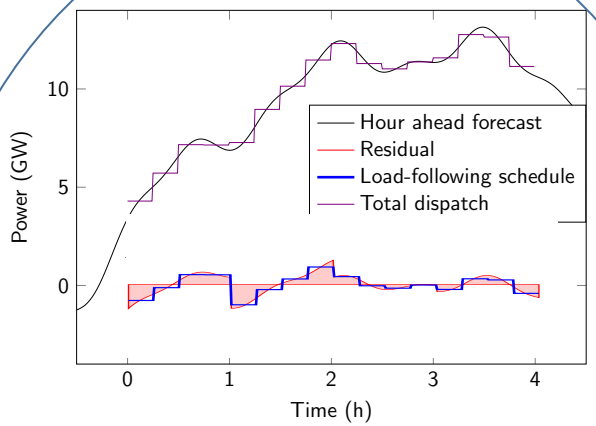
Coordinated Resource Management of Cyber-Physical-Social Power Systems

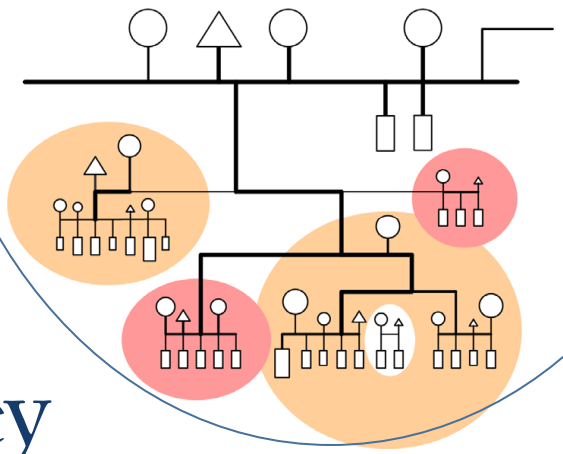
PIs: Callaway, Poolla, Varaiya (Berkeley)

Bitar (Cornell), Khargonekar (Florida)

Challenge:

- Growing uncertainty & variability in power system operations
- (now) most balancing done with combustion machines





Scientific Impact:

- Advances in game theory, stochastic optimization, testing new incentive mechanisms

Solution:

- Engage flexible loads
- Toward cyber-physical *social* systems (CPSS)

Broader Impact:

- Tools to operate and *plan* human-in-the-loop power systems
- Guarantees for the capacity of human-centric resources
- Testbeds w/ utilities, Air Force

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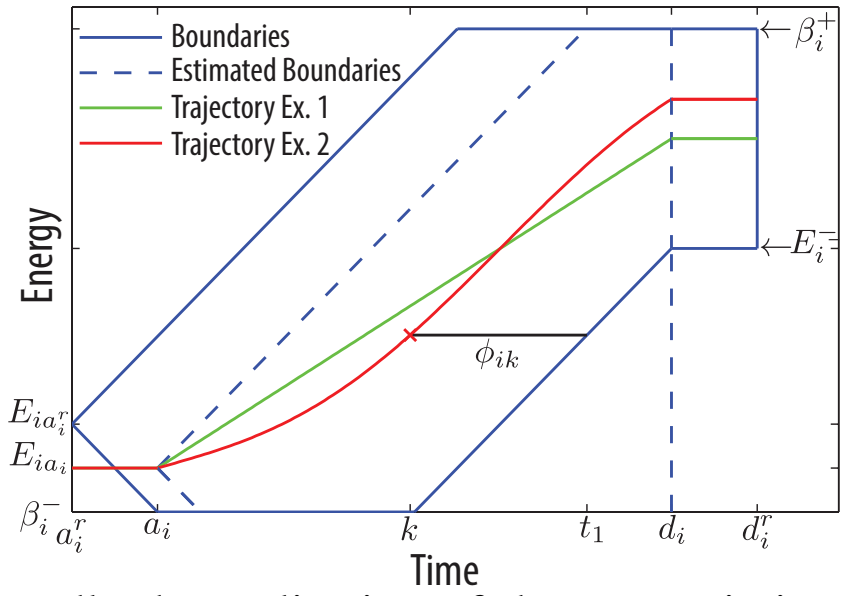
Foundations (1): Coordinated aggregation of demand-side resources

