

Societal Scale CPS Systems: Data Analytics, Privacy and Incentive Design

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Joint work Lillian Ratliff (UW), Roy Dong, Henrik Ohlsson (C3 Energy) and Alvaro Cardenas (UT Dallas), with Saurabh Amin (MIT) and Galina Schwartz

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Action Webs to Resilient CPS

Action Webs & Societal CPS

Incentive Design for Societal CPS

Data Analytics for Monetizing CPS Big Data

Conclusions and Future Research

Action Webs to Resilient CPS

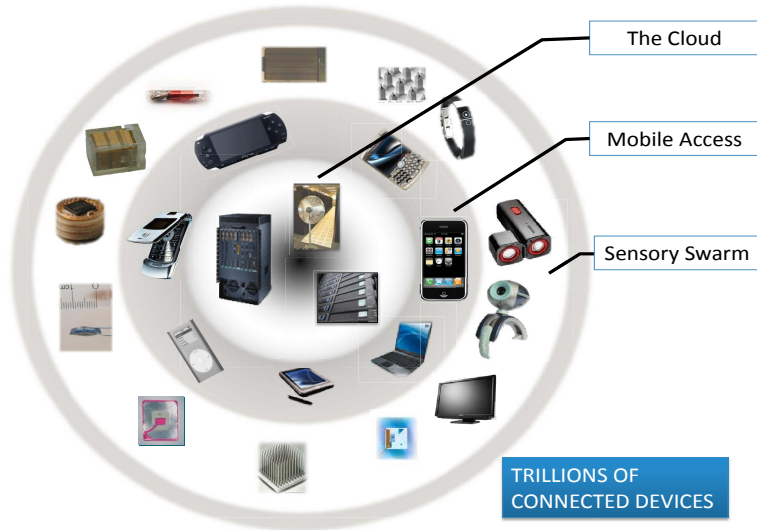
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The swarm at the edge of the cloud

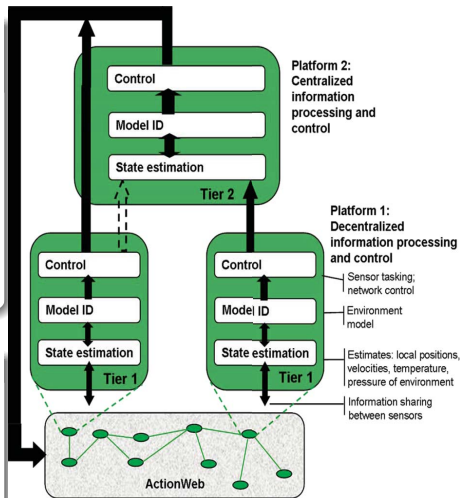


Action Webs

Observe and infer for planning and modifying action

- Dealing with uncertainty
- Tasking sensors
- Programming the ensemble
- Multiple objectives
- Embedding humans

Example: Building energy management

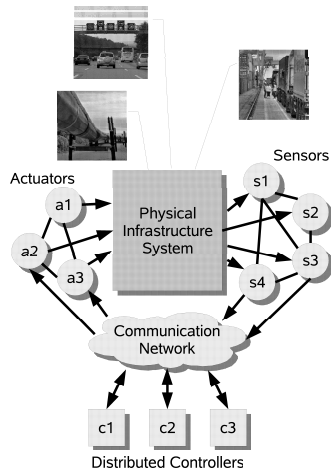


Courtesy: Claire Tomlin

From Action Webs to Resilient CPS

Resilient/High Confidence Networked Control

- Fault-tolerant networked control
 - Limits on stability, safety, & optimality
 - Scalable model predictive control
- Security & Resilient Control
 - Availability, Integrity, & Confidentiality
 - Graceful degradation
- Economic Incentives
 - Incentive Design for investing in security
 - Interdependent Risk Assessment & Cyber Insurance



Societal Scale CPS

A complex collection of sensors, controllers, compute nodes, and actuators that work together to improve our daily lives

- **From very small:** Ubiquitous, Pervasive, Disappearing, Perceptive, Ambient
- **To very large:** Always Connectable, Reliable, Scalable, Adaptive, Flexible

