FORCES
Welcome and Program Highlights

Shankar Sastry, UC Berkeley

Larry Rohrbough, UC Berkeley

The Investigator Team

Berkeley — **Alex Bayen, Shankar Sastry, Dawn Song, Claire Tomlin**

Massachusetts Institute of Technology — **Saurabh Amin, Hamsa Balakrishnan, Asuman Ozdaglar**

MICHIGAN — **Ian Hiskens, Demos Teneketzis**

VANDERBILT UNIVERSITY — **Gabor Karsai, Xenofon Koutsoukous, Janos Sztipanovits**

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CYBER-PHYSICAL SYSTEMS

5/29/15

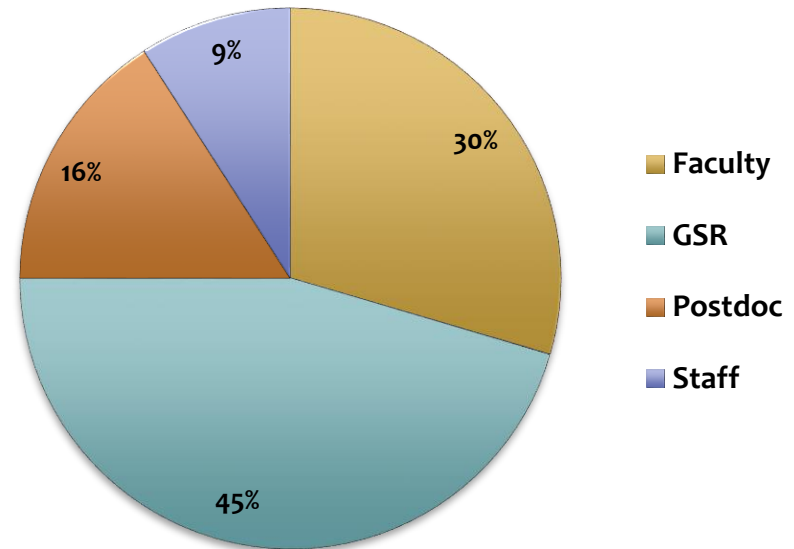# The Overall Team

* Total Participants = 44
  * Graduate Students = 20
  * Faculty = 13
  * Post Docs = 7
  * Staff = 4

* Demographics
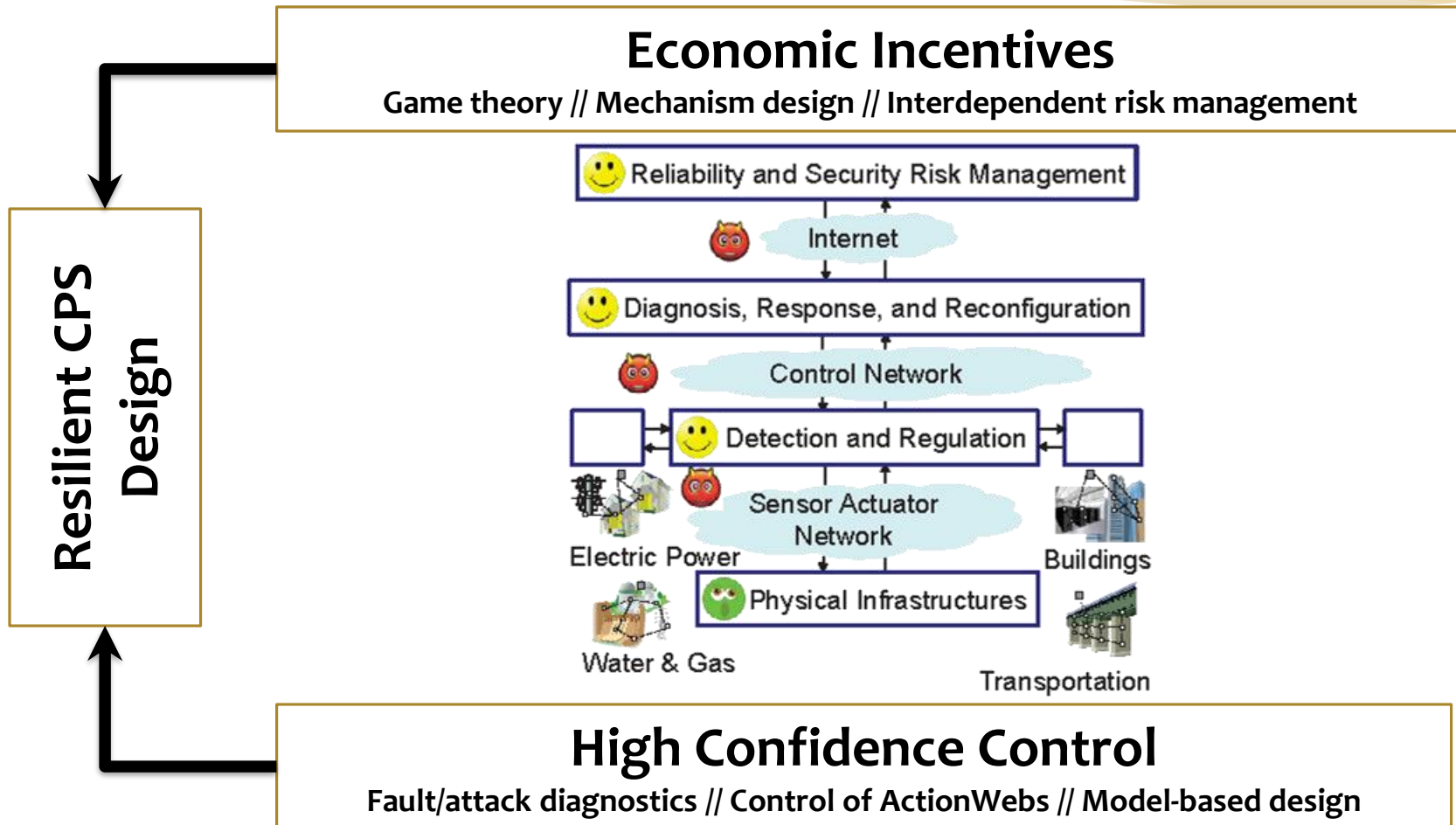 * Female = 27%
  * URM = 5%
  * U.S. Persons = 70%

