A real-world evaluation of NILM: tradeoffs between data collection and information effectiveness

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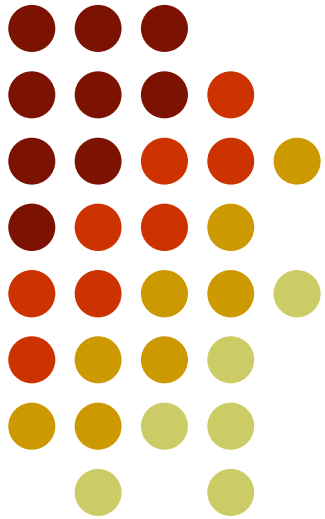

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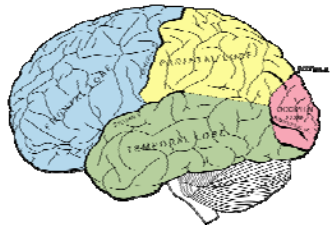
Vision

- Motivate energy conservation
- Facilitate appliance-specific energy awareness
  - Exploiting **low-cost data streams**
  - For **high-value information**
  - To **empower and motivate** consumers

Analog

AMR/AMI



User engagement

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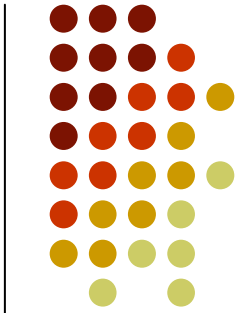
Information Value vs. Cost

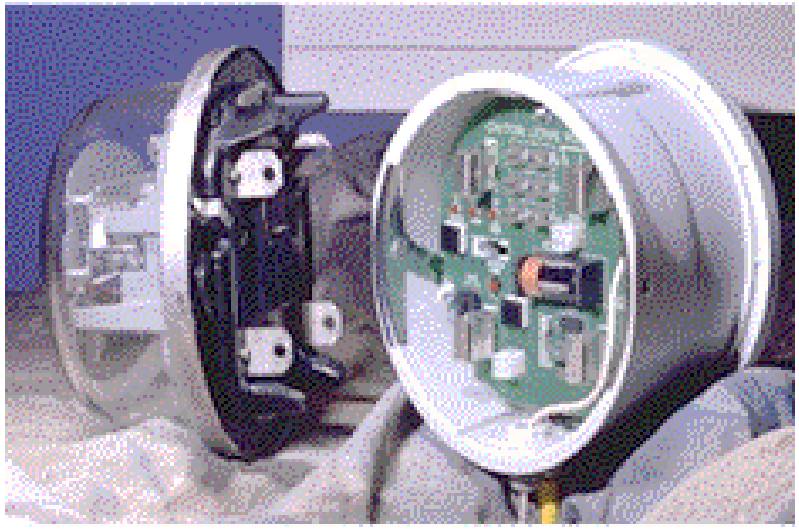


- Whole house
  - monthly: free
  - daily: free (some places)
  - real-time: $200
- Circuit-level: $2k - $10k
- Plug-level: $20k - $60k

- Hardware costs may fall. Labor won't.

