Controlling big, diverse, nonlinear load aggregations for grid services by adjusting device setpoints

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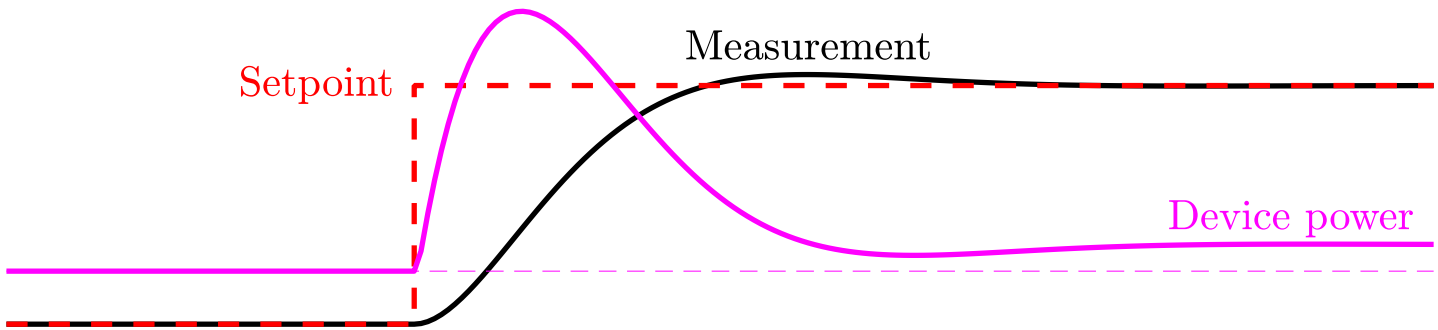
A control opportunity

- many electrical devices regulate measurements near setpoints
- devices increasingly accept setpoints via the Internet
- often, setpoints can be adjusted slightly without inconvenience
- setpoint adjustments cause device power perturbations

