

Non-Intrusive Load Monitoring: A Review of the State of the Art



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Civil & Environmental
ENGINEERING
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Outline



History



Present



Future (we'll talk about this later)

In the beginning, there were waveforms...

HISTORY



Definition

- A set of techniques used to obtain
 - ✓ estimates of the electrical consumption of individual appliances
 - ✓ from measurements of voltage and/or current
 - ✓ taken at a limited number of locations of the power distribution system in a building

Origins

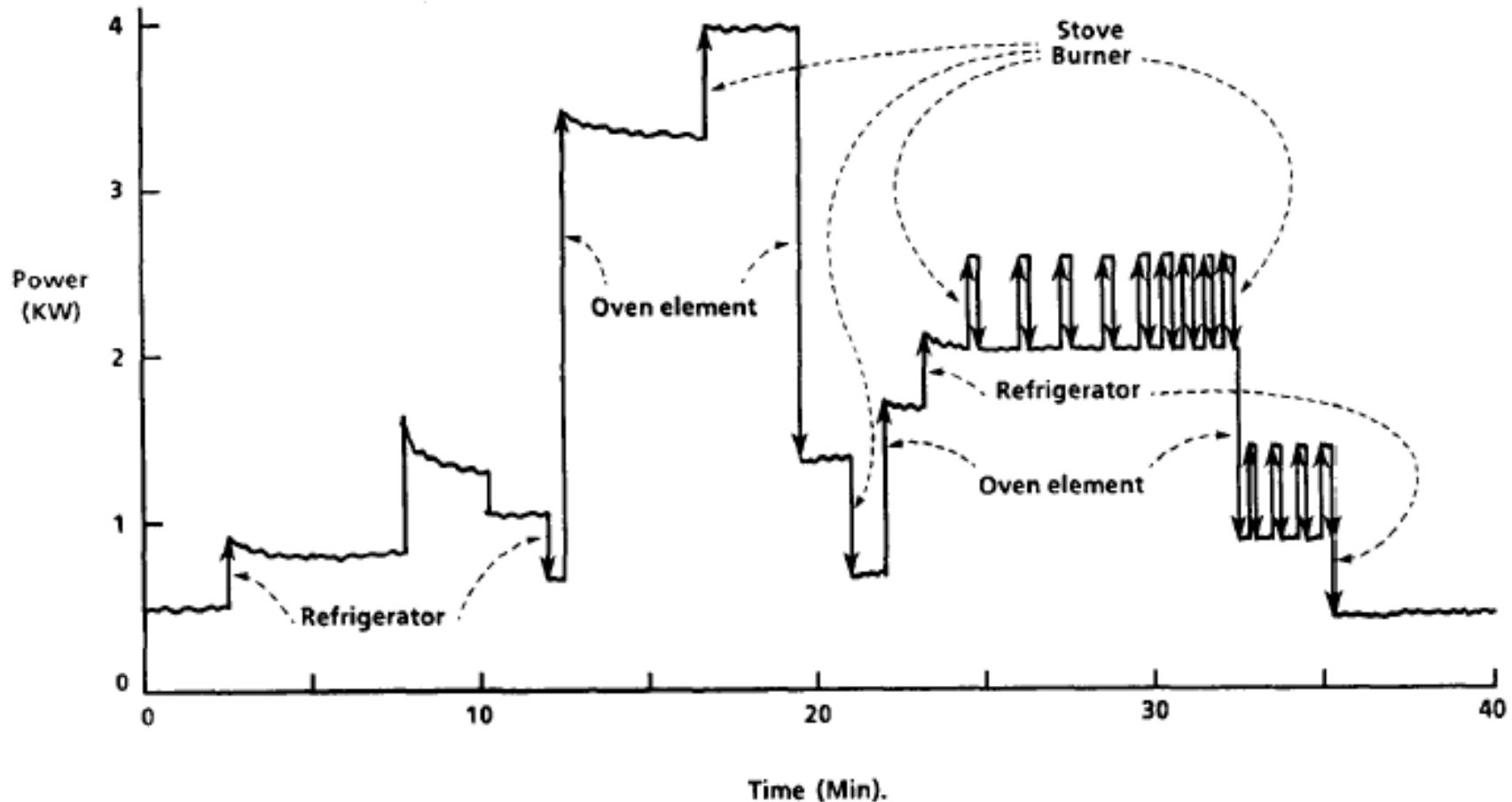


Figure from: G.W. Hart, "Nonintrusive appliance load monitoring," *Proceedings of the IEEE* 80, no. 12 (1992).

Origins

SIGNATURE SPACE
ACTON HOUSE (1)