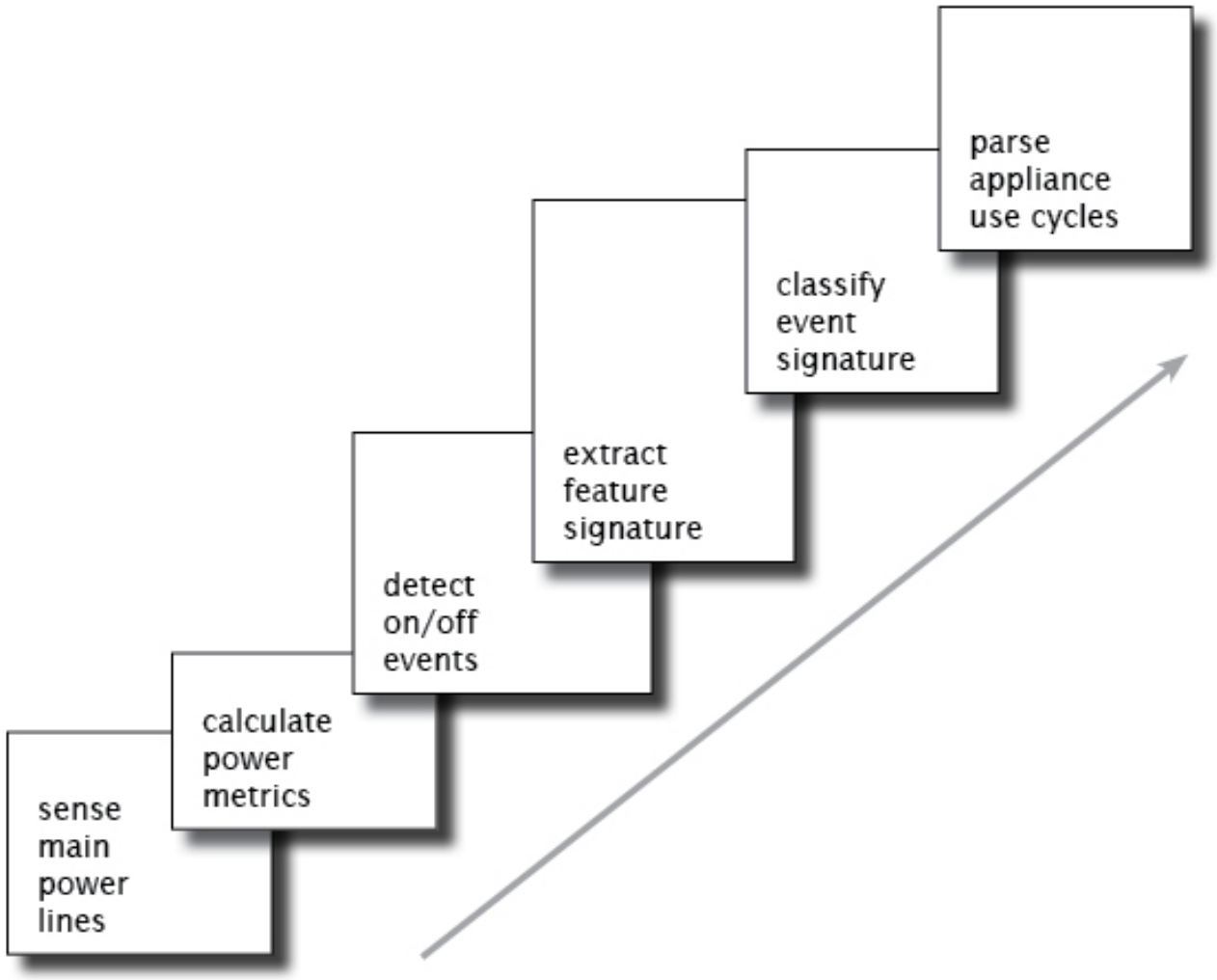
Non-Intrusive Load Monitoring

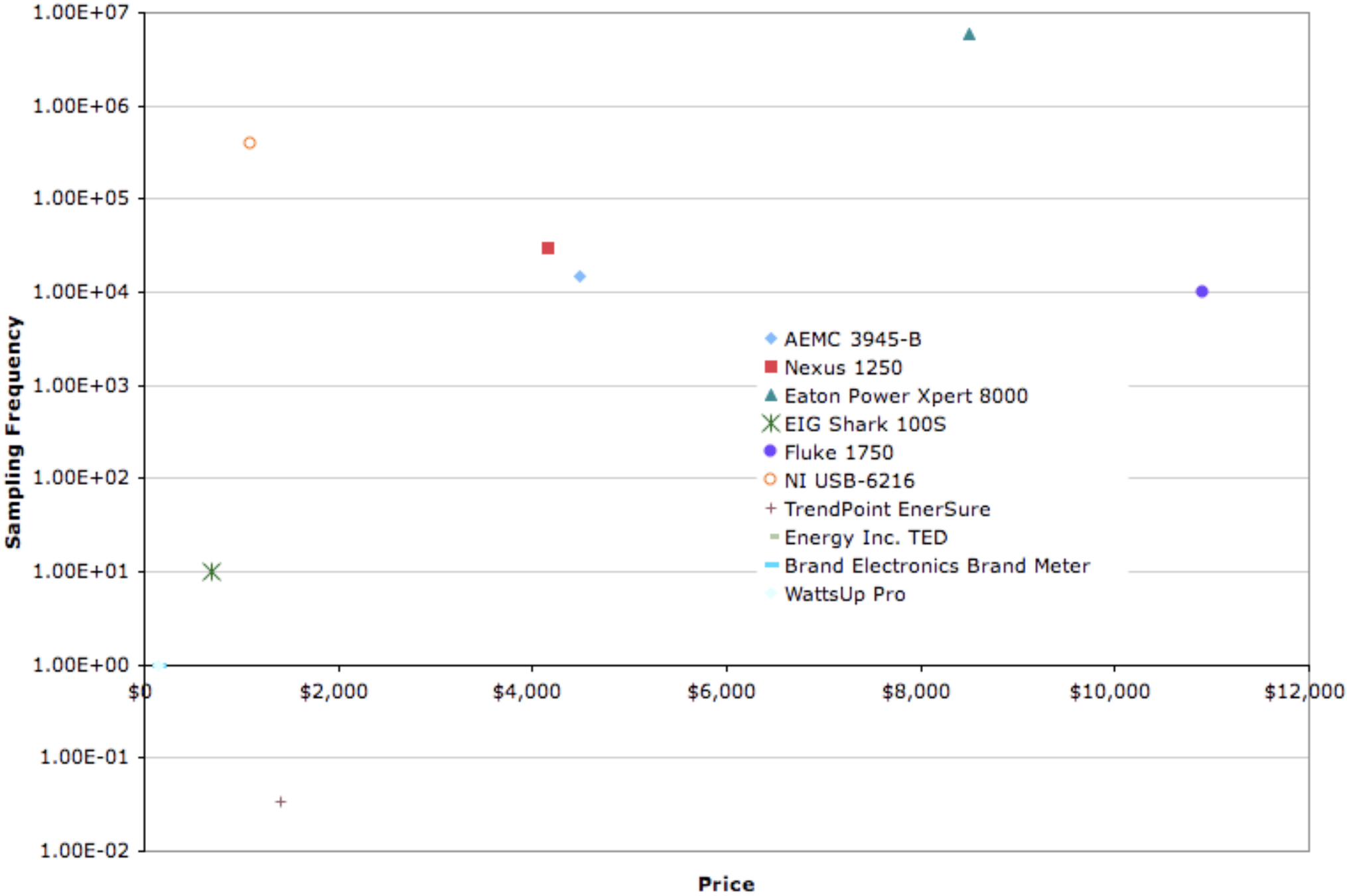
- NILM has been around for 20+ years.
- Very promising results in laboratory settings.
- One commercial product for utilities.
- Can it be adapted for low-cost hardware?



Source: Enetics, Inc.

Data flow


sense main power lines
calculate power metrics
detect on/off events
extract feature signature
classify event signature
parse appliance use cycles