Leads:
Poolla, Callaway

- Energy-defined end-uses as "tasks"
- Resource management: EDF, LLF, receding horizon control, non-cooperative games
- Results:
  - Optimal causal control policies do not exist
  - New convex SOC "trajectory following" approach performs best (centralized)



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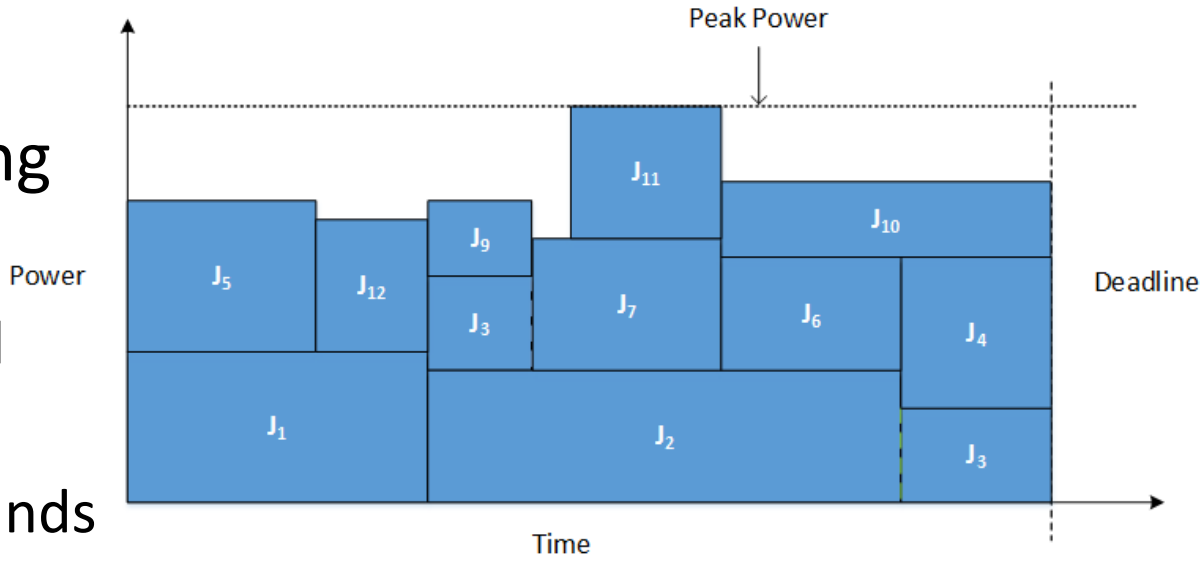
Foundations (1): Coordinated aggregation of demand-side resources

Lead: Khargonekar

- Offline scheduling for loads: minimizing max demand
  - Problem is NP-hard
  - *Strip-packing* heuristics have bounds provably 2-3 times optimal



- When cast as a non-cooperative dynamic game,
  - we can place a lower bound on the price of anarchy

