FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Nonintrusive Load Monitoring

Roy Dong, Henrik Ohlsson, Lillian Ratliff, S. Shankar Sastry

UC Berkeley

Berkeley UNIVERSITY OF CALIFORNIA

Massachusetts Institute of Technology

NSF

MICHIGAN

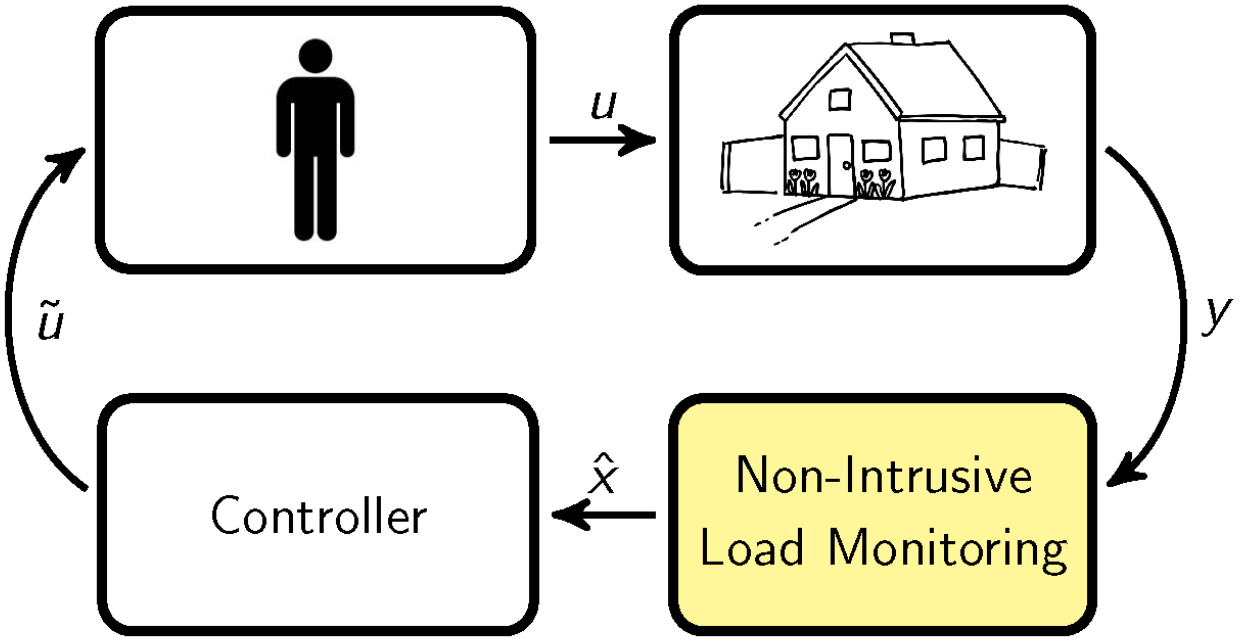
VANDERBILT UNIVERSITY

Nonintrusive Load Monitoring (NILM)

* Infeasible to install sensors at a plug-level in every household.
  * Cost of sensors and installation.
  * Network capacity.
* Would like to provide consumers high-resolution feedback on power usage.