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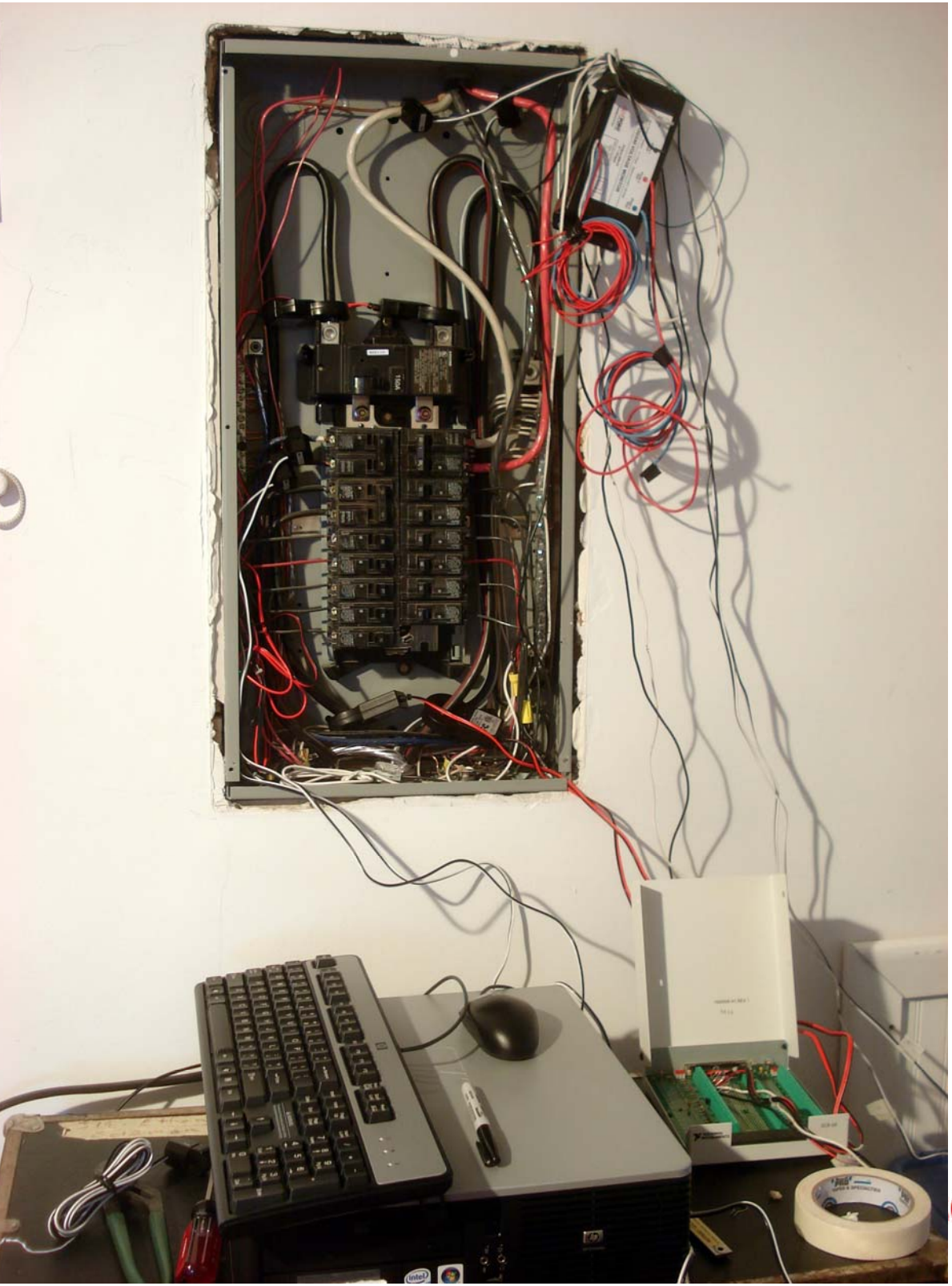