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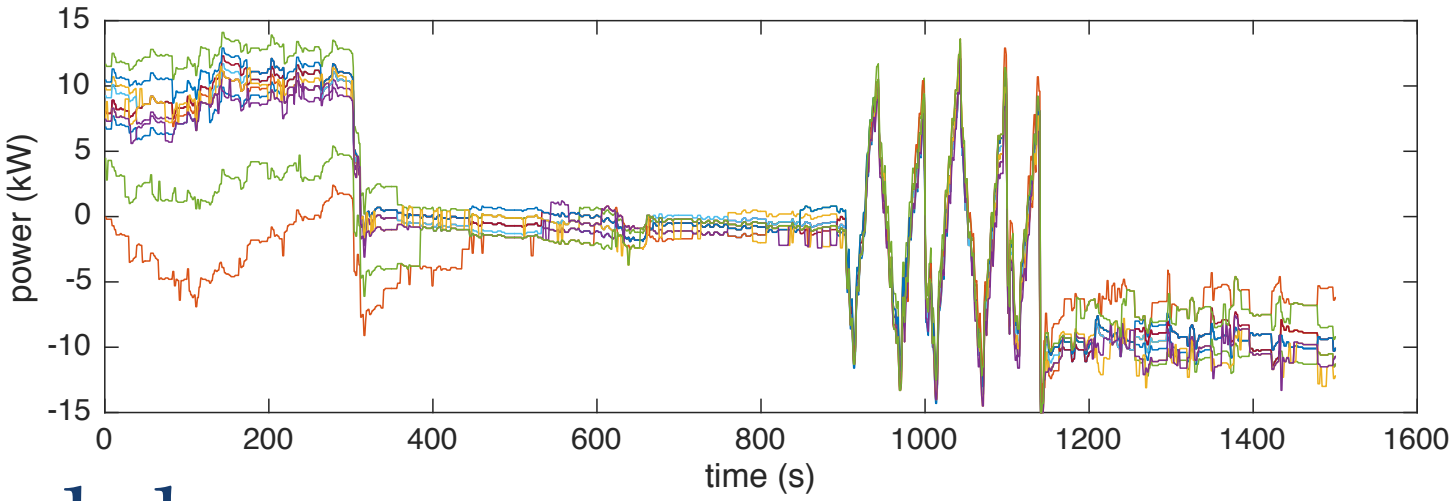
Testbed application (1): LA Air Force Base

Lead: Callaway

- 20 electric vehicles, ±150 kW total charging
- Integration with CA electricity market in collaboration with Lawrence Berkeley Lab
- Real-time control according to Juul *et al* 2015



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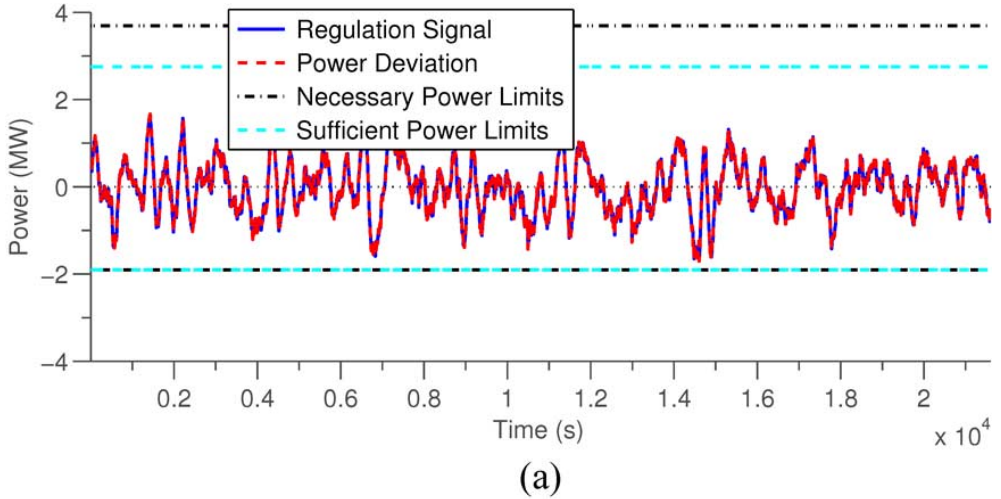
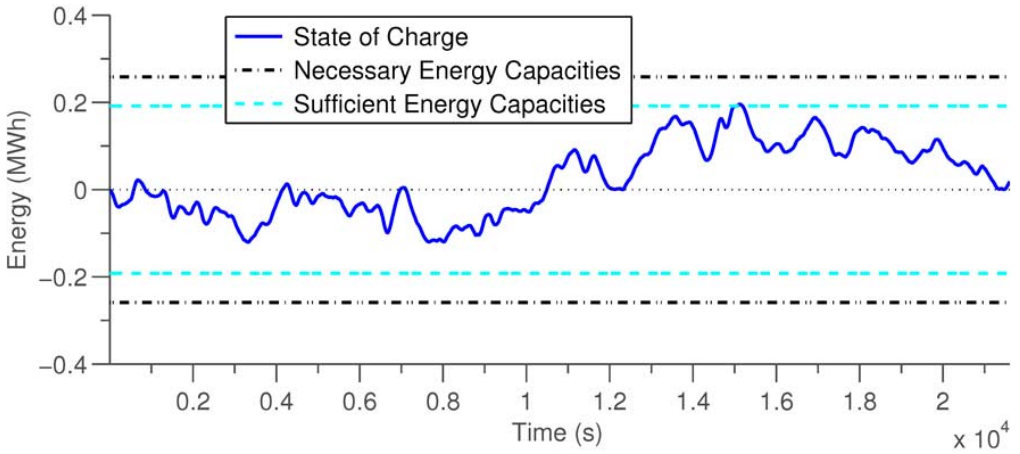
Foundations (2): Guaranteeing human-centered resource availability