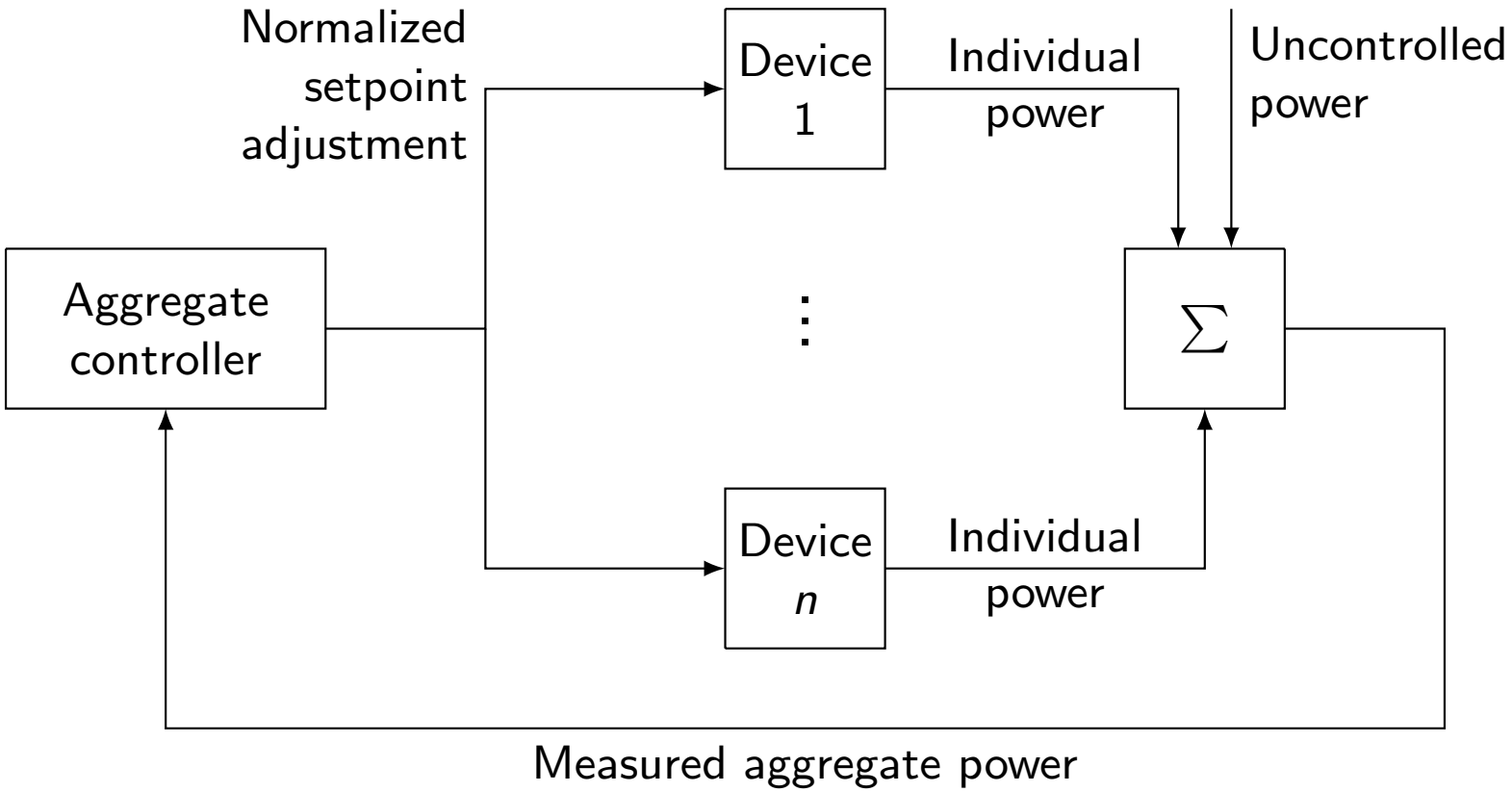


- aggregated over n devices, power perturbations can be large
- can we shape them to provide services to the power grid?

Example devices

collectively, these devices use about **half of U.S. electricity**

A scalable control architecture



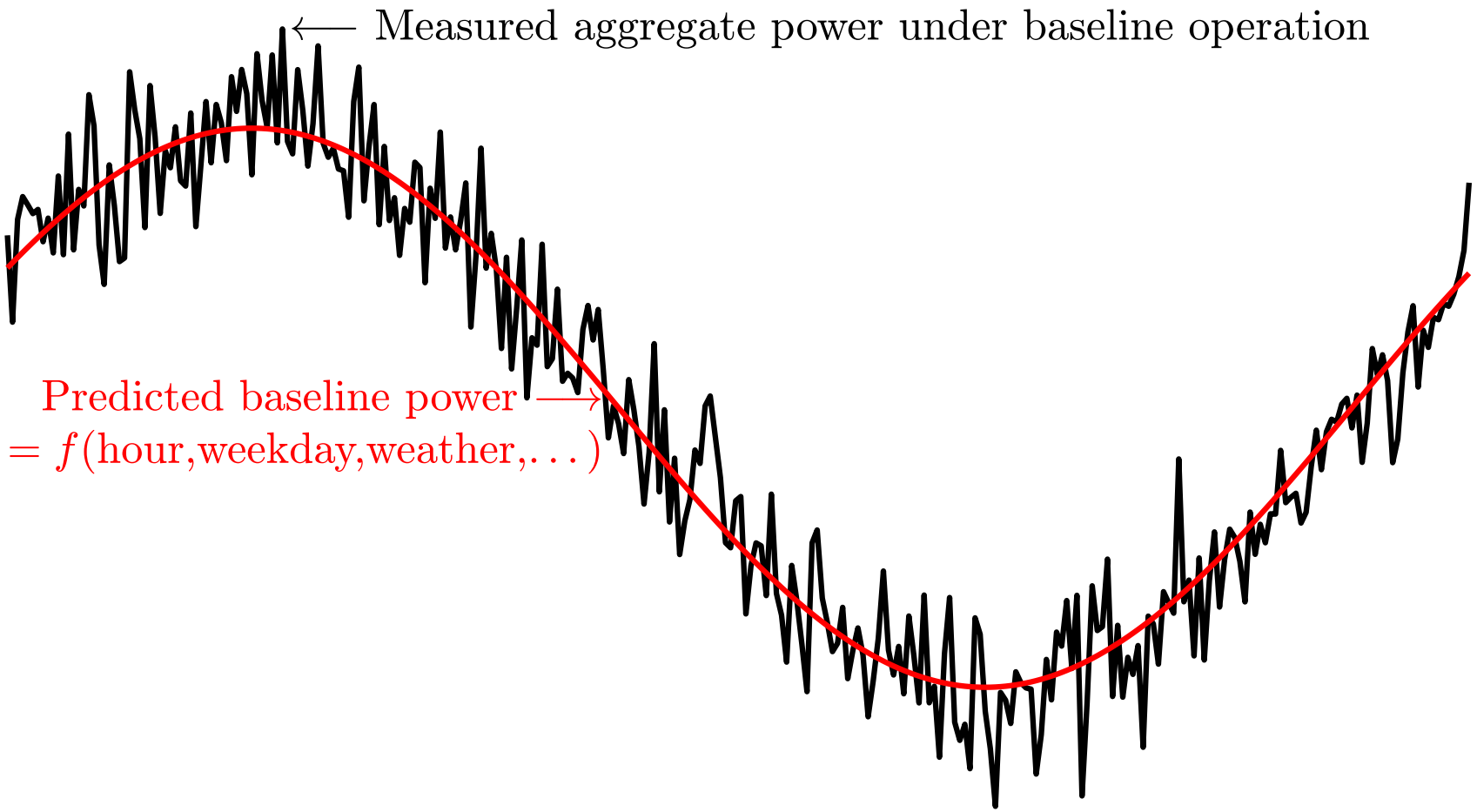
sensing and communication requirements are **independent of** n