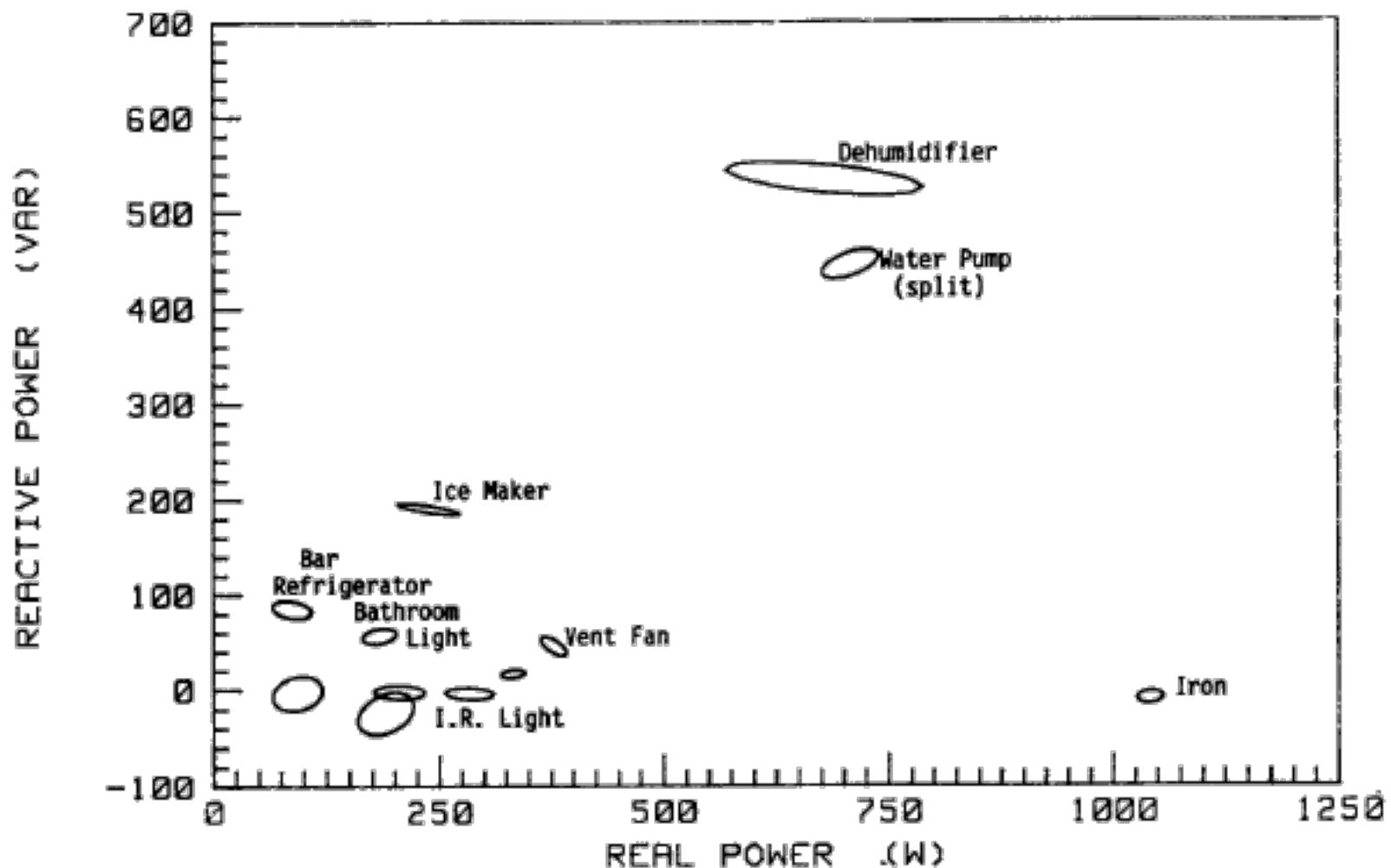
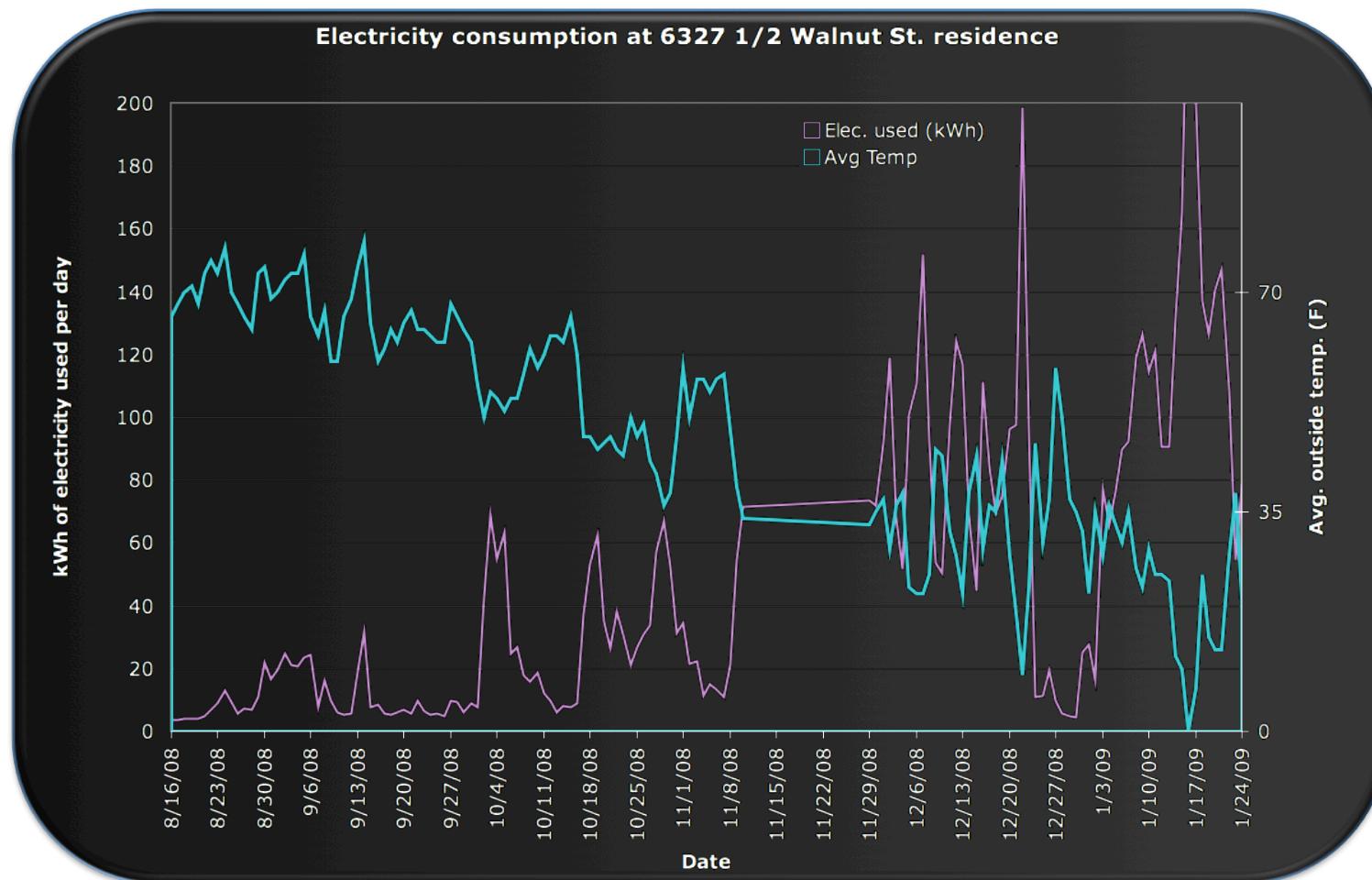