Lead: Poolla

- Thermostatically controlled loads, EVs have "slack"
- New results:
  - Model this slack as a "stochastic battery"
  - Provide sufficient conditions to guarantee the size of that slack



(a)



(b)

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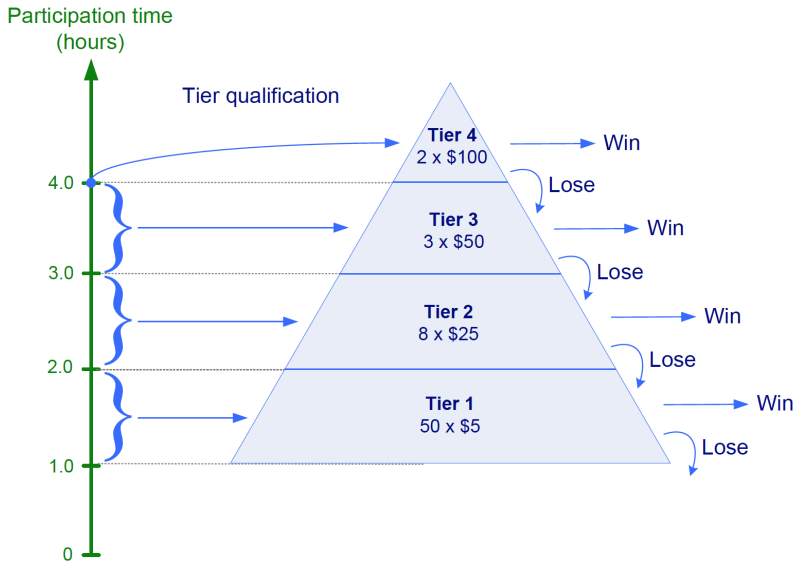
Foundations (3): Incentivizing human-in-the-loop power system operations

Lead: Bitar

- Individual vs collective action
  - Value of sole action low
  - Collective action has high value in aggregate
- Prospect theory: individuals respond to differently to incentives that are
  - Large, low probability vs
  - Small, high probability
- Result: algorithms to pool benefit and raffle reward that *could* produce larger response than reward based directly on contribution



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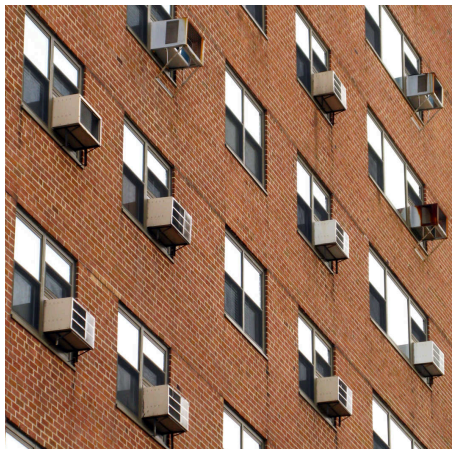
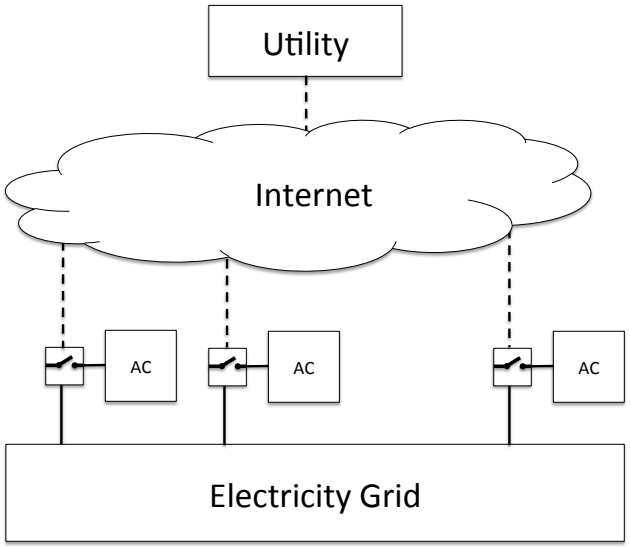
Testbed application (2): Residential AC