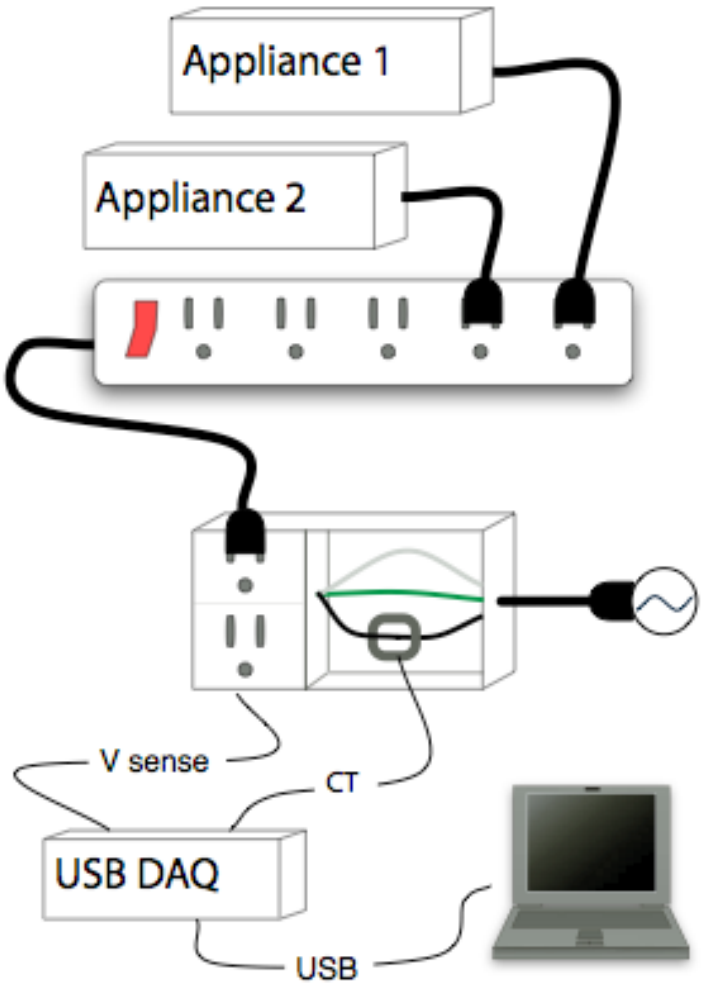

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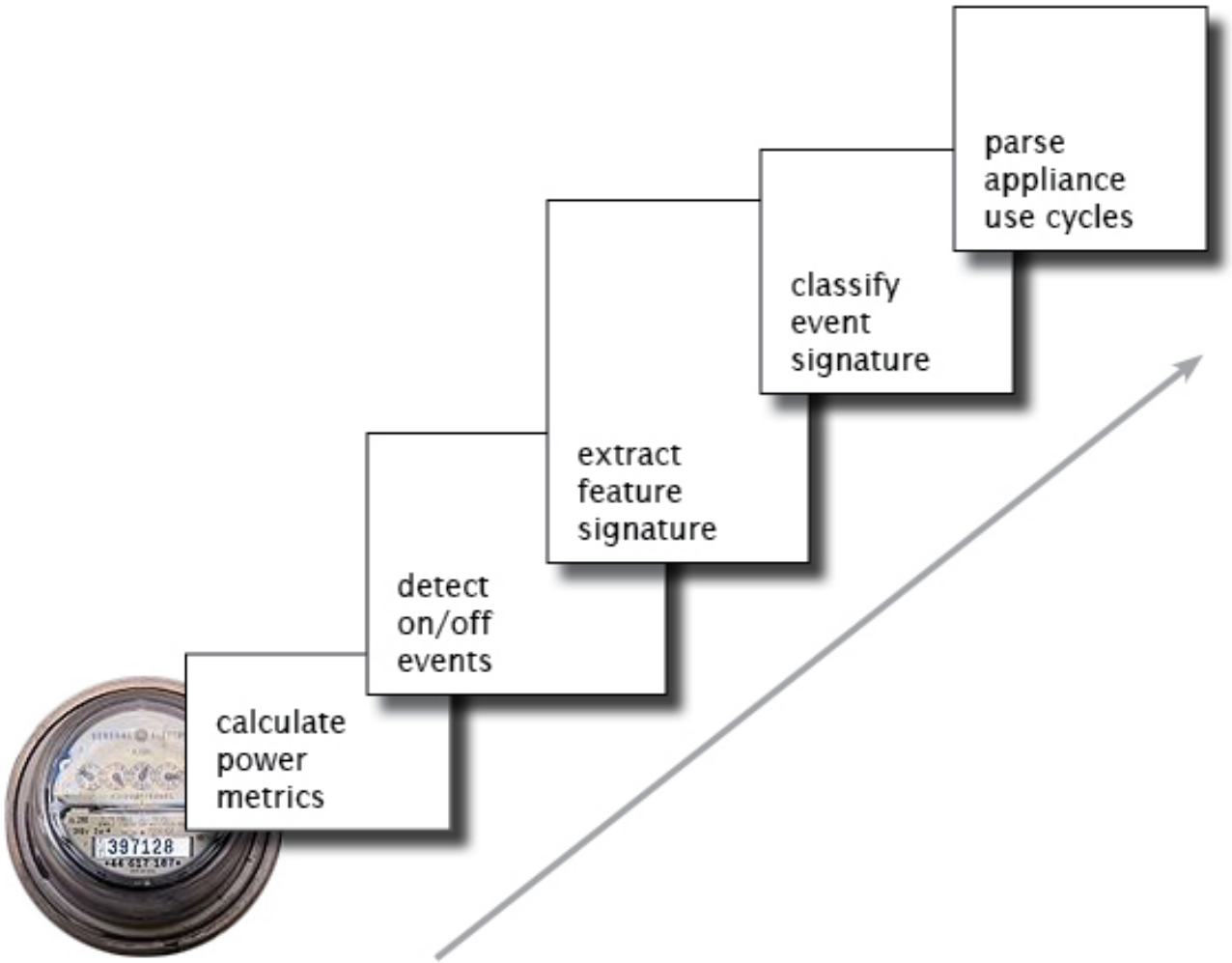
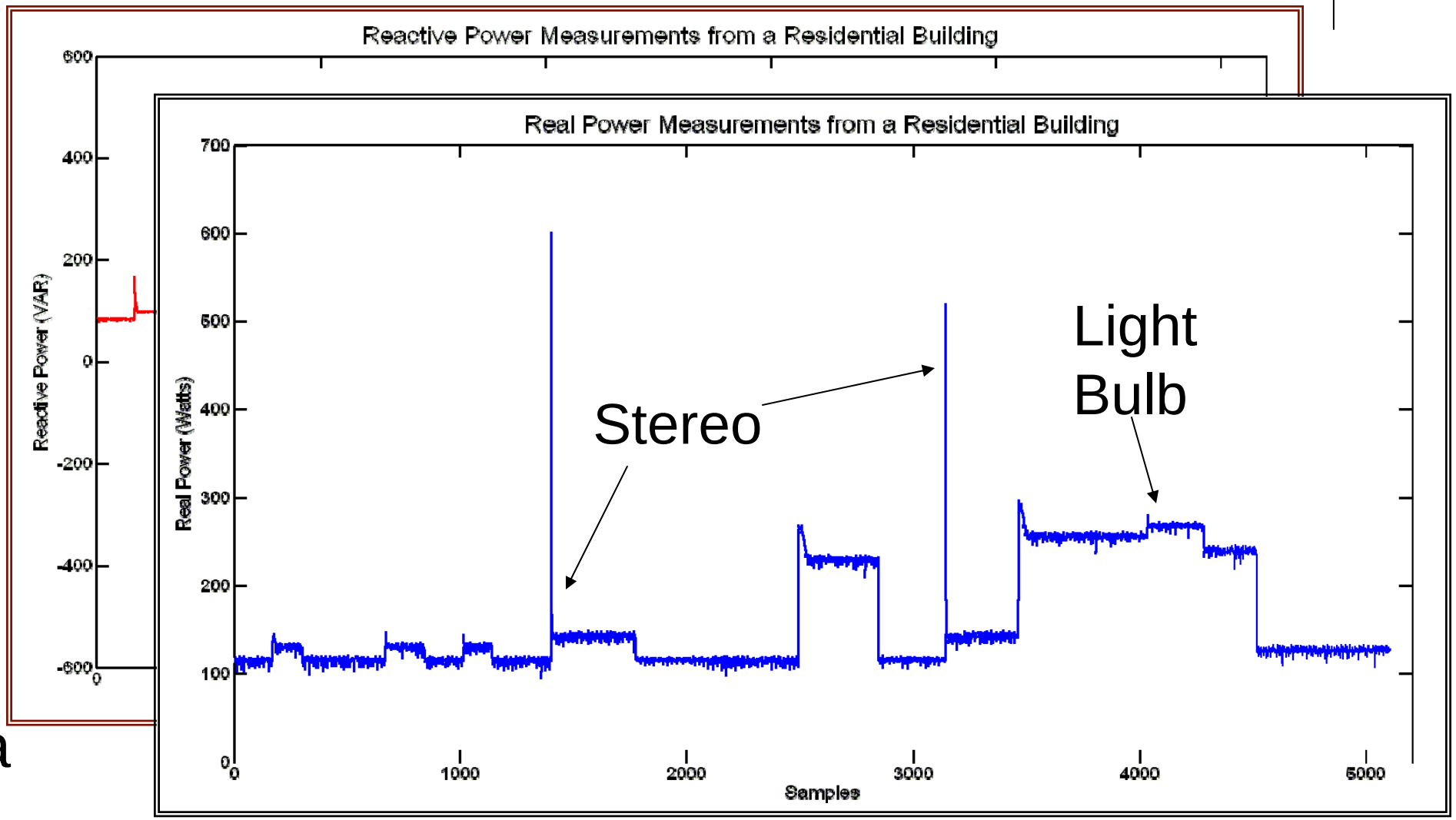
Data flow


parse
appliance
use cycles
classify
event
signature
extract
feature
signature
detect
on/off
events
calculate
power
metrics