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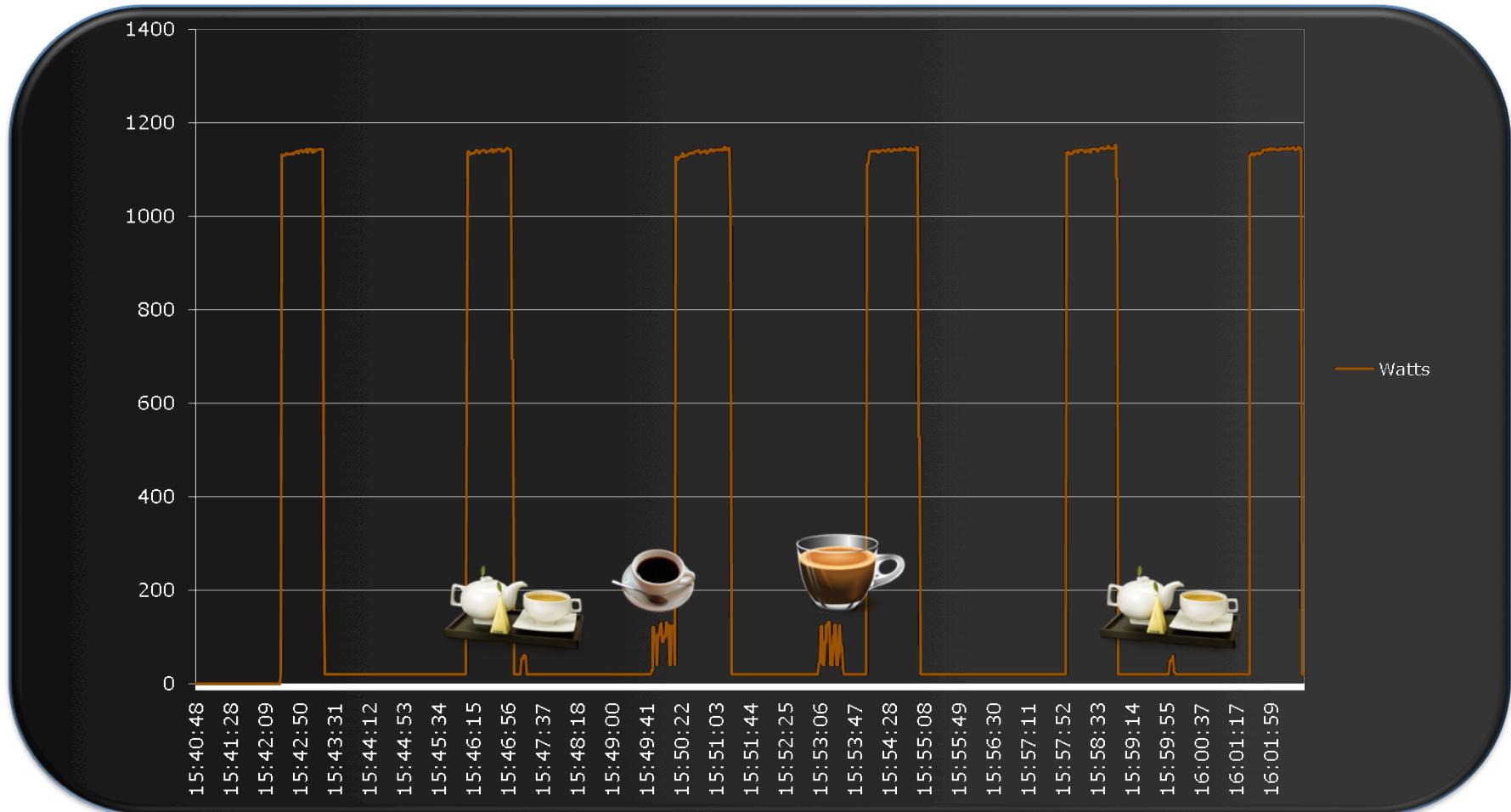
When does this make sense?



When does this make sense?



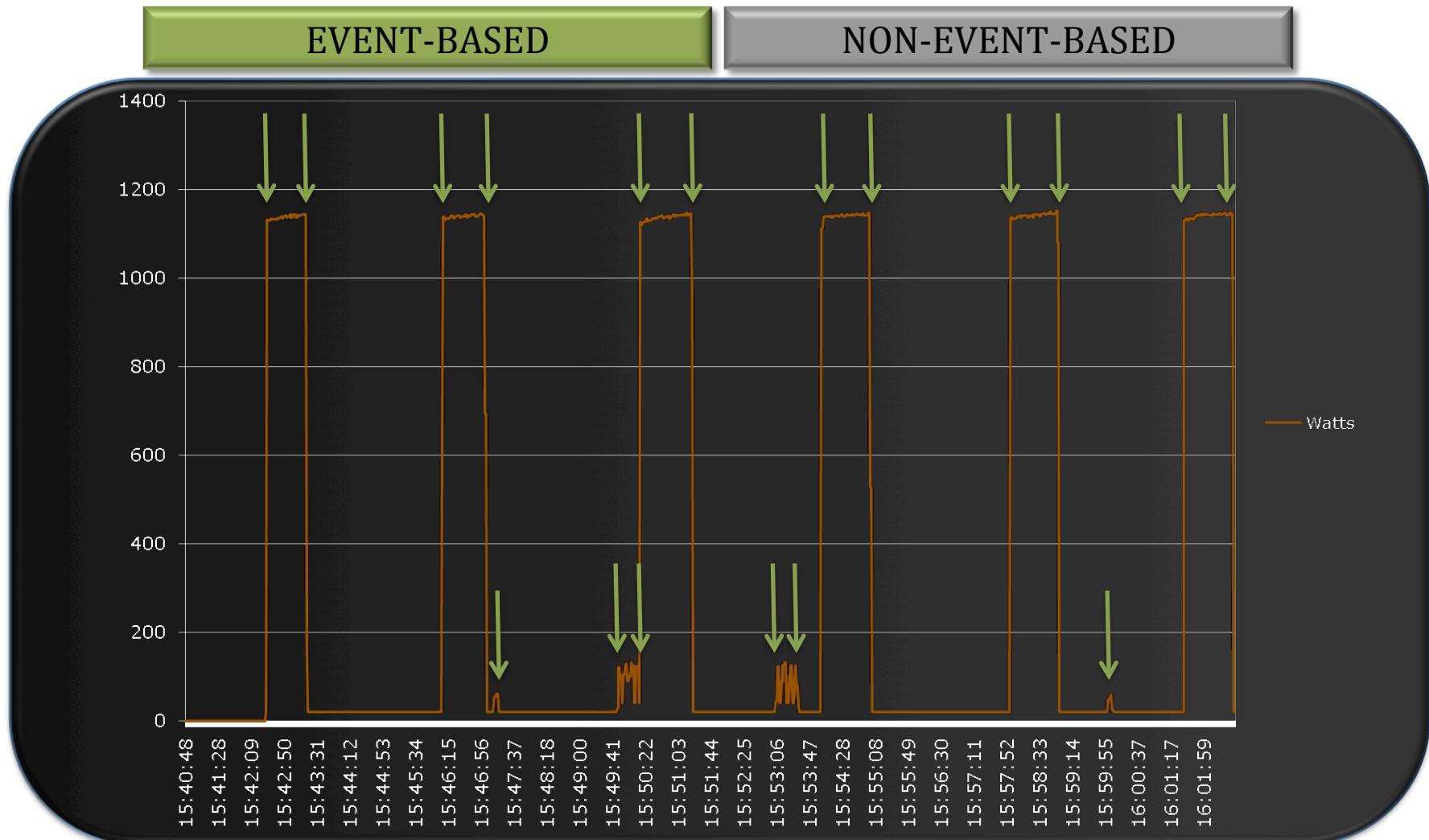
When does this make sense?



