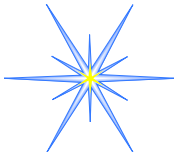
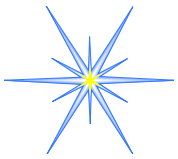


Research Challenges and Solutions for IoT/CPS
(a few from the many*)

John A. Stankovic
BP America Professor
University of Virginia

** See: Research Directions for the Internet of Things, invited paper, IEEE Internet of Things Journal, inaugural issue, Vol. 1, Issue 1, Feb. 2014, pp. 1-7.*



Vision – A Smart World

Smart Buttons

Smart Homes

Smart textiles

Smart City

Smart World

IoT/CPS

Smart Watch

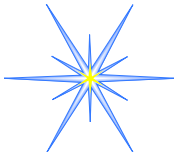
Smart Phone

Smart Skin

Smart Pills

Smart Swarms of Drones

University of Virginia



Vision

- What will it really take to build a smart world?
- Human analogy

100 Trillion Devices on the Internet

From the Washington Post

Consumers don't find smart homes all that smart

ASSOCIATED PRESS FILE PHOTOS

ABOVE: Former Nest CEO Tony Fadell talks about his company's product updates during a 2015 news conference in San Francisco. BELOW: A Nest Cam surveillance video camera was released as part of Google's attempt to turn homes into yet another thing that can be controlled and tracked over the Internet.

tect smoke alarm hit early problems that required the company to disable its most innovative feature — the ability to wave your hand under the detector to stop the alarm. (It was a particularly attractive feature for bad or at least smoke-heavy cooks.) The company also fielded very public complaints about faulty software that, as The New York Times reported, literally left people in the cold. Then, earlier this year, Nest announced that it would stop supporting the Revolv, a smart home hub that it acquired along with a smart appliance firm of the same name in 2014.

All of these announcements served, in some capacity, to highlight problems consumers are having with the smart home market. It sounds pretty great to have thermostats, light bulbs, ovens and security systems that anticipate our every move. The reality has been something less wonderful — a fractured market of occasionally buggy appliances that work with some, but not all, of the systems out there.

And, perhaps most tellingly, despite the public problems Nest was facing, no single company has positioned itself as an alternative.

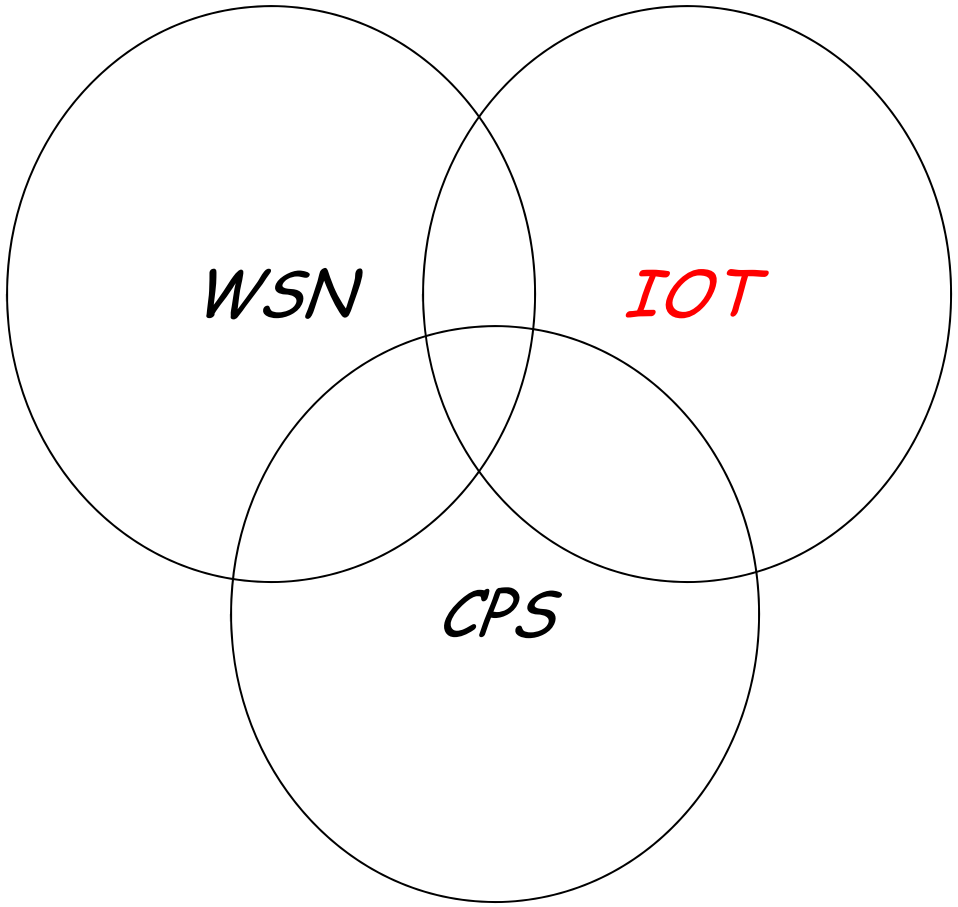
So, beyond the early adopters, consumers right

See **HOMES**, Page 11

A Long Way to Go

University of Virginia

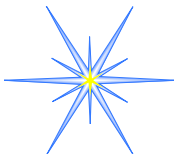
Research Communities



WSN – Wireless Sensor Networks

CPS – Cyber Physical Systems

IOT – Internet of Things



WSN – Wireless Sensor Networks

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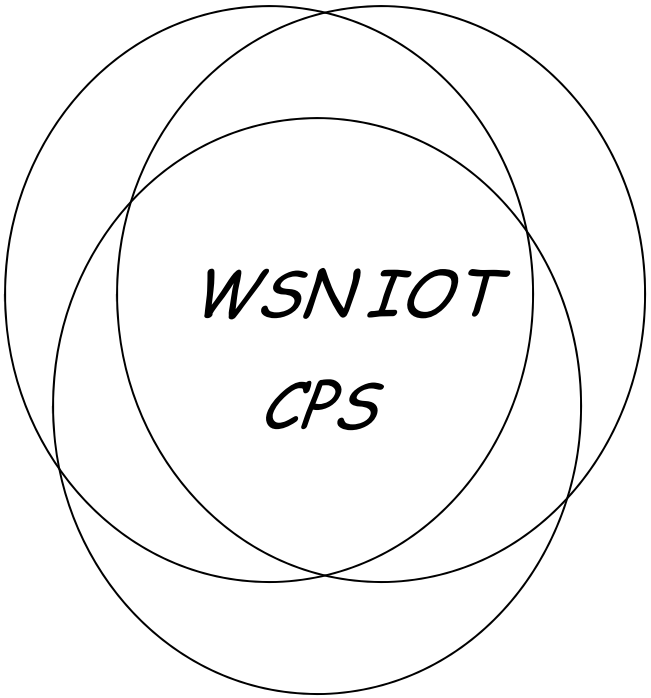
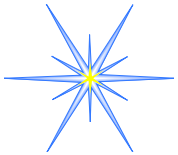
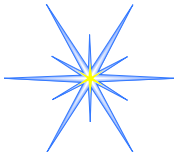


More and More Overlap
Especially as IoT Matures
(safety)



Take Away Message

- IOT Generation 1
  - Industry products
  - Relatively simple capabilities
  - Growing rapidly with M2M, IIOT, Smart Cities, IONT, IOHT, …
- IOT Generation 2/3
  - Towards a truly smart world
  - Many research questions (of CPS)



3 Overarching Research Qs

- Systems of Systems
  - Direct and Indirect Dependencies and Conflicts <at run time>
- Scaling/Density/Uncertainty
  - To 10-100s of trillions of devices and 100s of millions of apps
- Humans-in-the-Loop/Realisms
  - Behaviors and Physiology

Smart Cities

- Many services across many domains

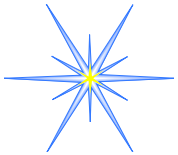
Emergency
- *Fire/Explosion Management*
- *Evacuation Aid*
- *Inclement Weather Alert*
- *Health-Care Dispatch*
- *Etc.*

Public Safety
- *Road Accident Management*
- *Risky Area Monitor*
- *Potential Terrorist Monitor*
- *Surveillance Drone*
- *Etc.*

Environment
- *Street Lights*
- *Robots Management*
- *Waste Management*
- *Pollution Control*
- *Etc.*

Transportation
- *Adaptive Traffic Light*
- *Emergency Vehicle Monitor*
- *Road Condition Monitor*
- *Traffic on Special Events*
- *Etc.*

