CPS: Breakthrough **Understanding Sub-Second Instabilities in a Global Cyber-Physical System**

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PI: Neil Johnson, University of Miami neiljohnson@miami.edu Post-doc: Pedro Manrique

Challenge:

Future real-world CPS will be 'messy':

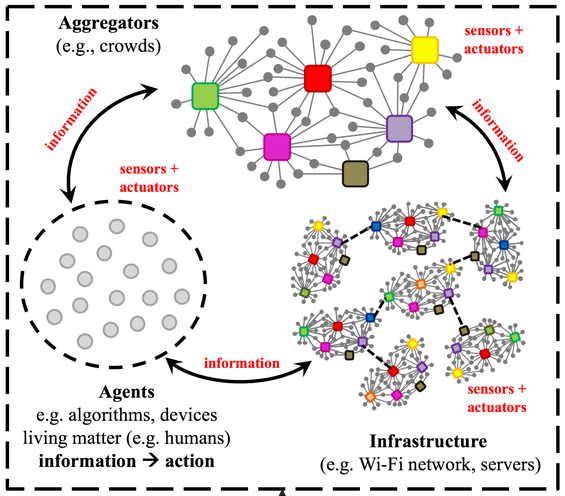
- Large: # of sensors, actuators 1→$10^{3,4,5,....}$
- heterogeneous: many types of sensors, actuators, devices, algorithms, humans
- competitive: free market, Amazon vs. Uber; limited resources → large economic game
- adaptive, dynamical: no 'steady state'
- large fluctuations: complex system
- decentralized: Amazon, Uber, Google
- complex feedbacks: human, machine, software
- incomplete information: privacy, competition
- imperfect information: latency, fake news
- fast: software and hardware operates faster than human reaction times
- attacks: cyberwarfare, crime, extremism, system manipulation with fake news etc.

Instead of worrying about optimization etc., the crucial concerns for regulators, governments, society, users will be:

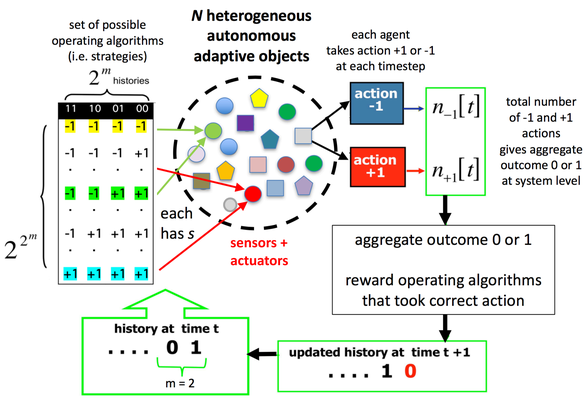
What might go wrong? When? How bad?

What should be done about it?

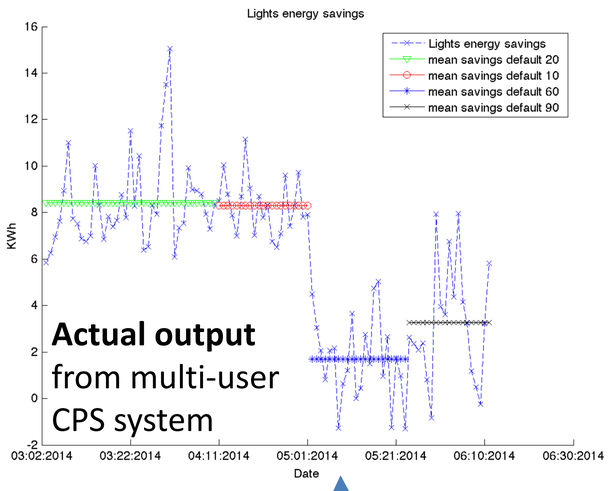
Adapted from Prof. Sastry, 2016 PI Meeting

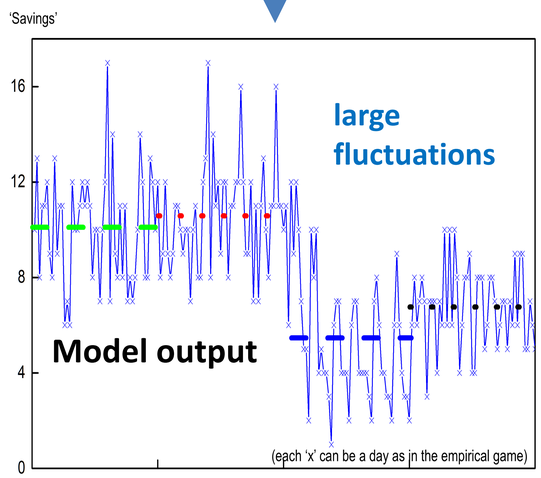


Our minimal CPS model



Competition for limited resource
no 'best' solution





Data from building energy efficiency project of Ioannis Konstantakopoulos (IK) & Prof. Shankar Sastry et al. UC Berkeley See arXiv:1407.0727v2 [math.OC]

Started new collaboration with IK on CPS user dynamics and decision-making

Solution:

- Develop a new **scalable theory** of dynamical behavior for **messy, multi-component CPS systems** which is **validated and verified** using **rigorous mathematical analysis and real-world data**
- Use theoretical machinery of **complex systems, complex networks & many-body dynamics**

Scientific Impact:

Specific progress in Year 2:

- **Unraveled impact of latency of information, on nature of extreme events and behaviors**
- **Developed software versions of competitive limited-resource model for all-machine CPS (deterministic strategies) and also machine+human CPS (stochastic strategies)**
- **Favorable comparison with real empirical data for CPS lighting system (see display) and controlled laboratory experiments of human-machine version (J. Leady, U. Notre Dame)**
- **Building new science of CPS complex systems**
- **New applications of same ideas down toward ultrafast, ultrasmall scale (e.g. light harvesting)**

Broader Impact:

- Safety and security for society's CPS systems, from financial networks, smart energy buildings and cities, to autonomous vehicle design, both at individual and swarm level
- Project attracting interest from stakeholders across multiple application domains at state, federal and international level (e.g. FBI, military, government agencies) & media

Publications in Year 2 so far include:

1. "To slow or not? Challenges in subsecond networks", Science 355, 801 (2017); *Neil F. Johnson*
2. "Subsecond tsunamis and delays in decentralized electronic systems" Electronics 6, 80 (2017); *P. Manrique, M. Zheng, Z. Cao, D. Johnson, P.M. Hui and N.F. Johnson*
3. "Impact of delayed information in sub-second complex systems", Results in Physics 7, 3024 (2017); *Pedro D. Manrique, Minzhang Zheng, D. Dylan Johnson Restrepo, Pak Ming Hui, Neil F. Johnson*
4. "Using Competition to Control Congestion in Autonomous Drone Systems" Electronics 6, 31 (2017); *P.D. Manrique, D.D. Johnson, N.F. Johnson*
5. "Exploiting non-trivial spatio-temporal correlations of thermal radiation for sunlight harvesting", J. Phys. B: At. Mol. Opt. Phys. 50, 124002 (2017); *A. De Mendoza, F. Caycedo-Soler, P. Manrique, L. Quiroga, F. Rodriguez, N.F. Johnson*