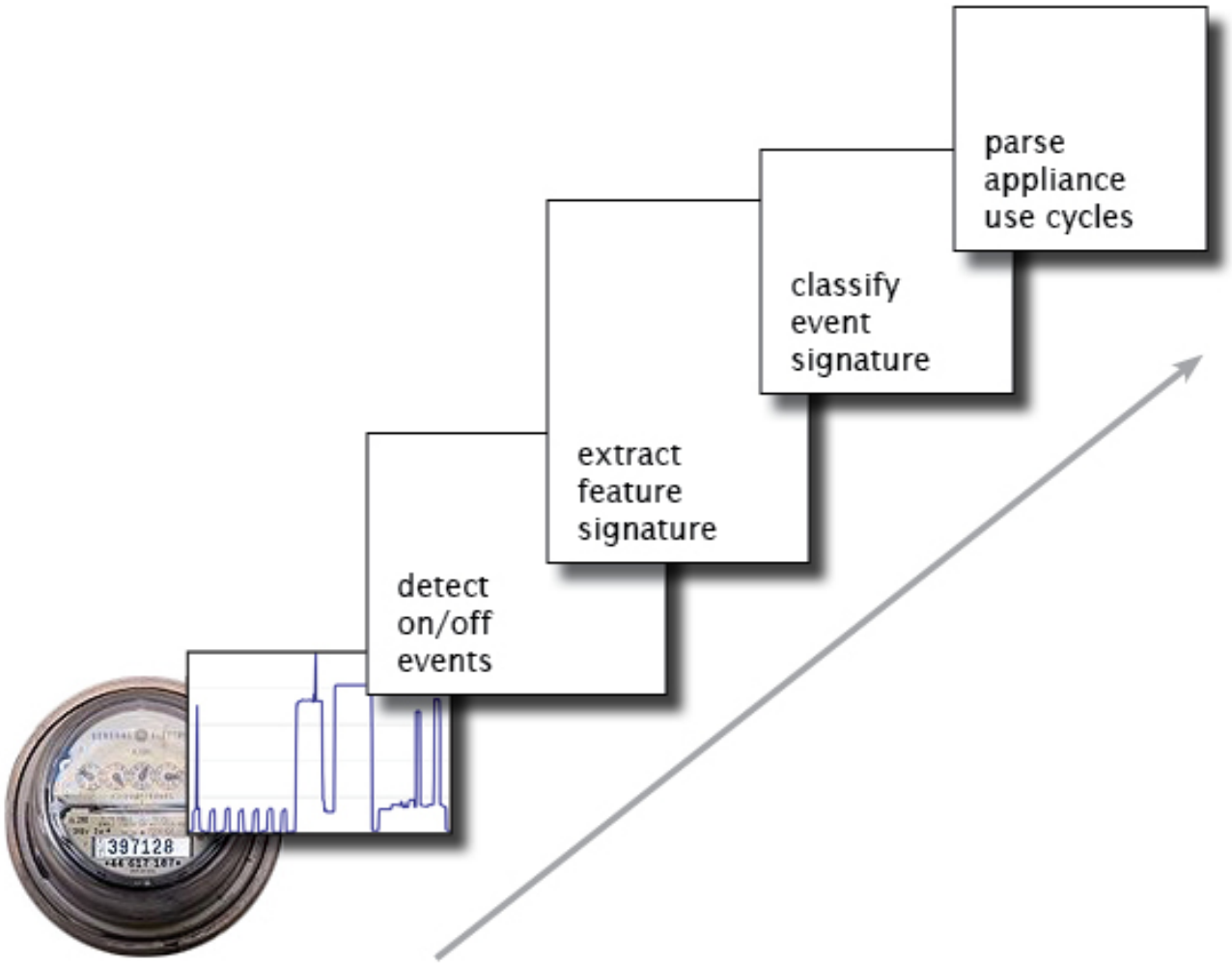
The obtained signals



Qa

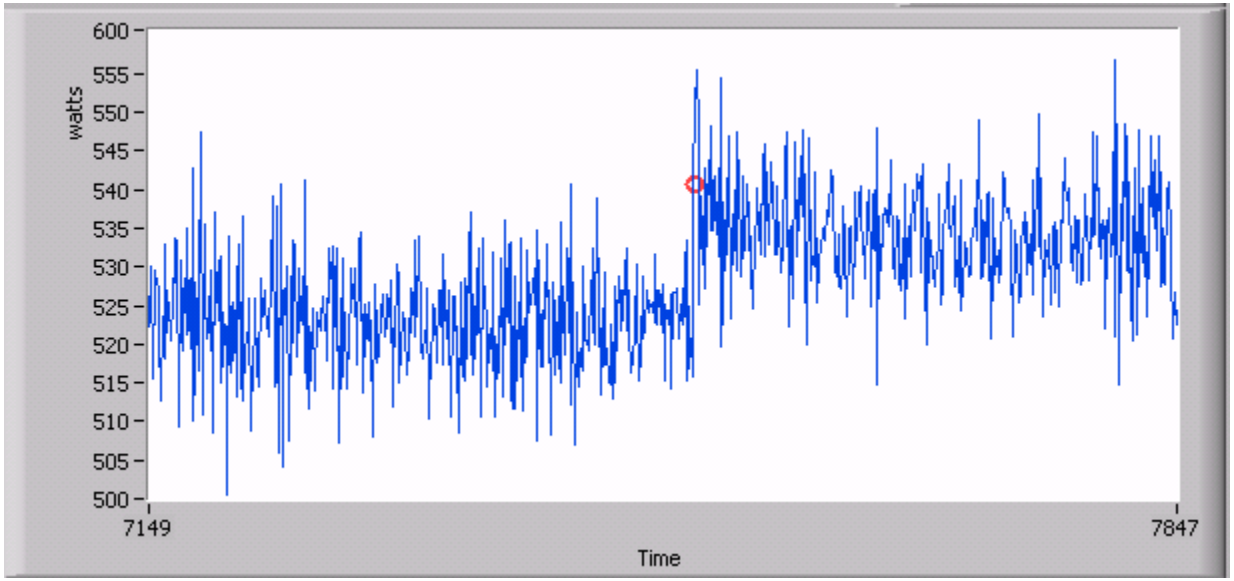
Pa

Data flow


parse
appliance
use cycles
classify
event
signature
extract
feature
signature
detect
on/off
events