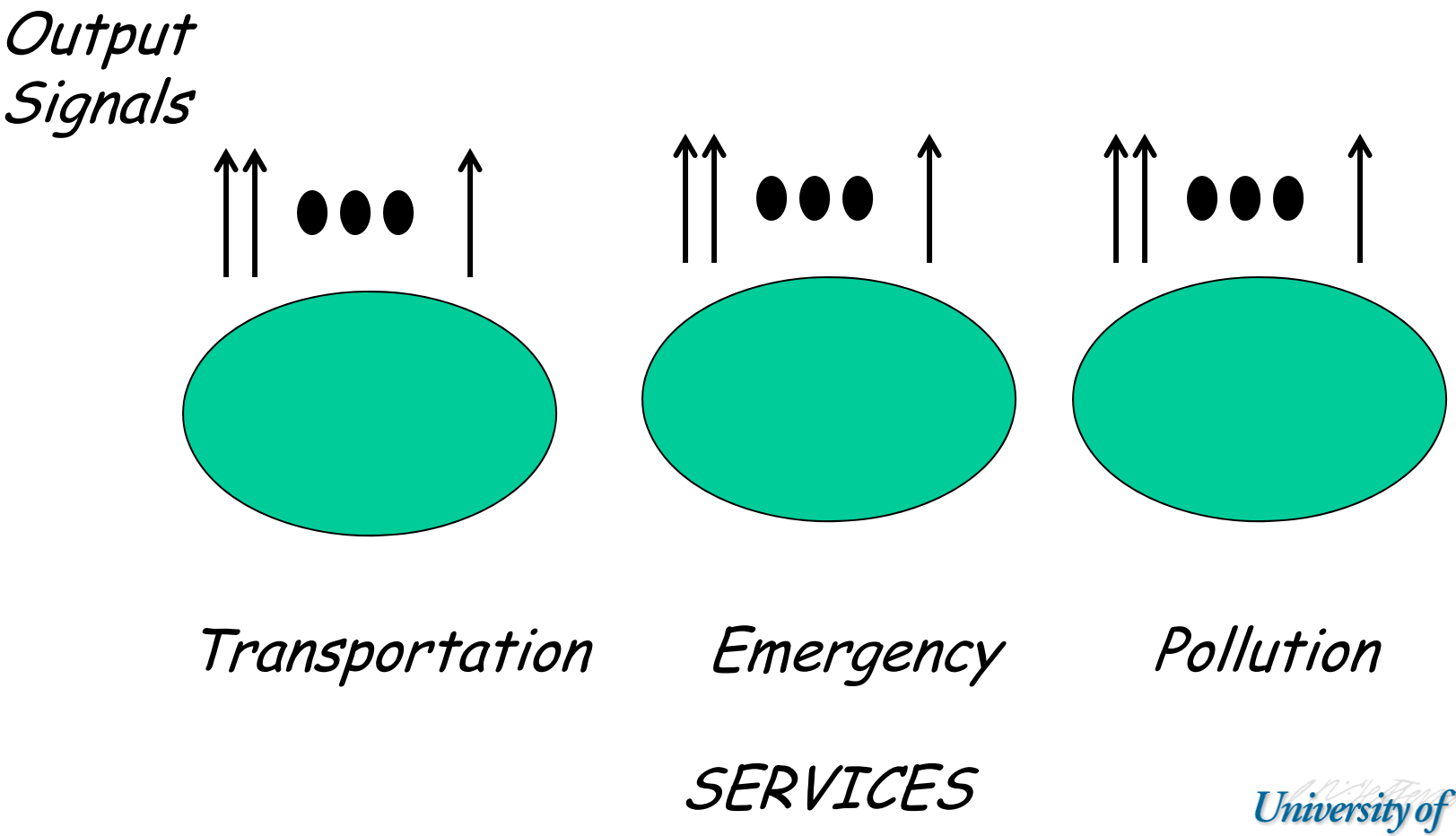
Energy
- *Water Usage Monitor*
- *Energy Usage Monitor*
- *Solar Energy Generation Optimization*



(New) System of Systems

- Operating in continuously evolving and open environments
- 2nd ary effects on environment
- Multi-scale in time and space
- Humans-in-the-Loop: safety
- Real-Time
- Independently developed services and apps