FORCES Personnel (all institutions)

Legend:
- Faculty — 30%
- GSR — 45%
- Postdoc — 16%
- Staff — 9%

Research Overview and Approach

Economic Incentives

Game theory // Mechanism design // Interdependent risk management

Reliability and Security Risk Management

Internet

Diagnosis, Response, and Reconfiguration

Control Network

Detection and Regulation

Sensor Actuator Network

Electric Power

Buildings

Physical Infrastructures

Water & Gas

Transportation

High Confidence Control

Fault/attack diagnostics // Control of ActionWebs // Model-based design

Resilient CPS Design

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Research Focus Areas

* **Economic Incentives**
  * Game theory
    * Deal with strategic adversaries
    * Model both security failures and reliability failures
  * Mechanism design and theory of incentives
    * Agents contribute to CPS efficiency and safety, while optimizing their individual objectives
    * Joint stochastic control and incentive-theoretic design
* **High Confidence Control**
  * Control for resilience against network-level attacks and faults
  * Including software:
    * Current CPS often run legacy code
    * Protocols often lack security, authentication, or privacy
    * Attacker can extract or control information and computation

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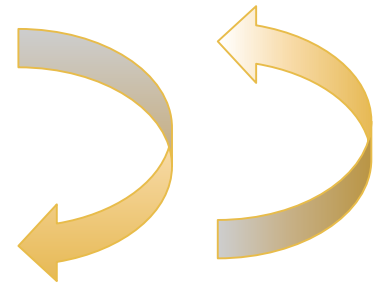CYBER-PHYSICAL SYSTEMS

Matrix of Research Projects

CPS for Transportation & Electric Power	Tools Based on High Confidence Control	Tools Based on Theory of Incentives
Active road traffic management	Distributed sensing and control	Congestion pricing and incentives
NextGen air traffic operations	Robust scheduling and routing	Strategic resource re-allocation
Smart electricity distribution	Distributed load control	Demand response schemes
Energy efficient building operations	Predictive control of devices	Energy saving incentives

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Research Integration Plan

	RC				EI			
	Diagnostics (F&A)	Robust/ Stoch. control	Model-based design	Secure design/ ops.	Game theory	Mechanism design	CPS risks mgmt.	Human in loop
Road (on/side)	★							
Air (space/port)								
Electricity (trans/dist)								
Energy (Ren./hybrid)				★				
CPS Sec. (Reliability/Res ilience)								
Codesign								★

Year 1 to Year 2 using results of xyz

Year 2 to Year 3 Joint with abc

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Measures of Research Program Success

* Short-term goals that can lead us to success:
    * New models, analysis, design results on RC+EI
    * Novel abstractions and understanding of h-CPS
    * Surprising / counterintuitive results, Aha moments,…
    * Resilient algorithms, better guarantees

    * Validation of applicability to one or more FORCES domains
    * New data sets, prototypes, code, design tool,..
    * Demos on traditional/new CPS platforms
    * Adoption of concepts / tools, direct relevance/ use by industry

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Education & Outreach Goals

* **Curriculum Development**
    * Contribute to the EE, CS, and Systems curricula in the area of economic incentives for large-scale cyber physical systems.
    * Real-world case studies from transportation, electricity, and information networks.
    * Development of K-12 module on CPS.
* **Broadening Participation**
    * Infuse the EE and CS pipeline with (1) more diverse participation in the area and (2) increase the number of women and URMs involved in cyber-physical systems work.
* **Engagement with Community**
    * Provide training to the students, researchers, and practitioners working in the area of cyber-physical systems.