Emerging Service Models

- Building energy management
- Automotive safety and control
- Management of metropolitan traffic flows
- Distributed health monitoring
- Smart Grid

Economic Impact

Electricity Grid:

- Utilities are currently utilizing smart meters for meter-to-cash. The potential of smart meters go far beyond this basic usage and the utilities are looking for a justification for their investments. The market for energy analytics in the smart grid is estimated to be worth 9.7 billion by 2020

Transportation Systems:

- It is estimated that more than 4.2 billion hours are wasted sitting in traffic, resulting in 2.8 billion gallons of wasted fuel and costing more than 87 billion dollars annually. By utilizing tools such as intelligent transportation systems (ITS) we can actively manage our transportation network to improve safety, efficiency, and multimodal connectivity.

Other Critical Infrastructures:

- Healthcare systems, Water systems, Natural gas and oil and other energy infrastructures

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Why Incentive Design?

- There is often a substantive gap between competitive Nash equilibria and the social planner's optimum (Hal Varian, et al).
- Due to information asymmetries and misaligned objectives, the actions taken by agents in S-CPS are not socially optimal.
- Incentives are the natural mechanism for aligning agents so that they behave in a socially optimal way.

In Energy CPS:

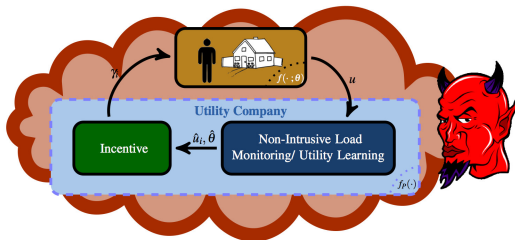
- Consumers and Utilities are not well informed about their energy consumption patterns; incentives allow utility companies to motivate consumers to use less energy.

In Transportation CPS:

- Drivers often travel at peak hours; incentives can be used to encourage drivers to shift their departure time by only a few minutes for some reward resulting in overall reduced congestion.

Incentives

- In the regulated energy market, utility companies are incentivized to reduce the overall consumption of their consumer base.
- Demand response programs incentivize customers to shift their demand thereby alleviating inaccuracies in load forecasting. Device-level incentives can be designed via non-intrusive load monitoring.
- Incentive Design needs a game theoretic model including data-driven models for agent behavior and their identification these during on-line operation.
- New Vulnerabilities: **Adversarial** agents who may **spoof** their energy signal, lie about their privacy needs or otherwise **disrupt** the energy system.