Existing Approaches

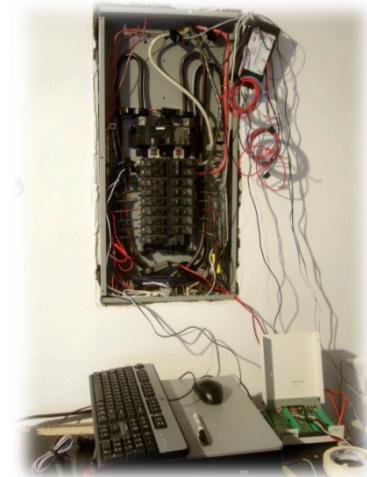
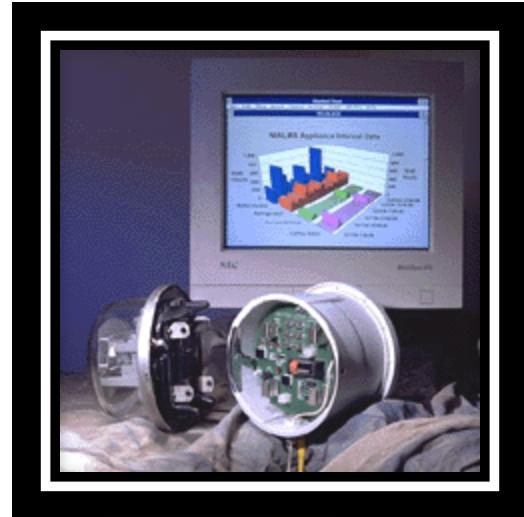
- Event-Based
- Non-Event-Based

Existing Approaches

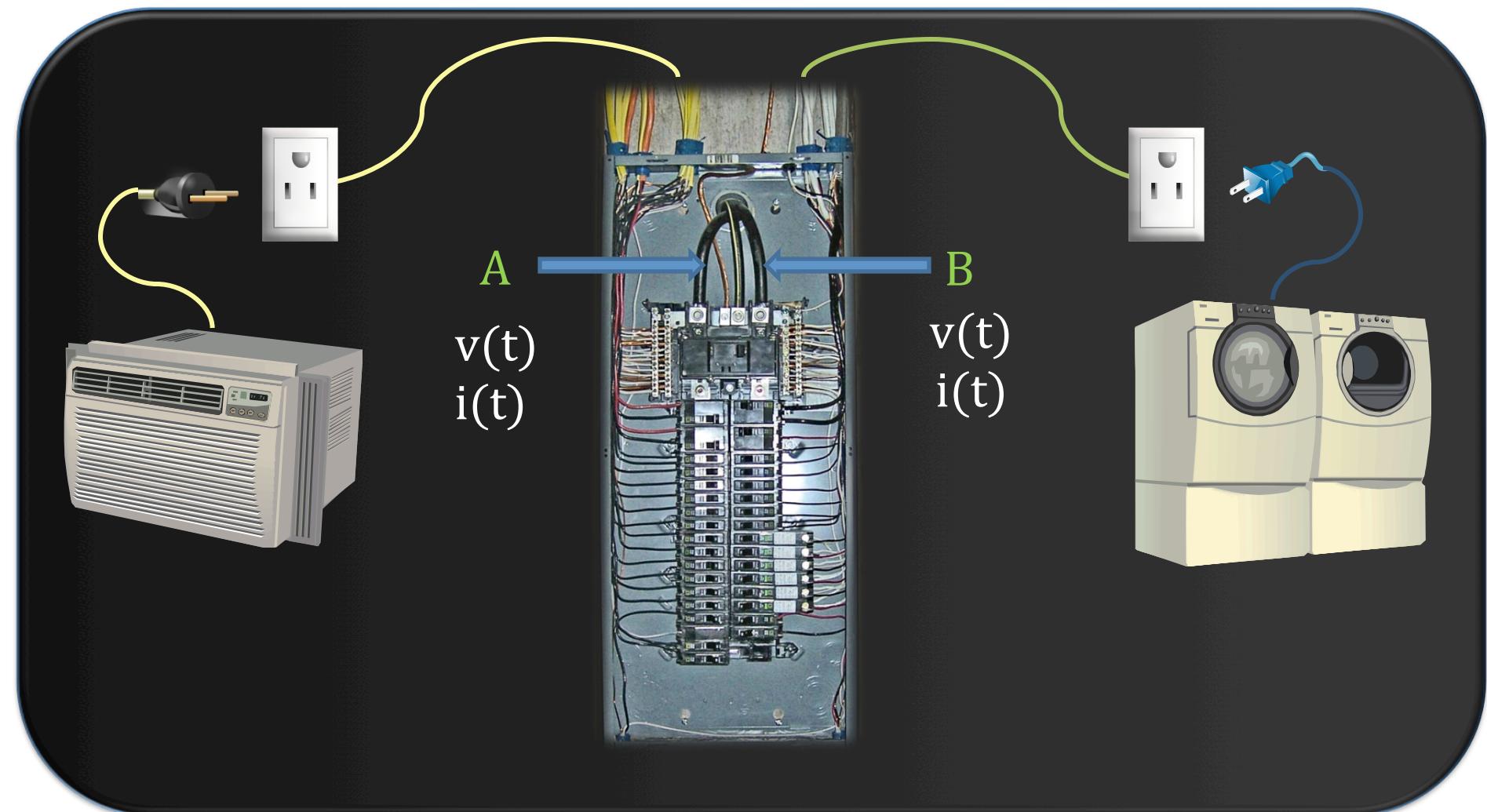


A typical event-based system

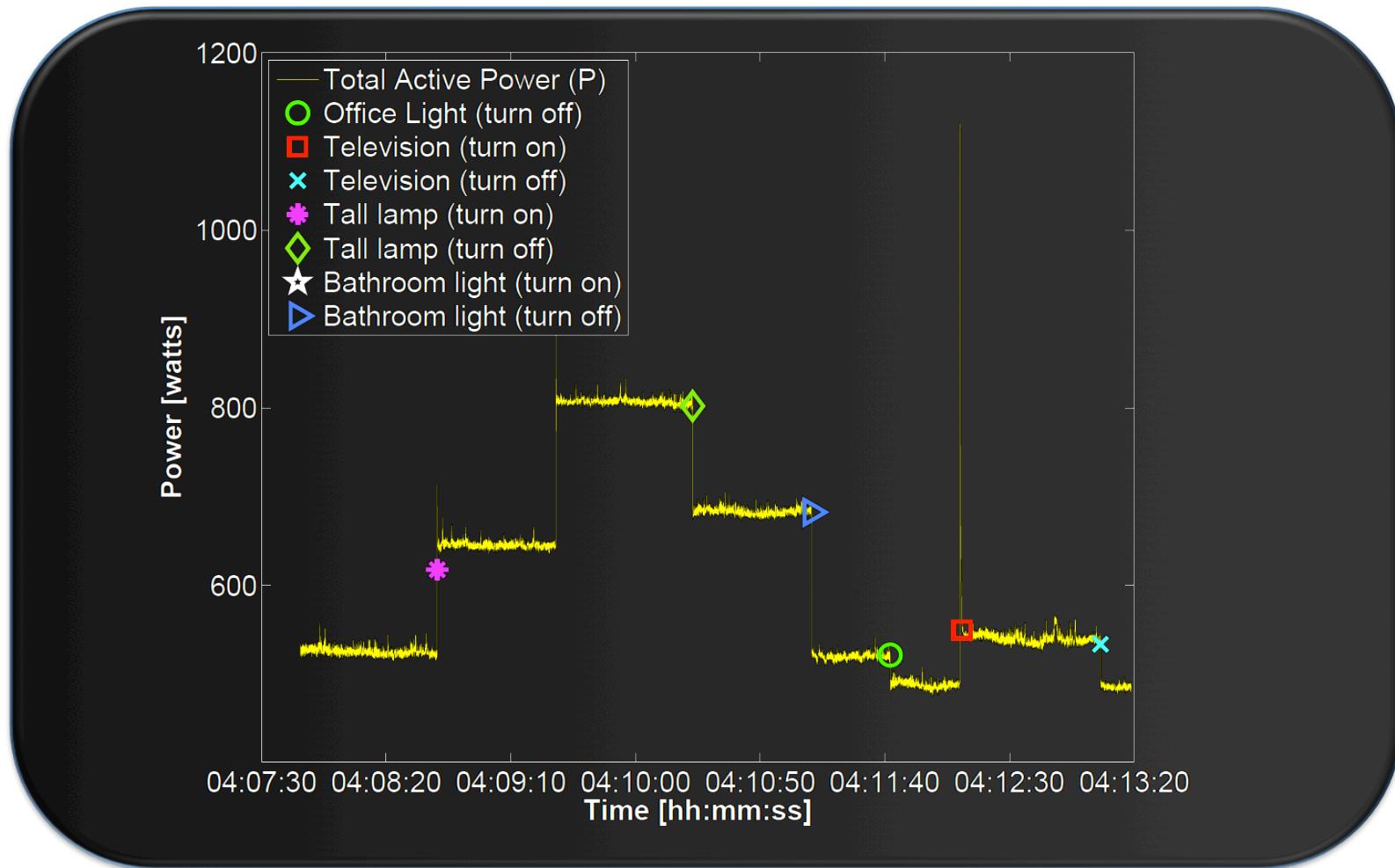
- Data Acquisition
- Event Detection
- Feature Extraction
- Classification
- Energy Computation



