Enabling Research for Infrastructure Resilience: An NSF Perspective

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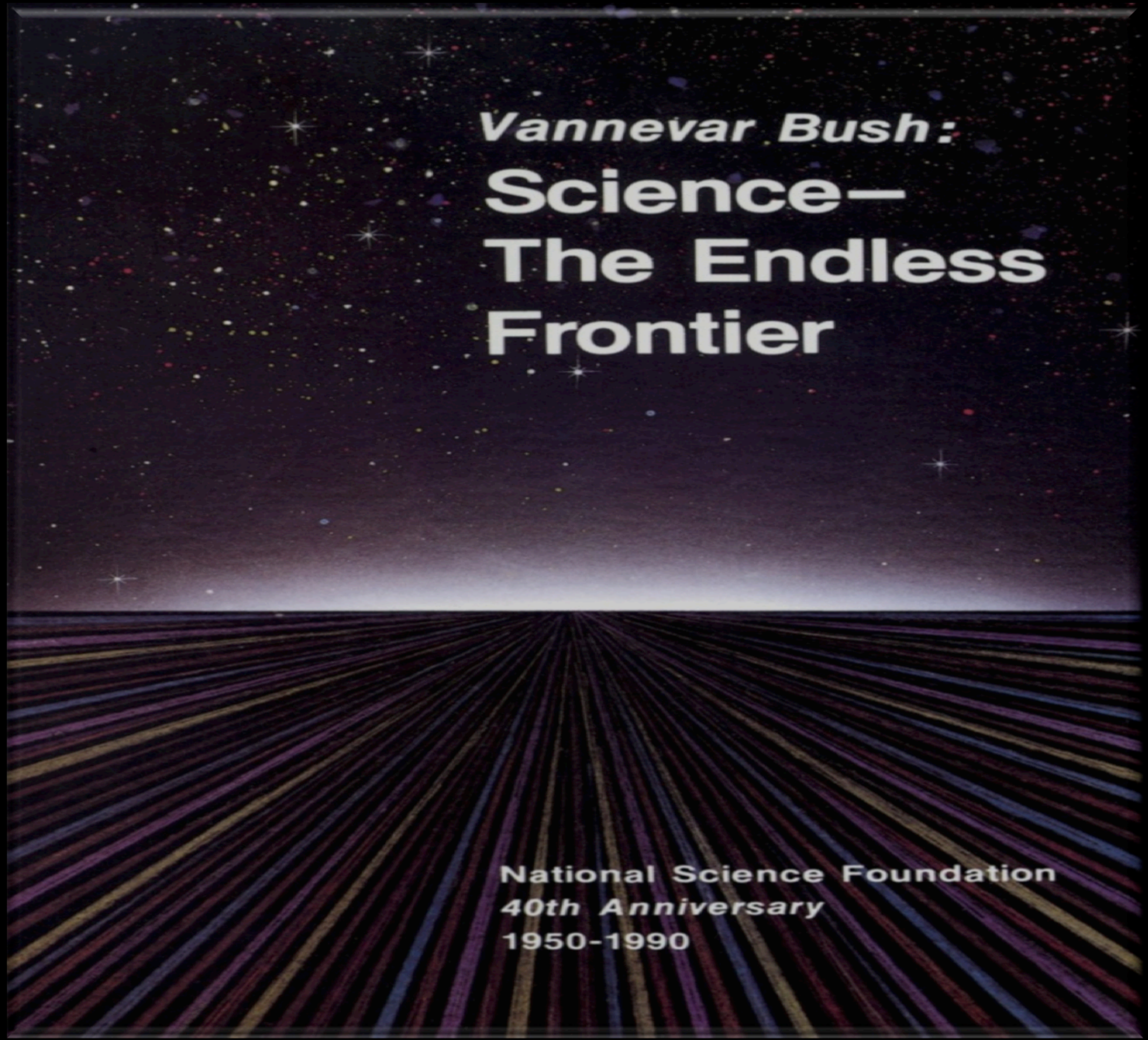
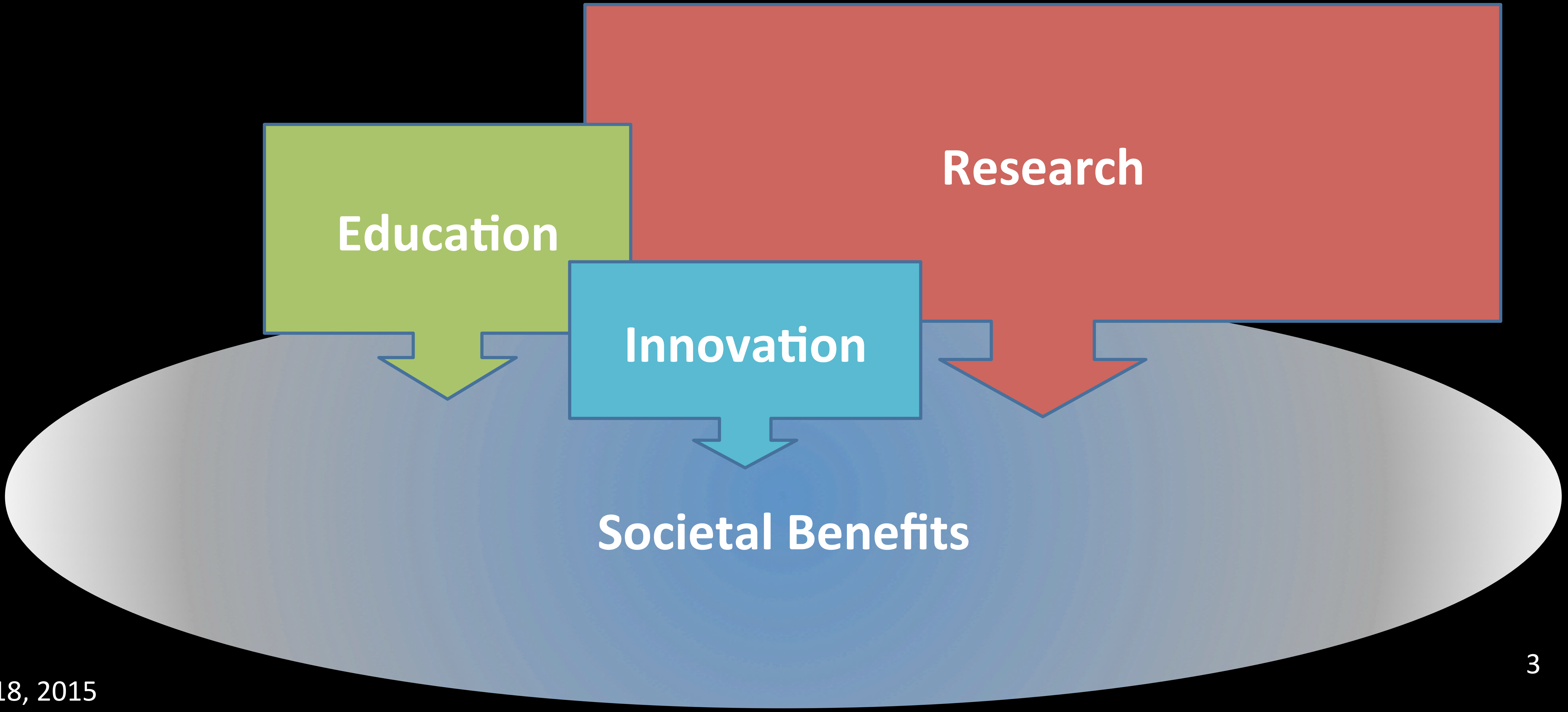
Resilience Week, Philadelphia
August 18, 2015



"to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF Act, 1950

NSF ENG: Investing in engineering research and education to foster innovations for benefit to society



Directorate for Engineering

Fundamental

EFRI

CBET
- Chemical & Biochemical Systems
- Bioengineering and Engineering Healthcare
- Environmental Engineering and Sustainability
- Transport, Thermal, & Fluid Phenomena

CMMI
- Advanced Manufacturing
- Mechanics and Engineering Materials
- Resilient and Sustainable Infrastructure
- Operations Design and Dynamical Systems

ECCS
- Electronics, Photonics, and Magnetic Devices
- Communications, Circuits, and Sensing Systems
- Energy, Power, Control and Networks

EEC
- Engineering Research Centers
- Engineering Education
- Engineering Workforce

Translational

IIP
- Academic Partnerships
- Small Business Partnerships

ENG R&RA Budget ($M)

	FY 2014 Actual*	FY 2015 Current Plan	FY 2016 Request	Change over FY 2015 Current Plan	
				Amount	Percent
CBET	$167.76	$177.82	$192.26	$14.44	8.1%
CMMI	195.23	209.52	222.73	13.21	6.3%
ECCS	100.37	110.43	119.24	8.81	8.0%
EEC	119.50	117.49	110.39	-7.10	-6.0%
IIP	205.99	226.98	248.11	21.13	9.3%
SBIR/STTR	*159.99*	*177.11*	*194.36*	*17.25*	*9.7%*
EFMA	44.27	50.07	56.49	6.42	12.8%
ENG TOTAL	**$833.12**	**$892.31**	**$949.22**	**$56.91**	**6.4%**

Critical Infrastructures are a mainstay of the national economy, security and societal functioning

Critical Infrastructure Sectors

Food and Agriculture	Banking and Finance	Chemical
Commercial Facilities	Communications	Critical Manufacturing
Dams	Defense Industrial Base	Emergency Services
Energy	Government Facilities	Healthcare and Public Health
Information Technology	National Monuments and Icons	Nuclear Reactors, Materials and Waste
Postal and Shipping	Transportation Systems	Water

Source: DHS

Critical Infrastructure and Extreme Events

- In the U.S. and much of the world, these infrastructures are
  - Aging
  - Operating at capacity limits
  - Often vulnerable due to their locations, e.g. in floodplains, along fault lines, proximate to urban areas vulnerable to malicious attack
- Each hurricane or storm sends us a stark reminder of the vulnerability of these infrastructures to extreme events
- Also vulnerable to man-made events

Infrastructure as a (cyber-enabled) Service

Interdependent Critical Infrastructure Systems (ICIs)

- Infrastructures are viewed as:
  - as networks of systems and processes
  - that function collaboratively and synergistically
  - that produce & distribute continuous flow of essential goods & services
  - as interdependent and connected

Interdependencies

- Dependencies
  - Direct, indirect, disjunctive (depends on >1 node) and conjunctive (depends on one of two nodes) dependenciees
- Interdependencies
  - Physical (e.g. through materials flows)
  - Cyber
  - Geographic
  - Logical (e.g. substitutability, shared resources)

  →Existence of feedback loop distinguishes from dependencies
- Failures can propagate from one system to the next due to these interconnectivities

Direct and Indirect Interdependencies

Direct interdependency: In a hazard event, emergency services (response/repair) required for restoration of critical services (power/transportation/healthcare…), and critical services enable emergency response/repair activities

(Socio-technical) Indirect interdependency: Electric power loss → water treatment failure → contaminated drinking water →human illness → employees cannot work → fuel not delivered to power plants → further power disruption

Resilience – the Concept

- Resilience as a term has taken on many meanings
- Common to most resilience definitions are two components (DHS):
  1) Ability to withstand disruption event with little loss in function
  2) Rapidly and efficiently restore functionality if loss incurred
- Many measures have been proposed:
  – Some focus on <u>time to recovery</u>
  – Others focus on <u>loss</u>: post-event performance over time, or after some elapsed time

FY14: Resilient Interdependent Infrastructure Systems (RIPS)

- To enhance understanding and design of interdependent critical infrastructure systems and processes resilient in the face of disruptions and failures from any cause
- ENG, CISE, and SBE funded 10 projects for $17M in FY 2014

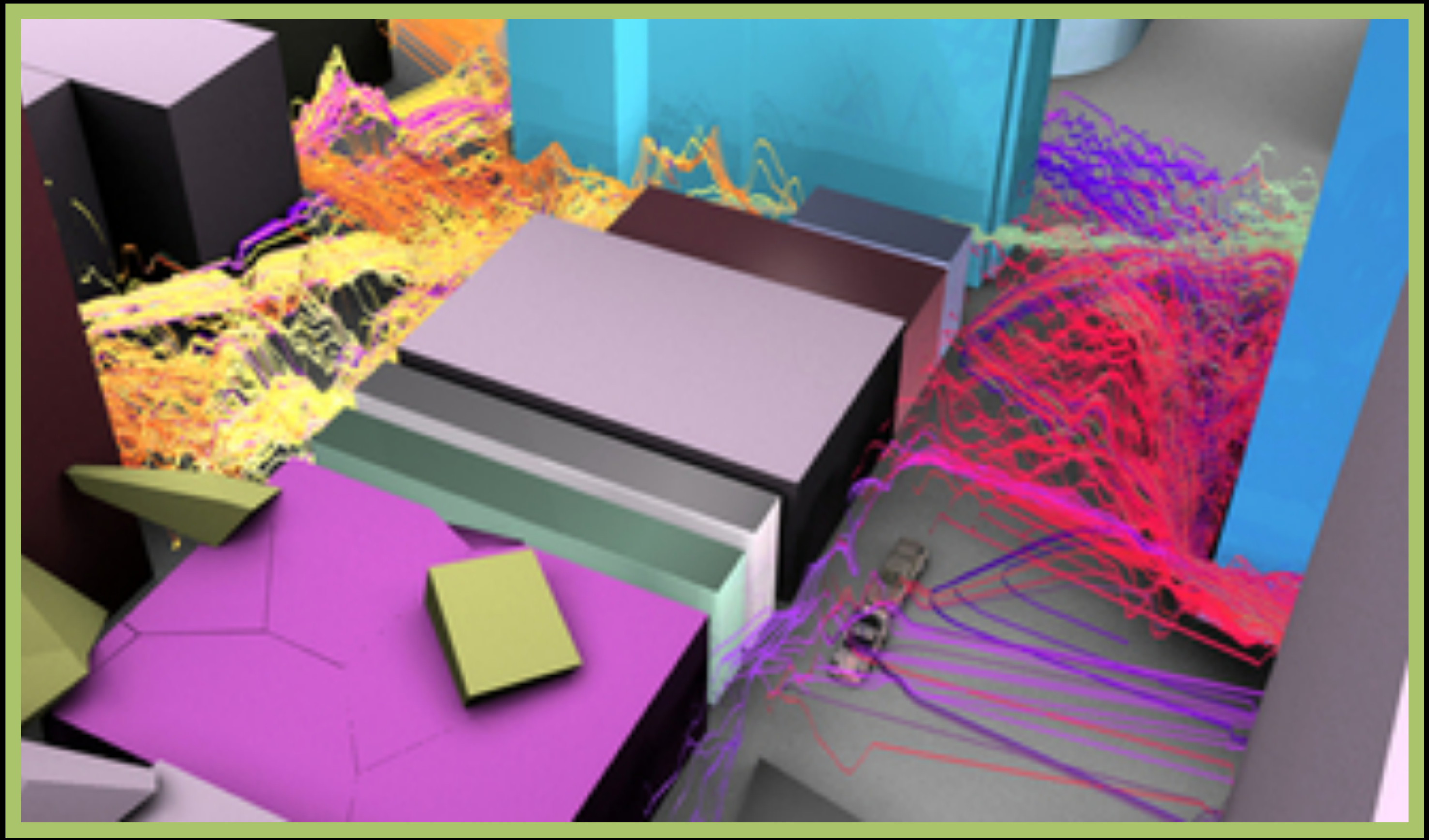
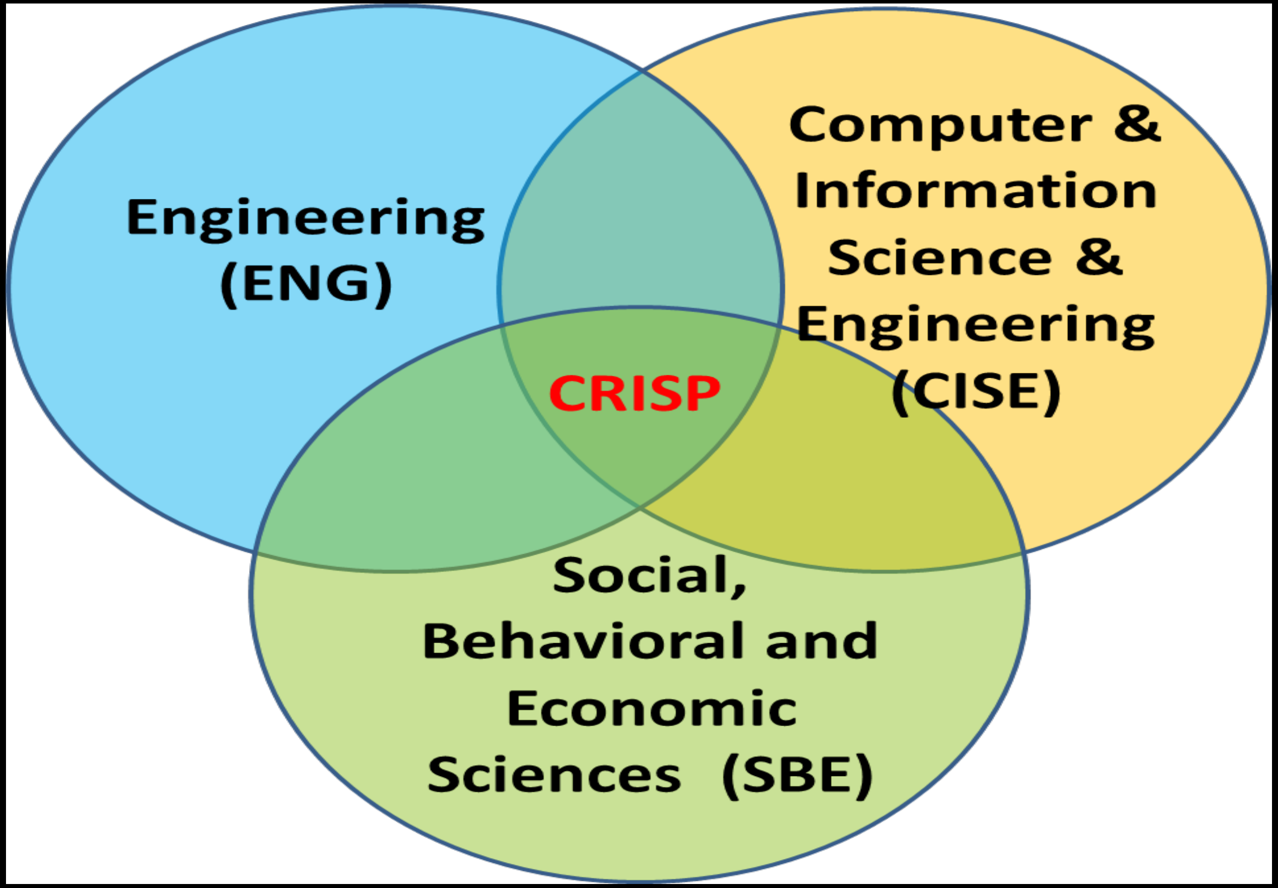


Image credit: Paul M. Torrens, Geography and UMIACS, University of Maryland, College Park

http://www.nsf.gov/news/news_summ.jsp?cntn_id=132852&org=NSF&from=news

FY15 CRISP: Critical Resilient Interdependent Infrastructure Systems & Processes

- FY15 funding for CRISP: $20 million
  - *Type 1 Awards*: 3-year projects, $500k max
  - *Type 2 Awards*: 3-4 year projects, $1M-$2.5M



CRISP Program Goals

1. Create new approaches/solutions for design/operation of infrastructures as processes/services
2. Enhance understanding/design of ICIs and processes under disruptions from any cause
   - natural, technological, organizational or malicious
   - various timescales and intensities
3. Create knowledge for innovation in ICIs to safely, securely, and effectively expand range of goods and services they enable
4. Improve ICI's effectiveness, efficiency, dependability

Emphasis on Multi-disciplinarity

- Engineering
- Computing
- Social and behavioral sciences

Proposal Statistics

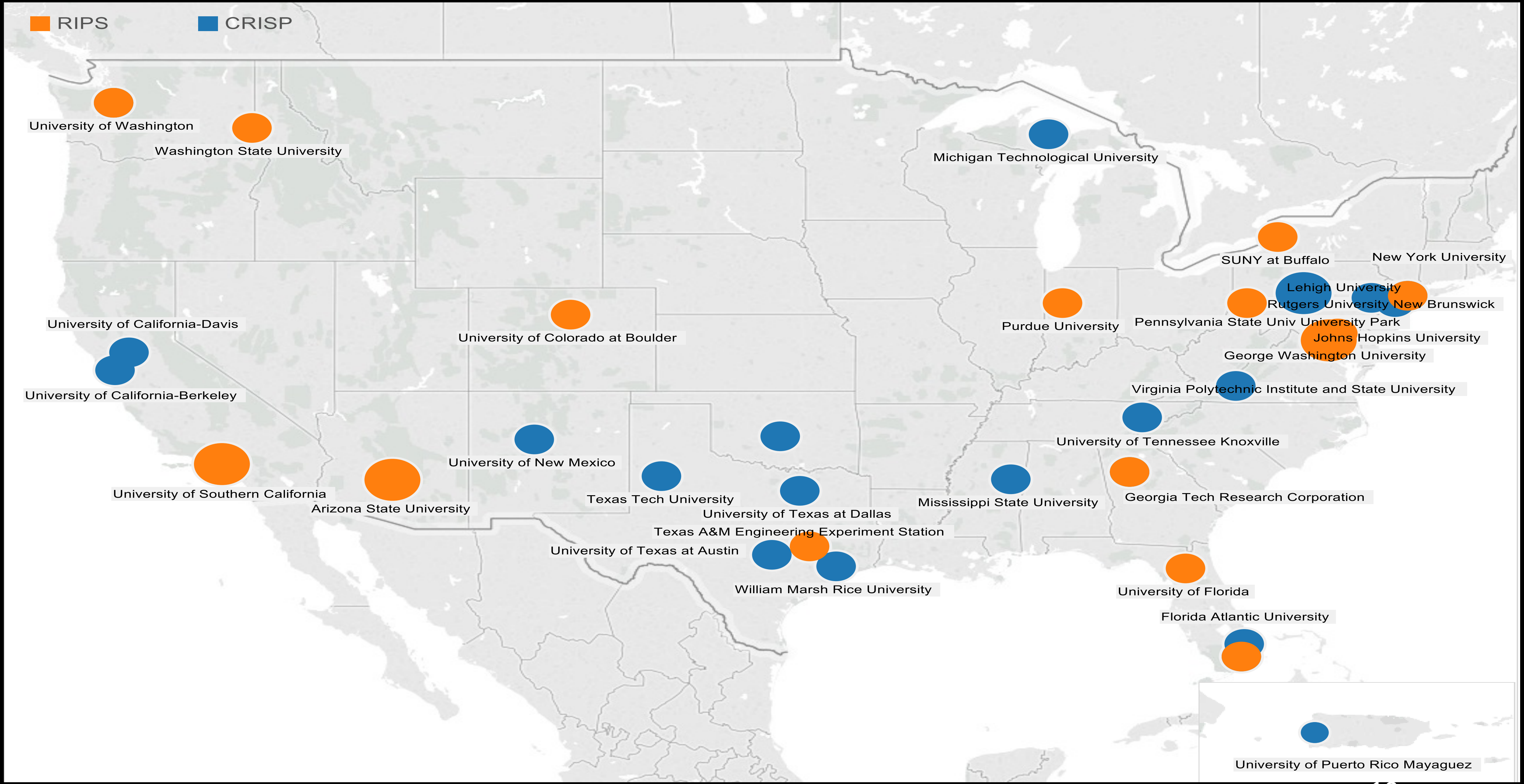
RIPS FY14

- **149** Proposals
  - **81** Competitive Projects
  - **369** Researchers
  - **57** Institutions

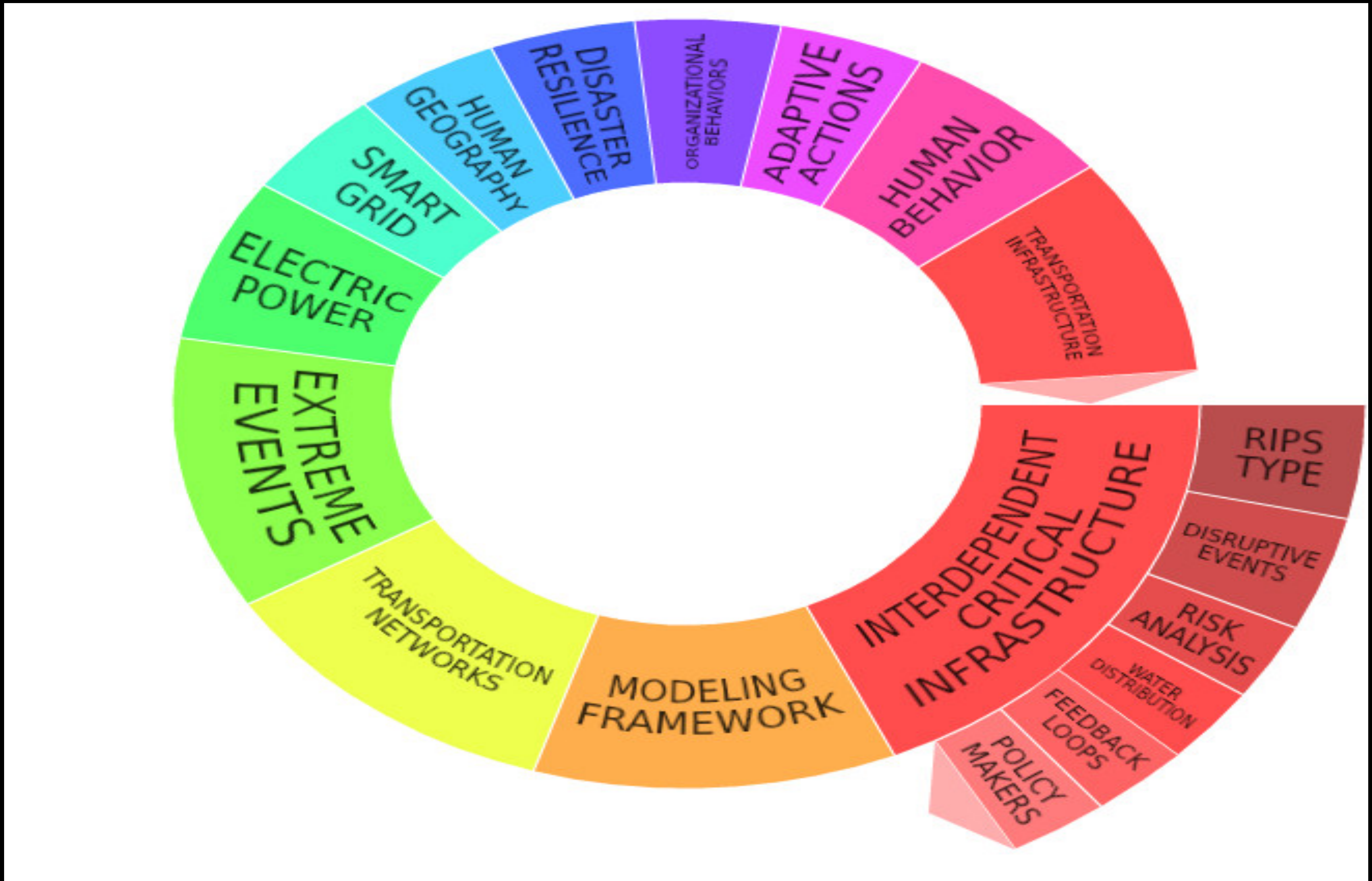
CRISP FY15

- **145** Proposals
  - **90** Competitive Projects
  - **439** Researchers
  - **90** Institutions

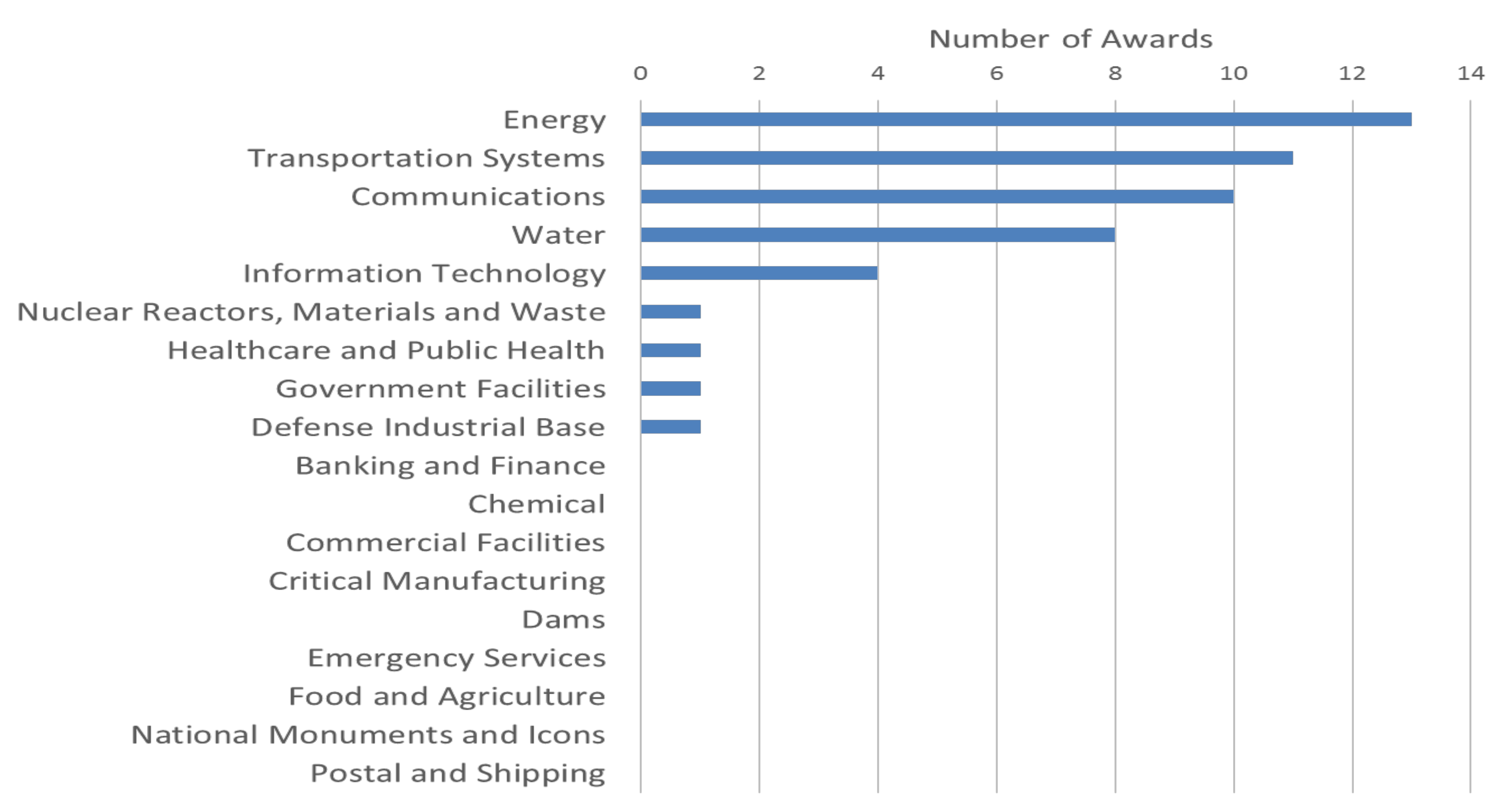
2014 RIPS and 2015 CRISP Awards



RIPS and CRISP Awards Topics



Targeted Infrastructures in the Awards



Studied Hazards in the Awards

- Hurricane/wind/flooding
- Earthquake
- Other extreme weather and impacts (sea level rise, storm surge, precipitation, drought)
- Terrorist attack (one study)
- Multi-hazard and compound hazards (one study)

Geographical Areas of Study in the Awards

Cities

- Atlanta
- Boulder
- Indianapolis
- Los Alamos
- Los Angeles
- NYC
- Phoenix
- San Diego
- San Francisco
- Washington DC

States - Regions

- Florida
- Maryland
- New England
- The Northeast
- The Southeast
- Tennessee
- Washington State

International

- Canada
- Japan
- New Zealand

CRISP Proposed Research Topics

- Water-Energy-Food Nexus
- Urban/Rural Infrastructure Resilience
- Autonomous Transportation Systems
- Smart Grid
- Alternative Energy
- Crowd-sourcing
- Community Resilience
- Climate Change
- Attack Scenarios

Methodological Approaches in the Awards

1) **Mathematical Modeling and Optimization**: graph theory; network models; stochastic and nonlinear optimization and modeling; Markov modeling; Bayesian networks; queueing theory; algorithms and heuristics; control theory; game theory; artificial intelligence
2) **Simulation**: agent-based approaches – both for discovery and validation

Methodological Approaches in the Awards

3) **Statistical**: statistical inference (correlation, regression, clustering, natural language processing); expert opinion; attitudinal studies; community surveys; time-geography theory; machine learning; network formation for social networks; behavioral studies of humans;…
4) **Reliability and systems modeling**
5) **Systems of systems and explanatory sciences**

Emerging Directions

- Multiple temporal and spatial scales
- Real-time monitoring and control
- Stochastic and dynamic interdependencies
- Water-Energy-Food Nexus (INFEWS)
- Society and governance as infrastructures
- New services
- Leveraging interdependencies to prevent or halt cascading failures
- Modular design to disconnect systems for real-time failure prevention

Emerging Directions

- Root-cause analysis from observed damage
- Prescriptive/normative models
- Community resilience considering long-term societal impacts (e.g. demographic shifts due to long-term losses in infrastructure services)
- Rural, urban, suburban issues
- Decentralizing services
- Role of social media (extensive coverage, potential inaccuracies) in monitoring/information dissemination

Emerging Directions

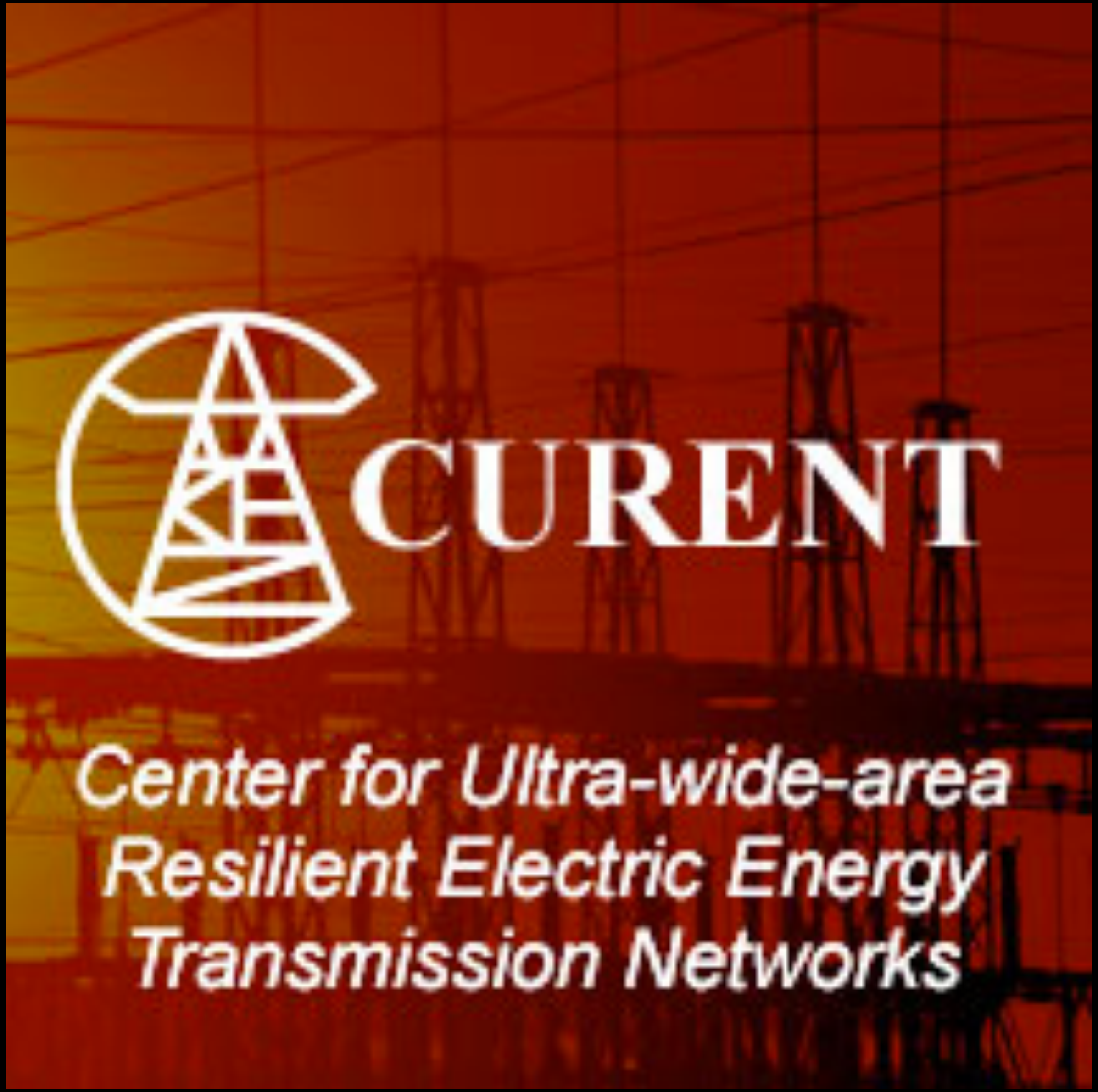
- Multi-functional system elements, e.g. end users as consumers and producers in the smart grid
- Multi-hazard (simultaneous)
- Workforce as an infrastructure or flows in and between infrastructures
- Role of humans in infrastructure

Potential Outcomes

- Major advances arising from “infrastructure as a cyber-enabled service” paradigm
- Deeper understanding of resilience in infrastructure systems
- Cross fertilization of ideas, techniques and solutions for improved resilience from multiple directions and infrastructures
- Collections of data sets
- Development of new fields of study and knowledge

Cyber-Physical Systems

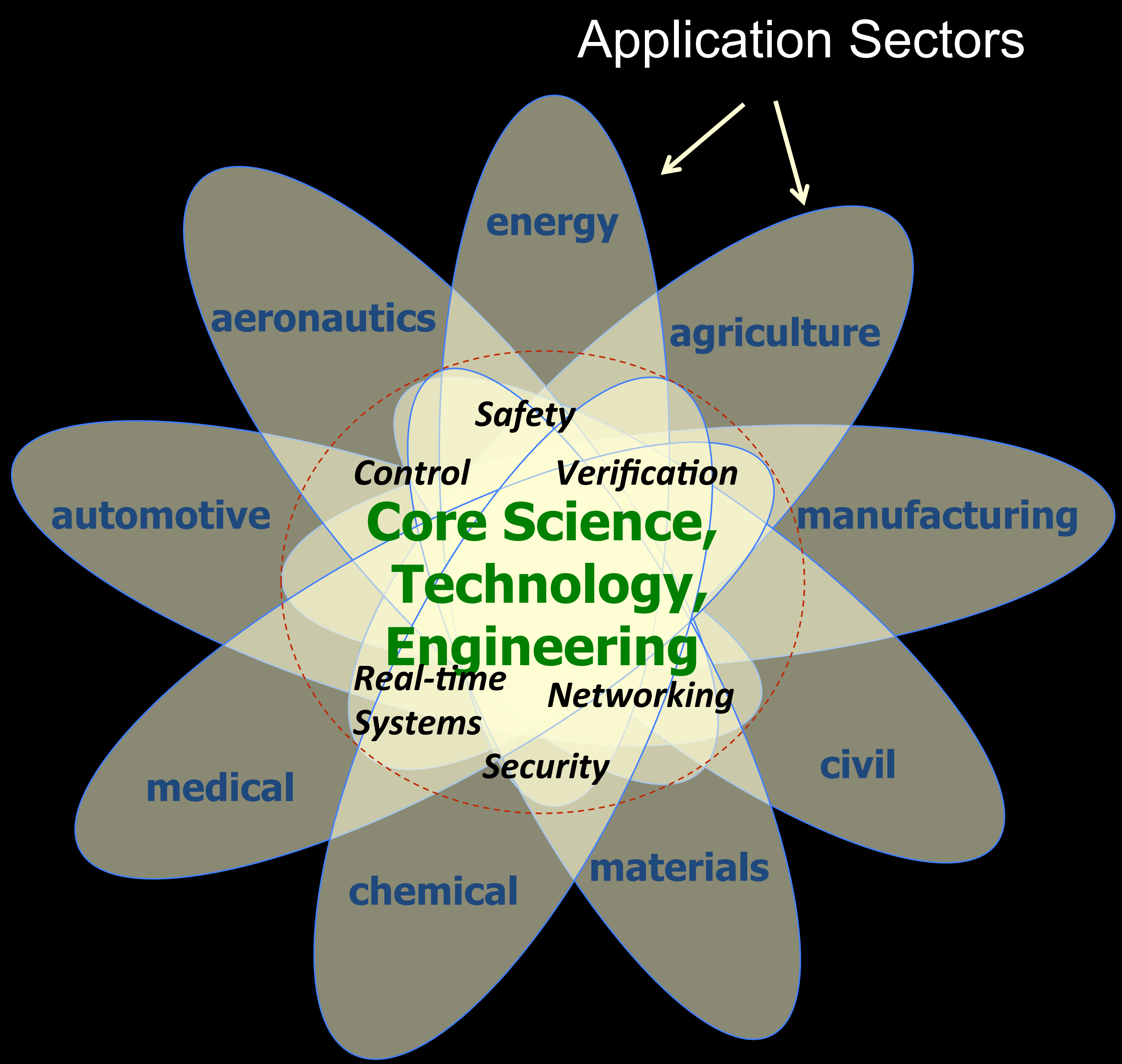
- Cyber-physical systems (CPS) are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components
- NSF aims to develop the core system science needed to engineer complex cyber-physical systems upon which people can depend with high confidence.
- ENG, MPS, DHS, DoT contributed \$35M in FY 2014



Credit: CURENT Engineering Research Center

CPS Approach

- Abstract from application sectors to more foundational principles
- Apply these principles to problems in new sectors
- Safe, secure, reliable, verification, real-time adaptation, …
- Applications to infrastructure systems



Big Data: Dynamic Data Systems

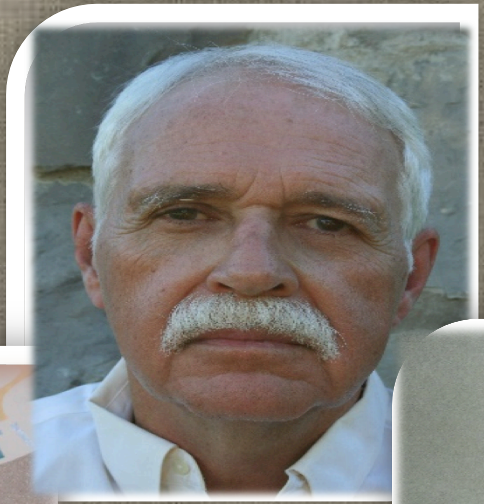
- Collaboration between ENG/ECCS and AFOSR
- Big data and computing issues arising from dynamic sensing and control in engineered and natural systems

- Thematic areas
  - Dynamic data from ubiquitous sensors and controllers
  - Large scale distributed computing for dynamic data
  - Interactions between data and computing in this context

Thanks to the Cognizant Program Officers

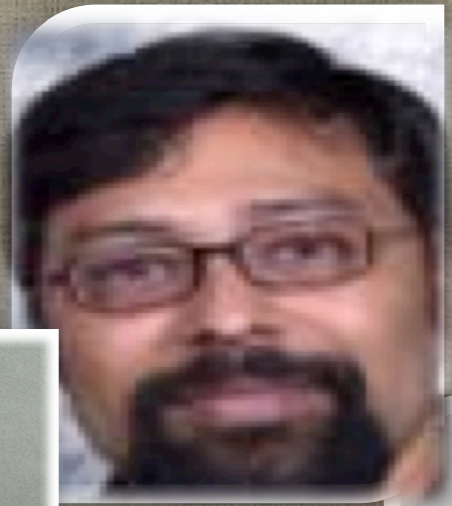
Elise Miller-Hooks
(ENG/CIS)

Bruce Hamilton
(ENG/CBET)



Robert
O'Connor
(SBE/SES)

Rajiv Ramnath
(CISE/ACI)



Sudipta
Sarangi
(SBE/SES)

Gurdip Singh
(CISE/CNS)

Dennis Wenger
(ENG/IMEE)

Thank you!

Questions? *Comments?*

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