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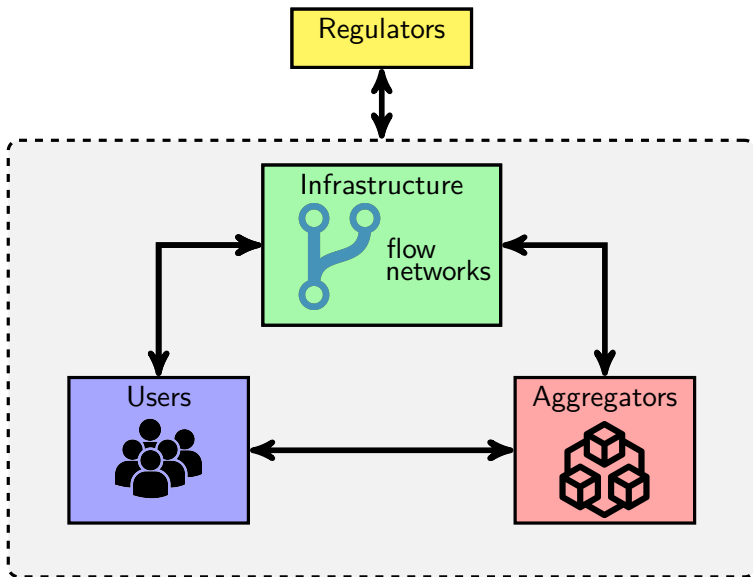
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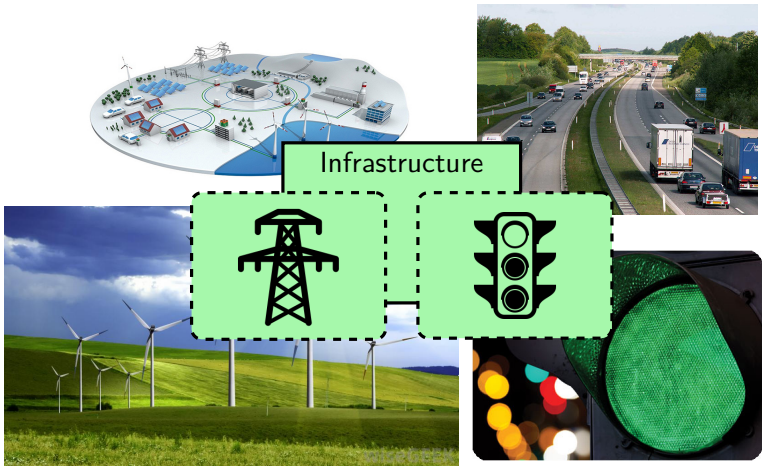
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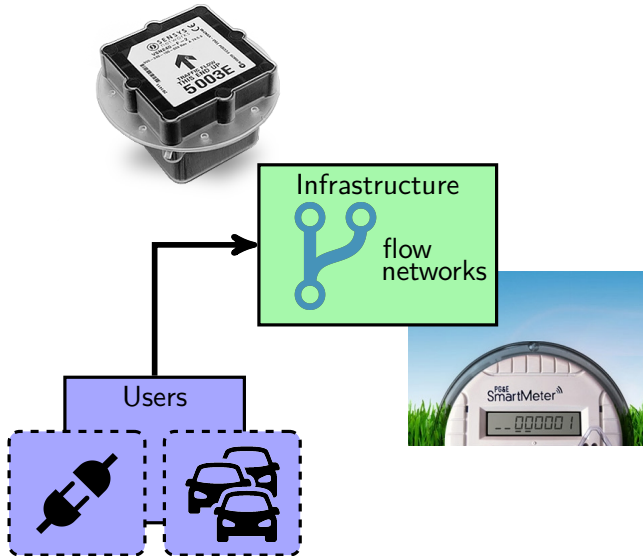
Emerging Data Market



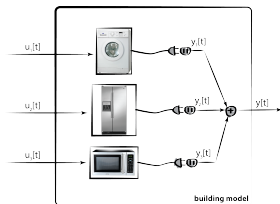
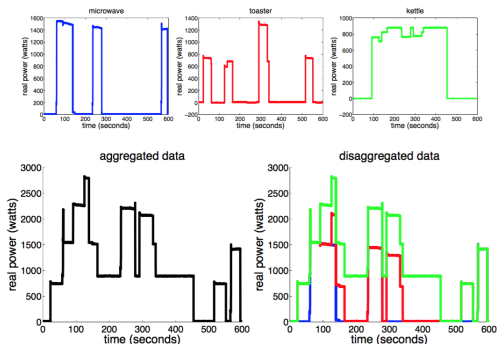
Smart, Connected Infrastructure



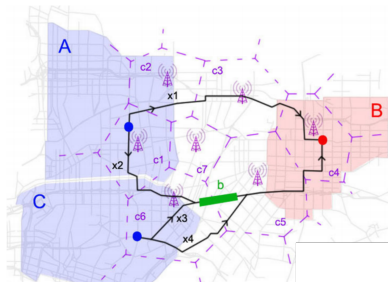
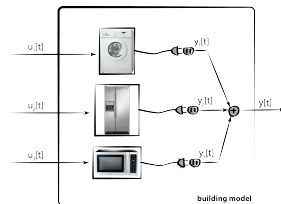
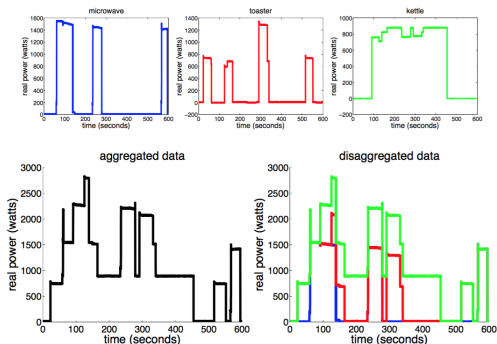
Operational Efficiency Informed by Usage Patterns