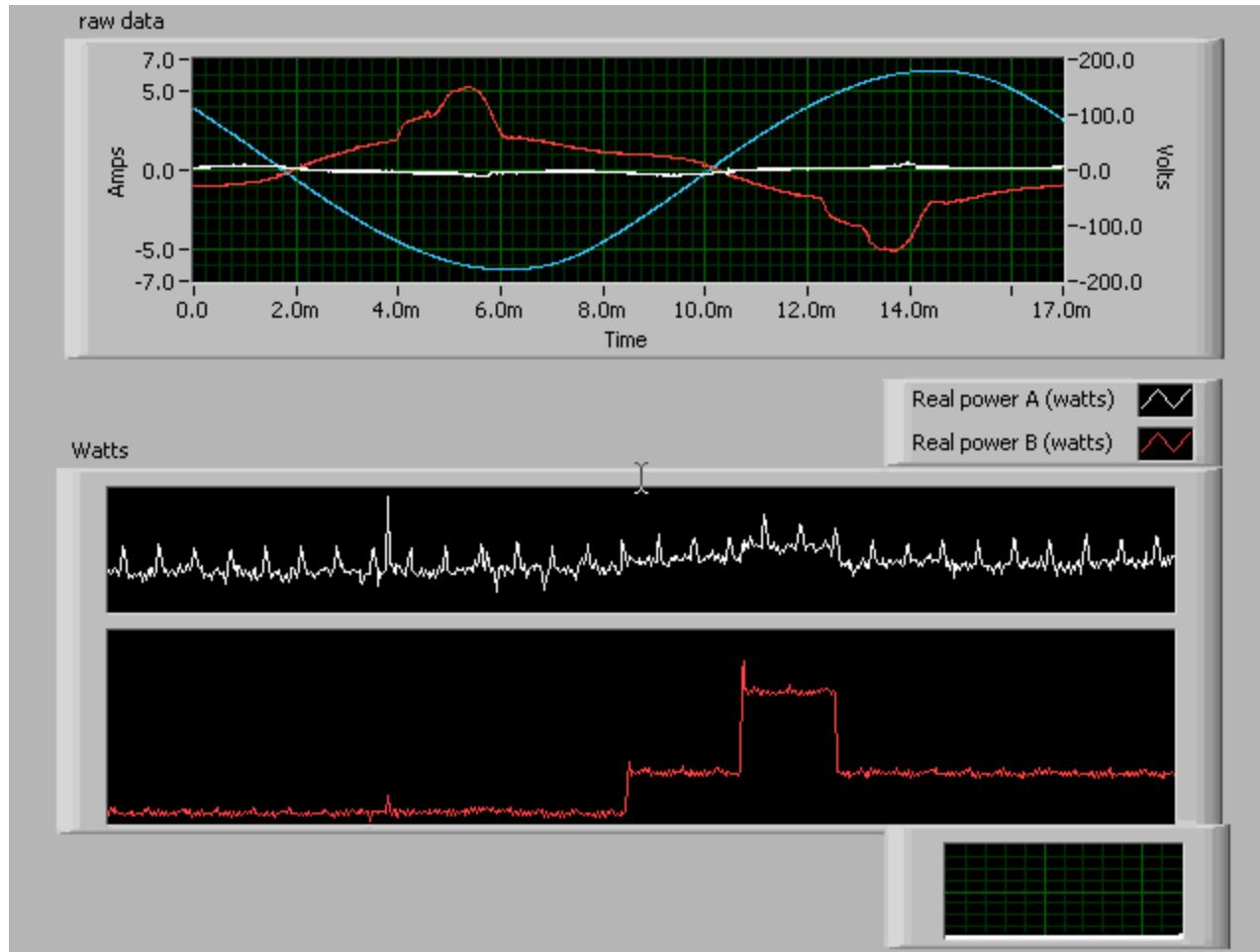
Data Acquisition



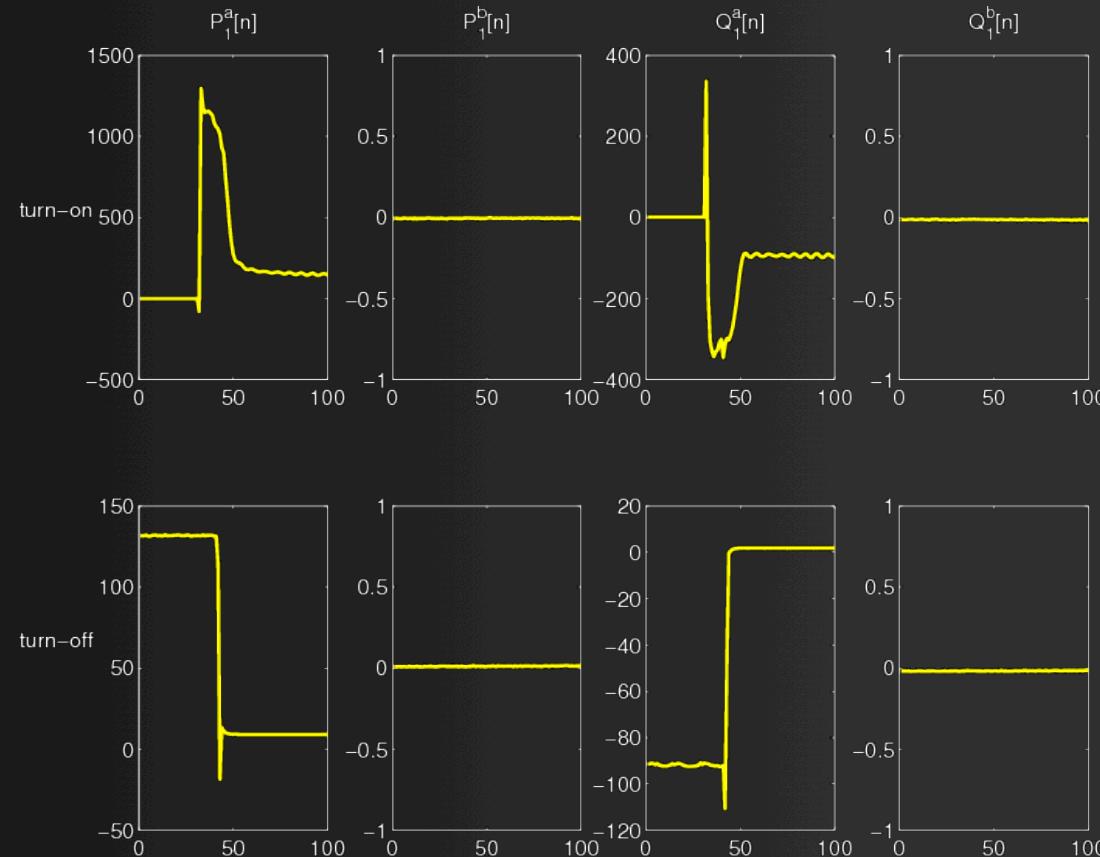
Detecting Events



Detecting Events



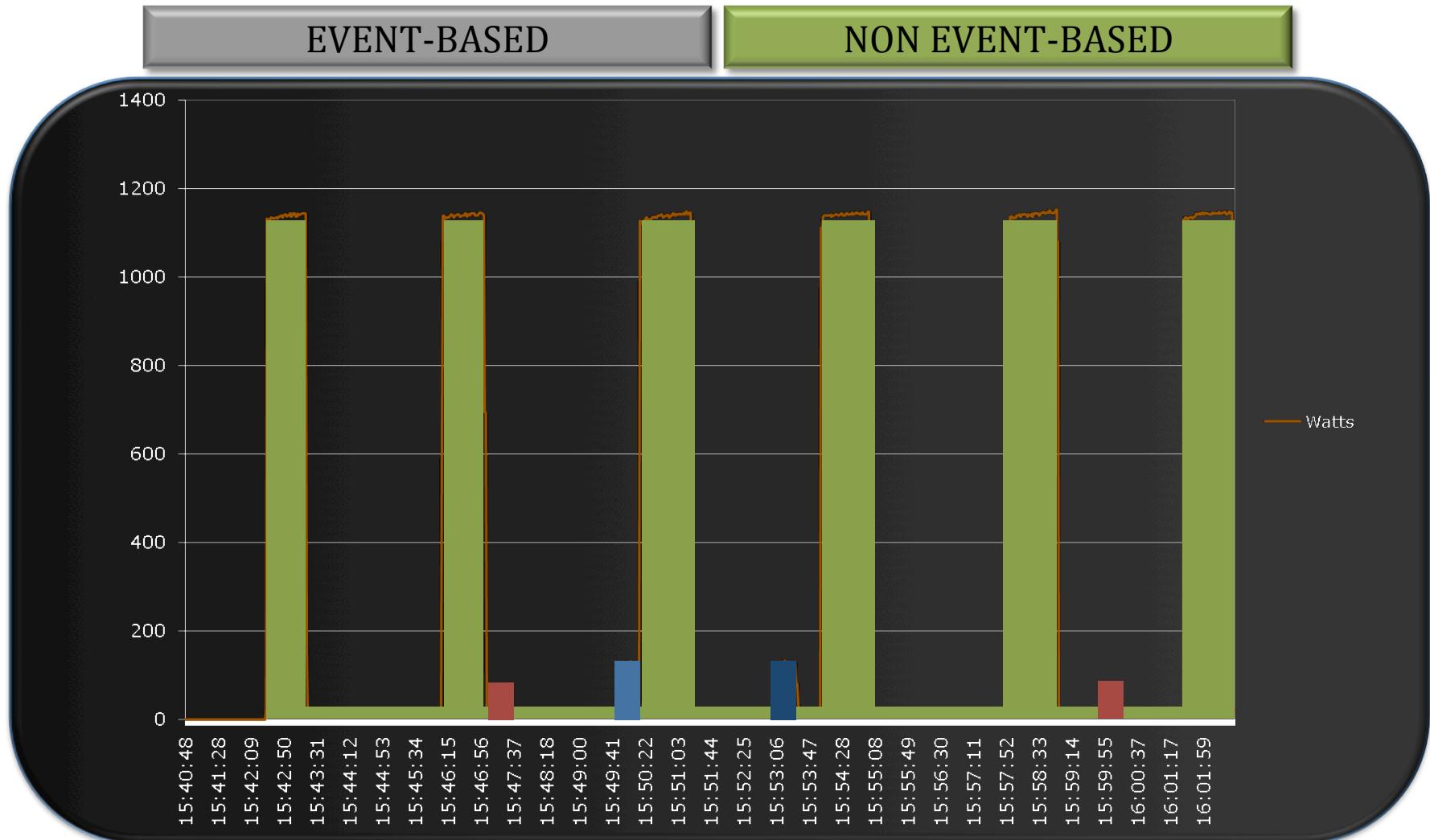
Classifying events



Existing Approaches

- Event-Based
 - Cycle-averaged statistics
 - Power metrics (P, Q, PF, etc.)
 - Transient shapes
 - Sub-cycle statistics
 - Current and/or Voltage Harmonics
 - High-frequency voltage noise
 - V-I Trajectory