A three-step control method

1. learn to predict aggregate power under baseline operation
2. learn how setpoint adjustments perturb aggregate power
3. embed baseline predictions and perturbation model in load-shifting optimization

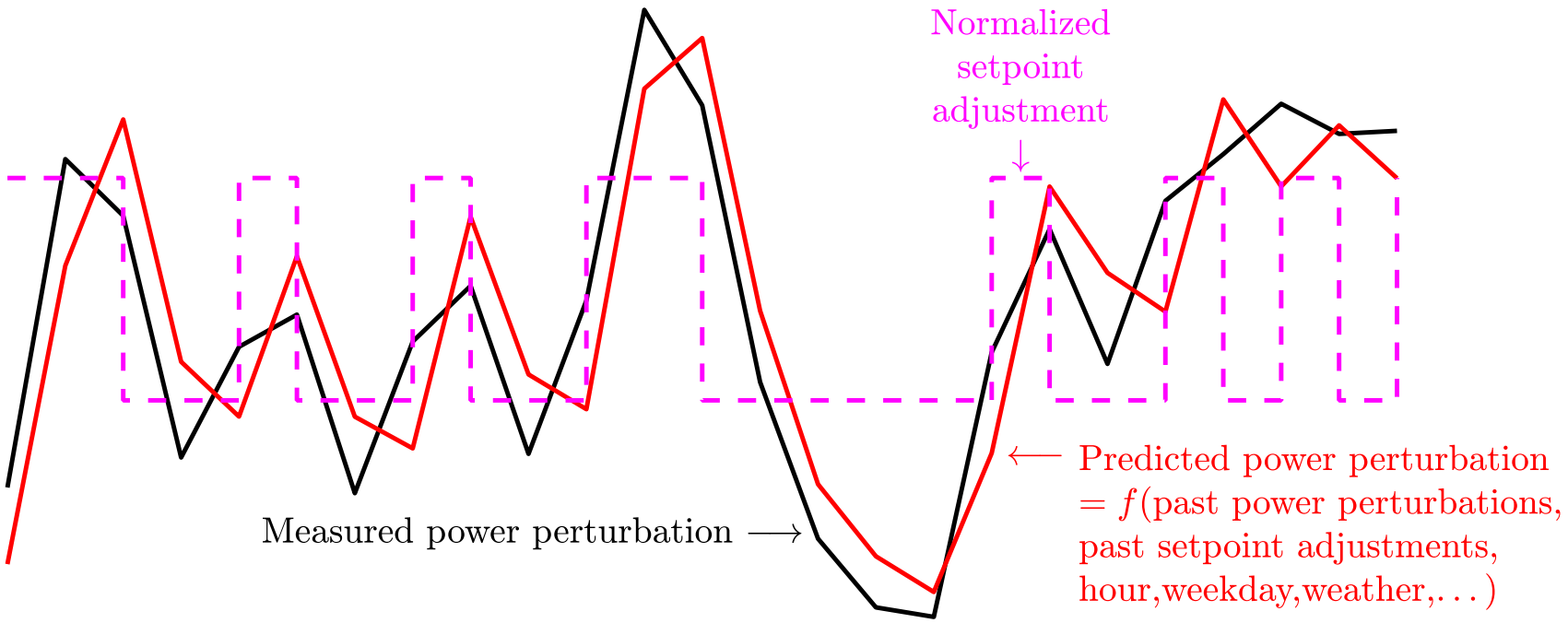
$\star$ problem dimensions in all three steps are **independent of** n

Step 1: Baseline prediction



here we use a feedforward neural network

Step 2: Perturbation system identification



here we use random binary inputs and a linear time-varying model

Step 3: Load-shifting optimization

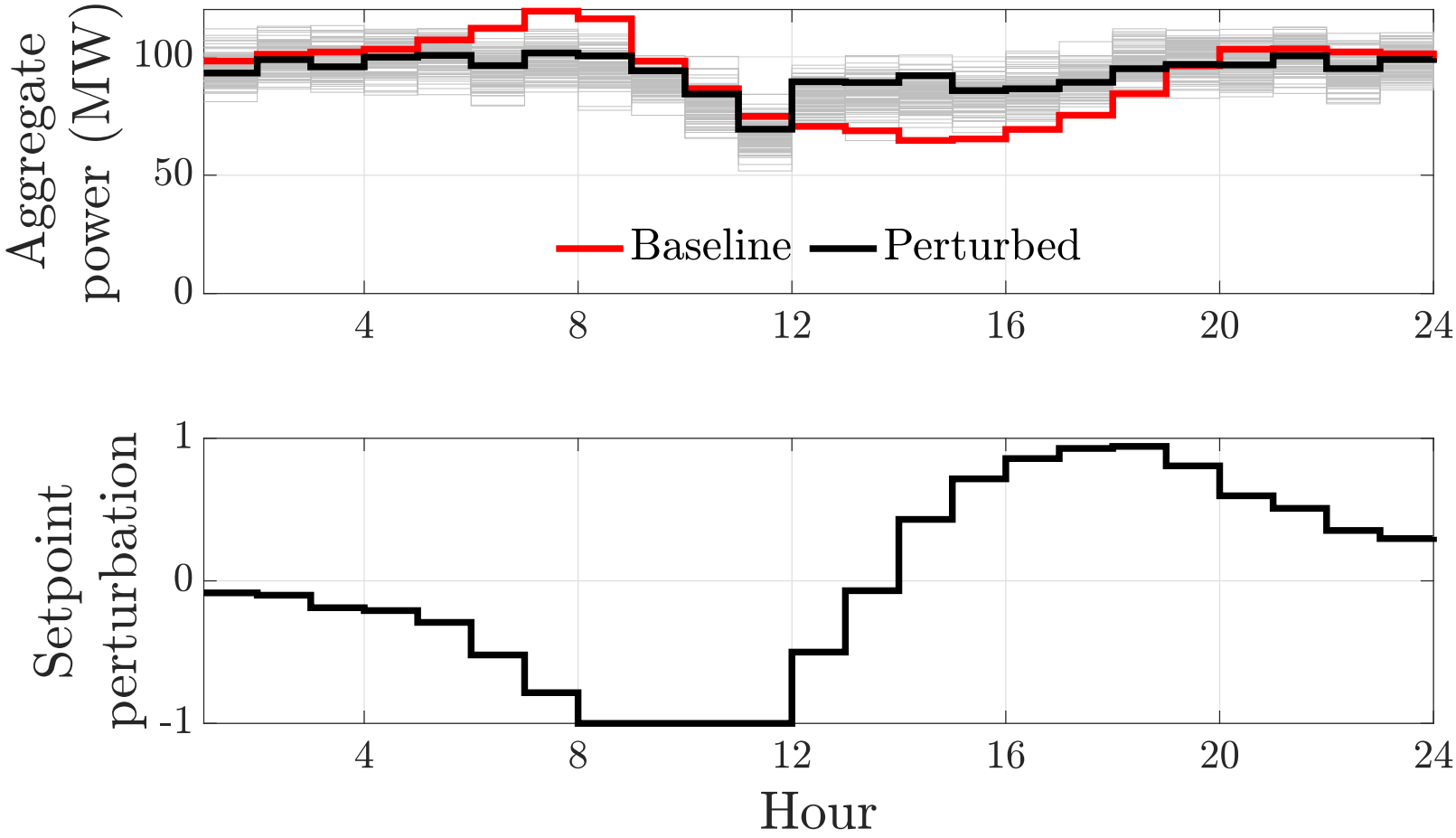
- **decide** a trajectory of normalized setpoint adjustments
- to **minimize** a cost related to grid-service performance
- **subject to**
  - ◇ the perturbation model (a set of equality constraints)
  - ◇ $-1 \leq$ normalized setpoint adjustments ≤ 1
- paper provides convex, risk-averse formulations for
  - ◇ peak shaving
  - ◇ arbitraging energy prices or electricity CO_2 intensities
  - ◇ planning capacity offers for regulation or reserve

Context for numerical examples

- simulations set in Austin during Winter Storm Uri (Feb '21)
- 50,000 diverse devices simulated, 115 MW peak load
- mild setpoint adjustments, *e.g.* ± 1 °C for heat pumps

Photo credit: CBS Austin

Peak shaved by 18 MW (16%) in this simulation



if similar (non-intrusive) load reductions had been possible state-wide, could blackouts have been avoided?

Summary

the data-driven control framework proposed here

- accommodates wide varieties of devices and grid services
- can be deployed at low cost using existing hardware
- can scale to gigawatt-sized aggregations
- requires no private information