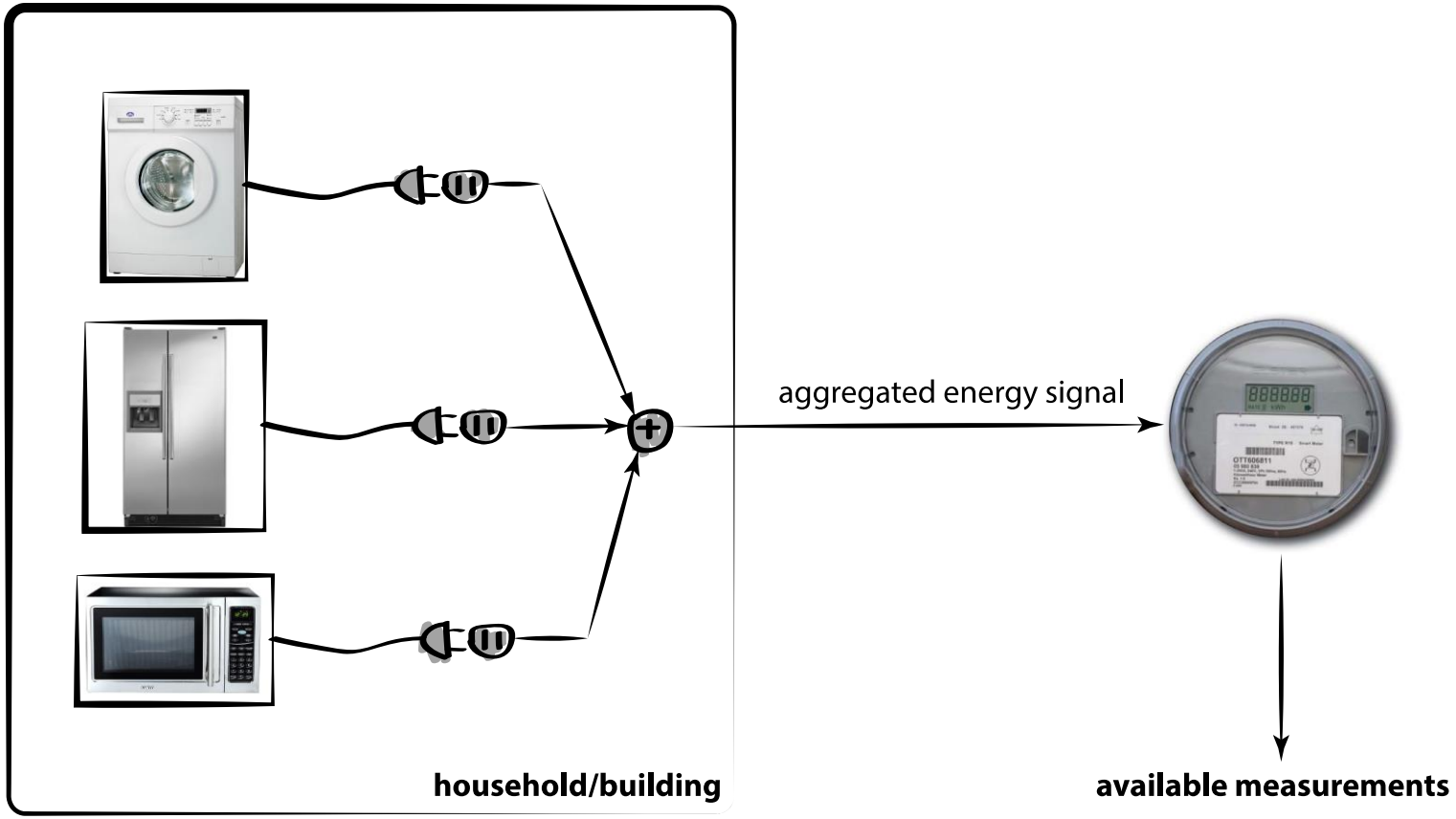
Nonintrusive Load Monitoring (NILM)

* Acts as an 'estimator' for the closed-loop smart grid.



FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

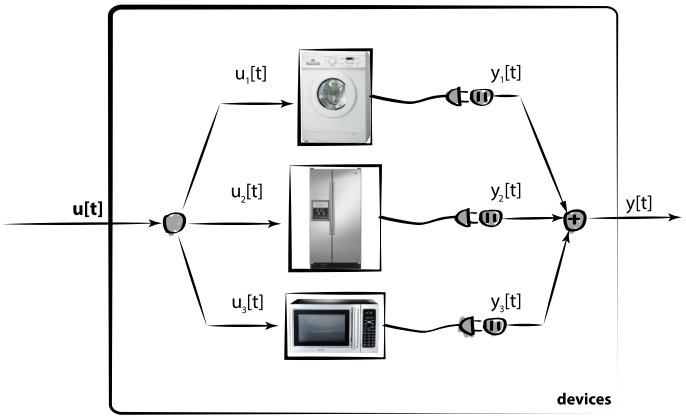
NILM Problem



FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Algorithms for NILM

* Previous work:
  * Phrased the energy disaggregation problem as a hybrid optimal control problem.
  * Used results from adaptive filtering to derive a tractable, recursive algorithm with theoretical guarantees.



FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Fundamental Limits of NILM

* Find conditions on which there *exists* an algorithm with a desired performance.
  * Analyze intrinsic information in the aggregate power consumption signal.
* Implications:
  * A model for understanding privacy risks in advanced metering infrastructures (AMIs).
  * Prescriptions for design of smart grid systems.
  * Benchmark for evaluating performance of NILM methods.