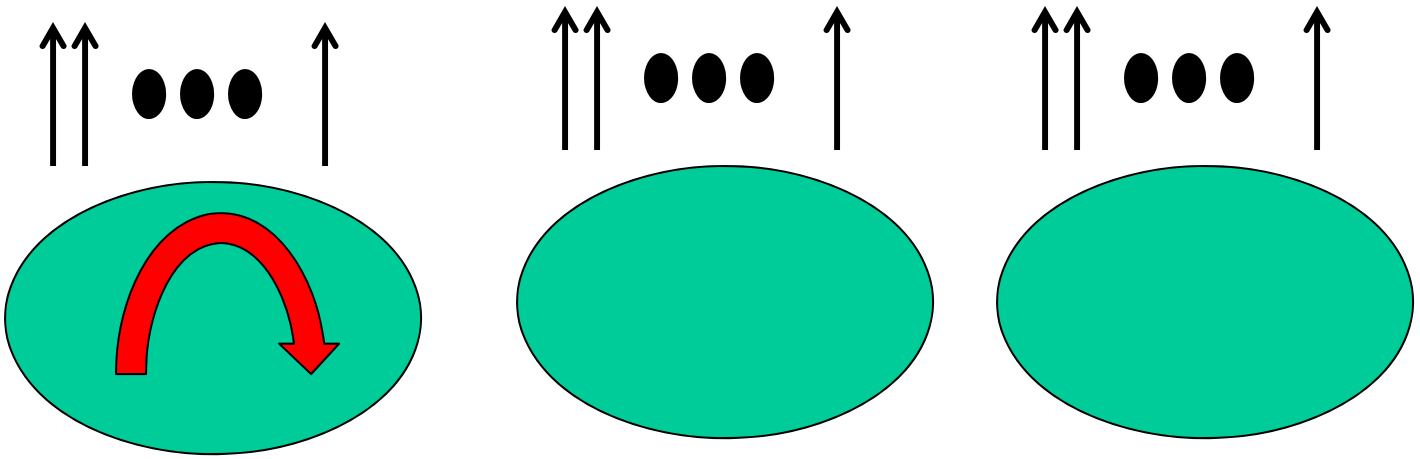
Services in a Smart City



Services

Research on : correctness, safety, security, privacy, realisms …

Output Signals



Transportation *Emergency* *Pollution*

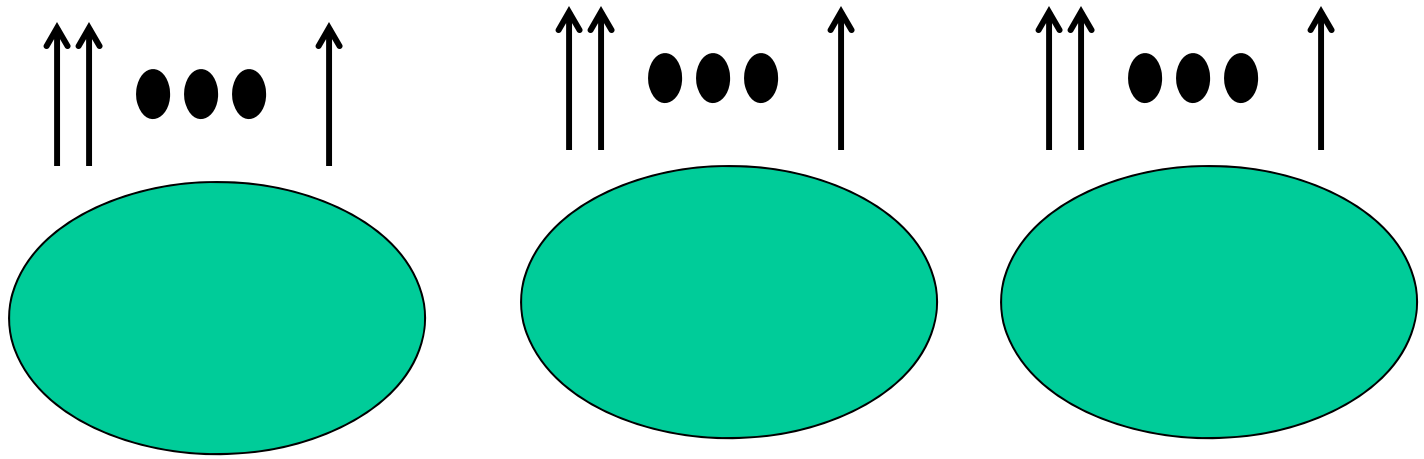
SERVICES

Services

Secondary/Implicit Impact

Impacts Pollution

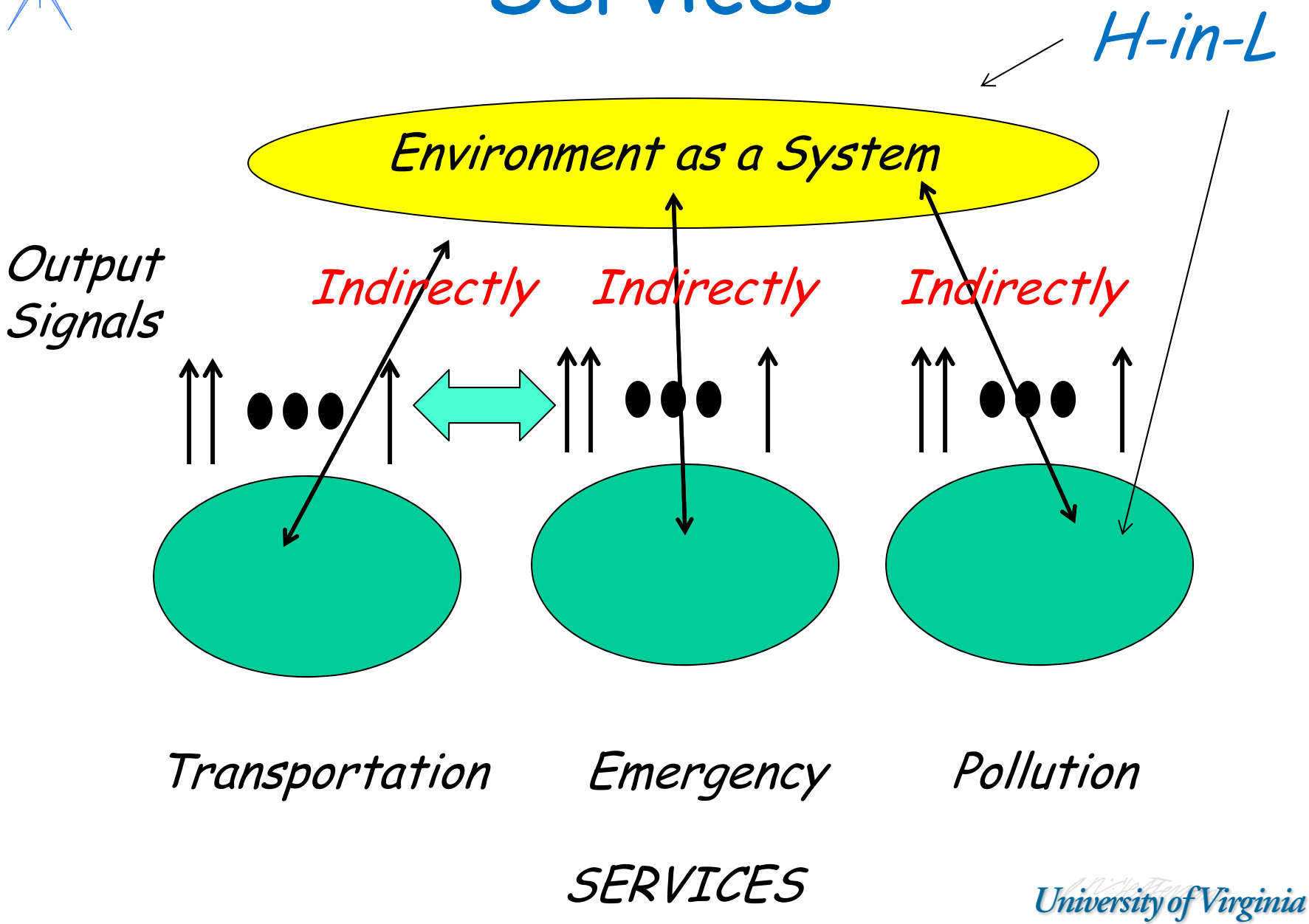
Impacts Transportation



Transportation *Emergency* *Pollution*

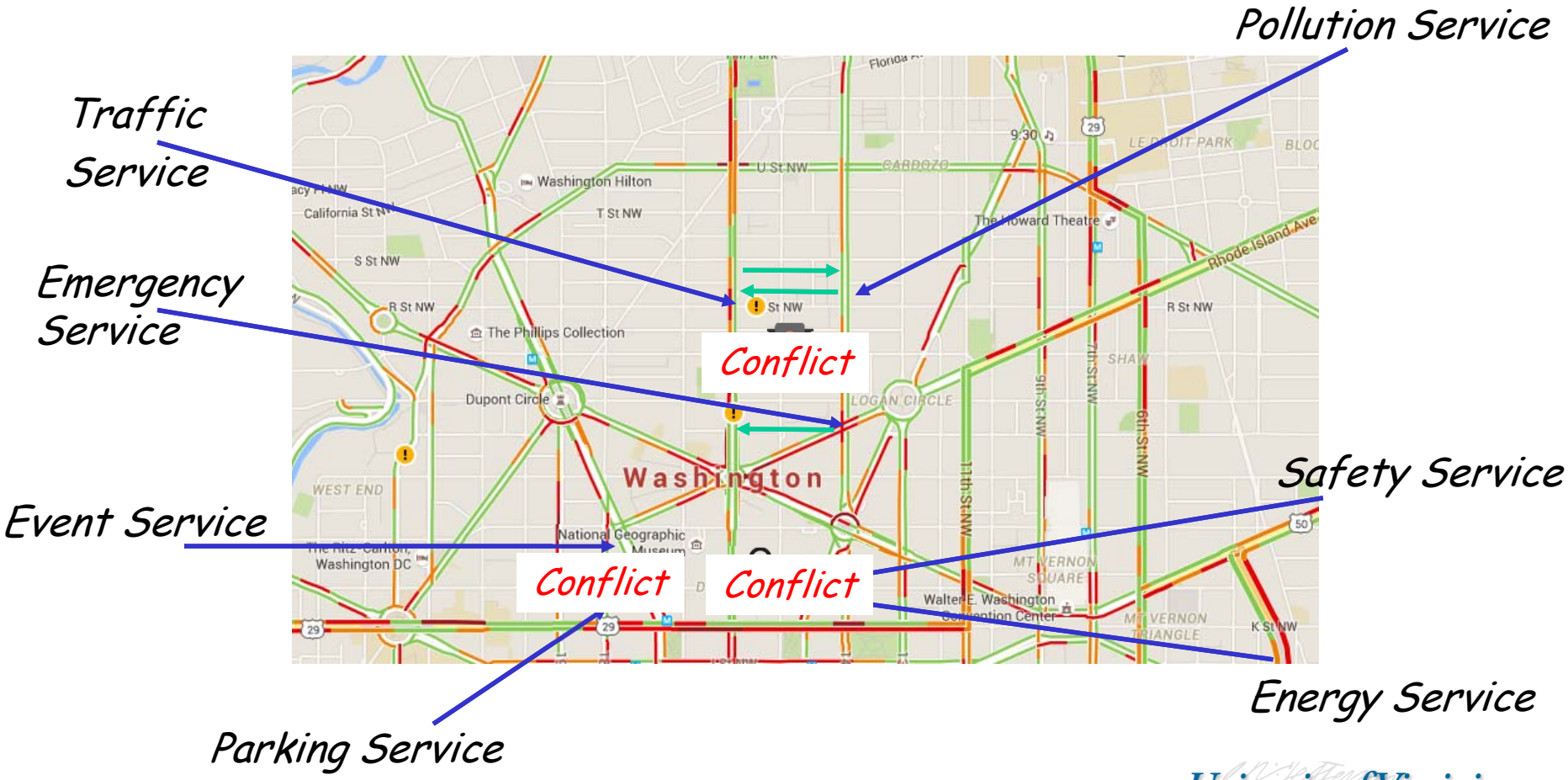
SERVICES

Services

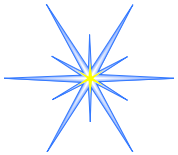

H-in-L
Environment as a System
Output Signals
Indirectly
Indirectly
Indirectly
Transportation
Emergency
Pollution
SERVICES