Lead: Bitar

- 400 customer DR pilot with Con Edison
  - Utility increases customer temperature 5F for 4 hours, 5 times / summer
  - Half of participants receive flat payment, half participate in lottery
- Results:
  - Lottery treatment group participated roughly 60% more
  - Participation reinforced with small early rewards
  - Participation less dependent on outside temperature, history of DR events for lottery group





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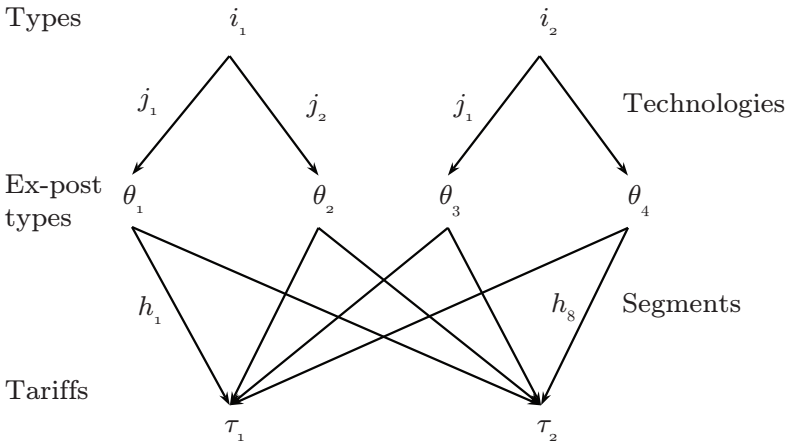
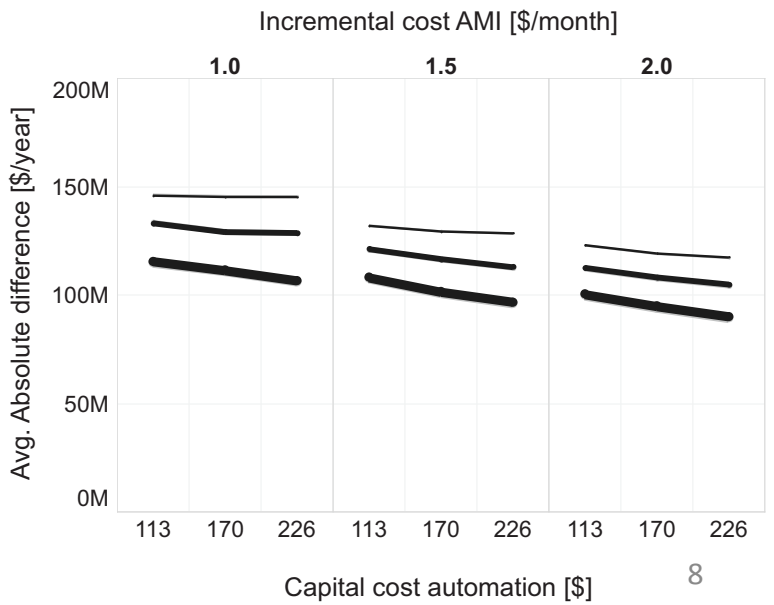
Foundations (4): Planning cyber physical social systems

Lead: Callaway

- Identifying the social welfare benefits of CPSS investments requires a long-run view
- Results:
  - theoretical underpinnings for capacity expansion with CPSS "priced in"
  - welfare benefits of CPSS infrastructure robust to cost





Continuing work

- Both testbeds will continue to serve as research platforms
  - Incentives for continuous DR with Con Edison
  - Deeper collaboration with California ISO → integration of EV charging into electricity markets
- Connecting incentive design testbed results to planning models