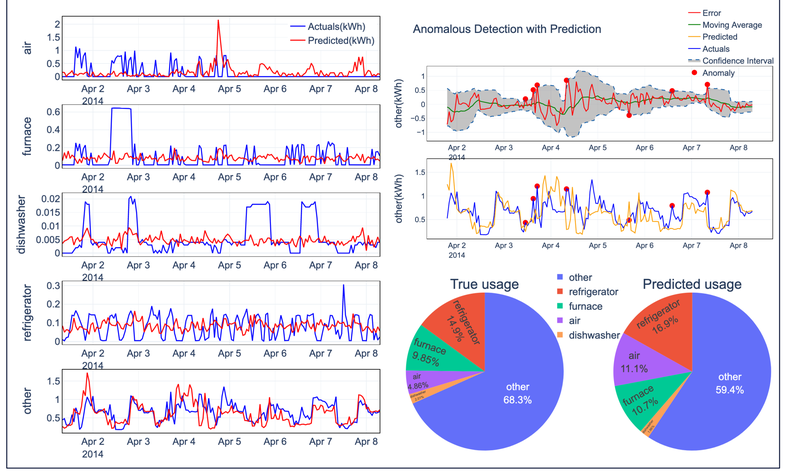
- require *over-complete* representations of data: $n \gg m, T$
- impose constraint that $\mathbf{A}_i$ be sparse to guarantee unique solution

non-negative sparse coding

$$\min_{\mathbf{A}_i\geq 0,\mathbf{B}_i\geq 0} \|\mathbf{X}_i - \mathbf{B}_i\mathbf{A}_i\|_F^2 + \lambda \sum_{p,q}(\mathbf{A}_i)_{pq} \quad \text{subject to} \quad \|\mathbf{B}_i^{(j)}\|_2 \leq 1, j = 1, \ldots, n$$

- $\mathbf{A}_i$, $\mathbf{B}_i$ be non-negative since energy usage by nature
- achieve sparsity of activations $\mathbf{A}_i$ by adding ℓ_1 regularization

Case Study



Problem Formulation

Goal: disaggregate new whole-home data $\bar{\mathbf{X}}'$ into components $\mathbf{X}'_1, \ldots, \mathbf{X}'_k$

- lots of methods one common denominator, Data
  - low-resolution smart meter data, e.g., 60-min
- perform unsupervised on test, and supervised on scaled houses

Assume we have $1:k$ appliances with

- individual energy reading of ith appliances (e.g. heater): $\mathbf{X}_i \in \mathbb{R}^{T\times m}$, where T hourly week data for m houses, e.g.,

$$\mathbf{X}_1 = \begin{bmatrix} App & x_1^{(j)} & \cdots & x_1^{(m)} \\ 1h & 0.8kWh & \cdot & \cdot \\ 2h & 0.7kWh & \cdot & \cdot \\ \vdots & \vdots & \cdot & \cdot \\ 168h & 0.1kWh & \cdots & \cdots \end{bmatrix}$$

- **one** aggregated test power consumption reading: $\bar{\mathbf{X}}' \leftarrow \sum_{1:k} \mathbf{X}'_i$

Discriminative Disaggregation

Goal: estimate the activation coefficient for each unknown appliance ($\hat{\mathbf{A}}'_i$)

discriminative disaggregation

$$\hat{\mathbf{A}}'_{1:k} = \arg\min_{\mathbf{A}'_{1:k}\geq 0} \left\| \bar{\mathbf{X}}' - [\mathbf{B}_1 \cdots \mathbf{B}_k] \begin{bmatrix} \mathbf{A}'_1 \\ \vdots \\ \mathbf{A}'_k \end{bmatrix} \right\|_F^2 + \lambda \sum_{i,p,q} (\mathbf{A}'_i)_{pq}$$

- $\mathbf{A}'_i (i = 1, \ldots, k)$: the activation matrix for the ith appliance's base matrix ($\mathbf{B}_i$)

Goal: disaggregate new whole-home data $\bar{\mathbf{X}}'$ into components $\mathbf{X}'_1, \ldots, \mathbf{X}'_k$

prediction model

$$\hat{\mathbf{X}}'_i = \mathbf{B}_i\hat{\mathbf{A}}'_i$$

- intuition: $\mathbf{B}_i$ is better at reconstructing the ith portion of aggregate signal than the other bases $\mathbf{B}_j$ for $j \neq i$.

Prospective Insurance Use Cases

- identify anomalous appliance to avoid energy wastage, e.g., light bulbs burning out too often

- detect device failure to avert disasters, e.g., house fire
- diagnose household electrical problems, e.g., circuit overload/short circuit

- assist occupancy monitoring

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