Enabling Resilient Situational Awareness in Disasters: A Cross-Layer Approach

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The Team and Collaborators (over the years)

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- **SRI Inc.**
  - Carolyn Talcott,Grit Denker,Minyoung Kim, Mark-Oliver Stehr, Murat Akbacak
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- **Honeywell Inc.**
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Government Agencies
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- Montgomery County, Maryland, City of Ontario, City of Los Angeles, State of CA OES, City of Irvine, County of Orange, City of Gainesville
- Washington Suburban Sanitary Commission, LA Dept. of Water and Power, DC Water, Orange County Public Works, Irvine Ranch Water District, DC Water
- SPAWAR, US AIrForce, US Marine Corps

responsphere

(((SCALE))) rescue
Safe Community Alerting Network
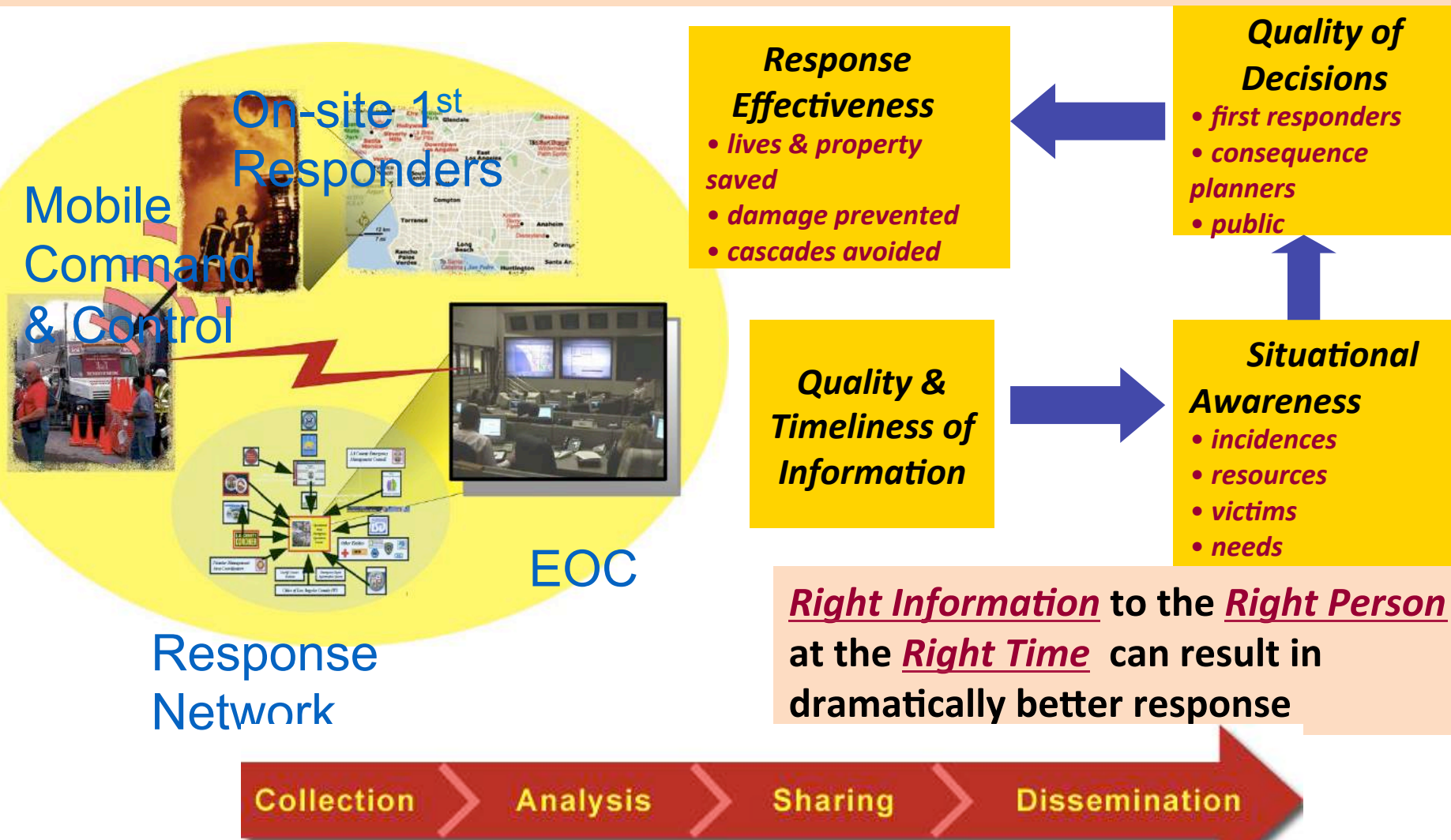
SAFIRE: Situational Awareness for Firefighters

