Cyber-Physical-Social Convergence in Smart Living: Challenges and Opportunities

(US-Morocco Workshop on Sensors and Wireless Networks for Smart Cities)

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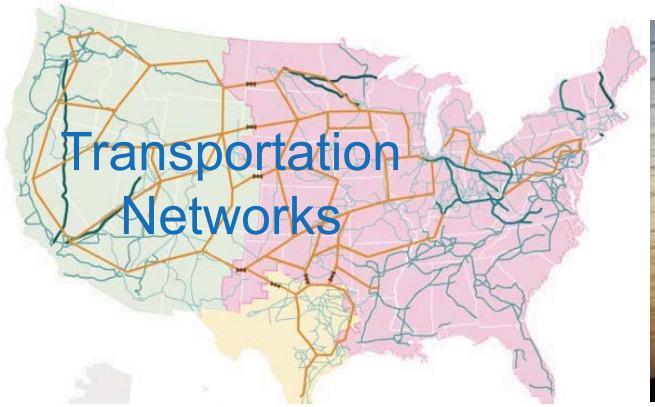
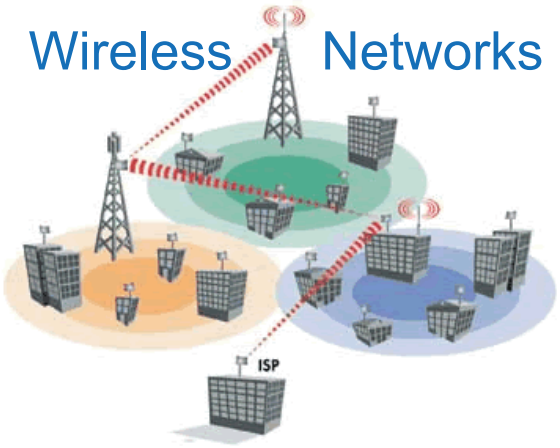
Smart Computing™
50 Years of Excellence

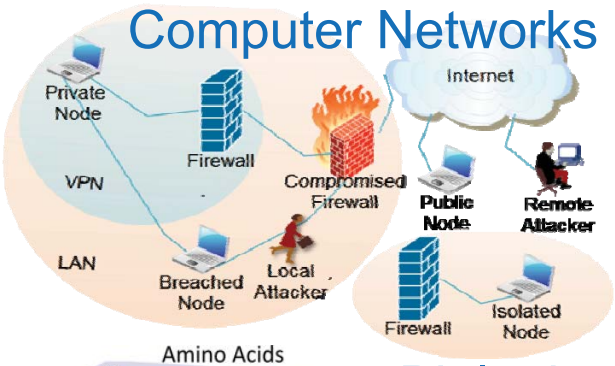
CELEBRATE WITH US
COMPUTER SCIENCE
GOLDEN JUBILEE
50

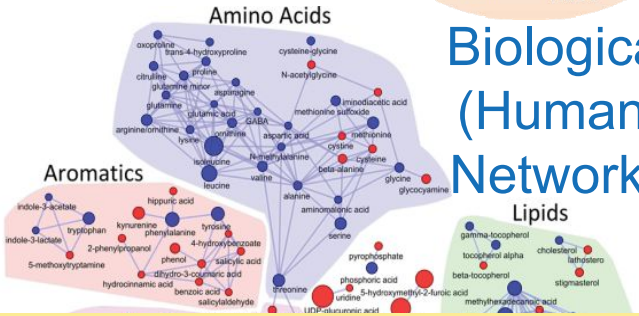
We are Networked…

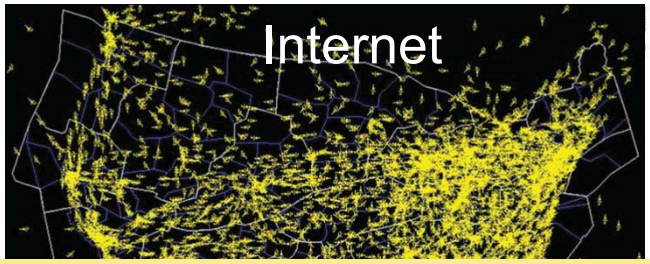
Motivation #1: We are Networked…









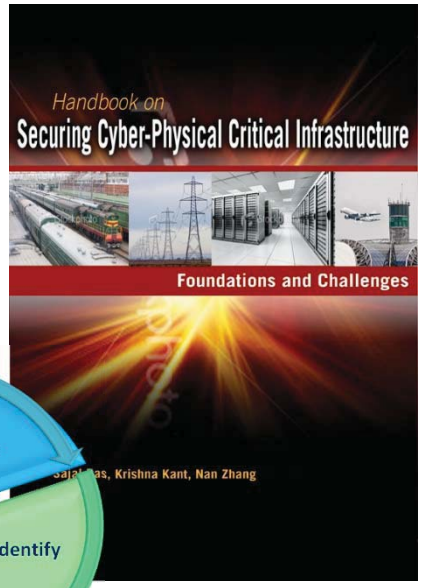


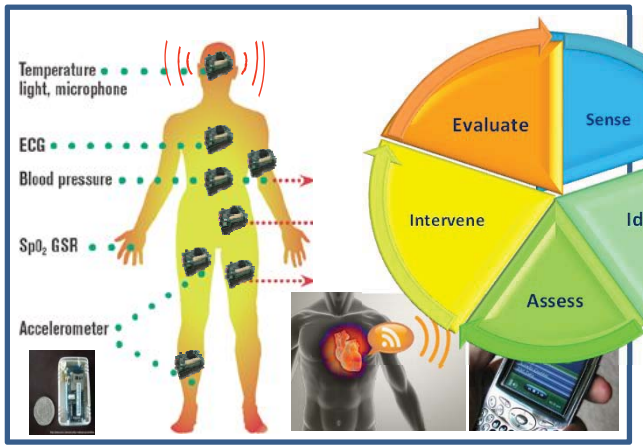
Characteristics: System of Systems, Complex, Large-scale, Heterogeneous

Challenges: Interdependency,Robustness, Cyber-Physical-Social, Big Data

Motivation #2: Societal (Global) Challenges

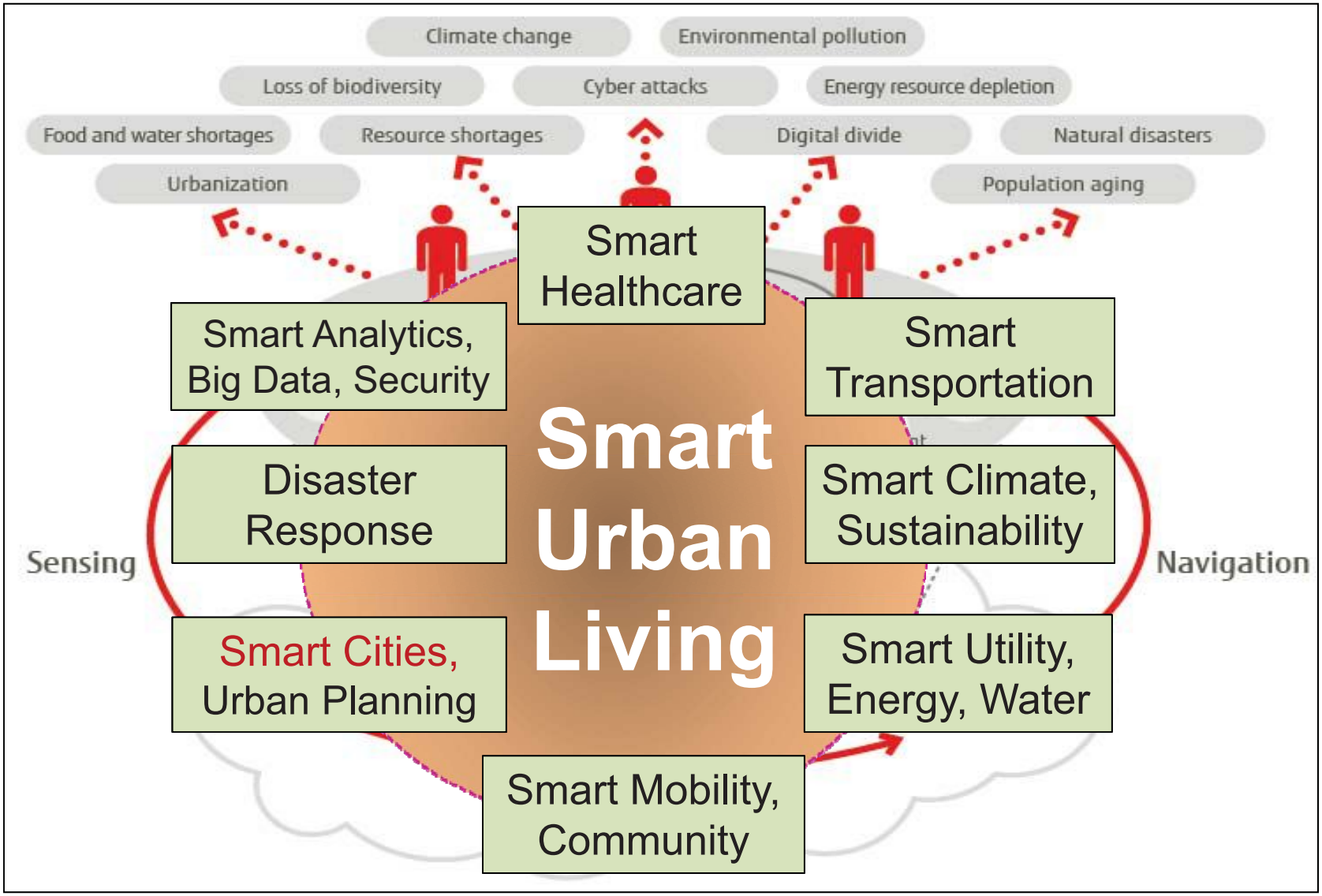
- **Energy and Sustainability**
  - Resource management
  - (energy, water, transportation)
- **Security**
  - Security and safety of people, infrastructures, assets
- **Healthcare**
  - Smart and connected health, wellness management
- **Extreme Events Management**
  - Natural and inflicted disasters, Emergency response





M. Conti, S. K. Das,,et al., "Looking Ahead in Pervasive Computing: Challenges and Opportunities in the Era of Cyber-Physical Convergence," *Pervasive and Mobile Computing*, 8(1): 2-21, Feb 2012.

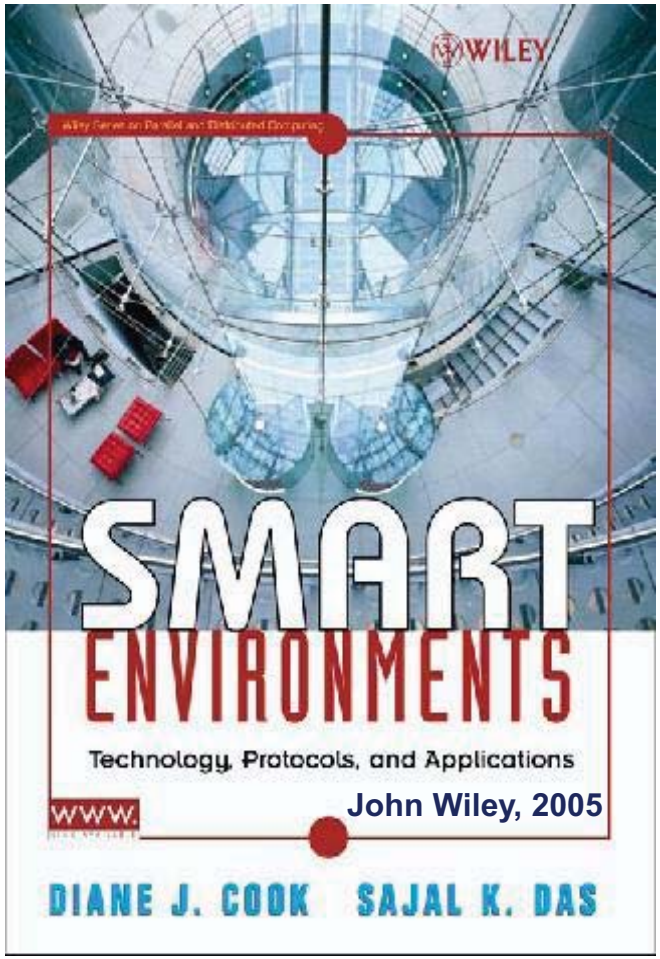
Smart Living: A New Frontier



What are the common invariants?

Experience and Historical Perspective

- 2001: NSF ITR-Medium project, *MAVHome: Designing Adaptive Versatile Smart Homes*
- 2003: ITR, *Pervasively Secure Infrastructures (PSI): Integrating Smart Sensing, Data Mining, Pervasive Networking, Community Computing*
- 2005: Wrote first book on *Smart Environments*
- 2006: Built *Smart Home* testbed @ UTA dorm
- 2008-2011: Program Director, NSF CISE/CNS
- 2012: NSF SCH project, *Crafting a Human-centric Environment Smart Healthcare*
- 2012: I-Corps, *Energy-Efficient Home (E2Home)* 2015: *Smart Analytics for Cognitive Healthcare*
- 2015: "Smart Living" – a signature area @ MST
- 2015: CPS projects – (Breakthrough) *Securing Smart Grid;* (Synergy) Threat Assessment Tools for Human-coupled CPS Infrastructures



A. Roy, S. K. Das, and K. Basu, "A Predictive Framework for Context-aware Resource Management in Smart Homes," *IEEE Transactions on Mobile Computing*, 6(11): 1270-1283, 2007.

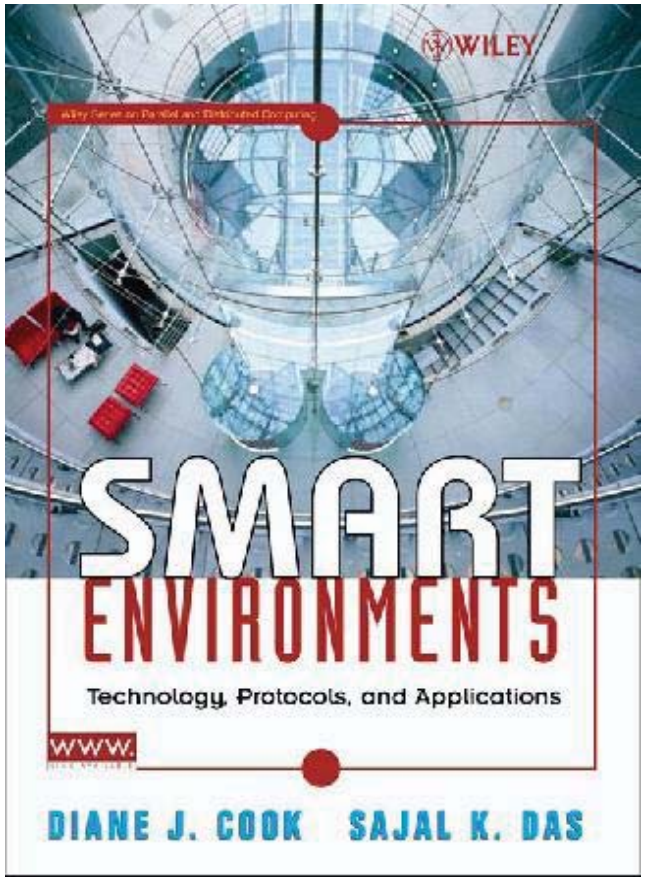
What is a Smart Environment?

• A Smart Environment is one that is able to autonomously *acquire* and *apply* knowledge about inhabitants and their surroundings (environment), and *adapt* to improve experience *without explicit awareness*

• Corollary: makes *intelligent decisions* in *automated, context-aware* manner
→ pervasive computing

• Context / Situation-awareness is the key

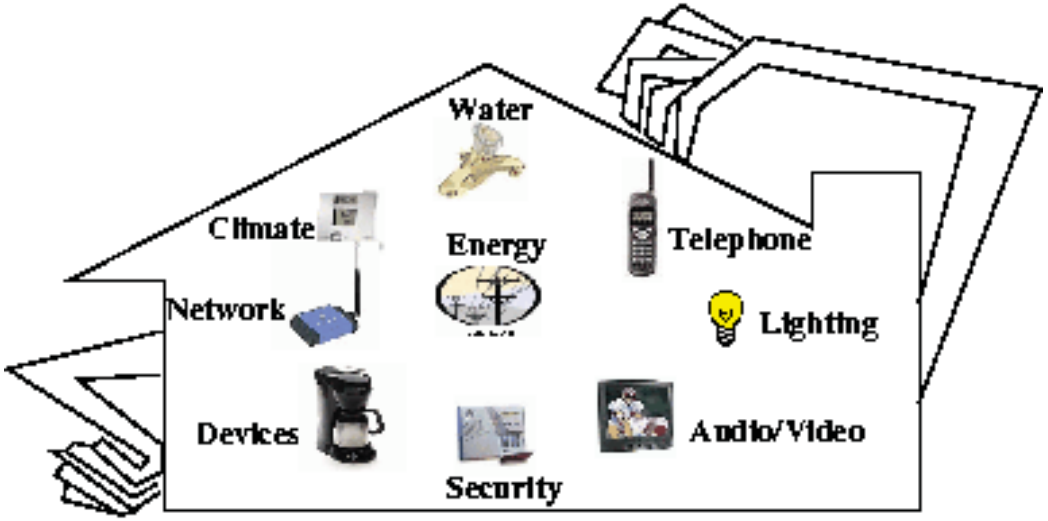
• Example Contexts:
  • Mobility, Activity, Occupancy, Preferences, …
  • Desire, Behavior, Mood, Emotions, …



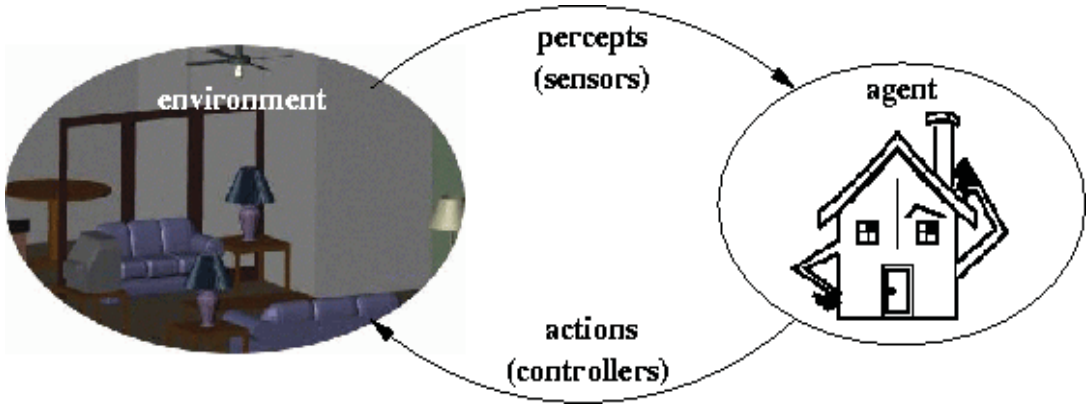
John Wiley, 2005

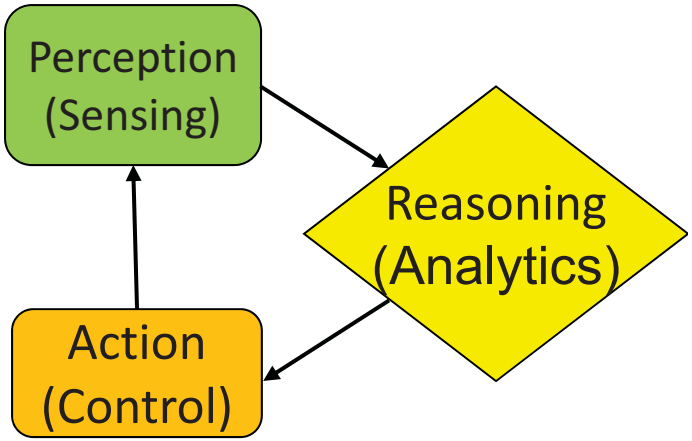
D. J. Cook and S. K. Das, "How Smart Are Our Environments? An Updated Look at State of the Art," *Pervasive and Mobile Computing*, Vol. 3, No. 2, Mar. 2007.

Smart Home as a Rational Agent



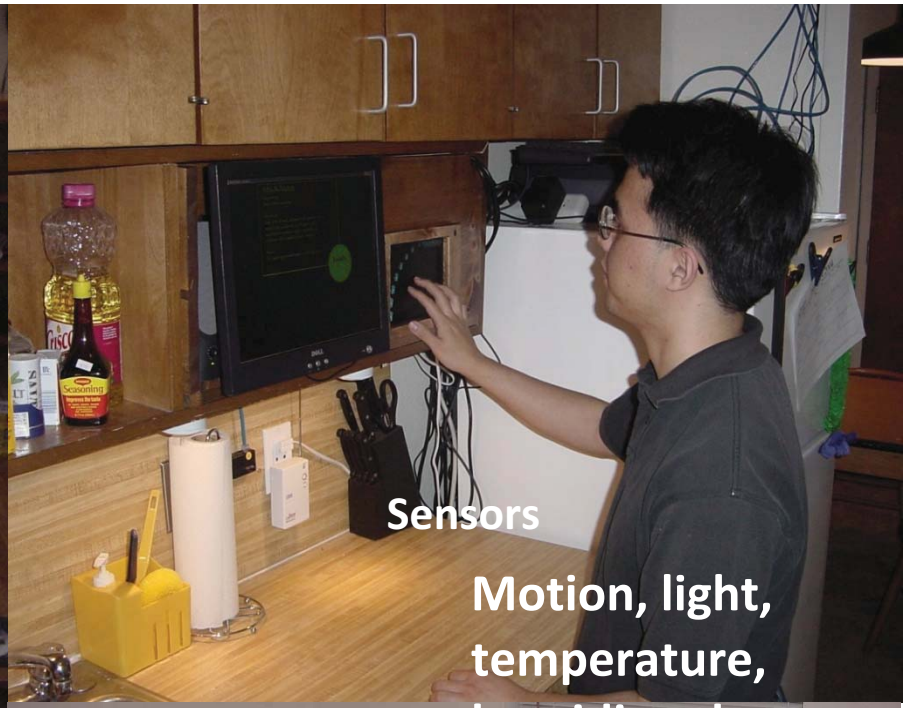
- *Perceives* the state of a home via *sensors* and *acts* on environment via *actuators (*controllers)
- *Reasons* about and adapts to inhabitants, predicts context and makes *intelligent decisions*





NSF ITR Project – MAVHome: Managing an Adaptive Versatile Home Environment, 2001-2006.

MavHome @ UT Arlington

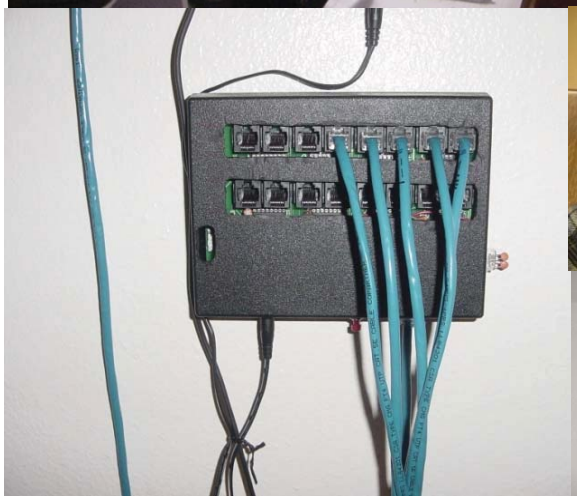


Sensors

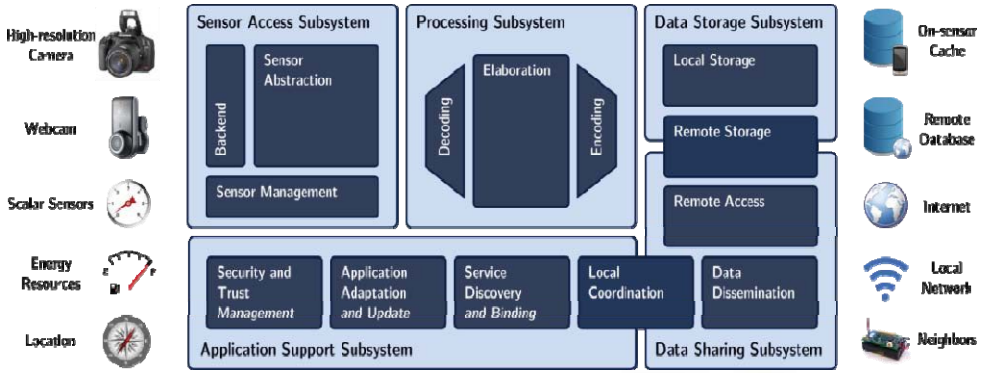
Motion, light, temperature, humidity, door, water leak, smoke, CO2

Controllers

Lights, fans, TV, receiver, mini-blinds, HVAC, diffusers

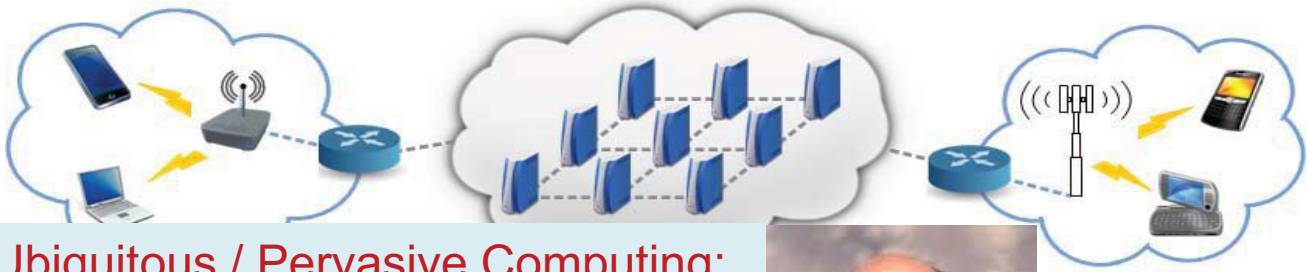


Enabling Technologies



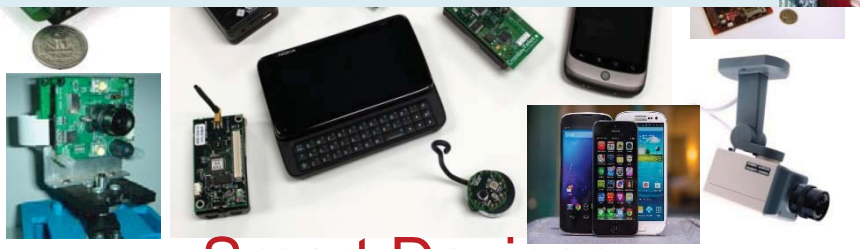
Software/Middleware Services

- Data to storage to computation to service
- Agent based technologies, J2ME
- Intelligent Decision Making
- M2M, HCI (voice, touch, GUI)

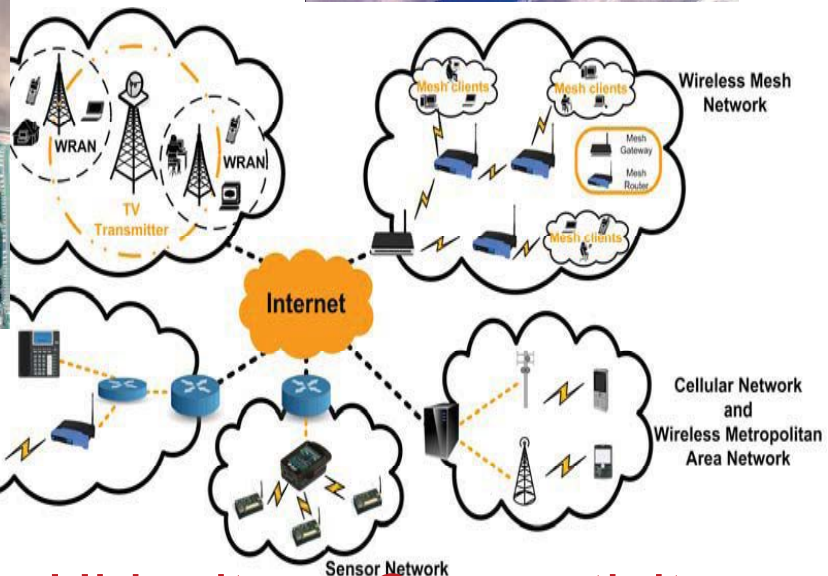


Ubiquitous / Pervasive Computing:

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they're indistinguishable from it." [*Mark Weiser, Computing for the 21st Century, Scientific American, 1991*]



Smart Devices



Ubiquitous Connectivity

Smartphone: A Rich Sensing Platform

- By 2019, number of smartphones is expected to triple to 5.6 billion

http://www.washingtontimes.com/news/2013/nov/11/number-smartphones-expected-triple-56-billion-2019/

- **Plethora of Sensors**
  - temperature, light, humidity, motion, acceleration, GPS, …
- **Multiple Wireless Interfaces**
  - WiFi, Bluetooth, long range cellular radio to connect to external sensors
- **Internet Access**
  - high-speed 3G/4G connection
- **Multimedia Sensing**
  - Audio, video, image, text

R. Fakoor, M. Raj, A. Nazi, M. Francesco, S. K. Das, "An Integrated Cloud-based Framework for Mobile Phone Sensing," *Proc. ACM SIGCOMM Workshop on Mobile Cloud Computing*, Helsinki, Aug 2012.

