Understanding the Role of Information in the Control of Cyber-Physical Systems

Bryce L. Ferguson

PhD Student, Department of Electrical and Computer Engineering, University of California, Santa Barbara

UCSB

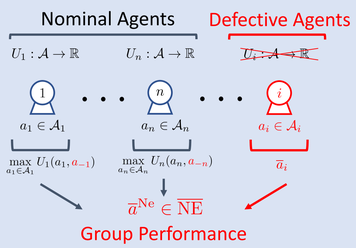
CCDC Control, Dynamical-Systems, and Computation

Information *in* control

Distributed Control with Limited Information

[CDC21,DGAA,CDC22]

Local Utility Design with Defective Agents

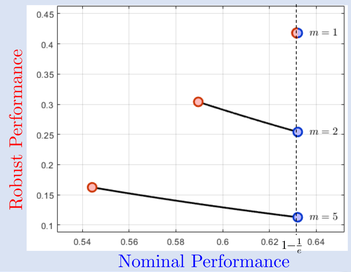


- Distributed Resource Allocation Problem
- Agents decide resources/tasks *locally*
- *Unknown* set of agents is defective

Objective: Design local objectives for robust performance guarantees

Results:

- Optimal, robust local utility rules as the solution to a linear program
- Performance guarantee of optimal design
- Characterization of trade-off between nominal and robust performance

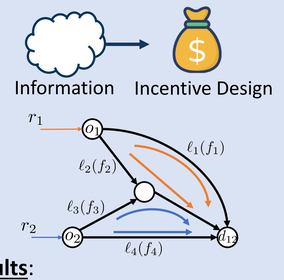


Insights: Uncertainty about hazards requires redesign of existing control rules and induces trade-off between robust and nominal performance.

Robust Incentive Mechanism Design

[CDC19, TCNS, ACC20, TAC, ACC21, CDC21, LCSS, TEAC]

Designing Incentives under Uncertainty

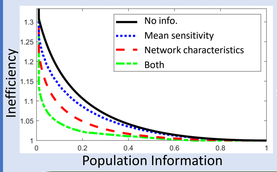


- Self-interested users route themselves through congestible network
- Network congestion can be improved with appropriate incentives
- Network structure and users' response to incentives may be unknown

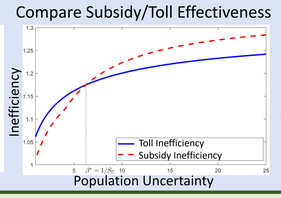
Objective: Design robust incentives with limited information.

Results:

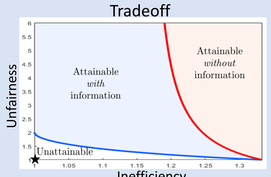
Characterize Value of Information



Compare Subsidy/Toll Effectiveness



Identify Fairness/Performance Tradeoff

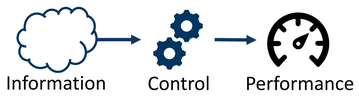


Insights: Characterization of the value of different pieces of information and the effectiveness of different incentive types.

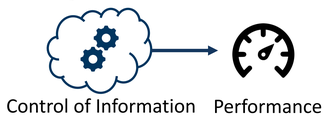
Research Interests and Vision

My research studies how we can *utilize information* in the control of large-scale cyber-physical systems. I study this in two paradigms:

The role of information at the *design phase*



Information's power to *influence behavior*



Distributed Decision Making

Local decision making in large-scale systems

- Performance a function of *collective behavior*
- Susceptible to *sub-system failures*?
- Local information affects overall performance


Robotic Fleets


Content Distribution


Resource Allocation

Cyber Physical Human Systems

Self-interested system users

- Performance a function of *collective behavior*
- Cannot directly control, *influence* in other ways?
- Information about *user response* affects capabilities


Traffic Networks


Power Grids


Supply Chains

Social-Centered Systems

Decisions based on individual beliefs

- Performance a function of *collective behavior*
- Users' prior knowledge affect behavior
- Beliefs can be changed by *signaling* information


Voting


Driving Patterns


Commerce

Acknowledgements

Collaborators: Jason R. Marden, Philip N. Brown, Rahul Chandan, Dario Paccagnan, Yixiao (Rey) Yue, Austin K. Chen, Daigo Shishika, Michael Dorothy Vijay Kumar, George J. Pappas

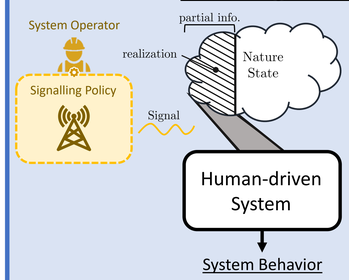
Research supported in part by: Army Research Office, Office of Naval Research, Air Force Office of Scientific Research, National Science Foundation.

Information *as* control

Strategic Information Signaling

[CDC22]

Revealing Information to Alter Users' Beliefs

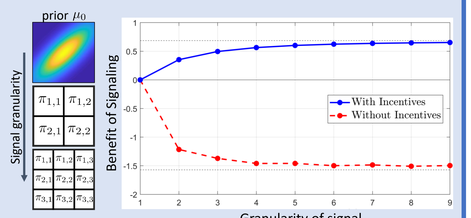


- Human system with *unknown state*
- *Belief of state* affects system behavior (e.g., driving patterns and traffic)
- System operator can *signal information* to *alter beliefs* and improve performance

Objective: Design signaling policy that improves system behavior

Results: (in Bayesian Congestion Games)

- Bounds on benefit of signaling (can help *or* hurt)
- Incentives *robustify* signaling
- Solve for optimal signals (w/ & w/o concurrent incentives)



Insights: Information signaling has the capability to help or hurt system performance, but incentives make revealing information only help.

Competing Information Providers

Information Senders with Different Objectives

- Social system that depends on user action
- Users make decisions without exact knowledge of the system state
- Senders/advertisers can signal information to the users
- Each sender has their *own objective*

$$\text{Posterior} = \mathbb{P}[\text{state}|\text{signals}]$$

Objective: Understand the interactions between *multiple* information senders

Directions:

- Characterize behavior in sender competition
- Identify opportunities to thwart malicious 'information' providers.
- Sender decision on cost/reliability/truthfulness
- Users' inferencing ability: Bayesian or otherwise?

Insights: Multiple information sender can compete in shaping users' beliefs. More senders can lead to polarization or greater uncertainty.

Bryce L. Ferguson blferguson@ece.ucsb.edu University of California, Santa Barbara https://web.ece.ucsb.edu/~blf/