Conflicts/Complicated

- Conflicts among Services in Smart Cities



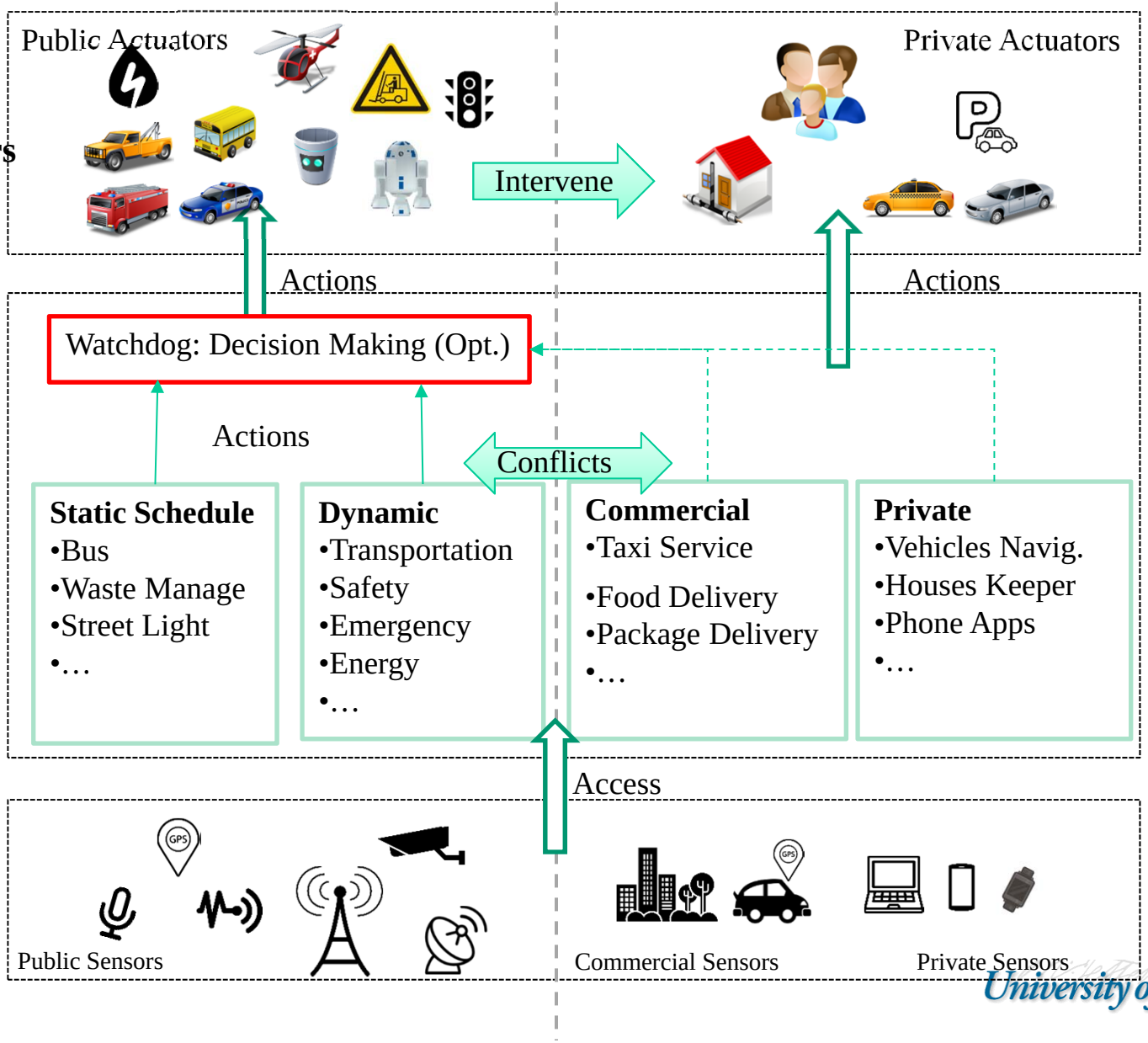
University of Virginia



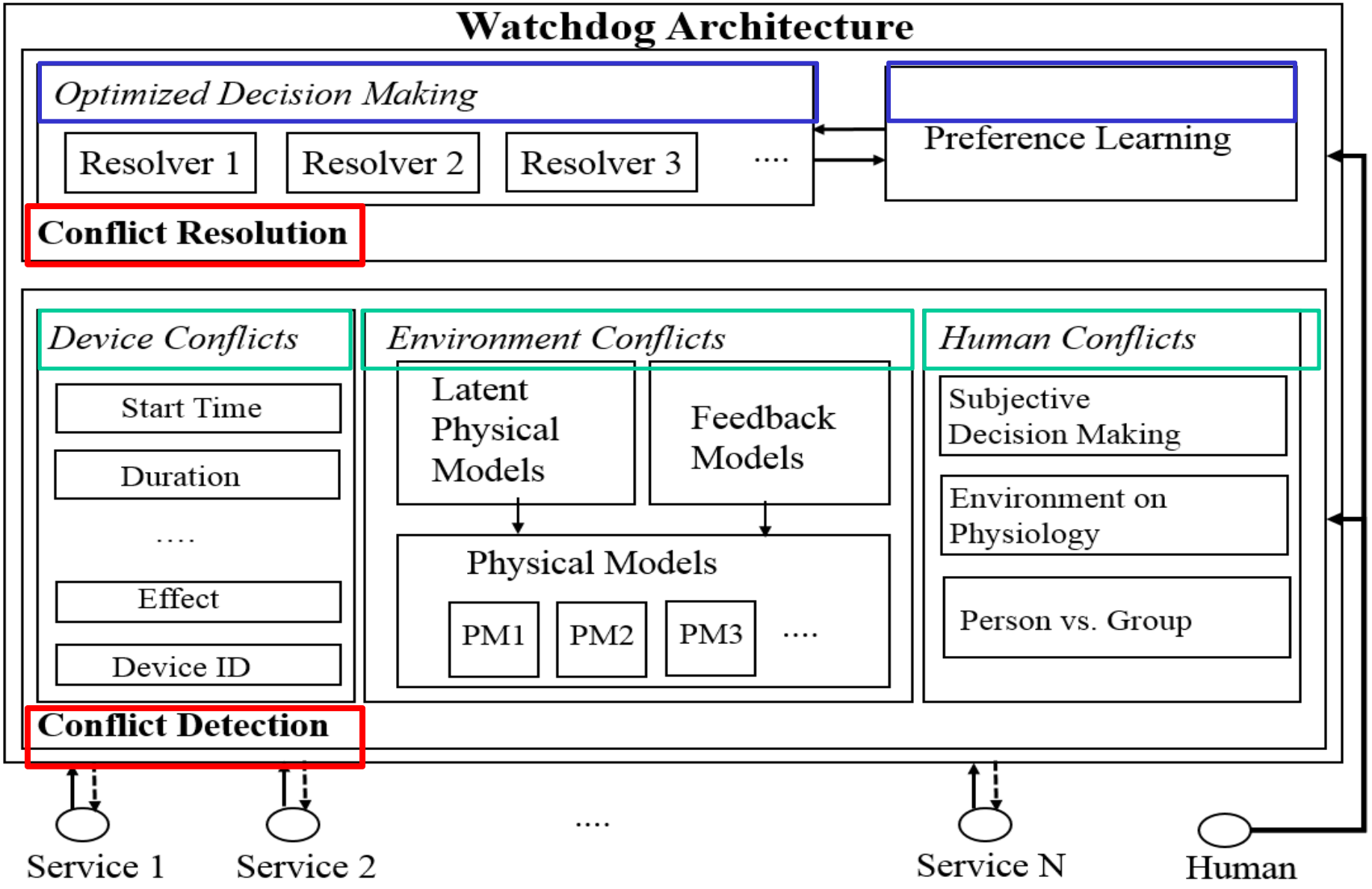
Important

- Effects are not instantaneous
  - May not occur for a time into the future
  - May last over a long interval of time
- Effects not in one location
  - An entire (dynamically changing) area may be affected

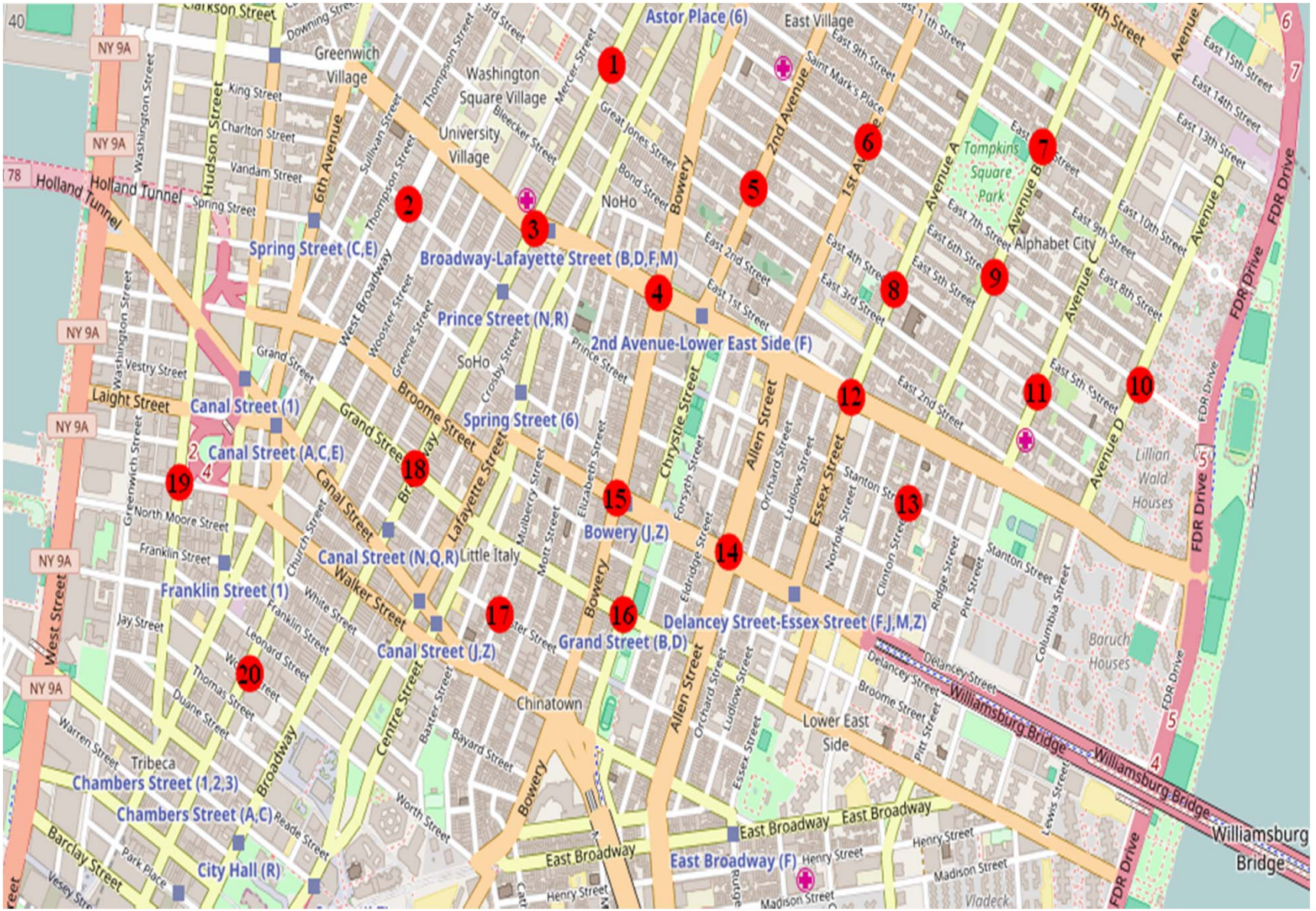
Smart Cities



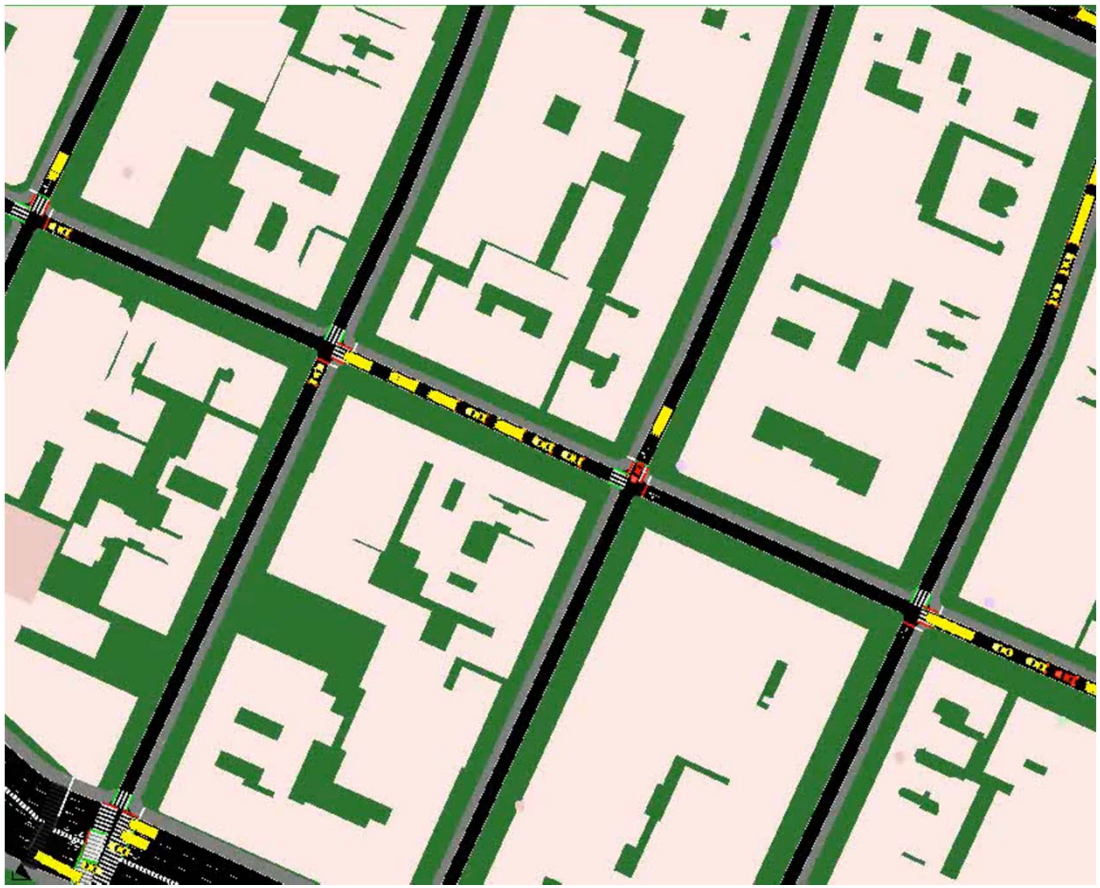
Soln: Watchdog Architecture



Smart Manhattan *with CityGuard*



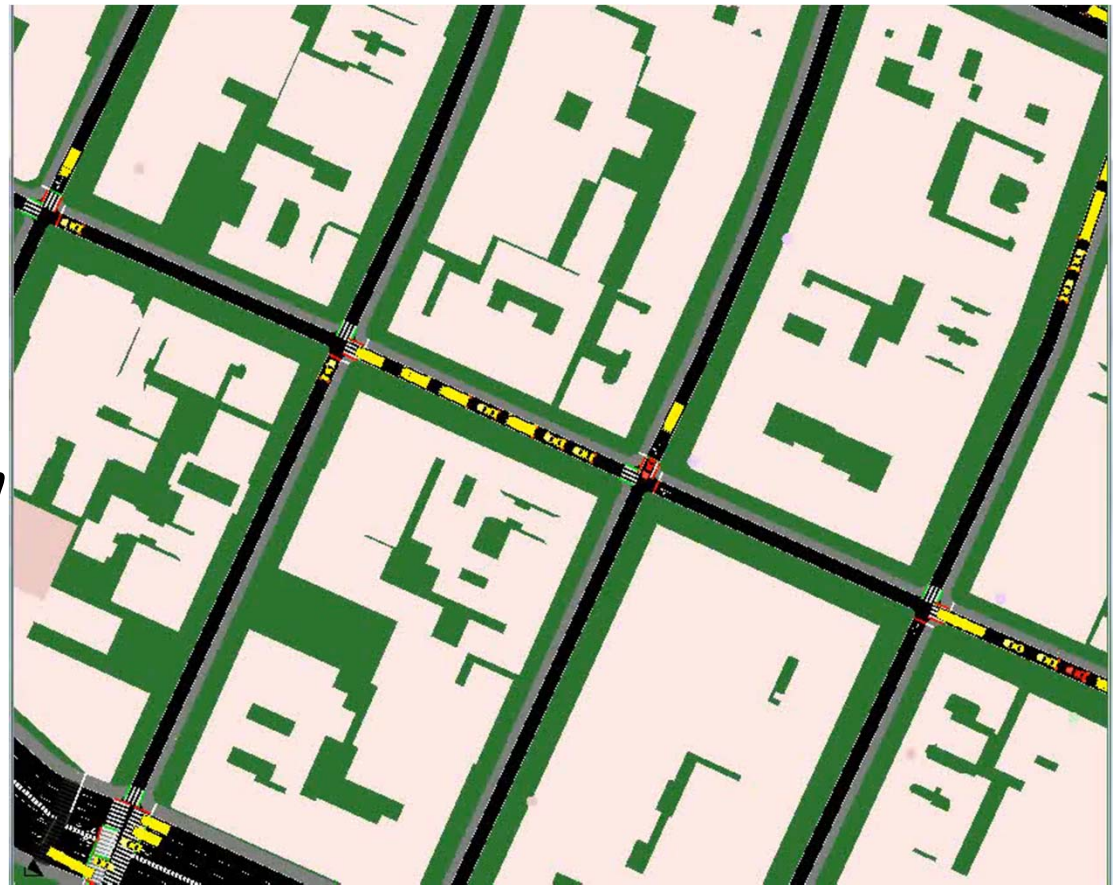
Without Smart Services



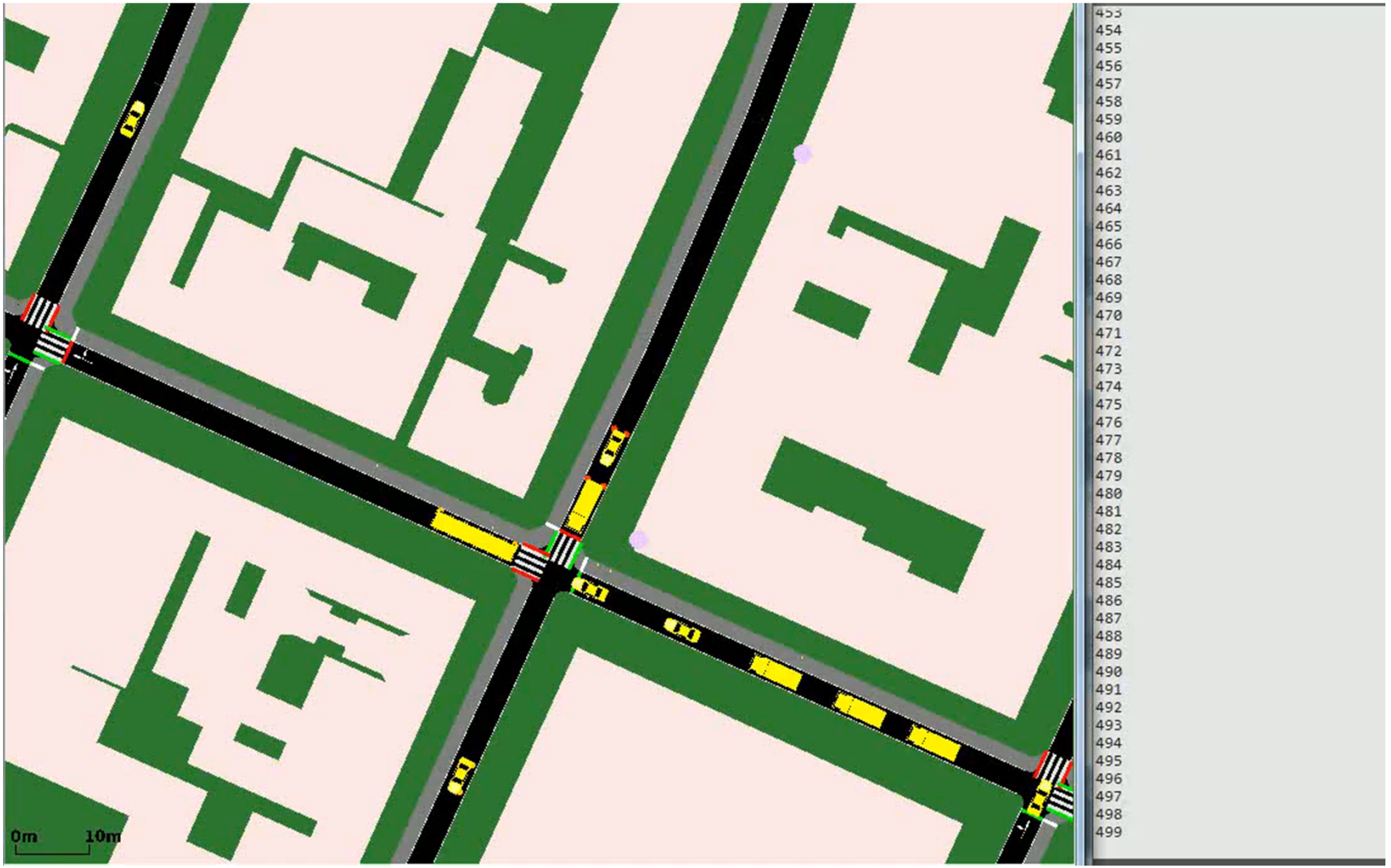
With Smart Traffic Services

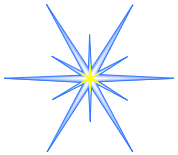
5 Services

- *Congestion*
- *Pedestrian*
- *Air Pollution*
- *Noise*
- *Emergency*



With CityGuard

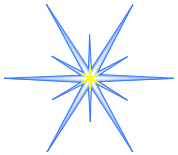




Overall Metrics

- Average speed
- Average delay
- Waiting times
- Noise level
- Air pollution levels

- See our paper



Scaling and Density Issues

- 10,000 devices/person
  - Ownership/Sharing