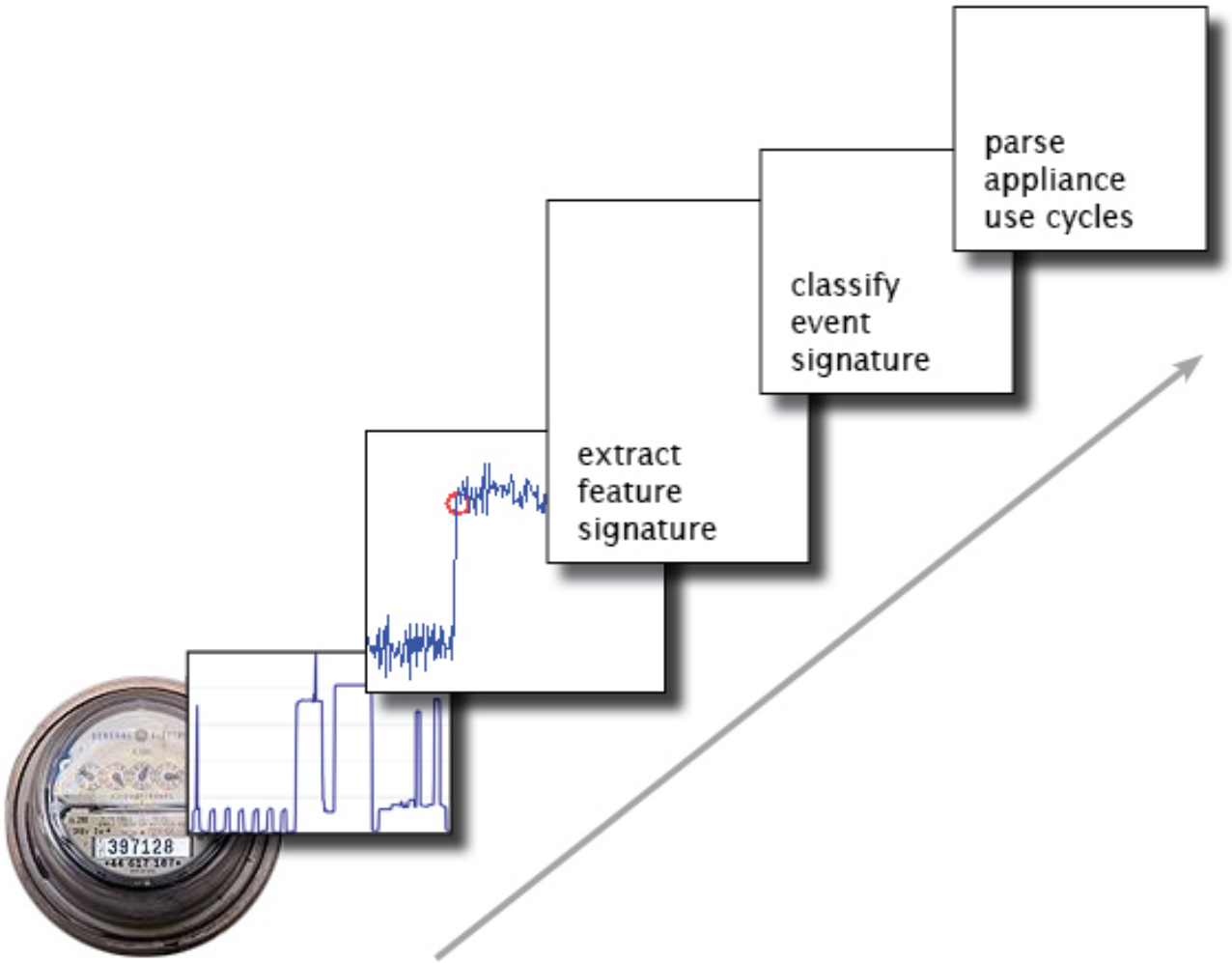
Event Detection

- Probabilistic approach
  - Generalized Likelihood Ratio

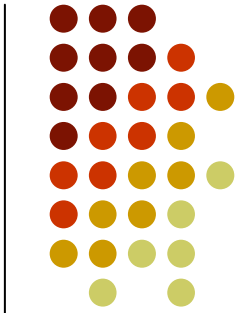


- Currently testing wavelets

Data flow


parse
appliance
use cycles
classify
event
signature
extract
feature
signature

Event Classification: Feature Extraction

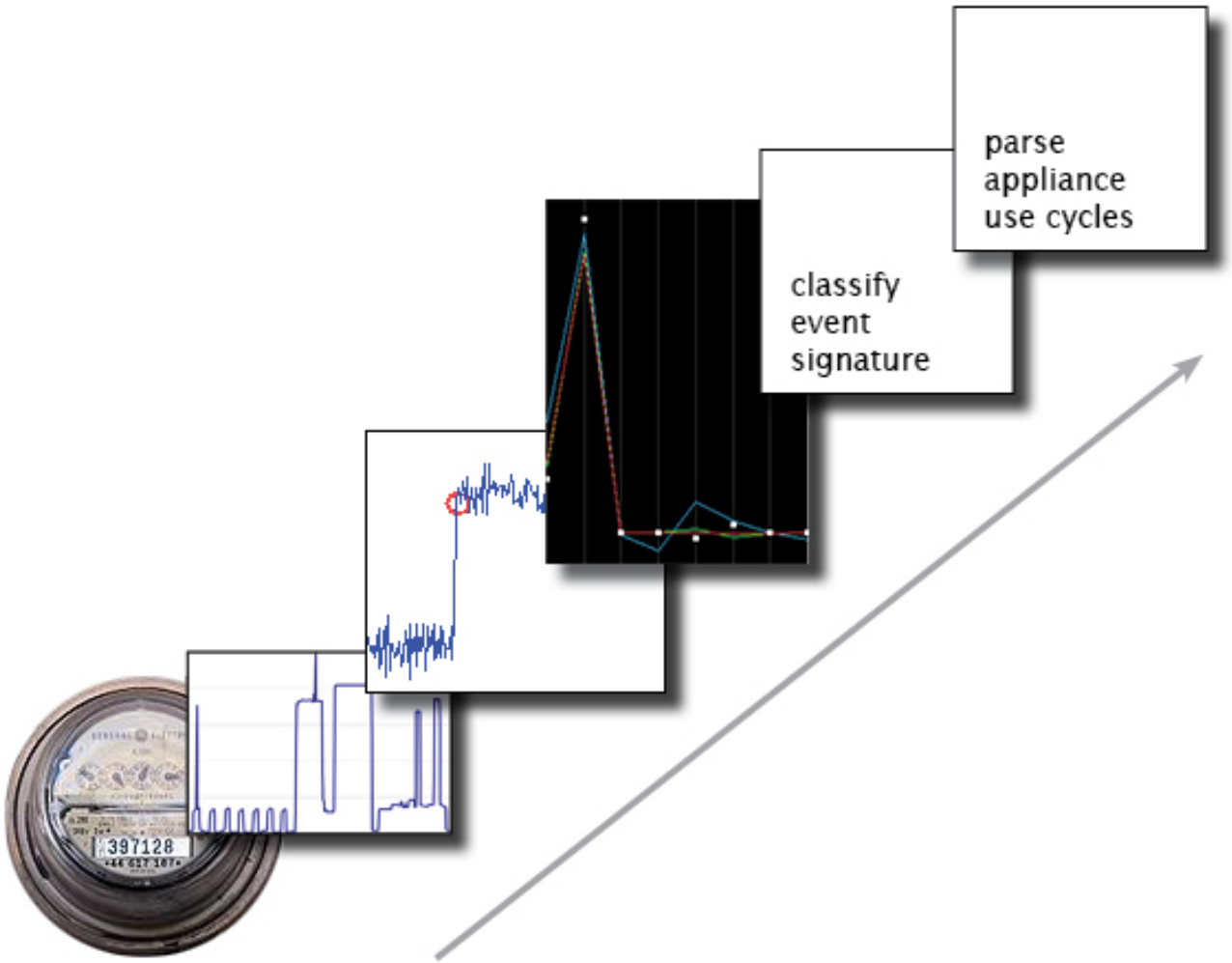


Electric Burner: **Electric Kettle:**

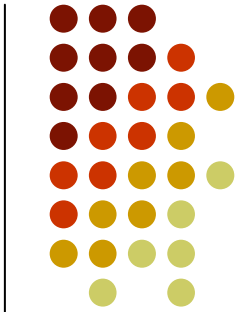
OFF – ON → ← **OFF – ON**

ON – OFF → ← **ON – OFF**

Data flow

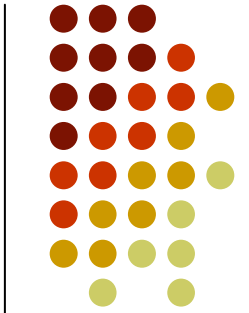


Event Classification: Training Classifiers