CYPRESS
Cyber Physical RESilience &Sustainability

Project RESCUE (2003-2009)

Transforming the ability to collect, analyze, share and disseminate information within the responding organizations and the public

On-site 1st Responders

Mobile Command & Control

EOC

Response Network

Response Effectiveness
• *lives & property saved*
• *damage prevented*
• *cascades avoided*

Quality of Decisions
• *first responders*
• *consequence planners*
• *public*

Quality & Timeliness of Information

Situational Awareness
• *incidences*
• *resources*
• *victims*
• *needs*

Right Information to the ***Right Person*** at the ***Right Time*** can result in dramatically better response

Collection > Analysis > Sharing > Dissemination

Why are cities/communities interesting?

Urban population – Economies of the future
- 54% of global population(2014) ,majority (2050)

Communities Need Infrastructure and Services
- Functional - operation of lifelines, societal processes
- *Non-functional* - Efficient, Dependable, Cost-effective, Flexible, Predictable, Secure, Privacy Protecting

Many stakeholders with varying tradeoffs
service providers, consumers, administrators, businesses, organizations
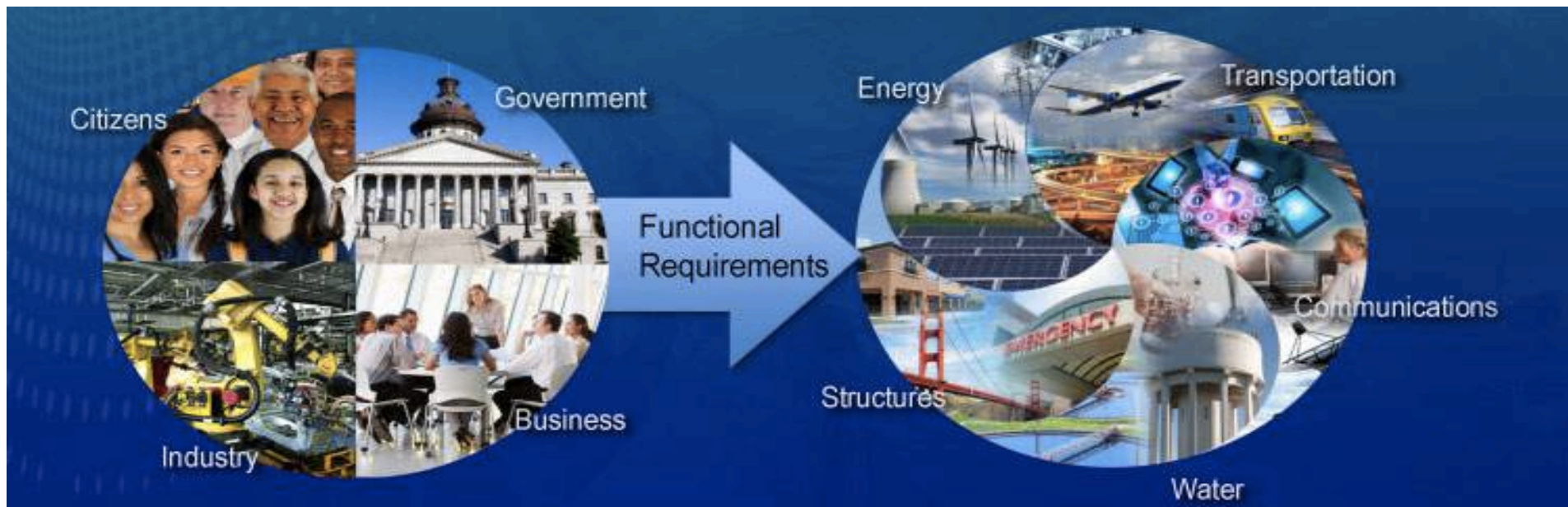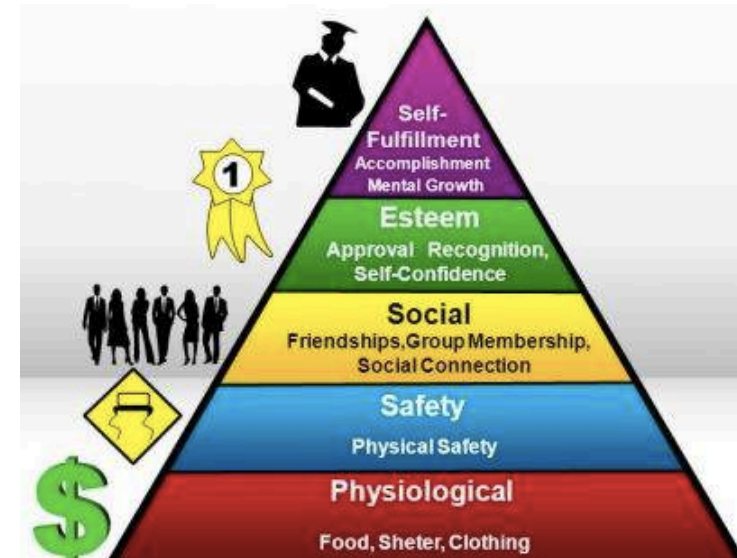
Internet of Things, Big Data, Cloud