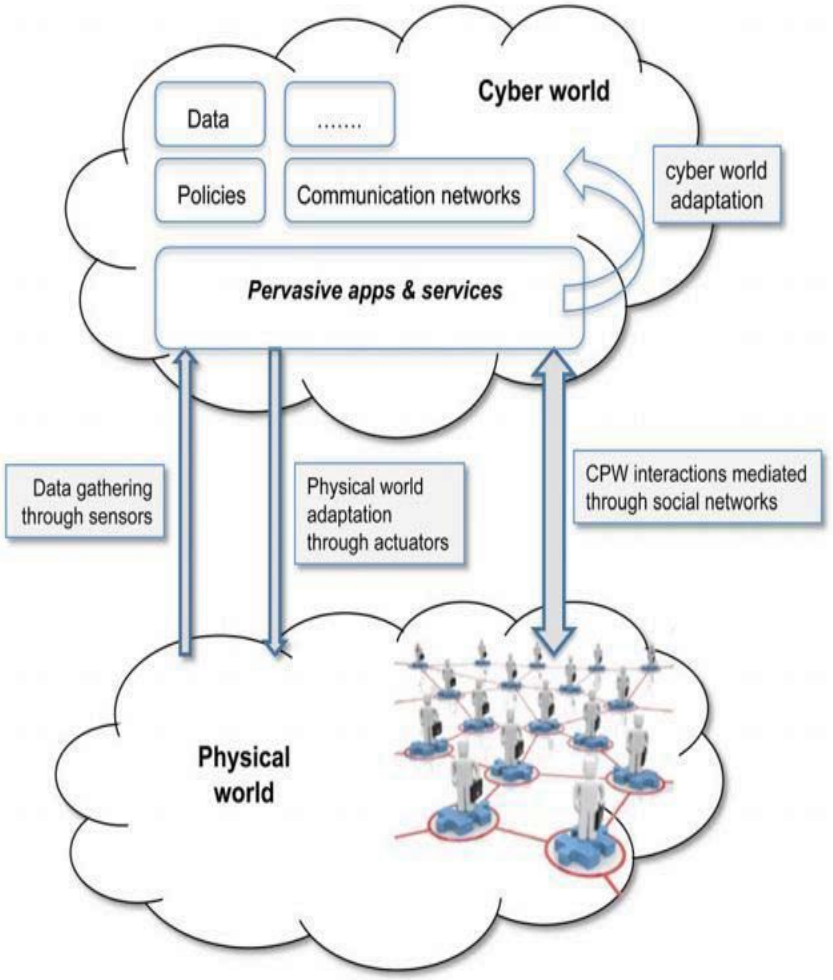
Cyber-Physical Systems (CPS)

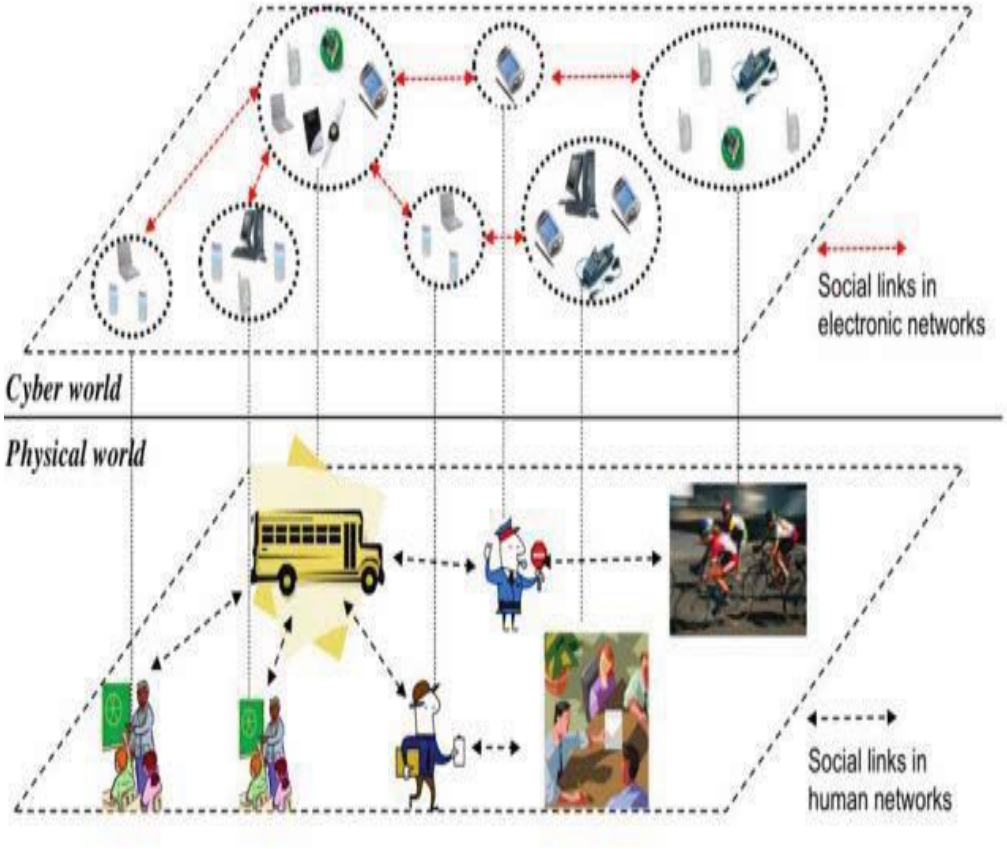
[NSF] CPS are natural or engineered systems that integrate sensing, communication, computing, and control

M. Conti, S. K. Das, et al. "Looking Ahead in Pervasive Computing: Challenges and Opportunities in the Era of Cyber-physical Convergence. *Pervasive and Mobile Computing, 8*(1): 2-21, 2012.

Cyber-Physical-Social (CPS) Convergence

Integration of cyber-physical systems with human in the loop (social / behavioral aspect – participatory sensing)