- Two different setups:
  - 17 appliances in an occupied residential building (Real World)
  - 8 appliances in a laboratory (Noise Free)
- Four different classifiers:
  - Gaussian Naïve Bayes
  - 1-Nearest Neighbor
  - AdaBoost
  - Decision Trees

Event Classification: Training Results

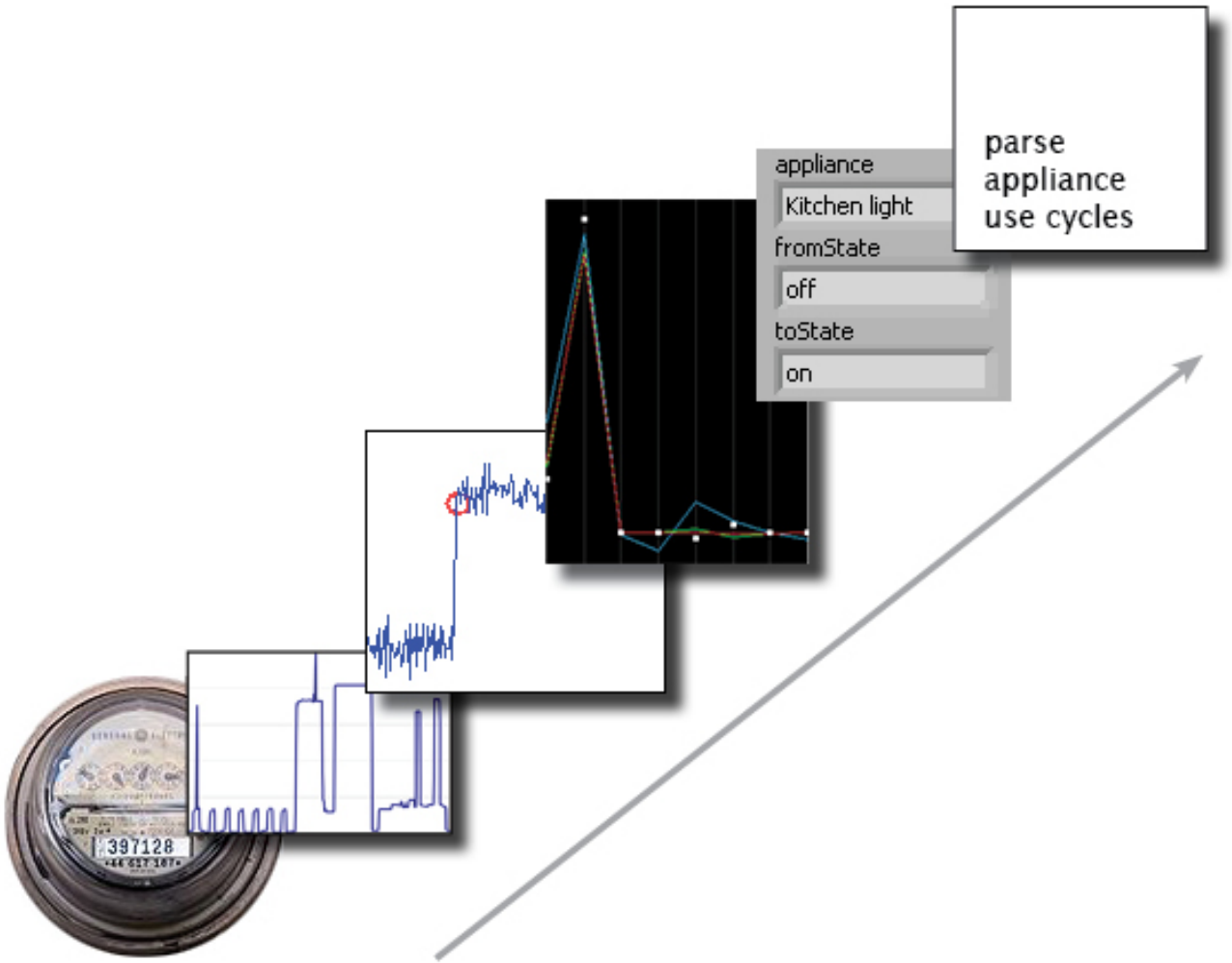


- **k-Nearest Neighbors (kNN)**
  - NF – 90% (RBF Coef.), RW – 81% (RBF Coef.)
- Gaussian Naïve Bayes (GNB)
  - NF – 83% (Delta), RW – 57% (Poly. Coef.)
- AdaBoost
  - NF – 76% (Poly. Coef.), RW – 0.50% (Poly. Coef.)
- Decision Trees
  - NF – 85% (Delta), RW – 58% (RBF Coef.)

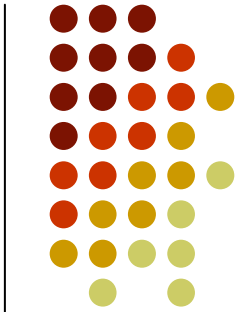
Event Classification: Validation Results

Validation Results (Accuracy in %)		GNB	kNN, k=1	Ada Boost	DT
Noise Free	Delta	52%	67%	**51%**	61%
	Whole Transient	38%	73%	--	58%
	Polynomial Coefficients	58%	67%	**51%**	52%
	Fourier Coefficients	64%	**79%**	2%	**64%**
	RBF Coefficients	**67%**	67%	**	**64%**
Real World	Delta	47%	73%	36%	42%
	Whole Transient	9%	73%	--	47%
	Polynomial Coefficients	**61%**	**80%**	**61%**	**57%**
	Fourier Coefficients	50%	**80%**	55%	54%
	RBF Coefficients	47%	76%	35%	54%

Data flow

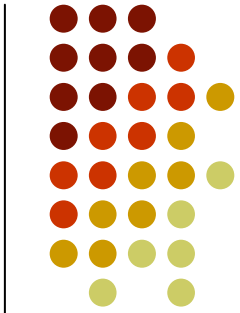

parse
appliance
use cycles
appliance
Kitchen light
fromState
off
toState
on

Testing sensitivity



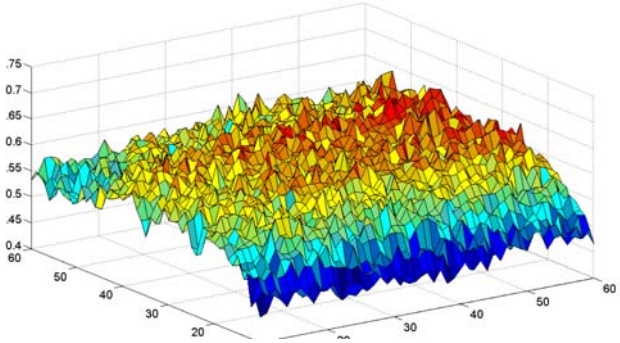
- Hardware: sampling each phase or total kW?
- Power metrics: real and reactive power?
- Sampling rate: 20 Hz - 15 seconds/sample?
  - Averaging vs. point samples
  - Continuously variable sampling rate
- Features of transitions: 2nd-order regression?

Evaluation metrics

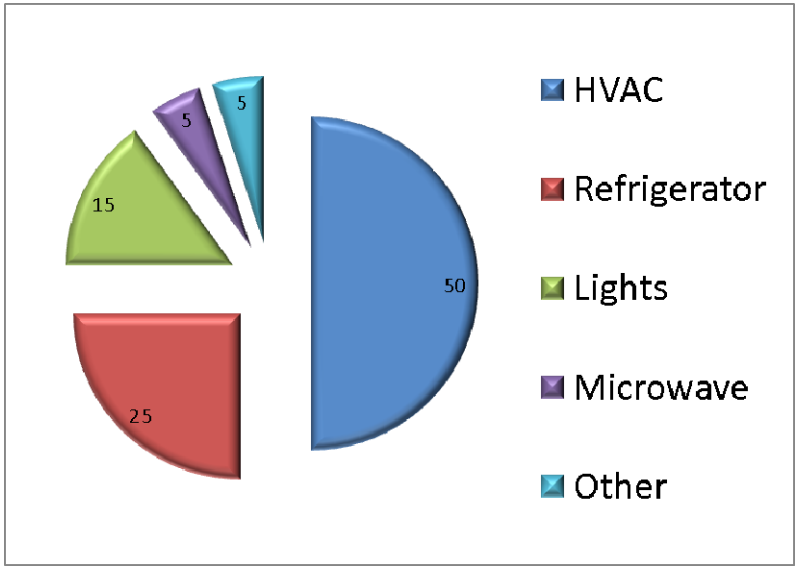


- 10 appliances = 80% of load
- Optimize algorithms for weighted metric:
  - F1 metric includes precision and recall
  - Weight according to appliance's portion of load
- Not just events, but duty cycle

Vision: many uses for detailed energy information



Machine Learning



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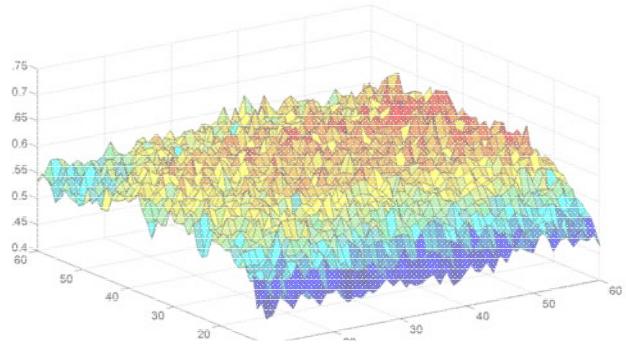
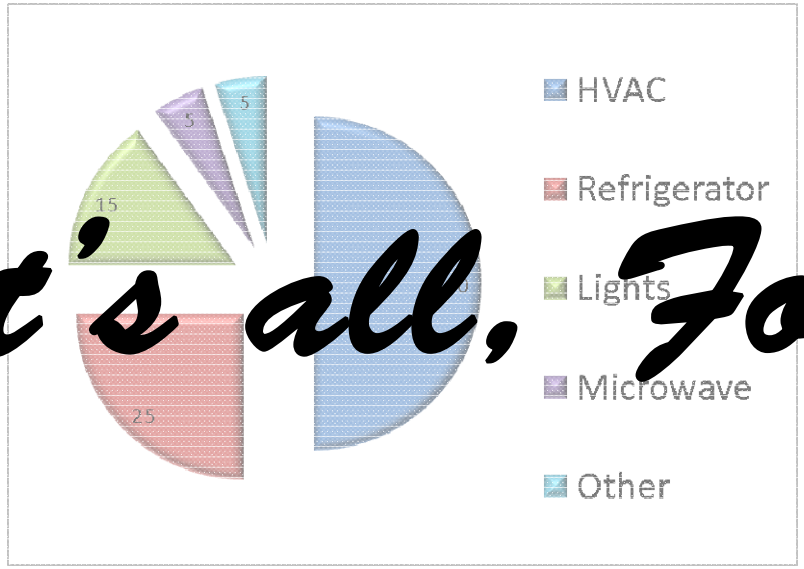
Vision: many uses for detailed energy information



Machine Learning



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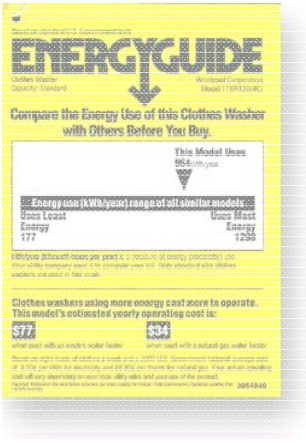
That's all, Folks!



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