Data Disaggregation

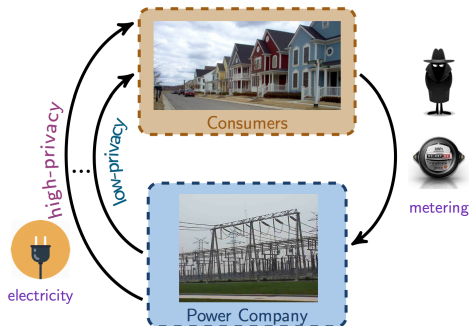


Data Disaggregation



How do people value their data? — Privacy as Good

Contribution: Designed service contracts differentiated by value of data to balance efficiency-vulnerability tradeoff

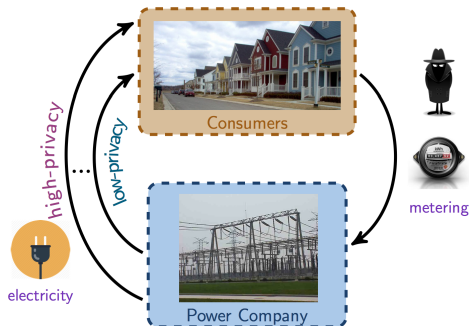


Results:

- Characterized contracts with privacy loss risk modeled using privacy metric and abstraction of loss.
- High-type free-rides \Rightarrow regulation to realize the social optimum.
- Privacy loss risk \Rightarrow incentive for investing in insurance.
- Designed insurance contracts for risk-averse utility company/consumer.

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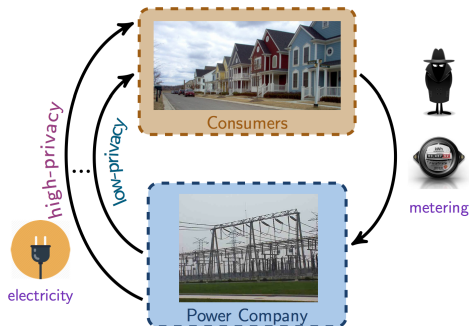
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Impact:

- Privacy loss risk motivates study of **security-insurance** investment.
- User valuations of data need to be factored in to improve efficiency.

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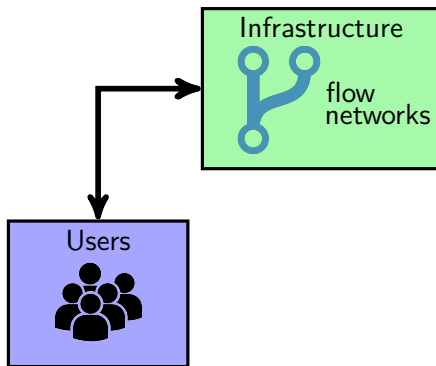
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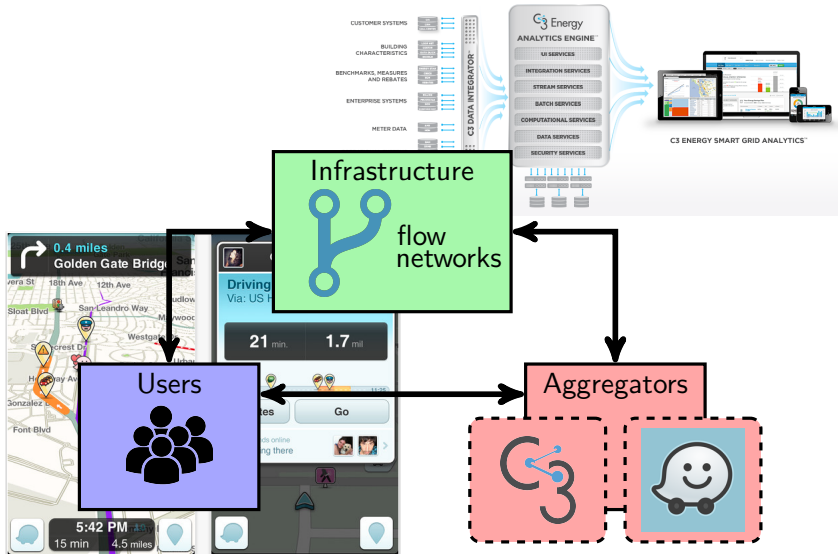
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Data as a Commodity