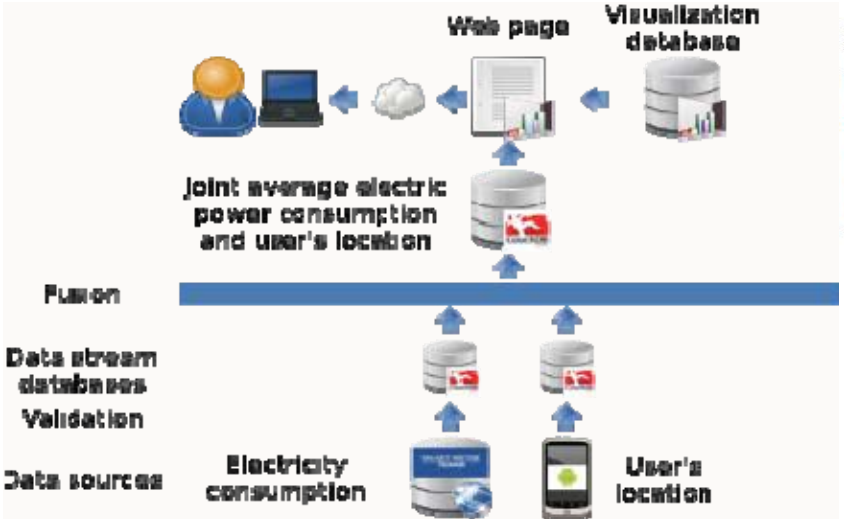


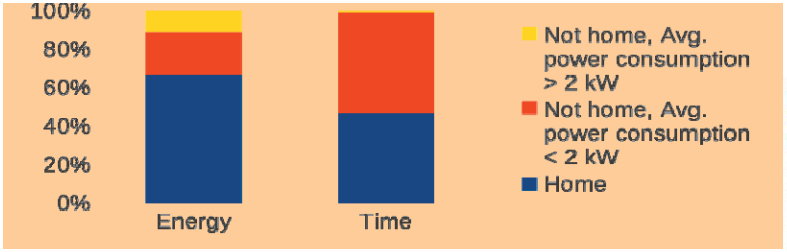


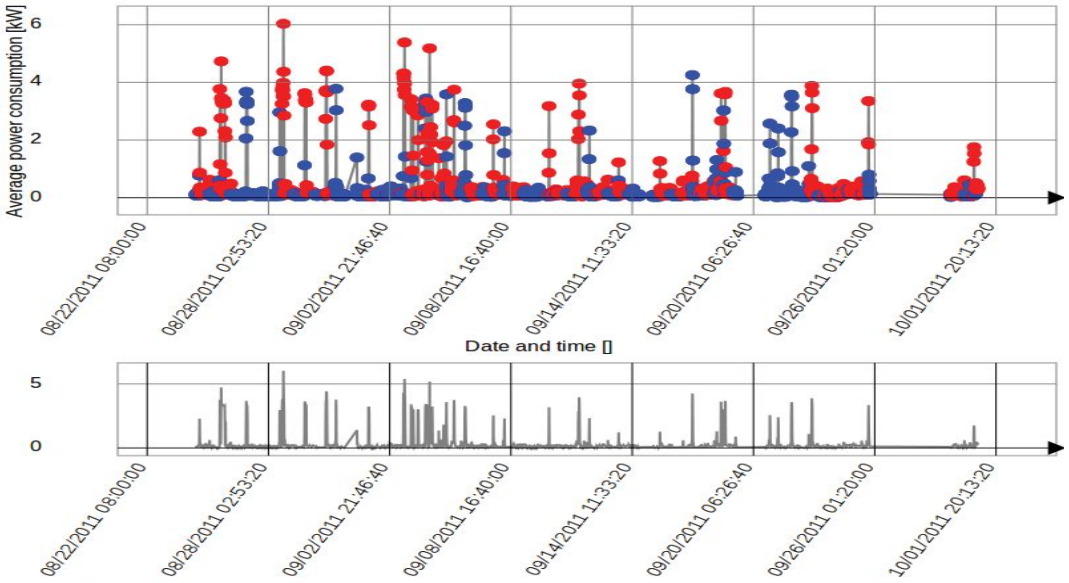
CPS (macro) → IoT (micro)

M. Conti, S. K. Das, et al. "Looking Ahead in Pervasive Computing: Challenges and Opportunities in the Era of Cyber-Physical Convergence. *Pervasive and Mobile Computing, 8*(1): 2-21, 2012.

E2Home: Energy-Efficient Homes (I-Corps)



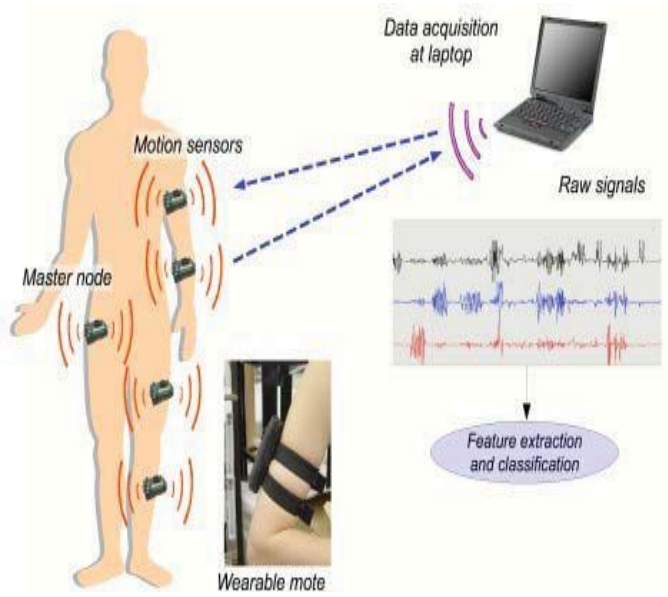




- G. Ghidini and S. K. Das, “Energy Efficient Homes (E2Home): A Web-based Application for Integrated Electricity Consumption from Contextual Information." *IEEE SmartGridComm* 2012. (Best Paper Award)
- A. De Paola, S. K. Das, et al. “Intelligent Management Systems for Energy Efficiency in Buildings: A Survey,” *ACM Computing Surveys*, 47(1):13:1-13:38, June 2014.
- G. Ghidini, S. K. Das, and D. Pesch, “Sensor Network Protocols for Greener Smart Environments”, Book Chapter, in Design Technologies for Green and Sustainable Computing Systems, P. P. Pande, A. Ganguly, K. Chakrabarty (eds.), Springer Verlag, May 2013.

Smart Health Care

NSF Smart Connected Health (SCH) Program
Crafting a Human-Centric Environment to Support Human Health Needs, (2011 - 2015)



Aging World Population

- By 2040, 23% US population 65+
- 9% of adults aged 65+ and 50% 0f adults aged 85+ need assistance

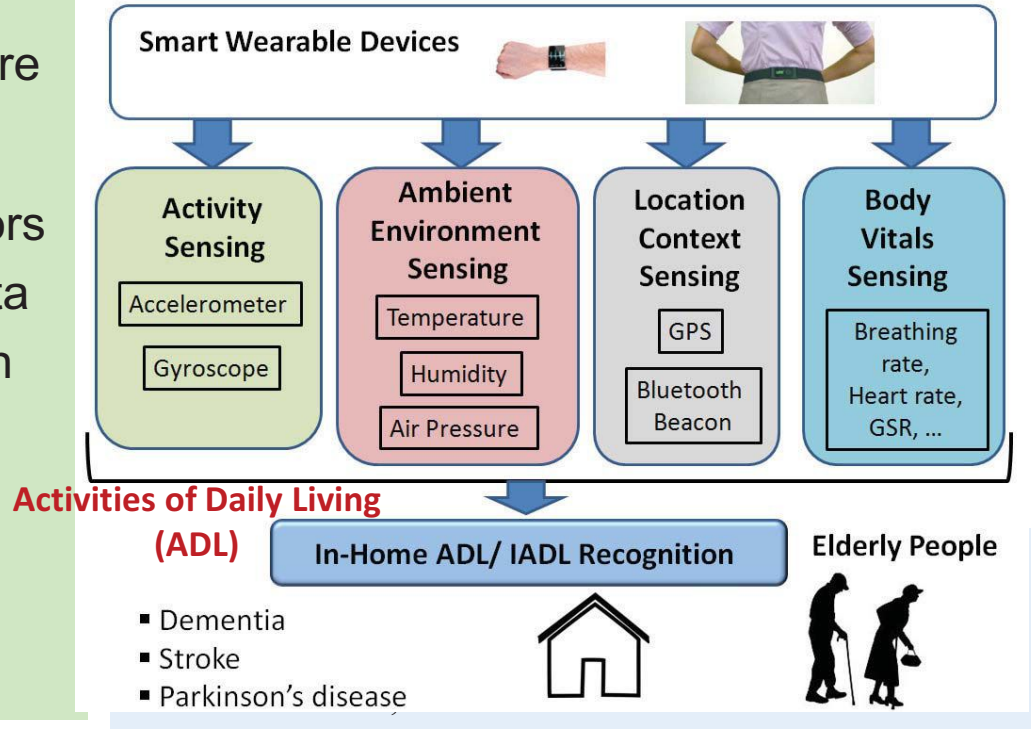
Goal: Automate and improve healthcare

Multi-modal Sensing Framework

- Monitor using heterogeneous sensors
- Fuse and process of multimodal data
- Efficient storage and fast notification

Implementation

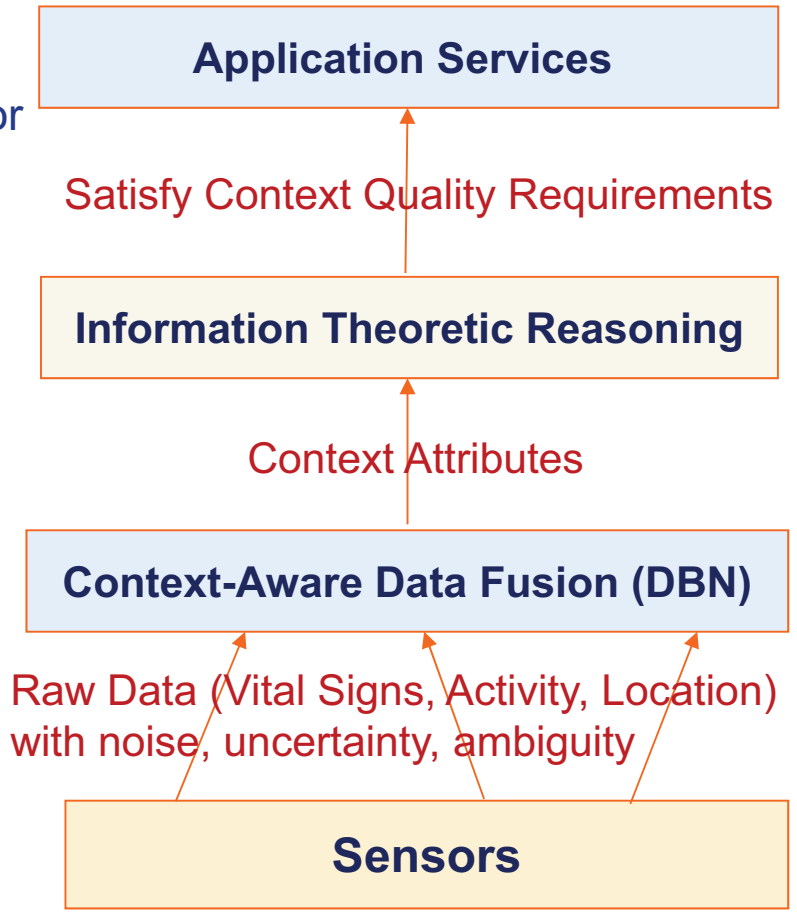
- Case Study: Elderly fall detection
- Middleware, CouchDB server
- Validation using sensor test bed