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Education & Outreach Highlights (1/3)

Curriculum Development

* CPS has attracted attention; several courses that address CPS:
  * Cyber Physical Systems (Seshia & Lee),
    https://www.youtube.com/watch?v=7zSCnnJE1cs
  * Cyber Physical System Fundamentals (TU Dortmund)
    https://www.youtube.com/watch?v=8HLJFlncMls
  * Cyber Physical System Summer School (Sangiovanni)

* FORCES Contribution
  * EI and RC modules that can be added to existing syllabi or online courses.
  * Further development on courses (across FORCES)
  * K-12 module for CPS (CY-BEAR)

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Education & Outreach Highlights (1/3)

Curriculum Development (cont.)

* **Resilient Infrastructure Networks (MIT/Amin)**
  * (Graduate) Control algorithms and game-theoretic tools to enable resilient operation of large-scale infrastructure networks. Dynamical network flow models, stability analysis, robust predictive control, fault and attack diagnostic tools. Strategic network design, routing games, congestion pricing, demand response, and incentive regulation. Design of operations management strategies for different reliability and security scenarios. Applications to transportation, logistics, electric-power, and water distribution networks.

* **Security of CPS (Vanderbilt/Koutsoukos)**
  * (Graduate) Security requirement for CPS, Vulnerability analysis; Intrusion detection; Security protocols; Assurance.

* **Computer security (Berkeley/Song)**
  * (Undergraduate) General security course with new material in security issues in cyber-physical systems.

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Education & Outreach Highlights (1/3)

Curriculum Development (cont.)

* **Air Transportation Operations Research (MIT/Balakrishnan)**

  * (Graduate) Covers analytical and algorithmic techniques for air transportation systems; includes discussions of key challenges pertaining to resilience and security of air traffic infrastructure; control, optimization and game-theoretic algorithms for air transportation systems.

* **Stochastic control (Michigan/Teneketzis)**

  * Projects in Stochastic hybrid systems, game theory, decentralized control, mechanism design.

* **Infrastructure for vehicle electrification (Michigan/Hiskens)**

  * Fundamentals of the physical and cyber infrastructures that will underpin large-scale integration of plug-in electric vehicles. Control strategies are considered for economically and equitably coordinating the charging of large numbers of electric vehicle, whilst ensuring that grid loading limits are respected.

* **Power system dynamics and control (Michigan/Hiskens)**

  * Hybrid dynamical systems perspective in introducing students to the dynamic behavior of power systems; resilient control strategies that enable recovery from large disturbances are considered

Education & Outreach Highlights (2/3)

Broadening Participation – New and Enhanced Activities

* **Student/Faculty/Professional**
  * Women in Cybersecurity (WiCyS) 2015: Sponsorship, recruiting, infusion of CPS topics

* **High School**
  * CY-BEAR: GenCyber (NSF/NSA) summer program emphasizing security of CPS

* **Middle School**
  * Girls in Engineering: summer camp engaging students in STEM, focus on CPS

# Education & Outreach Highlights (3/3)

Engagement with Community

* 2014 IEEE Conference on Decision and Control
  * Ratliff and Ohlsson workshop: "Big Data Meets CPS"
  * Amin and Balakrishnan workshop: "Resilient Control of CPS"
* CPSWeek 2015
  * HSCC: Steering Committee (Tomlin), PC (Balakrishnan)
  * ICCPS: General Co-Chair (Bayen), TPC Co-Chair (Koutsoukos), TPC (Amin), Session Chairs (Bayen, Koutsoukos)
* 2015 Institute for Pure & Applied Mathematics (IPAM)
  * Summer 2015: Amin, Ozdaglar, Schwartz summer school: "Games and Contracts for Cyber-Physical Security"
  * Fall 2015: Bayen, "New Directions in Mathematical Approaches for Traffic Flow Management"

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International Partnerships (1/2)

Resilient Water Networks
(Saurabh Amin, Lina Sela – MIT)