Existing Approaches



Origins of Non Event-Based

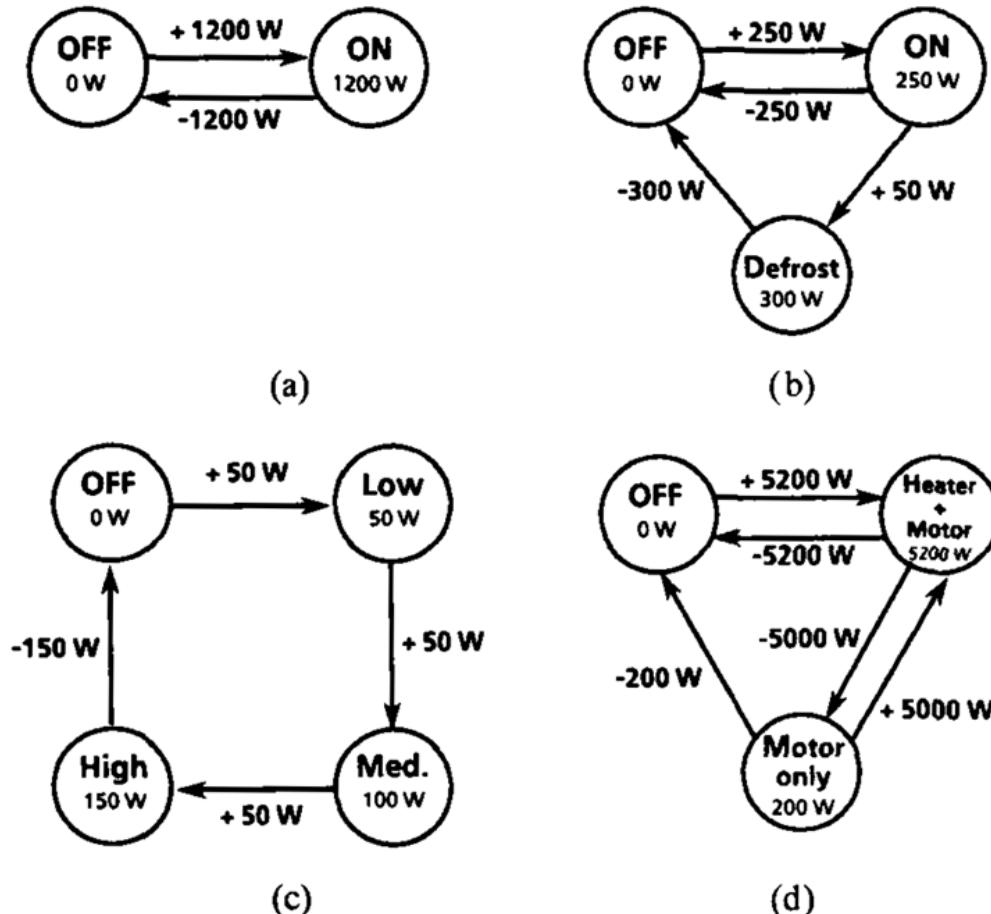


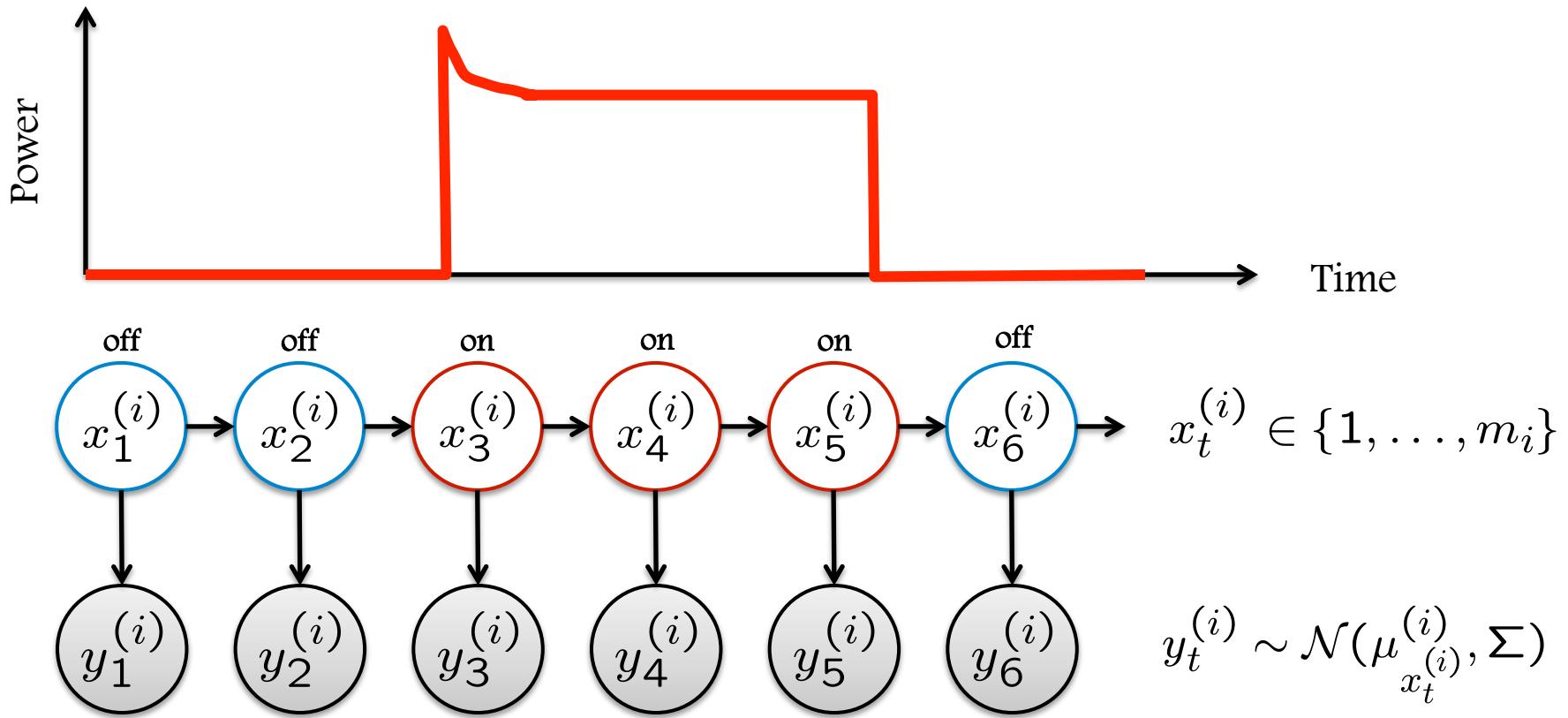
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Fig. 4. Finite-state appliance models: (a) generic 1200 W two-state appliance, e.g., toaster; (b) refrigerator with defrost state; (c) "three-Way" lamp; (d) clothes dryer.

Existing Approaches

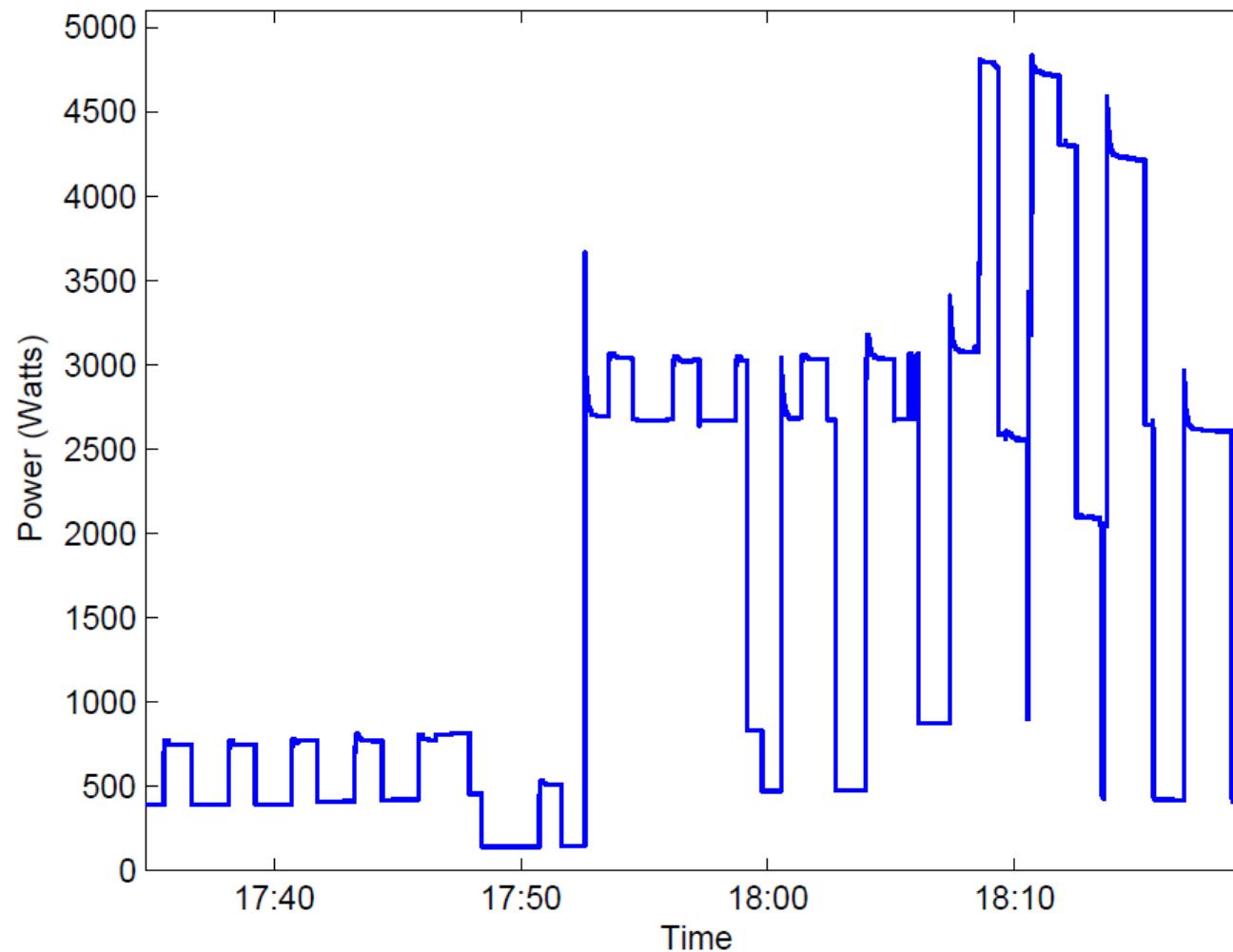
- Non-Event-Based
 - Probabilistic approaches (next talk)
 - Latent Variable Models
 - e.g., (Factorial) Hidden Markov Models
 - Blind Source Separation
 - e.g., sparse-coding, non-negative matrix factorization
 - Time Series Motif Mining

Devices as Hidden Markov Models



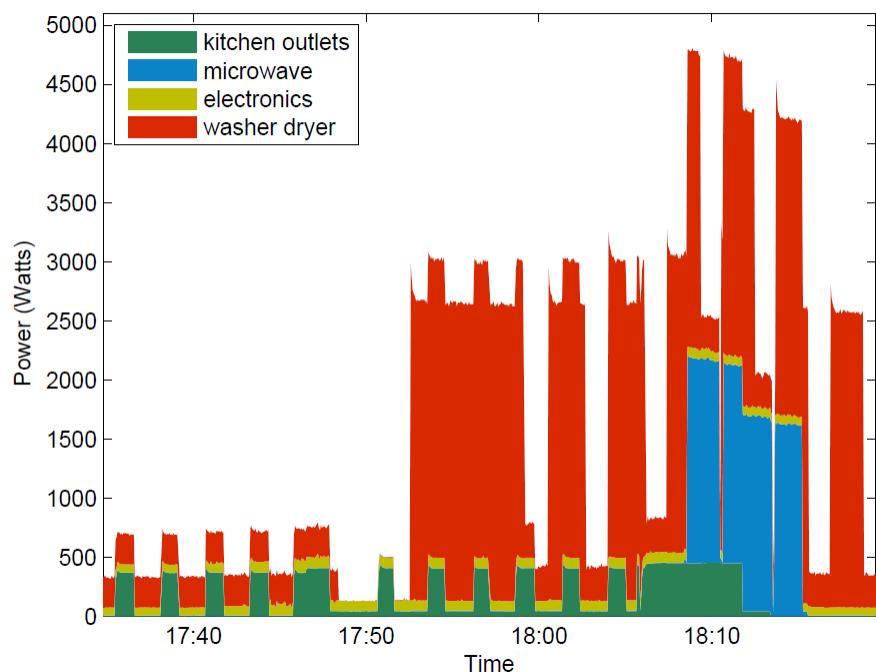
HMM Performance

Total Power

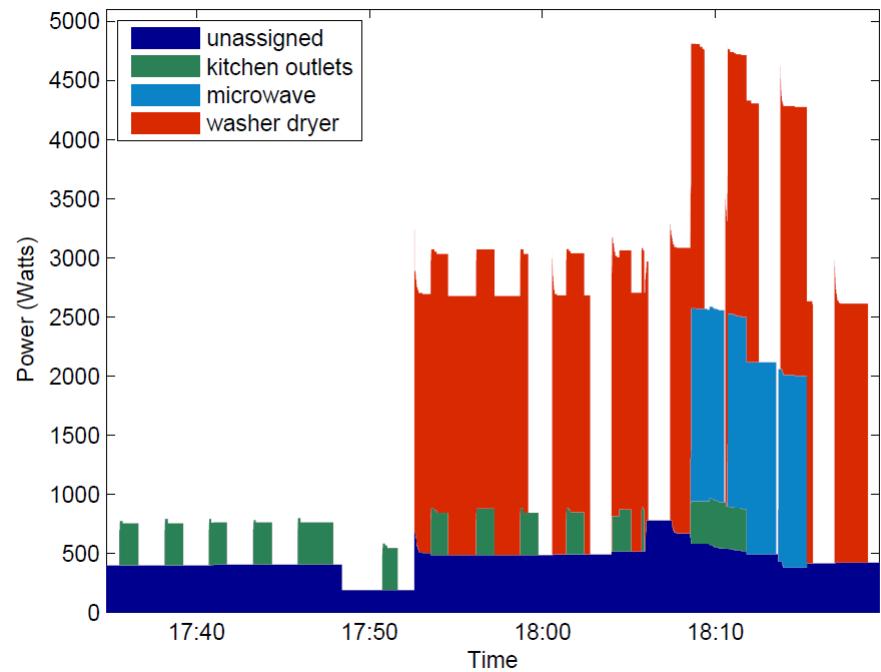


HMM Performance

True Breakdown



HMM Approach



Fast-forward 30 years, to 2012

PRESENT



Carnegie Mellon

Challenges



Supervision

- Training and labeling
- Unsupervised?
- Datasets
- Performance metrics



Loads

- Variable loads
- Multistate loads
- Same loads
- Always on
- Simultaneous events

Software

- No formal evaluation of performance
 - Reported accuracies range from 60 – 90%
 - So what?
- Event-based approaches more popular in commercial implementations
- Non-event based more popular in academic circles, recently
- No open-source implementation of any approach

The End

QUESTIONS?



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