Efficient, Quality-adaptive Framework

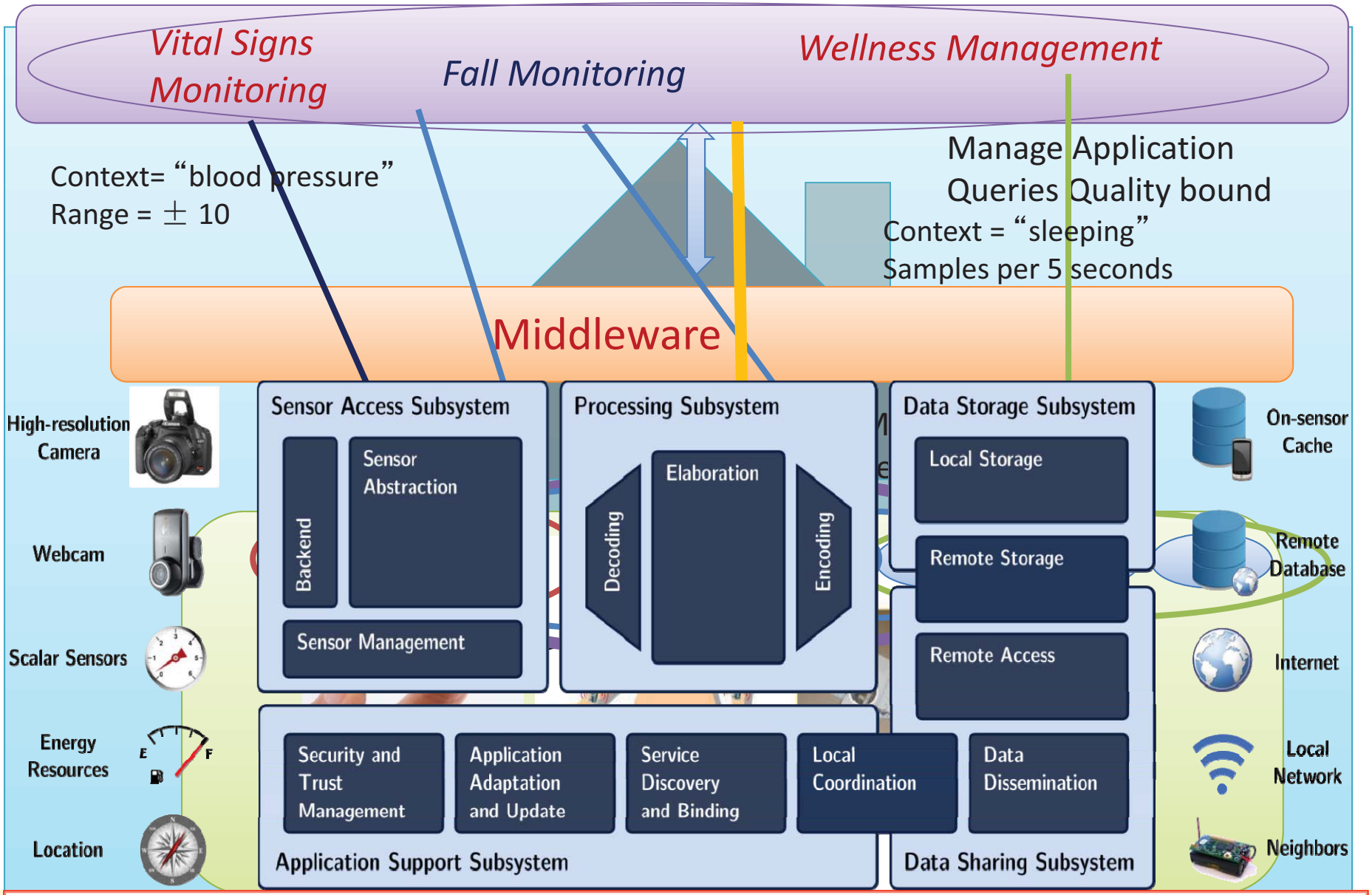
- Context
  - Sample sensor streams to detect vital signs, activity (walking/sleeping), movement, behavior
  - Optimize sampling rate for minimum accuracy
- Context aware multi-modal data fusion
  - Characterize uncertainty and ambiguity
  - Dynamic Bayesian Network model
- Intelligent management of sensor information
  - Information theoretic reasoning
  - Optimal sensor parameter selection
  - Ambiguity/error reduction in state estimation
- Quality-aware context determination

  Tradeoff: Context quality vs. cost (energy)



N. Roy, A. Misra, C. Julien , S. K. Das, "Energy-Efficient Quality-Adaptive Framework for Multi-Modal Sensor Context Recognition", *Proc. IEEE PerCom* 2011. (Best Paper Candidate). Extended version to appear in *IEEE/ACM Transactions on Networking.*

Smart Healthcare



N. Roy, S. K. Das, and C. Julien, "Resource-Optimized Quality-Assured Ambiguous Context Mediation Framework in Pervasive Environments," *IEEE Transactions on Mobile Computing*, 11(2): 218-229, Feb 2012.

CPS Challenges in Smart Living (1)

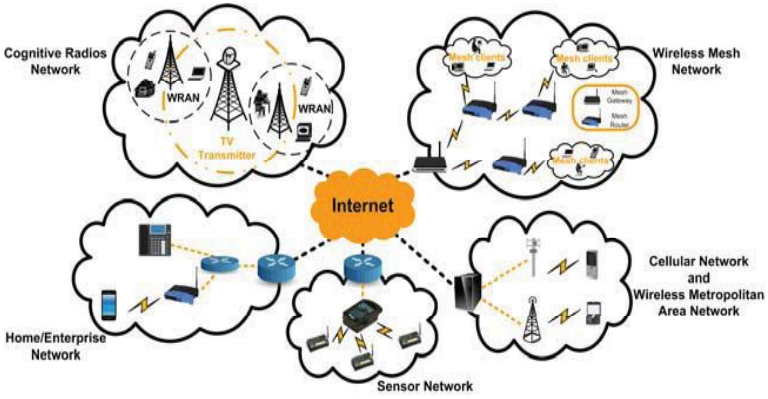
- Dealing with Heterogeneity and Scale

➢ How to manage co-existence and inter-operability of diverse wireless, sensing and communication technologies and protocols?

➢ How to discover communications, computing and IoT services dynamically and at scale?

- Dealing with Inherent Uncertainty

➢ How to handle uncertainty at every level – sensing, wireless communications, mobility, topology control, routing, resource (e.g., energy) and service availability?



➢ How to design energy-efficient algorithms and protocols for sensing (data gathering, fusion, duty cycling, coverage) and control?

➢ How to cope with uncertainty, perturbation, and changing requirements for smart living?

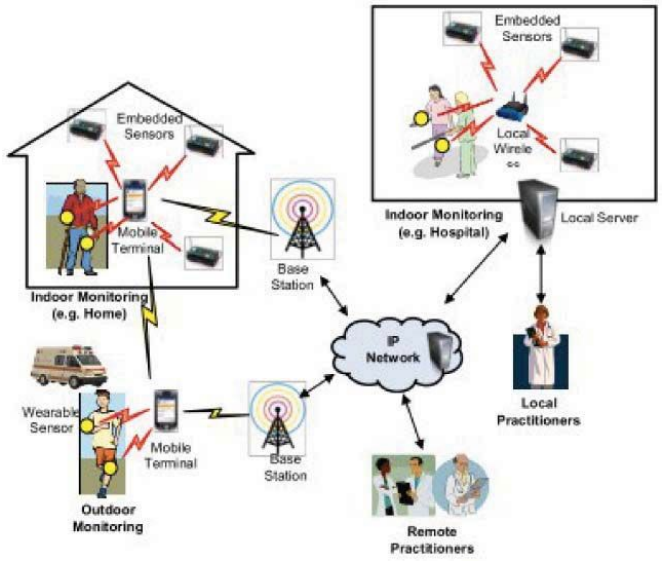
B. Carballido Villaverde, R. de Paz Alberola, A. J. Jara, S. Fedor, S. K. Das, and D. Pesch, "Service Discovery Protocols for Constrained Machine-to-Machine Communications", *IEEE Communications Surveys and Tutorials*, 16(1): 41-60 (2014).

CPS Challenges in Smart Living (2)

- Multimodal Fusion & Intelligent Decisions

➢ What is the semantic model for multi-modal sensory information fusion and knowledge extraction for real-time decision making?

➢ How to unambiguously determine context and situation awareness despite uncertain, noisy and incomplete data / information?



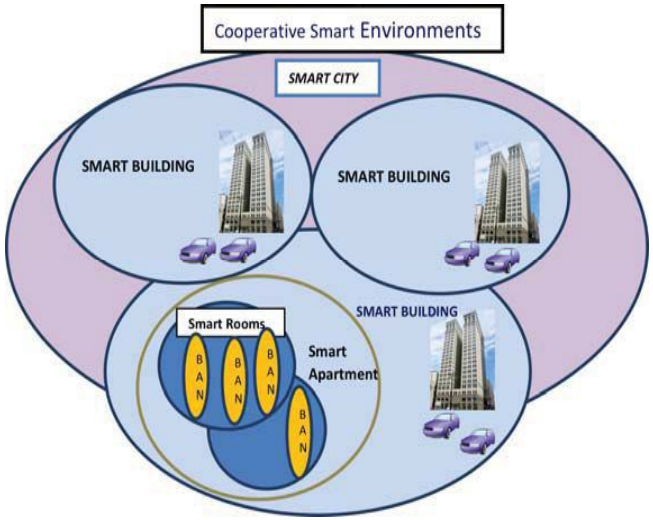
- Model Development

➢ What data-driven models are able to capture system dynamics, impact propagation and stability in the presence of uncertainty?

➢ What is the impact of resource limitations in wireless spectrum and energy?

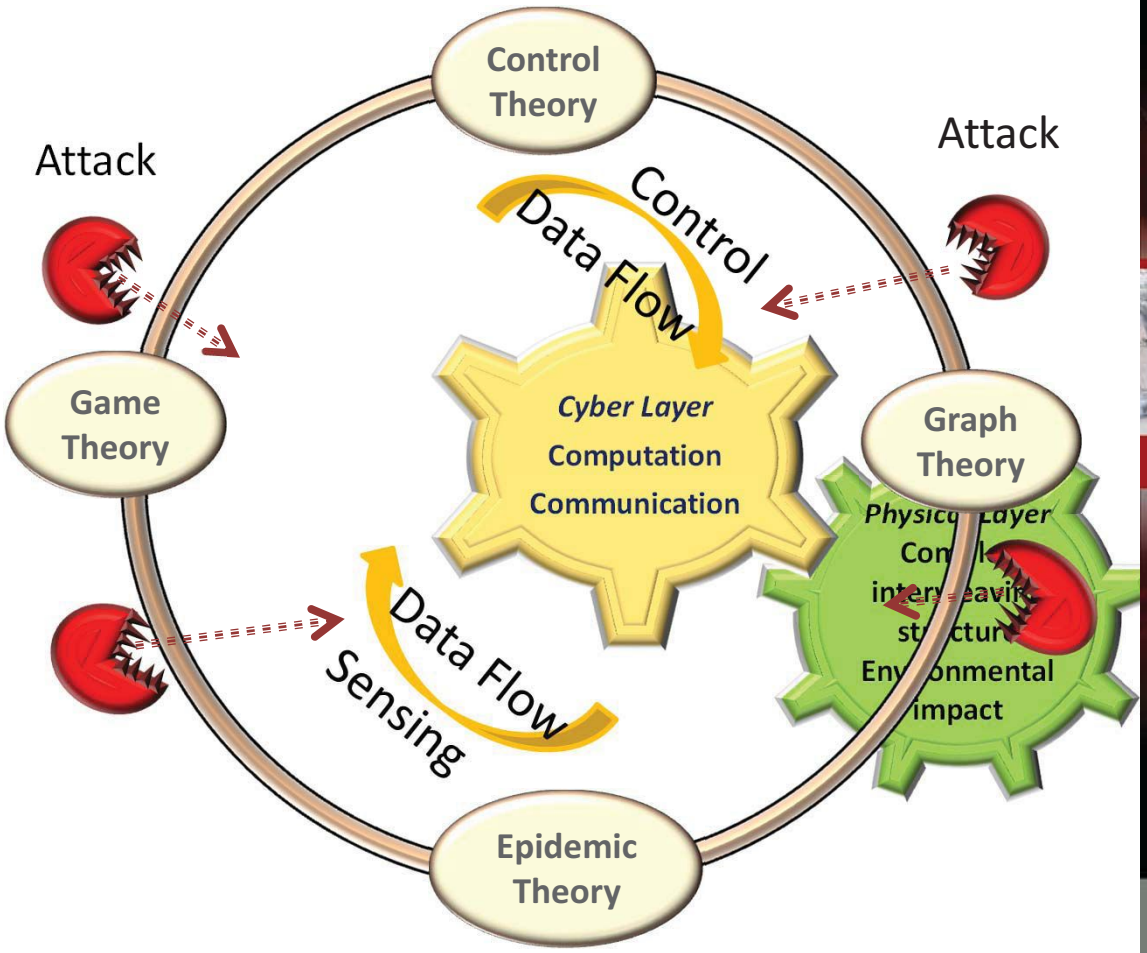
CPS Challenges in Smart Living (3)

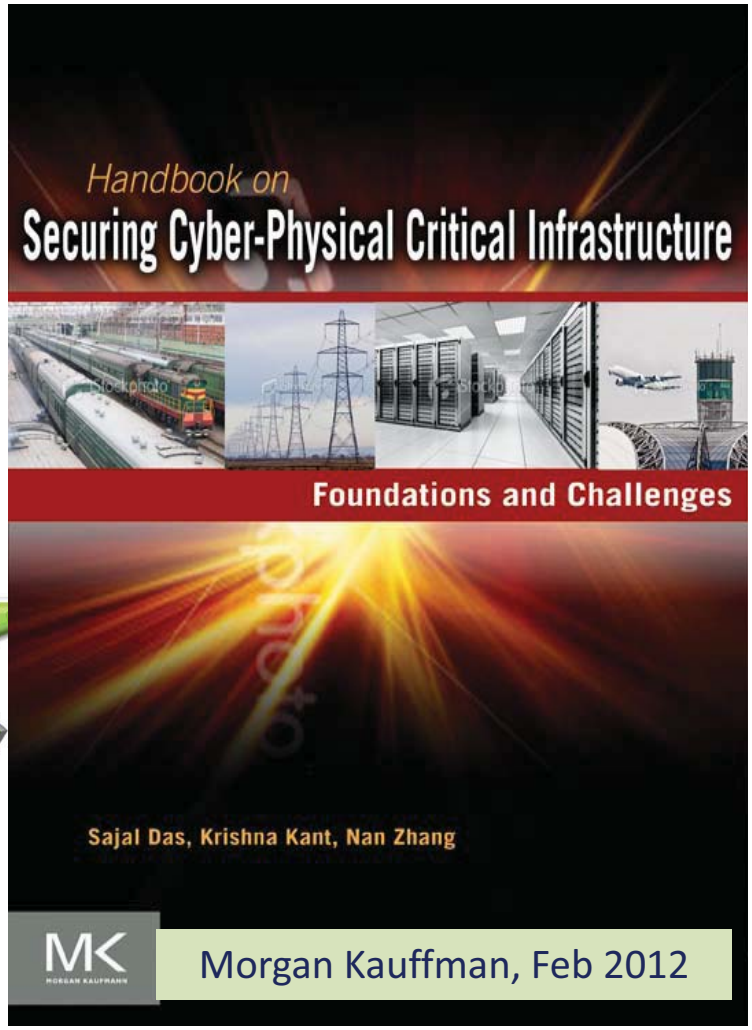
- Robustness, Security, Trust and Privacy
  - How to trust sensed data (*participatory sensing, crowdsourcing*) to make robust decisions?
  - How to guarantee information reliability?
  - How to tackle adversarial / malicious behavior? How to prevent cascade failures?
  - How to find hidden correlation among seemingly unrelated events?



- Complex Interdependency
  - How to model interdependency among various smart spaces impacting our daily lives? How to dynamically manage information for efficiency?
  - How to manage Big Data analytics to build meaningful learning and predictive models?
  - What are the impacts of social dynamics and human behavior on Smart Living?