* **Resilient Water CPS in Sinapore**
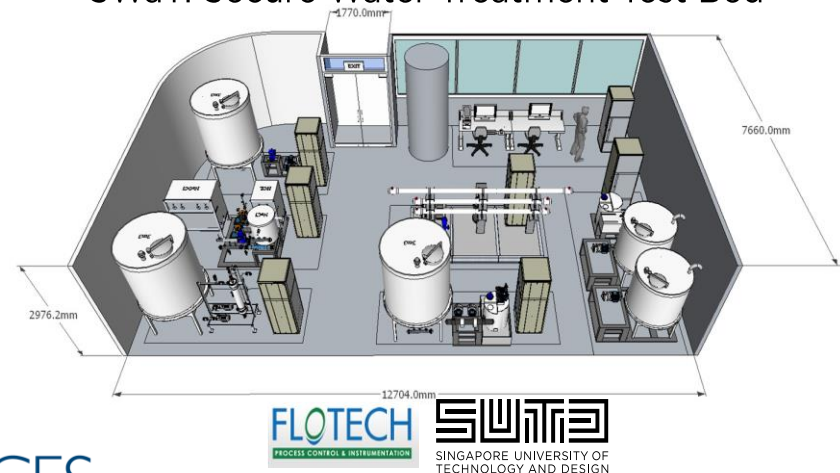 * MIT, SMART-CENSAM,
  * Visenti Pte., PUB, NRF
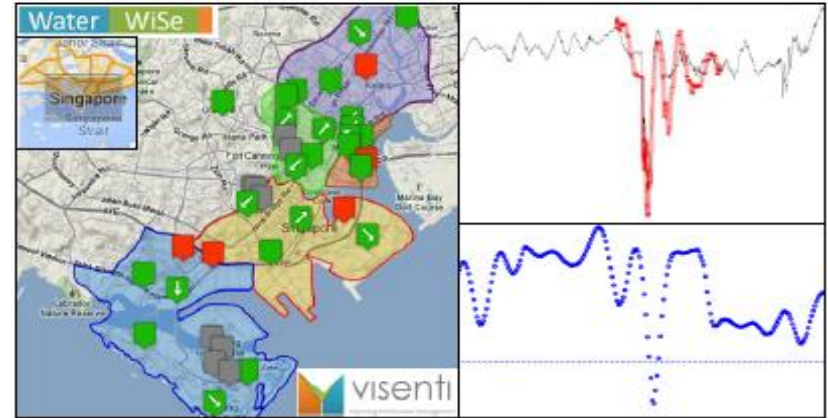
* **SWaT: Secure Water Treatment**
  * Funded by: Ministry of Defense
  * Design review: PUB and SUTD
  * Extensions: water storage and distribution
* **FORCES research contributions**
  * Network control
  * Vulnerability assessment
  * Resilient monitoring and diagnostics

SWaT: Secure Water Treatment Test Bed

FLOTECH
PROCESS CONTROL & INSTRUMENTATION

SUTD
SINGAPORE UNIVERSITY OF
TECHNOLOGY AND DESIGN

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International Partnerships (2/2)

Resilient Societal-Scale Cyber-Physical Systems
(Larry Rohrbough, Anil Aswani, Anthony Joseph, Kameshwar Poolla, Shankar Sastry – Berkeley)

* Republic of the Philippines: Philippine California Advanced Research Institutes (PCARI)

  * Resilient Societal-Scale Cyber-Physical Systems

    * Multi-year research program focused on improving the resilience (faults, failures, attacks) of key Philippine infrastructures—energy, smart buildings

    * US-PH graduate student exchanges

    * New courses development

  * Partners UC Berkeley (EECS, IEOR, ME) and University of the Philippines (CS, CE), other Philippine physical infrastructure stakeholders

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Awards & Recognition

* Berkeley EECS Eli Jury Award for top student research in Systems
  * Insoon Yang

* Berkeley EECS Leon Chua Award for top student research in Nonlinear Science
  * Walid Krichene

* CUTC Milton Pikarsky Memorial Award in Science and Technology
  * Jack Reilly (Google)

* Michigan Engineering Graduate Symposium
  * Mohammad Rasouli, System and Communication Engineering, 1st place award
  * Erik Miehling, Power and Energy, 2nd place award

Taking Stock of FORCES

* Common themes have emerged:
    * Integration of economic incentives and high confidence control
    * Utility-based privacy: the increasingly important role of privacy in CPS systems
    * Big data meets CPS: decision making in real time

* Application Domains where Impact is being made:
    * Air Transportation
    * Road Transportation
    * Energy Infrastructures: Demand Side, Distribution, …
    * Water

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Moving Forward…

* Industry collaboration:
  * UTRC, Honeywell, C3 Energy, SDGE
* Government:
  * FAA, NASA, Federal and State DOTs, EPRI
* Education efforts:
  * Young researcher talks
  * Course modules, UROPs, conference workshops
* Team efforts:
  * Active collaborations between students and faculty of four campuses: First sets of joint papers out
* Outreach:
  * CY-BEAR + GIRLS IN ENGINEERING

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