  - Configuration and Reconfiguration
  - Management
  - Privacy and Security
  - Sharing –A sensing and actuation utility
- Runtime Dynamics Paramount
  - Interference/Conflicts
  - Safe
  - Operational

Vision

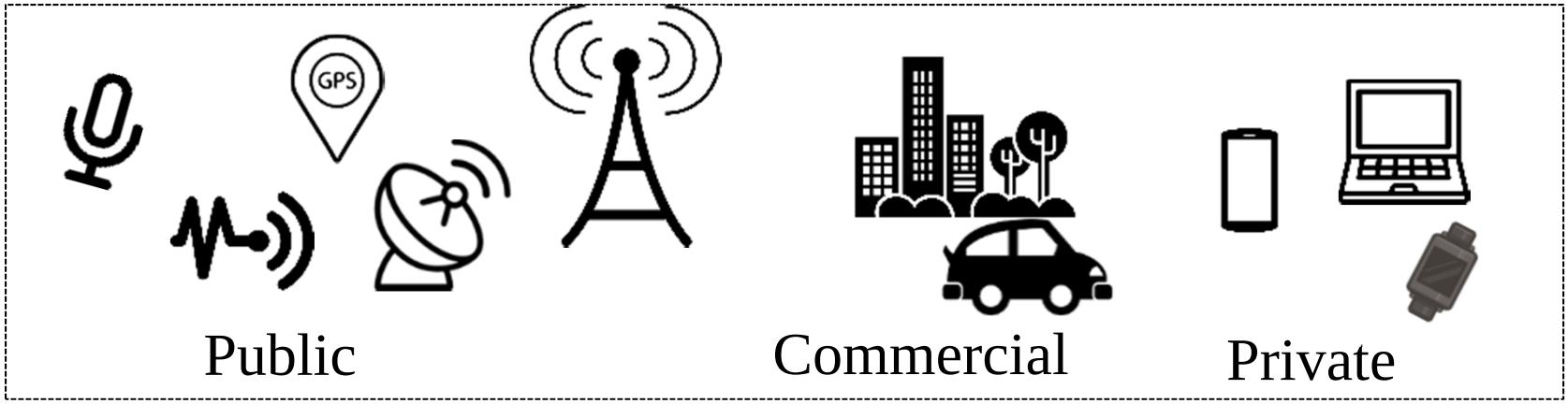
- Need a plug-n-play sensing and actuation utility



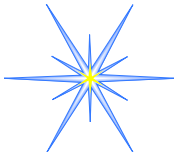
Need a S&A Utility

Mobility

Sensor and Actuation Layer

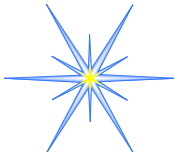


Ownership Sharing Management



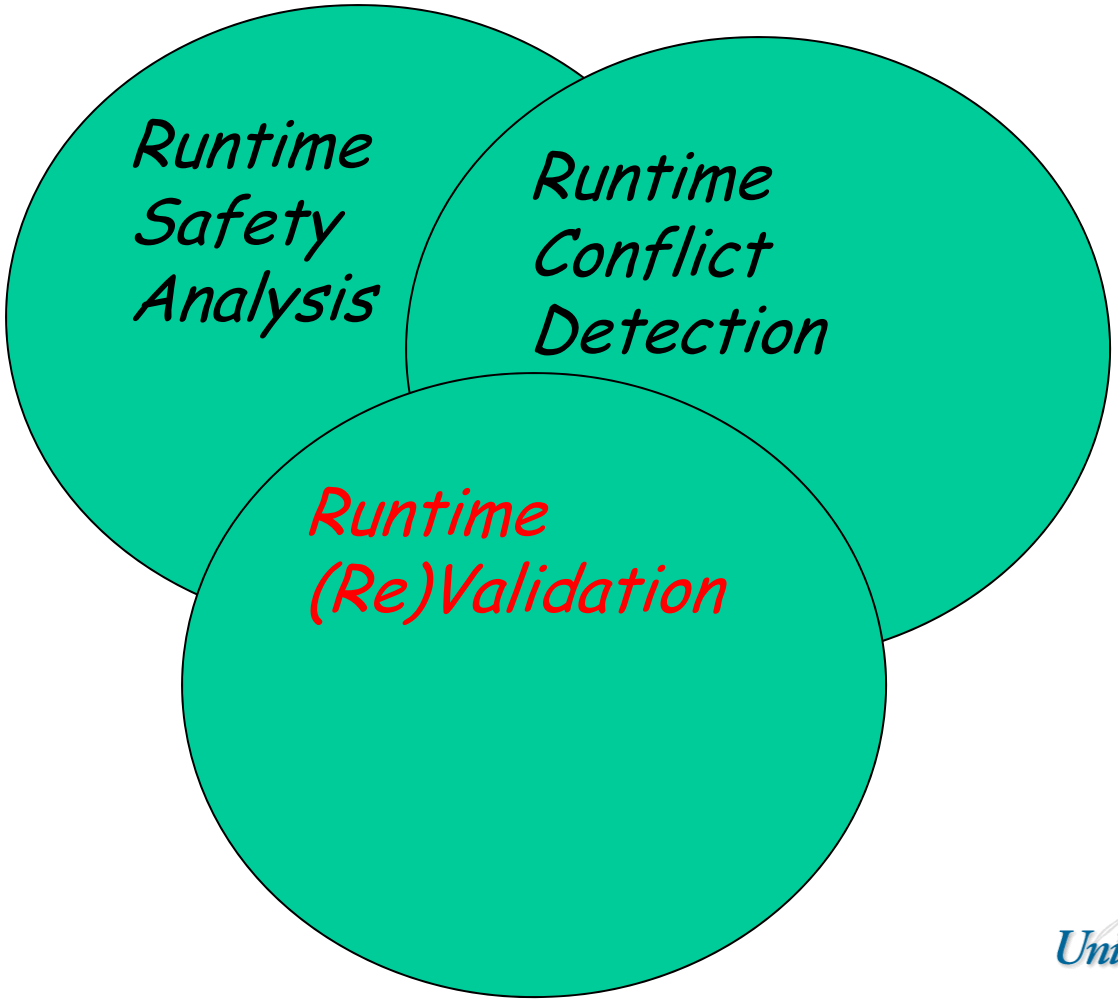
Characteristics of S&A

- Handles density
  - 5G, LEDs, White space, …
- S and A receptacles (wireless and not)
  - Plug and play
- Security
- Privacy
- Robustness
- Energy

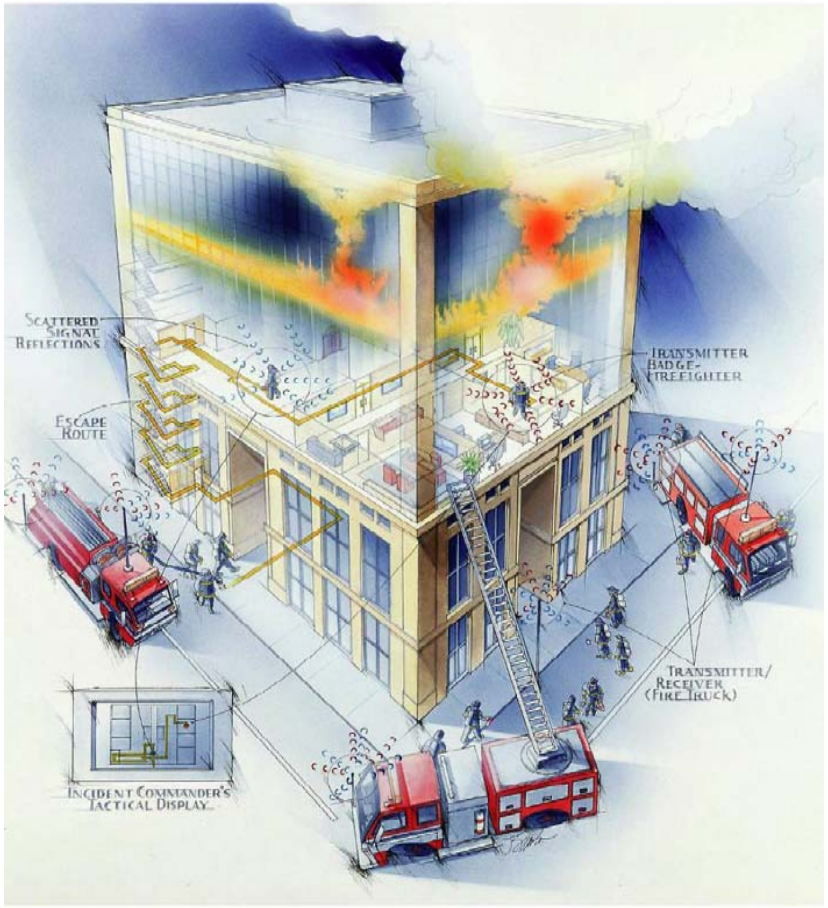


Runtime Dynamics

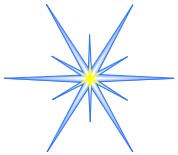
Three related needs



(Re)Validate: Run Time Assurance (RTA)



- Safety Critical
- Long Lived
- Dynamics of Environmental Changes
- Influences Correctness/Safety



Soln: Validate-Aware Cyber

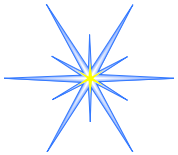
- Validate and Re-validate that system is still operational (at semantics level)
  - Emulate sensor readings
  - Reduce tests: focus on key functionality
  - Overlap tests and system operation
  - Evolve required tests
  - SW design for ease of RTA

See Run Time Assurance paper in IPSN 2010.

Humans-in-the-Loop

Important but only one type

University of Virginia



Internet of Healthcare Things

Vision

WebMD
Big Data Collections
Analytics
Data Mining

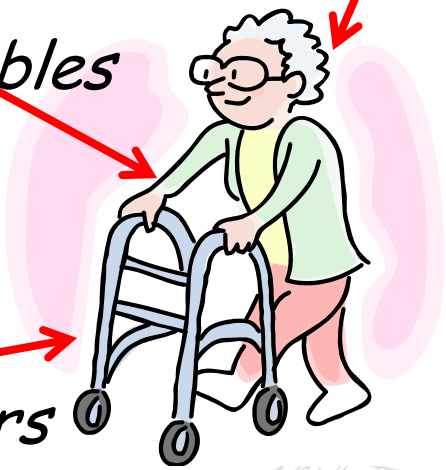
General Population

Actuations
Holistic

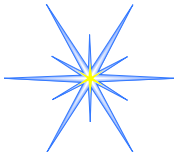
Nano-pills
Pacemaker

Wearables

Sensors

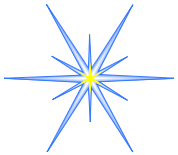


University of Virginia



Research Directions

- Integrate control with Big Data
- Conflicts and Safety
- Realisms
- Human in the loops-of-loops



Integrate with Big Data

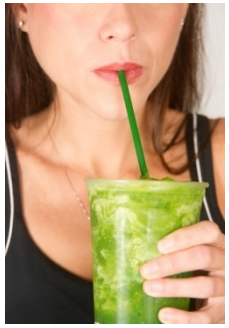
- WebMD, …
- New Big Data Collections

- Real-Time Analytics (NLP)
- Extract right information at the right time (NLP/DM)
  - Personalized
  - Context dependent
  - Avoid overwhelming amounts of data

Conflicts

Drink kale juice daily as it is rich in fiber and vitamins

App1



WebMD

Avoid sudden increase of cruciferous vegetables if you are on Coumadin

Accessing Web

Unknown Relationships

S. Preum, A. Mondol, M. Ma, H.Wang, and J. Stankovic, PreCluDe: Conflict Detection in Textual Health Advice, Percom 2017, March 2017.

University of Virginia

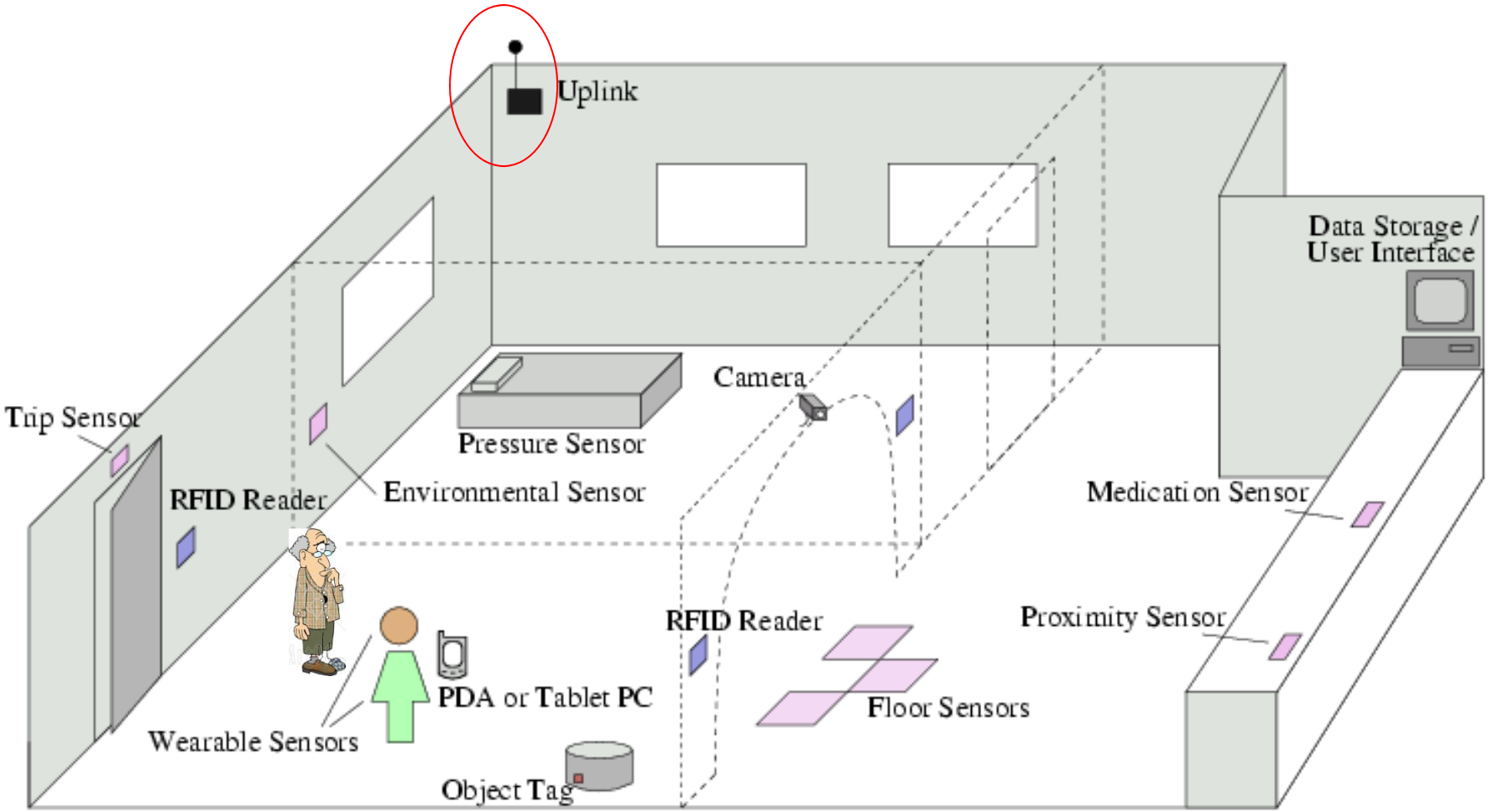
Conflicts

- App2: Exercise today
  - But person is 8.5 mo. pregnant and needs to keep feet elevated
- Read info on WebMD - exercise twice per day when pregnant

Context/Person Dependent

Overall: Confusing/unsafe Information

Realisms - Home Health Care

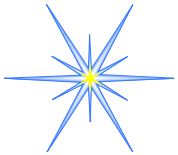


Realisms

- Humans and their Behaviors are not simple
- Human Physiology is not simple
- Environments are not simple

Realisms - Behaviors

- Activity Recognition (AR) of ADLs
  - Higher accuracy required
  - Overlapped activities
  - Across room activities
  - Many realities (missing data) ….



Behaviors

- Normal behavior is very complex
  - Per day
  - On Wednesdays
  - Two times per week
  - Every other month
  - In summer when condition X exists
  - Grouping of activities
  - Context dependent
  - …

E. Hoque, R. Dickerson, S. Masud Preum A. Barth, M. Hansen, and J. Stankovic, Holmes: A Comprehensive Anomaly Detection System for Daily In-Home Activities, DCOSS, June 2015.

Physiology

- Example: Impact Heart Rate
- Secondary Impact: 7800 physiological parameters

decrease

increase

S. Munir, M. Ahmed, and J. Stankovic, EyePhy: Detecting Dependencies in Cyber-Physical System Apps due to Human-in-the-Loop, Mobiquitous, July 2015.

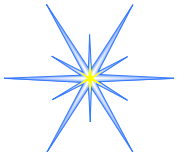
University of Virginia

Environment – Acoustics

Physiological: Sneezing, nose blowing, sniffling, clearing throat, hiccup, eating, burp, humming, laughter, drinking, snoring

Objects: phone vibrating or ringing, typing, mouse wheel, unwrapping food, papers rustling, clothes rustling, television, piano, moving furniture, doors opening and closing, objects dropping or moving, footsteps, pouring liquid, coffee percolation, dishwasher, cleaning sounds

Ambient: truck backing up, siren, birds chirping, passing airplane, traffic, motorized tools (lawnmower, etc)



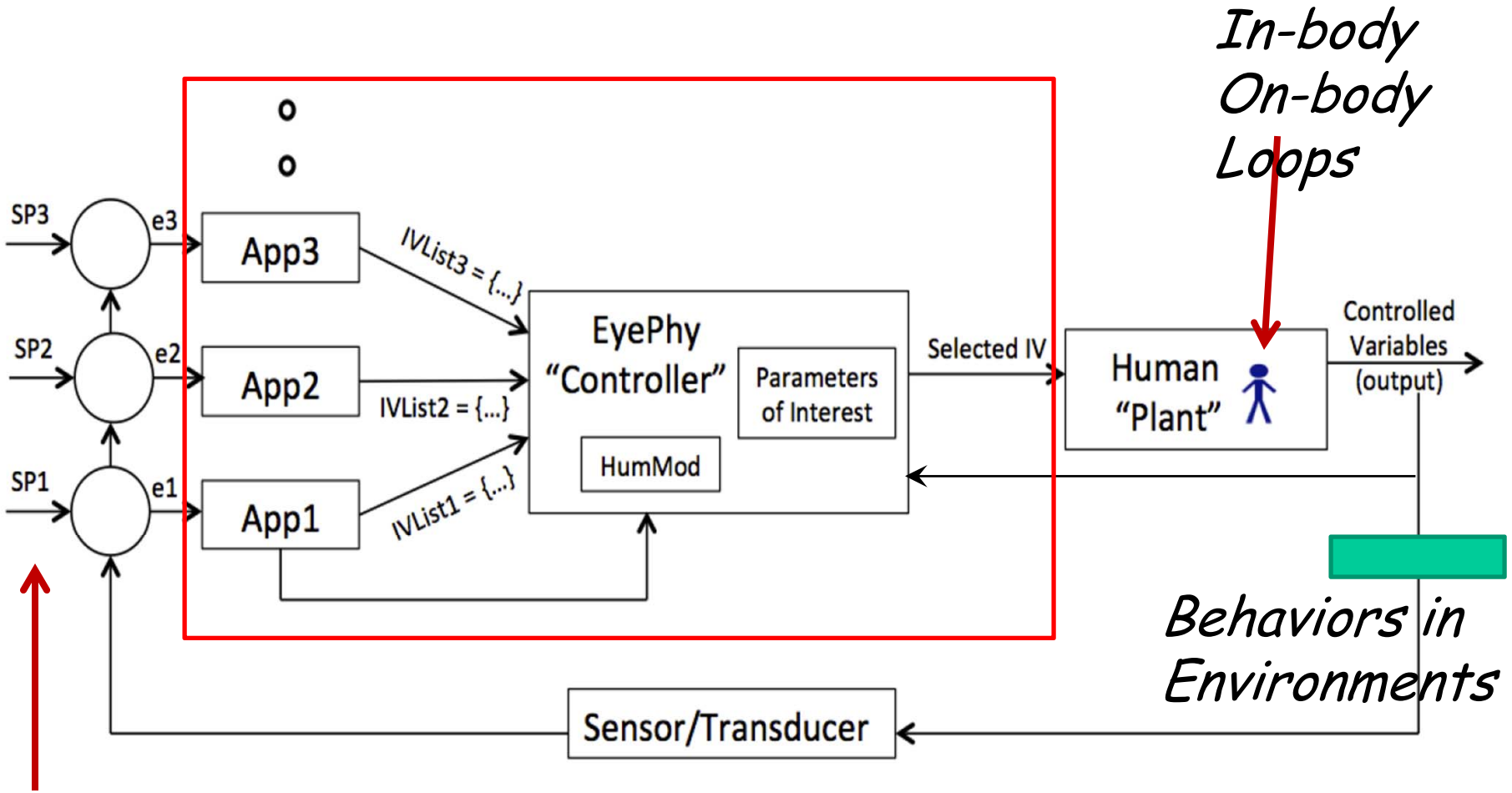
Main Point

- Many current solutions work ONLY when humans and environments are (assumed to be) *very constrained*
  - *Often won't work in open IOT systems*
  - *Need to be more adaptive, dynamic and personalized*

Humans-in-Loops-of-Loops

- In-Body
- On-Body (wearables: a revolution)
- In-situ (in home)
- In-situ (out-of-home)
- Medical Web sites
- Continuously growing Big Data information

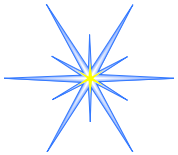
Control Loop Architecture



S. Munir, M. Ahmed, and J. Stankovic, EyePhy: Detecting Dependencies in Cyber-Physical System Apps due to Human-in-the-Loop, Mobiquitous, July 2015.

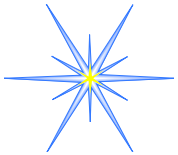
Loops of Loops Research

- Behavioral, physiological, environmental models for feedback loops
  - Uncertainties
- Stochastic Semantic Hierarchical Control
  - Duration of effects
  - Uniqueness of individuals
  - Predictive control
  - Mathematics of control theory?



Summary - What's New

- Systems of systems
  - Independently developed/open envir.
  - Competing objectives
  - High degree of interference
  - (non-linear, non-stationary, state space ill defined and evolving)
- Density and Scale
- Human behaviors and physiology as integral part of systems



Summary: IoT/CPS

- Runtime Realisms are paramount
  - CPS SW development improvements needed
    - *aware software
- Incredibly complex runtime dynamics
  - Safety, security, privacy, …