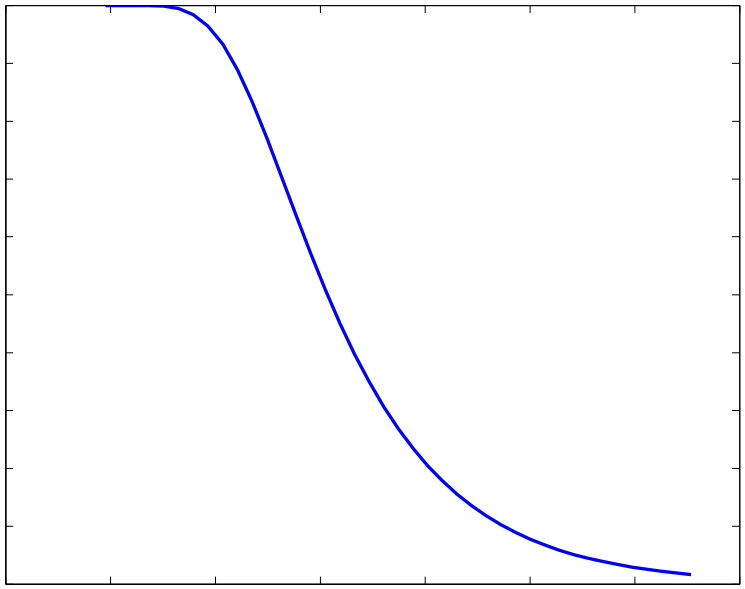
Preliminary Results

* Phrase the problem as a hypothesis testing problem.
* A simplified, easier problem: distinguish two scenarios.
  * Optimal solution: Separating hyperplane.
* Probability of distinguishing two scenarios is bounded above by:

$$\frac{1}{2}\left(1-\operatorname{erf}\left(\frac{-\frac{1}{\|a\|_2}(a^\top \mu_0 + b)}{\sqrt{2\sigma^2}}\right)\right)$$

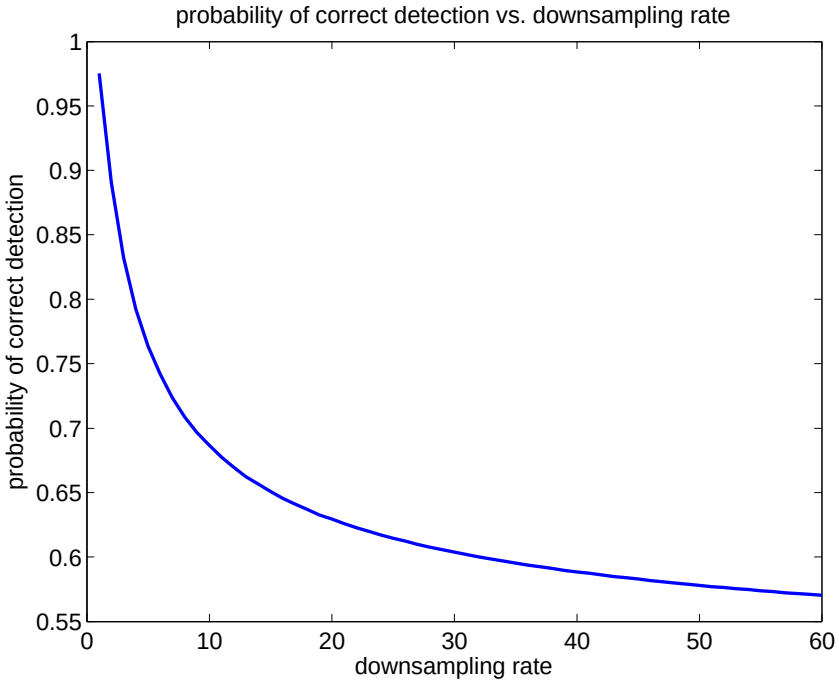
Preliminary Results

* Probability of distinguishing a toaster and a kettle as function of our *measurement and modeling error*:



Preliminary Results

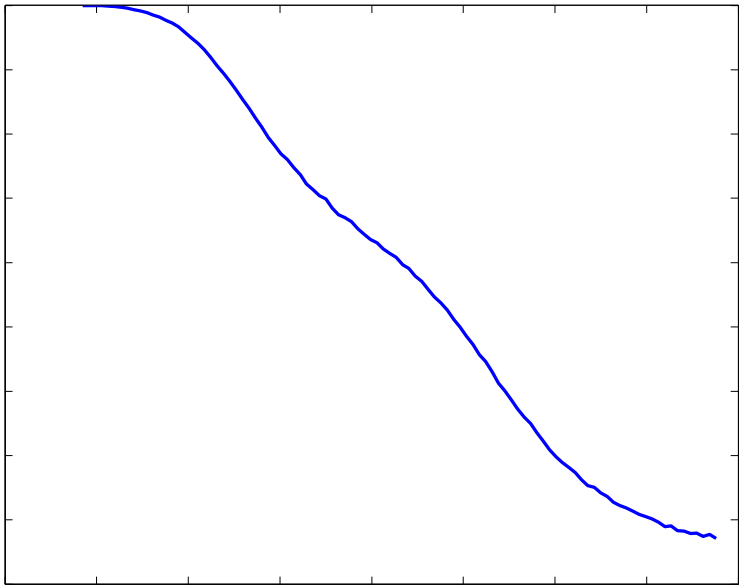
* Probability of distinguishing a toaster and a kettle as function of the *sampling rate*:



FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Preliminary Results

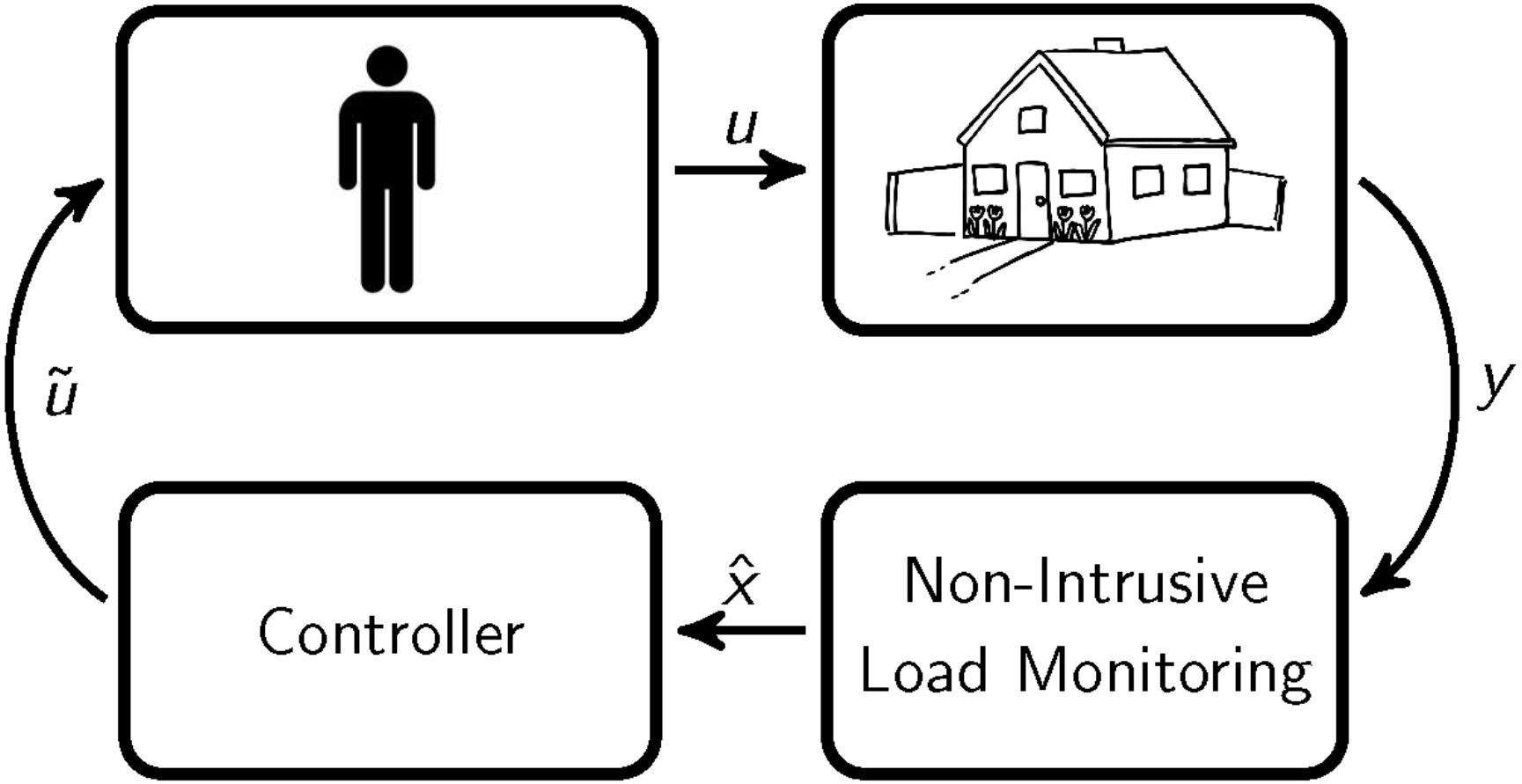
* Probability of successful NILM of 6 devices as a function of *measurement and modeling error*:



σ

FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

Big Picture



FORCES
FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS