Cyber-Physical Systems and IoT Research Challenges

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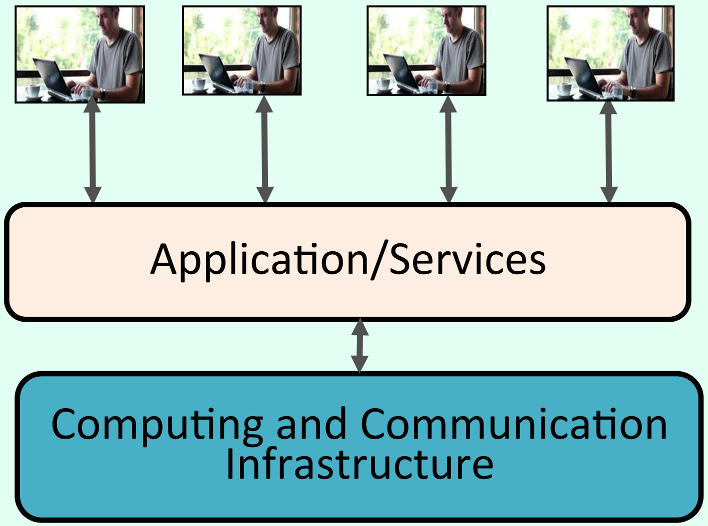
Traditional Distributed Computing

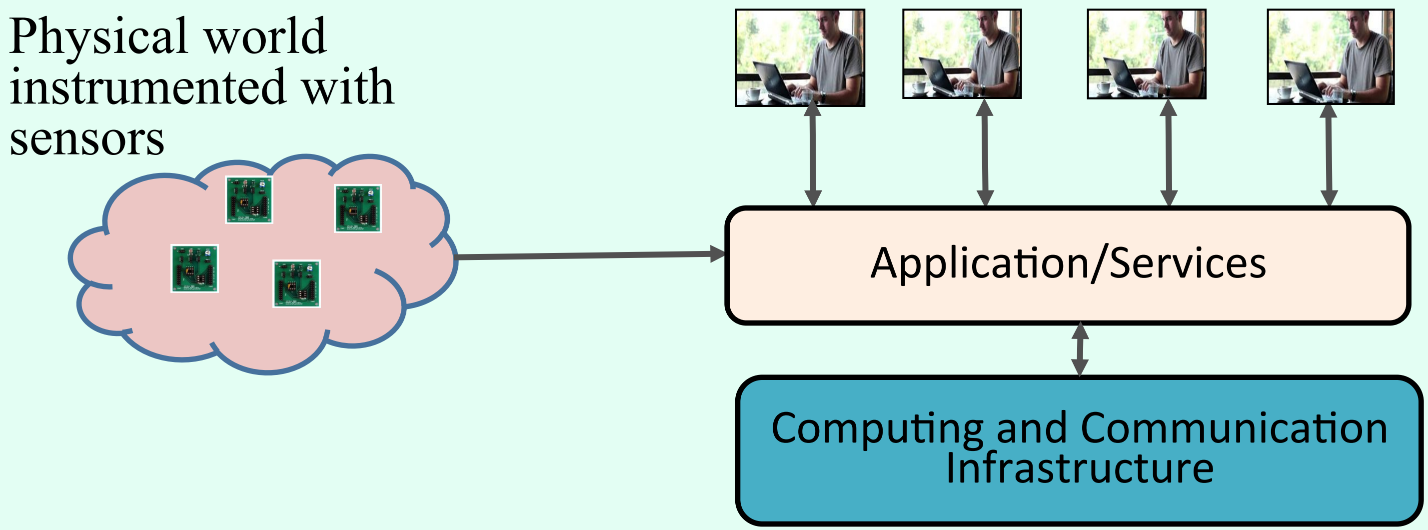
- Services
  - Airline/hotel reservation
  - Office automation
  - Social networking

    :



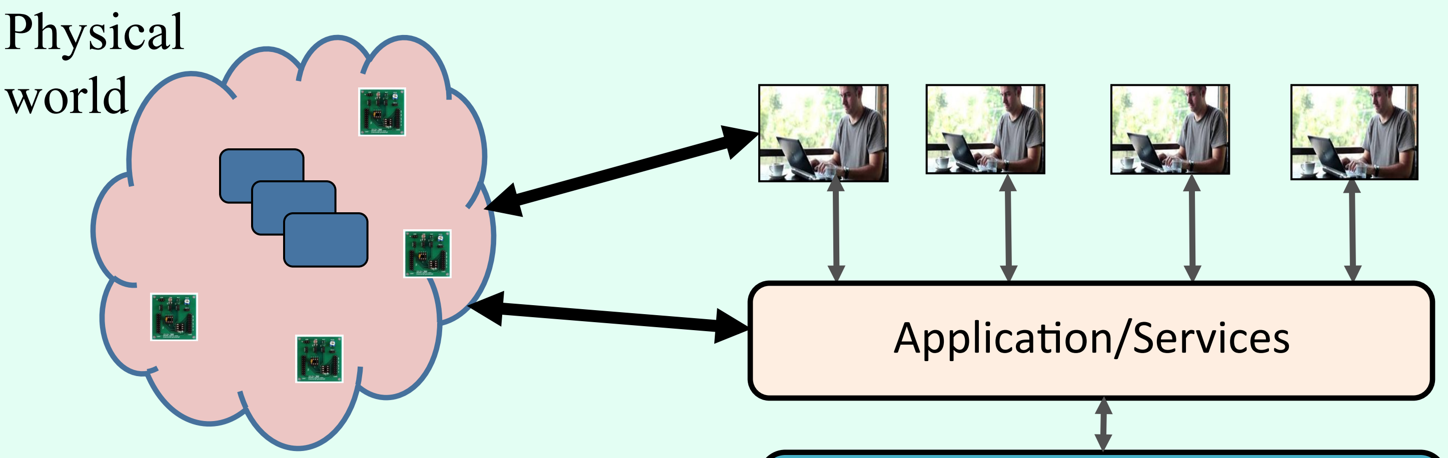
- Distributed infrastructure is transparent to users

Sensor Networks



- More data
- Real-time data
- Sensors provide data directly to applications

Cyber Physical Systems: Interactions with the physical world



Physical world:

- Physical Entities
- Humans
- Physical sensors

Cyber-Physical Systems

Deeply integrating computation, communication, and control into physical systems

- Pervasive computation, sensing and control
- Networked at multi- and extreme scales
- Dynamically reorganizing/ reconfiguring
- High degrees of automation
- Dependable operation with high assurance of reliability, safety, security and usability

Transportation

- Faster and safer aircraft
- Improved use of airspace
- Safer, more efficient cars

Energy and Industrial Automation

- Homes and offices that are more energy efficient and cheaper to operate
- Distributed micro-generation for the grid

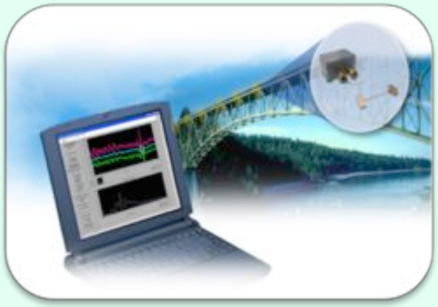
Healthcare and Biomedical

- Increased use of effective in-home care
- More capable devices for diagnosis
- New internal and external prosthetics

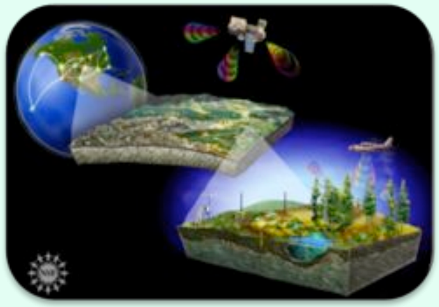
Critical Infrastructure

- More reliable power grid
- Highways that allow denser traffic with increased safety

CPS and National Priorities



Manufacturing, Robotics, & Smart Systems

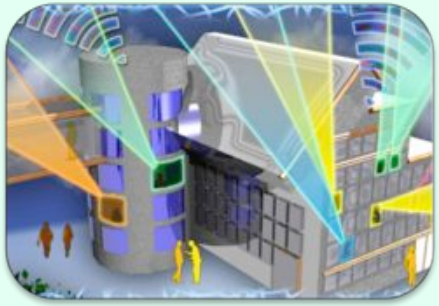


Environment & Sustainability

Emergency Response & Disaster Resiliency

Health & Wellbeing

Transportation & Energy

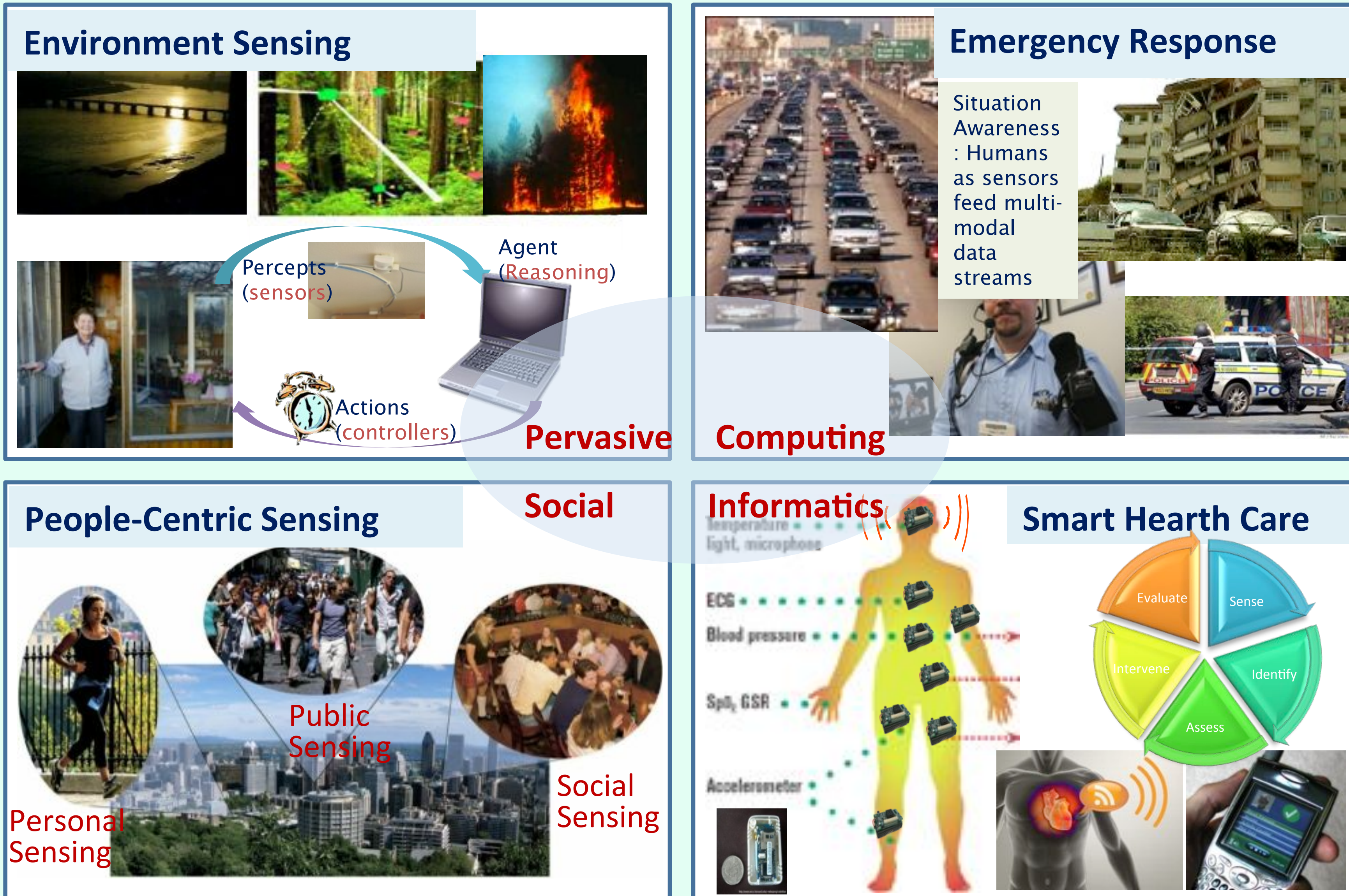


Broadband & Universal Connectivity

Secure Cyberspace

Education and Workforce Development

Smart Systems: Sensing, Computation, and Control



Source: Sajal Das, Keith Marzullo

Credit: Image courtesy of University of Florida

Imagine a world …

Cyber-physical systems: A
sense of the future

Smart Infrastructure

Imagine a day where…

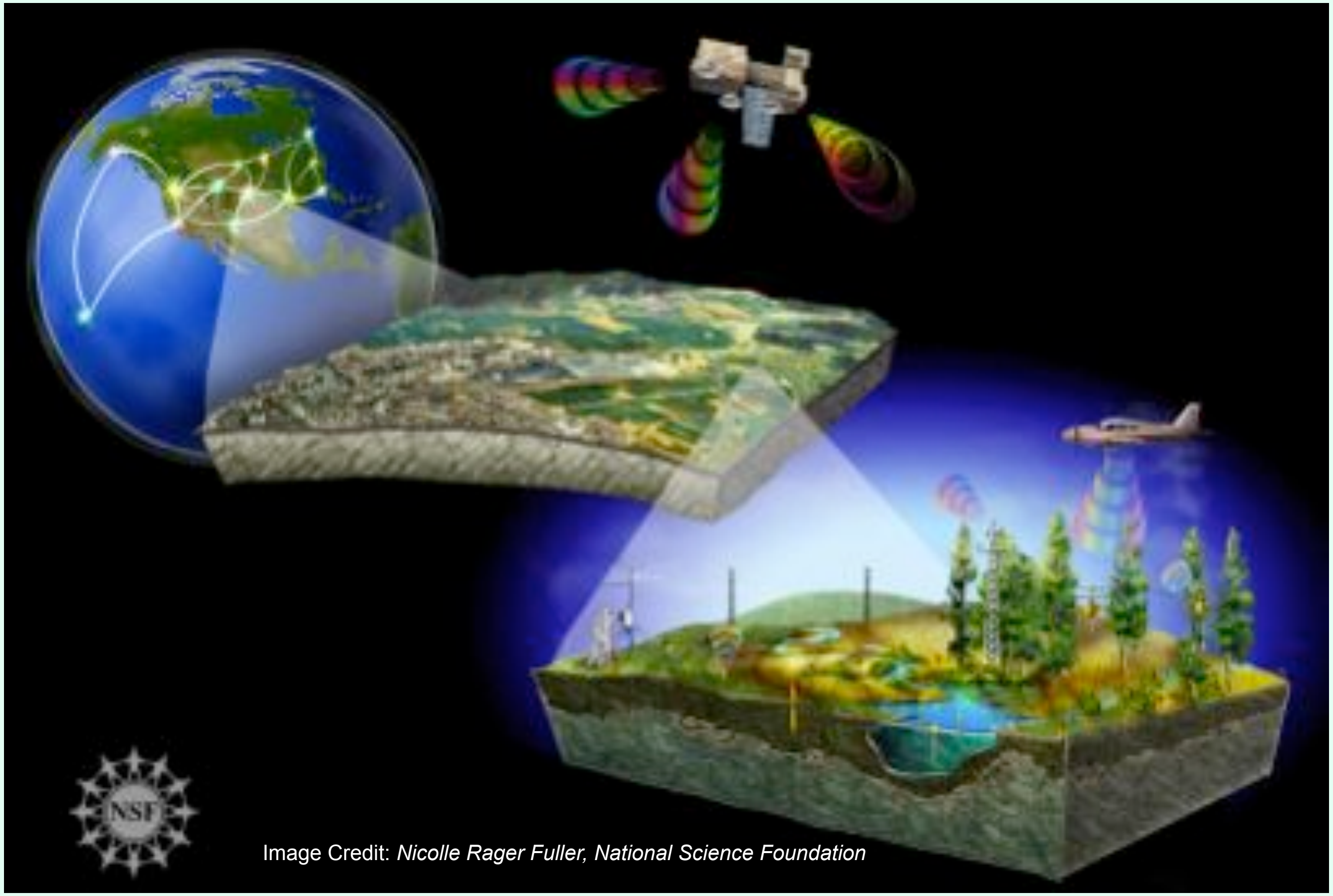
static infrastructure is adaptable and safe

Image Credit: *MicroStrain, Inc.*

Environment and Sustainability

Imagine a day where…

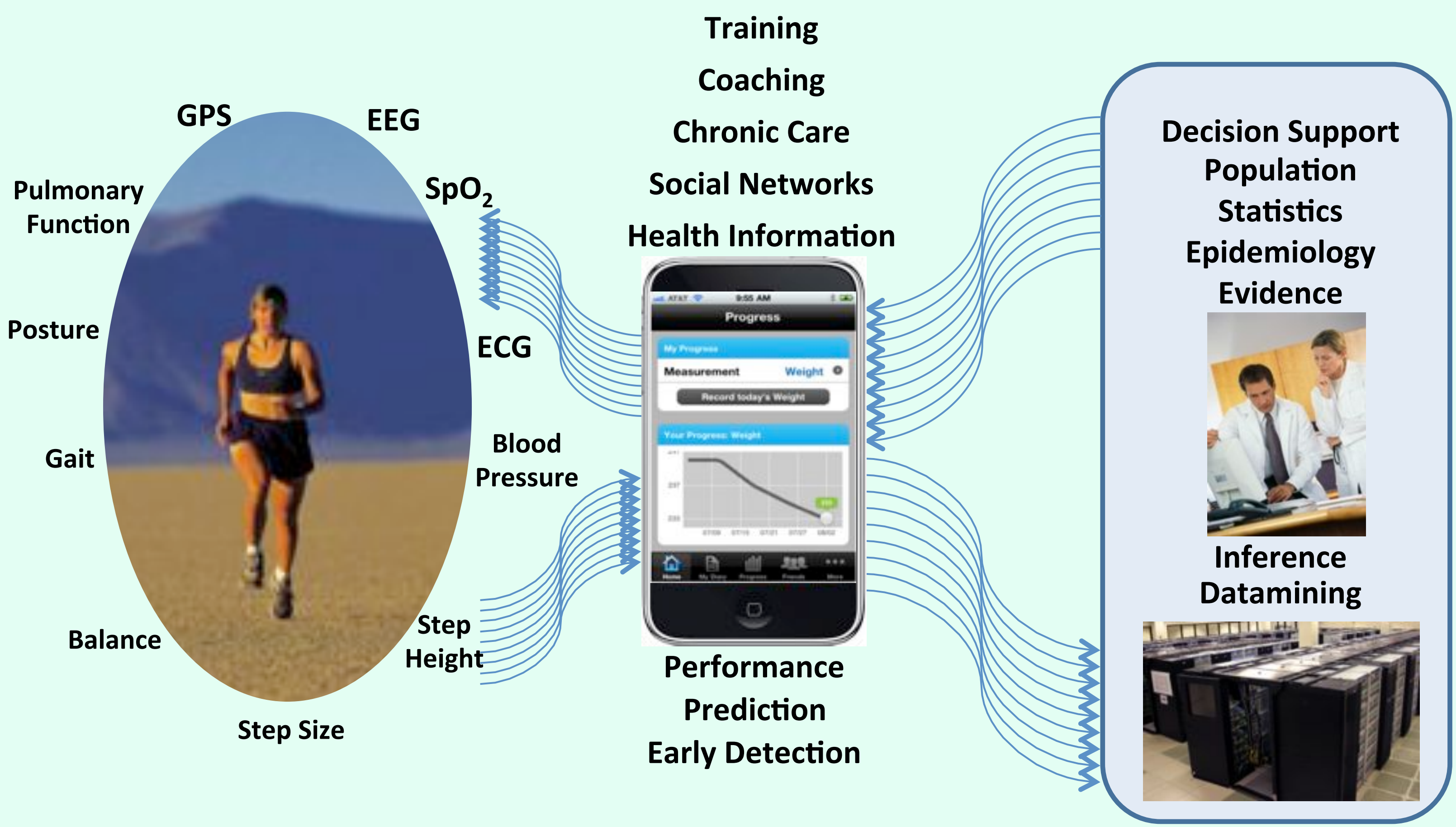
we can forecast and mitigate ecological change



Health and Wellbeing

Imagine a day where…

wellbeing is pervasive and healthcare is personalized



Smart Grids

Imagine a day where…

energy is efficiently used and intelligently managed

Image Credit: *Cisco, Inc.*

Emergency Response

Imagine a day where…

we can prevent, mitigate, and recover from disasters

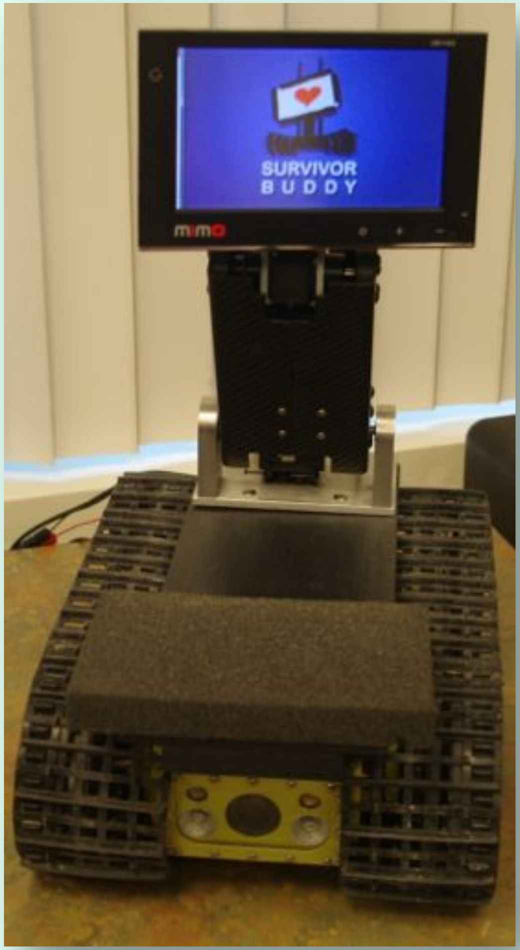


Image Credits: *Karen Geary, NSF* (left) and *Texas A&M University* (right)

Transportation: Safety and Energy

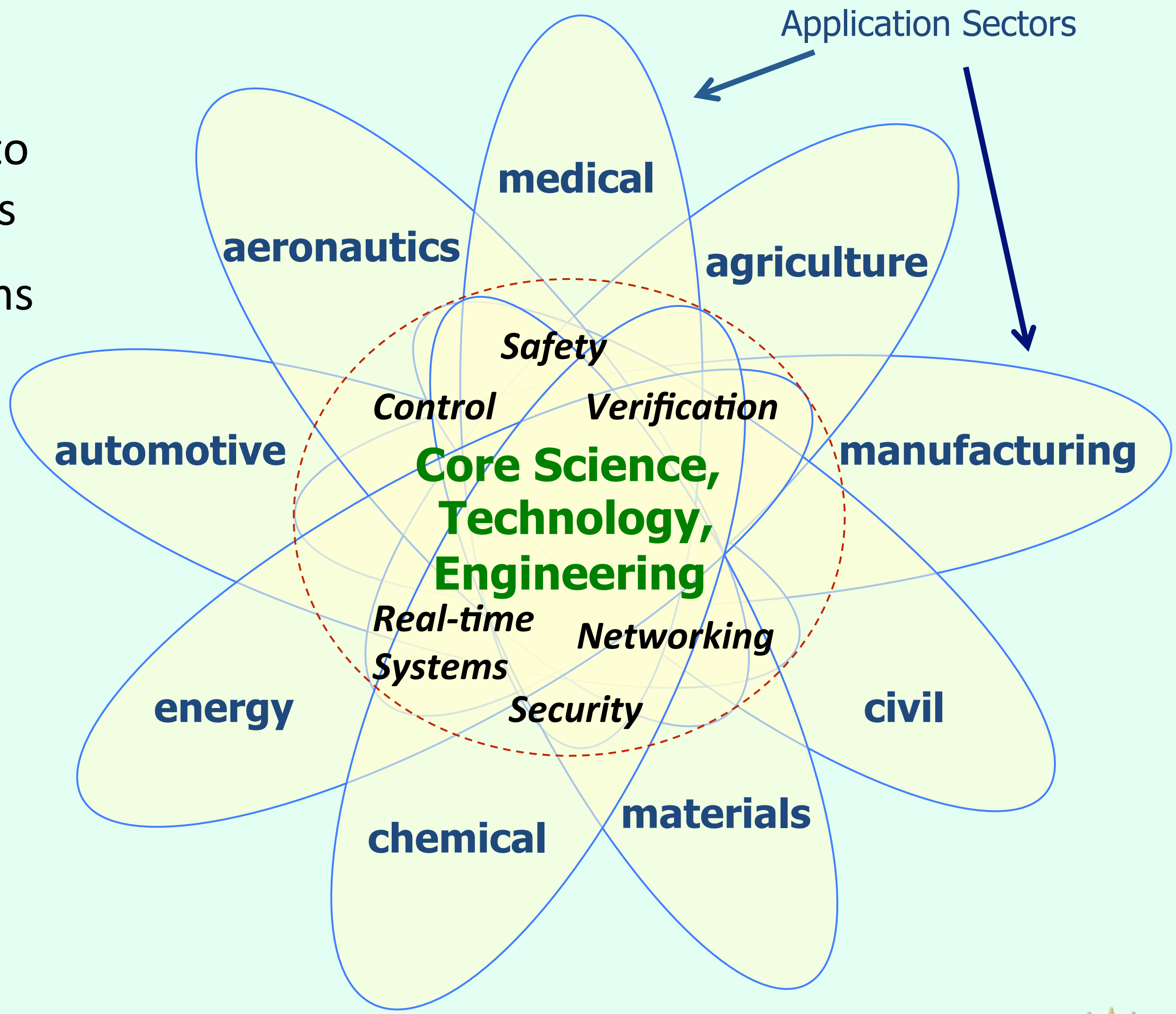
Imagine a day where…

traffic fatalities no longer exist

Image Credit: *PaulStamatiou.com*

CPS Research Model

- Abstract from sectors to more general principles
- Apply these to problems in new sectors
- Build a new CPS community
- Encourage other communities to join



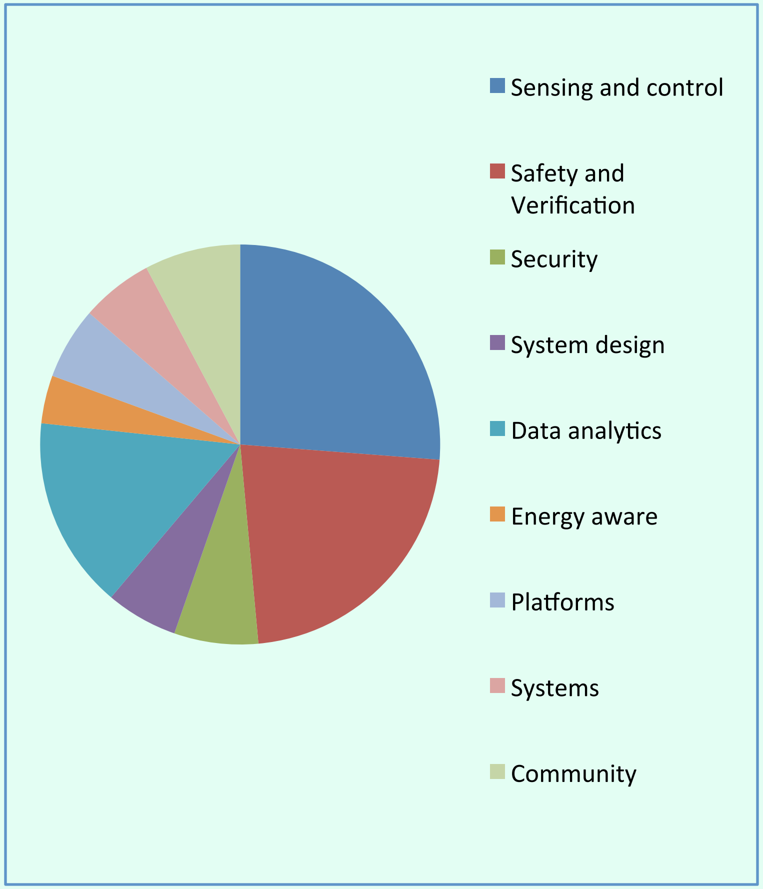
Some CPS Program Info

- Foundation-wide initiative including Directorate for Computer and Information Science and Engineering (CISE) and Directorate of Engineering

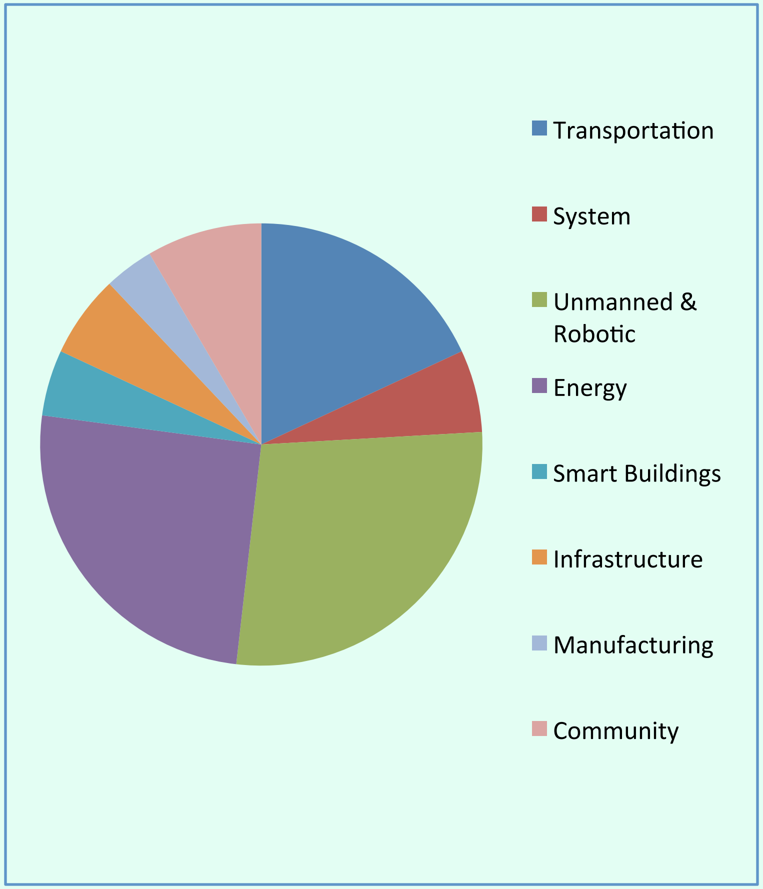
- Since CPS Launch in 2009:
  - Over $250M investment
  - 250 awards
  - 350+ PIs and Co-PIs in 35 states
  - 60 new awards in FY14 (35 projects)
  - Over $40M investment in FY14

CPS Portfolio Overview

Grants by Research Area



Grants by Application Domain



Geographic Map of Active CPS Grants

	# of Grants
Arizona	5
California	30
Colorado	4
Connecticut	1
District of Columbia	1
Delaware	1
Florida	5
Georgia	7
Iowa	4
Illinois	13
Indiana	9
Kansas	2
Massachusetts	19
Maryland	4
Michigan	14
Minnesota	2
Missouri	2
North Carolina	11
New Jersey	5
New Mexico	1
New York	14
Ohio	4
Oregon	1
Pennsylvania	29
South Carolina	1
Tennessee	9
Texas	13
Utah	1
Virginia	5
Washington	4
Wisconsin	2

CPS Frontiers / Large Portfolio 2009-2014

Roseline (May '14)

- Quality of time and synchronization for CPS
- Multiple domains
- UCLA, UCSD, UCSB, CMU, Utah

Correct By Design Control Software Synthesis for Highly Dynamic Syst (May '13)

- Formal synthesis of complex control software
- Robotics and transportation
- Michigan, UCLA, TAMU

Foundations of Resilient Systems (May '13)

- Economic incentives and resilience for CPS in energy, and transportation
- UCB, MIT, Michigan, Vanderbilt

Science of Integration for CPS (Oct '10)

- Foundations for composition of complex systems including passivity based design
- Tools and architectures
- Vanderbilt, Notre Dame, UMD

Center for Autonomous Transportation (Oct '10)

- Technologies for autonomous vehicles emphasizing safety, rapid verification, sensor fusion
- CMU

Safety, Security, and Reliability of Medical Device CPS (Oct '10)

- Technologies for design, implement, and certification of medical devices
- Interoperability , closing loop with human
- Penn, MGH

Action Webs (Sept '09)

- Theory of networked, embedded, sensor rich systems
- Stochastic hybrid systems
- Multi-objective control for safety and efificiency
- UCB, MIT

Community Building - Cyber-Physical Systems Virtual Organization

- Collaborative web-site building
- Membership and Group Management
- File sharing, Metadata search

Agency Partners

- National Science Foundation
- National Security Agency
- Office of the Director of National Intelligence
- Advanced Research Projects Agency-Energy
- Department of Transportation / FHWA
- Defense Advanced Research Projects Agency

Technical Approach and Key Innovations

Building upon the open-source Drupal content management system, this project provides virtual organization technologies to facilitate electronic community building by connecting researchers, students, educators and industry practitioners within the growing, cross-disciplinary field of cyber-physical systems.

Long-Term Research Vision

Complement the existing knowledge dissemination repository to make the VO an action destination

Virtual Organization Content/Usage

- +140 special interest groups • 14,000 web pages • 21,000 versioned file artifacts uploaded • 4,000 active users • 2 terabytes of data served • 6,000 community announcements posted

On-Site Community Events Supported

- +80 CPS-related conferences, planning meetings, seminars, and workshops organized
- 5 Annual CPS PI meetings, 1 SaTC PI Meeting, +4 HCSS Conferences, 3 Science of Security Conferences

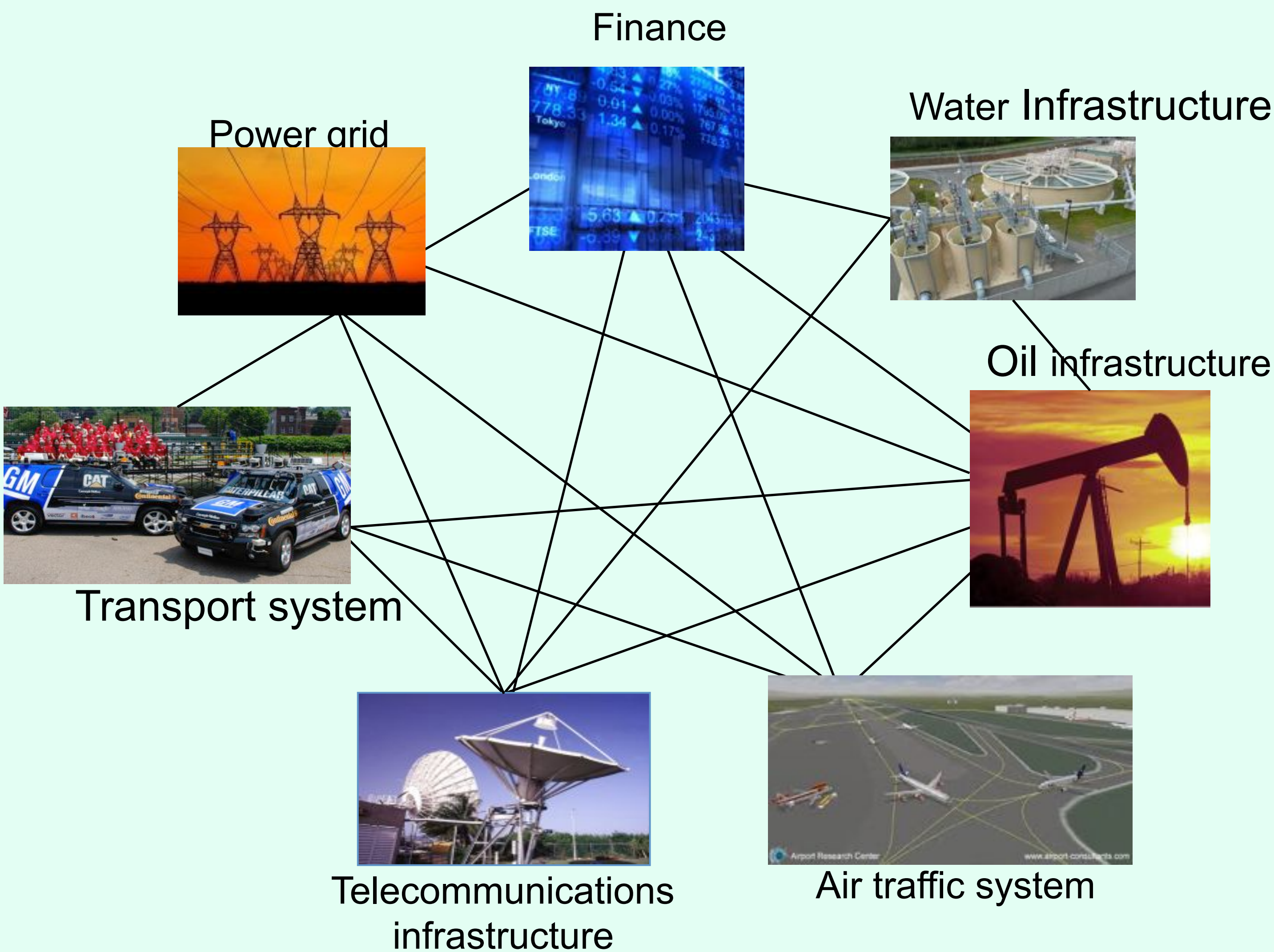
Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) at the National Science Foundation (NSF)

Directorates for: (1) Engineering; (2) Computer & Information Systems & Engineering; (3) Social, Behavioral & Economic Sciences

Solicitation: NSF 15-531

Infrastructure Systems

Imagine a day where…
everything is interdependent



Interdependencies

Types:

- Cyber
- Physical - output of one system forms an input for another
- Logical
- Geographic – co-located infrastructures
- Local vs global dependencies

Impacts:

- Cascading failure
- Performance
- Security

Partnerships For Innovation: Building Innovation Capacity (PFI:BIC)

- Academe-industry partnerships
  - Interdisciplinary academic research team
  - At least one industry partner

- Build technological and human innovation capacity.

NSF Engineering Directorate, Industrial Innovation and Partnerships
NSF CISE Directorate, Computer and Network Systems
NSF SBE Directorate

Smart Service Systems

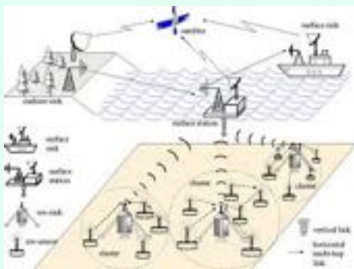
- **Service systems**
  - socio-technical configurations of people, technologies, and information
  - designed to deliver services that create and deliver value

- **Smart service system**
  - capable of learning, adaptation, and decision making
  - Improved response to a future situation.

PFI: BIC program

Existing Research and Technologies

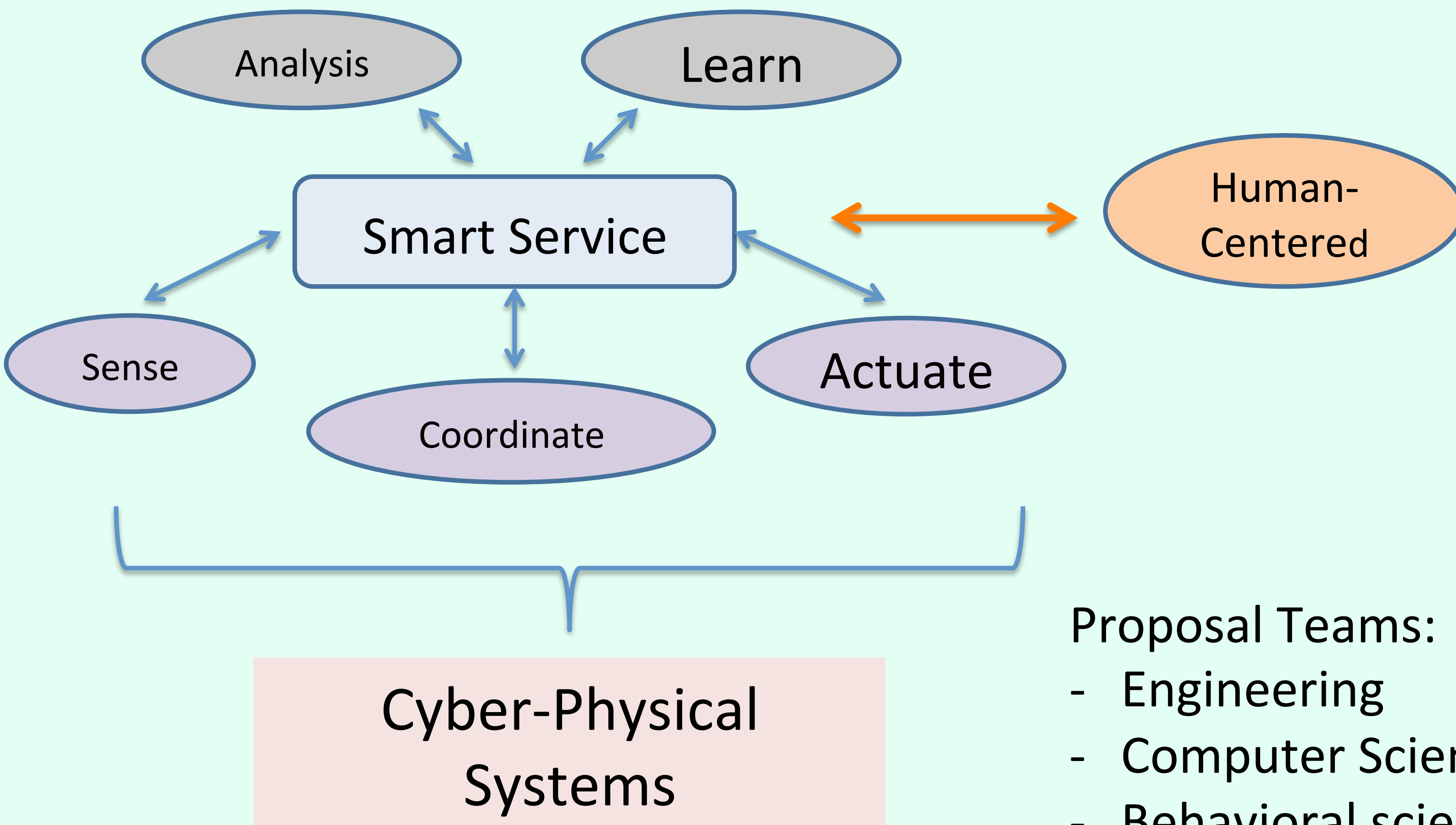
Commercialized services



PFI: BIC Goals:

- Integration of technologies to create innovative services
- Research needed to realize market value

Smart Service Systems

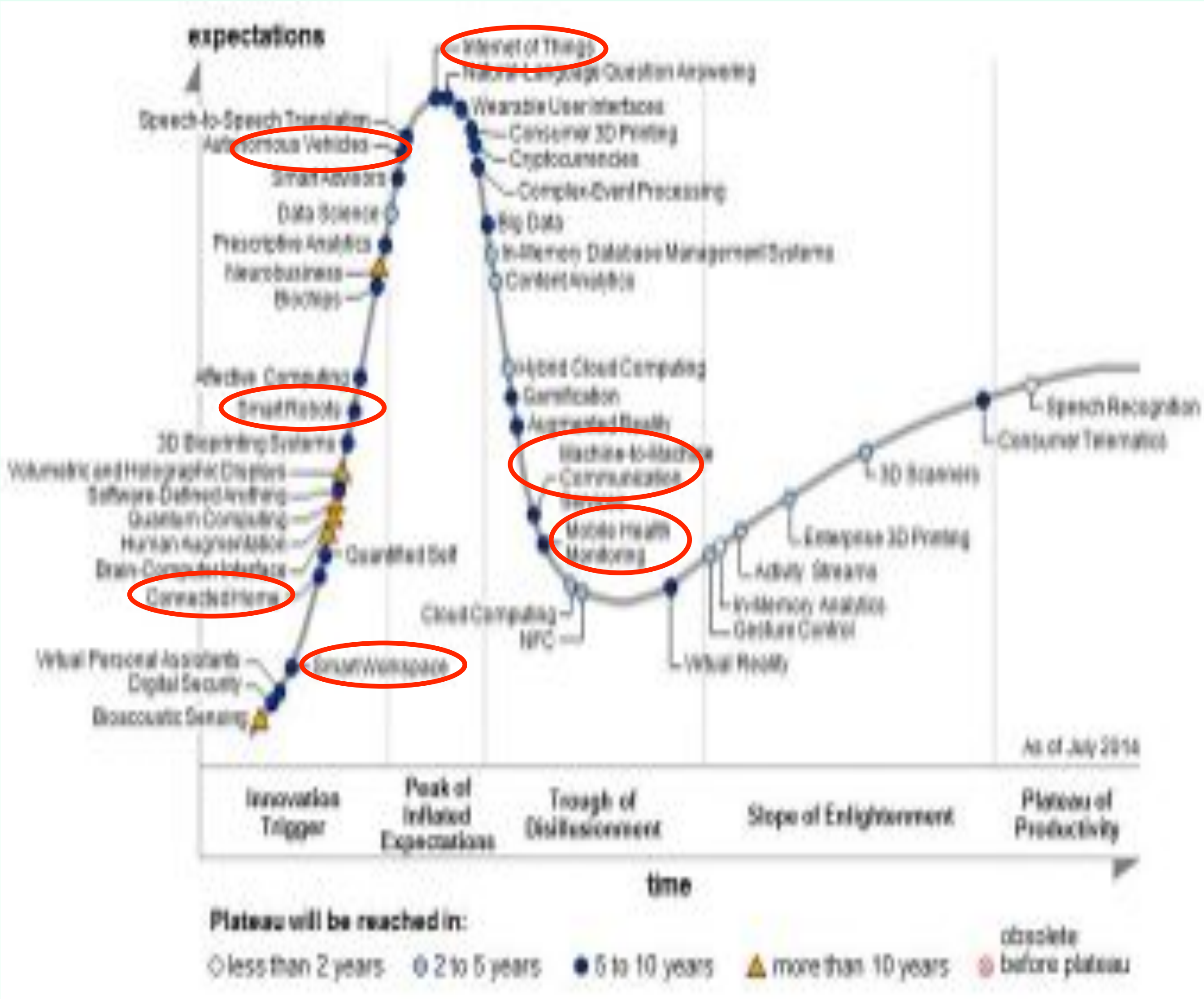


Proposal Teams:
- Engineering
- Computer Science
- Behavioral science

Smart Cities

- Internet of Things
- Cyber Physical Systems
- Industrial Internet
- Smart Infrastructure
- Extensible Distributed Systems
- Urban Science

IoT in Perspective



Source: Gartner Hype Cycle for Emerging

Smart, connected home

IoT Core Technologies

- Security and Privacy
- Energy Management
- Real-time computing
- Sensors and Actuators
- Wireless Networking
- Signal Processing
- Sensing and Control
- Mobile Computing
- Big Data

IoT Research Challenges*

- Massive Scaling
- Architecture and Dependencies
- Knowledge and Big Data
- Robustness
- Openness
- Security and Privacy
- Human Integration

* Borrowing heavily from: "Research Directions for the Internet of Things", Jack Stankovic, IEEE Internet of Things Journal, Vol. 1, No. 1, February 2014

Massive Scaling as number of smart devices being deployed eventually reaches trillions

- How to name, authenticate access, maintain, protect, and support
- Architectural model to support heterogeneity of devices and applications
- Standards and protocols – beyond IPv6?
- Energy management / harvesting / low power
- Data storage and management
- Real-time behavior
- Reliability

Unsafe Internet of Things Environments

But! Today's IoT systems are fundamentally unsafe and subject to a range of vulnerabilities

- Study of top 10 IoT devices across multiple categories finds vulnerabilities in 70% of devices [*Source: HP*]
- March 2014: "Remote-steering" attack demonstrated on recent car models [*Source: Forbes*]
- August 2014: IoT baby monitor in Texas hacked; parents enter room to find strangers swearing and yelling remotely at two-year old girl [*Source: CNN*]
- October 2014: "First cyber-death [IoT related] will happen this year" [*Source: Independent (UK)]*
- …

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Security experts take aim at the Internet of (unsafe) Things

Elizabeth Weise, USATODAY 6:17 p.m. EDT August 7, 2014

(Photo: Manuel-F-O Getty Images/iStockphoto)

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LAS VEGAS — The day is fast approaching when your thermostat, washer, even the light bulbs in your lamps will contain embedded computers so they can talk to you and you to them.

Having your fridge order more milk when supplies get low, your house cool before you get home and your light bulbs tell you just before they need replacing might be nice, but security experts say these connections, called the Internet of Things, carry with them the potential for catastrophe.

They could just as easily tell a thief that you haven't been home in a week, because the fridge door hasn't been opened.

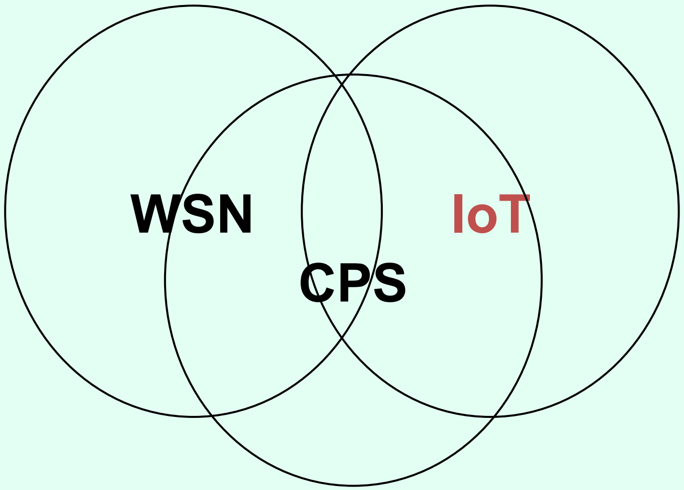
Security

- IoT devices may be highly vulnerable to security attacks
  - Vulnerability to malware out of the box
  - Minimal processing may be challenging for attack detection, real-time response, and encryption
  - Open design & wireless interfaces
  - Random failures may mask attacks
  - Recovery and resilience of system may be enhanced with redundancy
  - Update approach? Authentication?
  - Security architecture for heterogeneous environments including ‘green fields’ and legacy systems

Privacy

- Privacy Policies and enforcement amongst the diversity of heterogeneous elements
  - Where do the policies get enforced?
  - Data owners interaction among domains – perhaps there is a need for an IoT privacy language
  - Aggregation at the device may be challenge – responding to higher level requests for reduced data sets
  - Provenance for verification of adherence to policy
- Information leakage

IoT and CPS – Embrace the Synergies



WSN –Wireless Sensor Networks

CPS – Cyber Physical Systems

IoT – Internet of Things

Safety

Control ***Verification***

Core Science, Technology, Engineering

Real-time Systems ***Networking***

Security

- IoT & CPS share many core technology elements
- Open Programmable Devices and Objects are here
  - By 2020, 26B smart devices: lights, locks, security sensors …
  - By 2019, 70% homes with IoT devices
- Developers and IoT Apps are coming!
- 1,400 global developer survey – 40% working on IoT apps today

[*Source:* Evans Data Corporation]

CPS Program Relationship with IoT

- CPS Program typically dealt with "big" scope systems
  - Airplanes and automobiles are CPS on grand scale with hundreds of networked processors, sensors, and actuators integrating with the physical world in real-time
  - Smart grid very large numbers of processors, sensors, actuators
  - Human in the loop or on the loop
  - Integration and composition
  - Security and Privacy
- IoT scale dwarfs our traditional view of cyber physical systems but share many of the same technologies and challenges - but at scale, with potentially ad-hoc and opportunistic connections, and with potentially even more stringent challenges in security and privacy

Conclusion

Internet of Things

Cyber Physical Systems

Industrial Internet

Smart Cities

Resilient Infrastructure

Extensible Distributed Systems

Smart Services