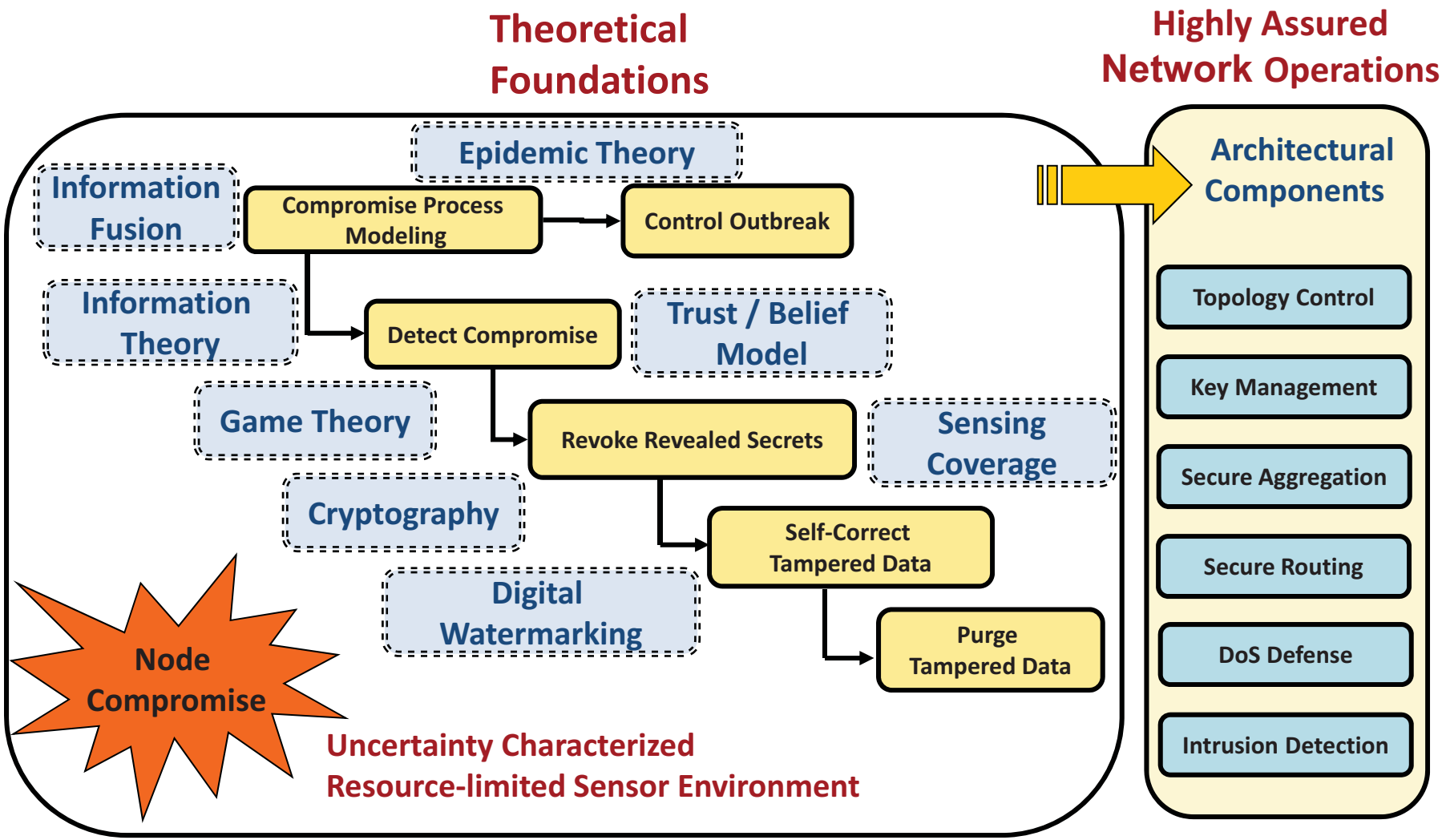
Foundations of CPS Security





M. Xue, S. Roy, S. K. Das, "Security and Discoverability of Spread Dynamics in Cyber-Physical Networks," *IEEE Transactions on Parallel and Distributed Systems* (special issue on CPS), 23(9): 1694-1707, Sept 2012.

Multi-Level Security Framework



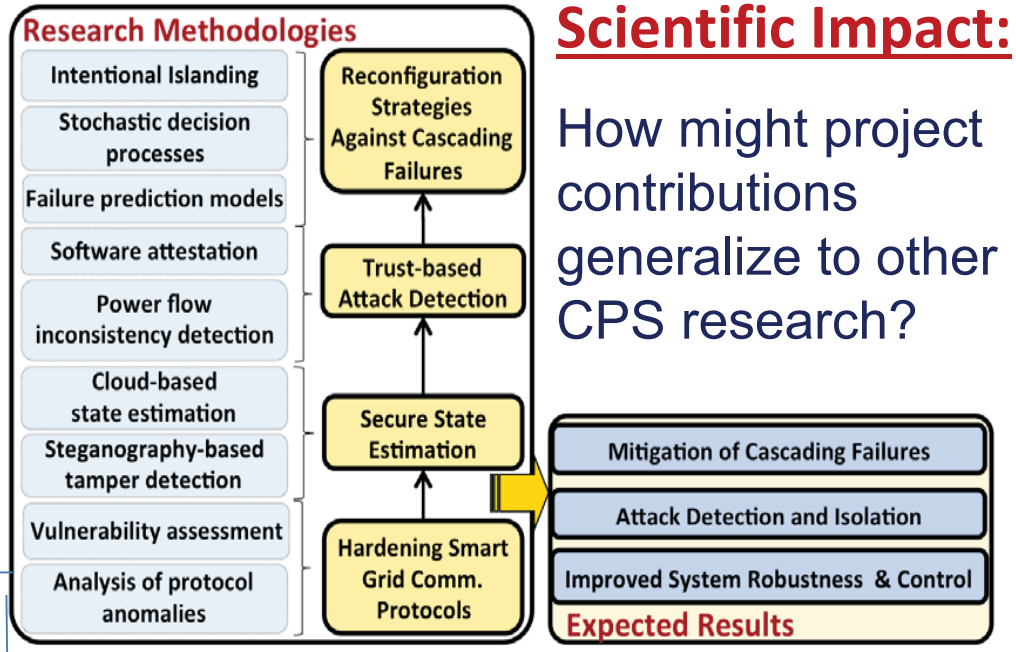
CPS: Breakthrough: Securing Smart Grid by Understanding Communications Infrastructure Dependencies (NSF Project, Sept 1, 2015 – August 31, 2018)

Challenges:

- Characterize inter-dependence between Smart Grid and communication systems
- Robust state estimation and protocols
- Detect impacts (failures and attacks) and prevent cascades.
- Build models for attack mitigation.
- Validate with real test-bed.

Solution Methodologies:

- Substation Protocol hardening
- Steganography based robust state estimation
- Game theory and trust models for attack detection, failure spreading
- Situation-aware models for threat monitoring, analytics, decision control



Scientific Impact:

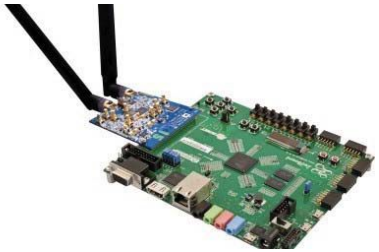
How might project contributions generalize to other CPS research?

Broader Impacts:

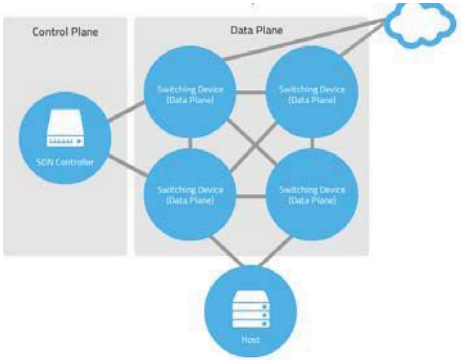
- Influencing the standards
- Multi-disciplinary security training in coupled CPS.
- Experiential learning in real-life micro-grid facility

Opportunity - Software Defined Infrastructure

From SDR, SDN, Computer and Storage Virtualization



Software Defined Radio



Software Defined Network

Software Defined Virtualization

To software defined Buildings, Roads, and Cities

Software Defined Buildings

Software Defined Roads

Software Defined Cities

Opportunity - IoT Enables Smart Living

Smart Energy Management

Smart Healthcare

Smart Transportation

Smart Water Management

IoT Middleware

Management

Service Organisation

IoT Process Management

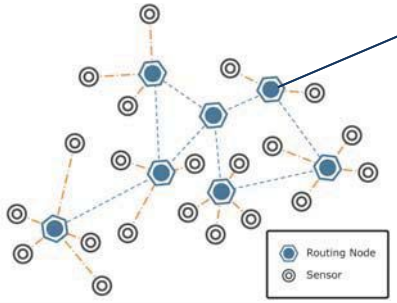
Virtual Entity

IoT Services

Security

Internet

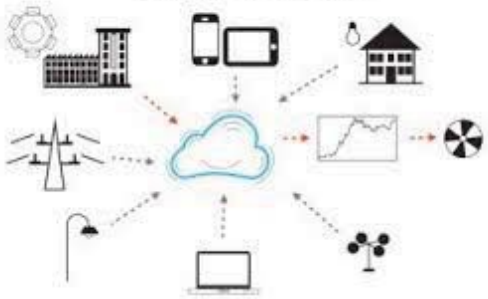
Sensor/Actuator Networks



Body Area Networks

Participatory Sensing

SensorCloud



Smart Living is the Way to Go!

Uncertainty Reasoning

Stochastic Optimization

Dynamic Control

Game Theory

Information Theory

Spread Dynamics

System Model

Resource Management

Robustness

Security

Context Recognition

Adaptivity

Scalability

Figure of Merit

S. Roy, M. Xue, and S. K. Das, "Security and Discoverability of Spread Dynamics in Cyber-Physical Networks," *IEEE Trans. on Parallel and Distributed Systems* (special issue on CPS), 23(9): 1694-1707, Sept 2012.

2nd IEEE International Conference on Smart Computing, SMARTCOMP2016

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Important Dates

Workshop Proposal Submission: November 15, 2015

Notification: December 14, 2015

Conference Paper Registration: December 14, 2015

Conference Paper Submission: December 21, 2015

Conference Paper Notification: March 21, 2016

Camera ready: April 15, 2016

CALL FOR PAPERS

The 2nd IEEE International Conference on Smart Computing (SMARTCOMP 2016) advances multidisciplinary research on the use of technology and the design of smart computing systems that improve the human experience and promote resource sustainability

SMARTCOMP 2016 invites original papers on smart computing. Topics of interest include, but are not limited to, all aspects of smart computing such as pervasive/ubiquitous computing, cloud computing, sensor networks, internet of things, big data analytics, security and privacy, social computing, cognitive computing, cyber-physical systems, smart buildings, smart cities and grids. We encourage submissions that showcase fundamental research to address challenges in enabling Smart and Connected Communities. Submissions should be targeted to one of the following five major areas:

- Smart Cyber-Physical Environments and Energy/Water/Agriculture/Transportation/Healthcare/Banking Infrastructure
- Security, Privacy, and Economics in Smart Environments
- Smart Computing Technologies
- Future Smart Computing Paradigms
- Smart Human Environments, Health, Entertainment, and Social Activities
- Smart Energy Management and Analytics'

Submission Guidelines

Paper submissions should be no longer than 8 pages and formatted according to the IEEE conference template. Papers must be submitted electronically as PDF files, through EasyChair.

All submitted papers will be subject to peer reviews by Technical Program Committee members and other experts in the field. All presented papers will be published in the conference proceedings and submitted to the IEEE Xplore Digital Library. Selected high-quality papers will be invited to submit (with substantial extension) to a special issue of the Elsevier Journal on *Pervasive and Mobile Computing* (SCI indexed).

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Looking for Collaborators!

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