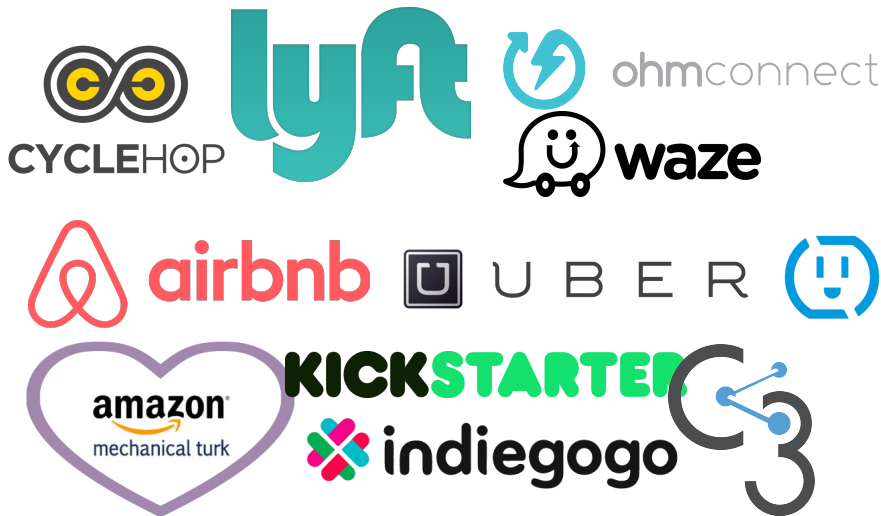


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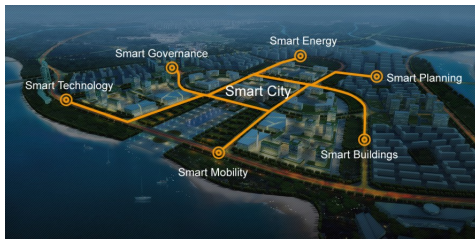
Shared Economy

A smart infrastructure empowered by the Internet of Things (IoT) has at its core an ecosystem consisting of a *shared economy*.



Infrastructure Evolution

The shared economy will require service providers to evolve in order to provide **improved services** that are **competitive in the new marketplace**



- Companies emerging that capitalizing on streaming data.
- Forcing existing infrastructure systems to modify their operational model in order to survive.

Not Just Existing Infrastructure: New infrastructure systems are emerging! (e.g. UAVs+UTM monitoring health of road, water, power networks)

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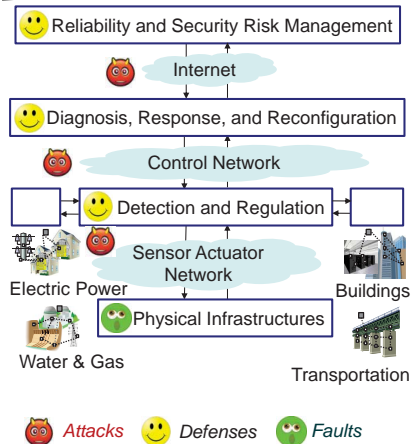
Issues in Societal Scale CPS

Issues Addressed

- Incentive Design
- Disaggregation and Fundamental Privacy Bounds
- Privacy Aware Contract Design: Free Riding and Adverse Selection
- Insurance against Loss of Privacy

Next Steps

- New Vulnerabilities, Attacks and Defenses
 - Financial attacks
 - Increased reliability and preventive maintenance
 - Incentivize investments in security, privacy



Thank you for your attention. Questions?

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