YOUR HOME/COMMUNITY IN THE CLOUD ACCESSIBLE ANYTIME ANYWHERE

The IoT Revolution

- **Systems that empower everyday physical devices to connect to the internet to send & receive messages**
- **Over 50 billion devices connected by 2030**
- **Expected to reach a trillion by next decade**

The Mobile Revolution

- **6 billiion devices by 2020**
- **Mobile traffic to exceed 15 exabytes of data by each month by 2018**

The Big Data/Cloud Revolution

- **180 zettabytes of data (or 180 trillion gigabytes) in 2025 from <10 zettabytes in 2015,**
- **$203 billion big data analytics market in 2020?**

New Systems, New interactions, New vulnerabilities?

The Internet of "Broken" Things

IoT has reached its hype peak – Gartner

- Massive scalability
- Heterogeneity/Interoperability
- Security/Privacy
- DEPENDABILITY is key!

NO DEPENDABILITY,
NO INTERNET OF THINGS

For the Internet of Things to become a reality the sensor networks which form its backbone must provide dependable real-time information all the time, on time. The RELYonIT project team is working to ensure dependability by testing possible solutions on FIRE's test beds.
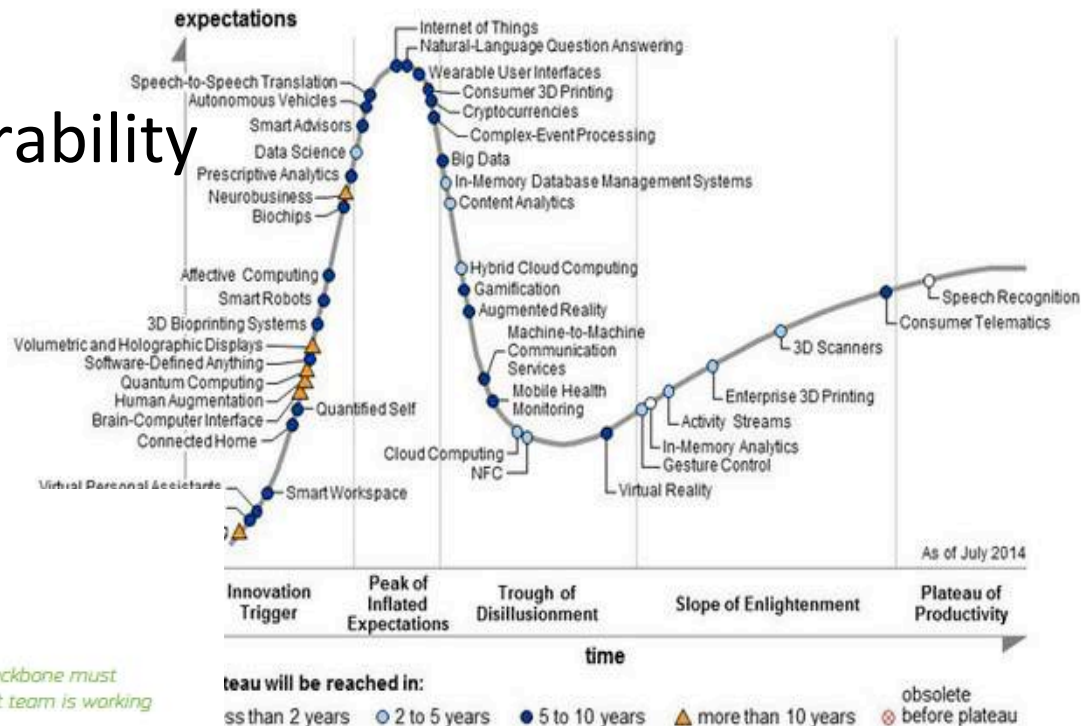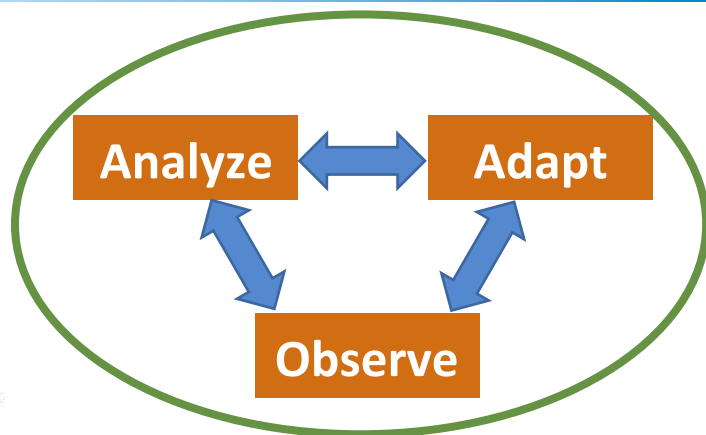
*"The term resilience refers to the ability to prepare for and **adapt to changing conditions** and withstand and **recover rapidly from disruptions**. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents - President Policy Directive 21 - Critical Infrastructure Security and Resilience February 12, 2013*
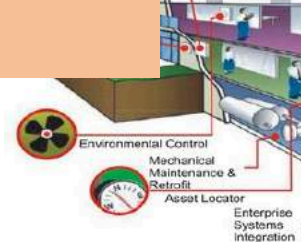
IoT-Enabled Smart Communities - Sample Projects

SCALE: Safe Community Awareness and Alerting

**SciFIRE:
Fire Situational Awareness in Smart Buildings**

AquaSCALE: Resilient Community-Scale Smart Water Infrastructure

SCALE (Smart Community Awareness and Alerting)
A SmartAmerica Project – Democratizing IoT

Extending the Internet of Things to Everyone: Residents of an affordable housing complex who cannot otherwise afford broadband are given smart community sensors. A resident, possibly elderly, is in distress and the sensor sends a signal to the nearest base station.

County Facility Equipped with Antenna

Cloud-based public safety awareness and alert system

MONTGOMERY HOUSING PARTNERSHIP

Dispatch Center

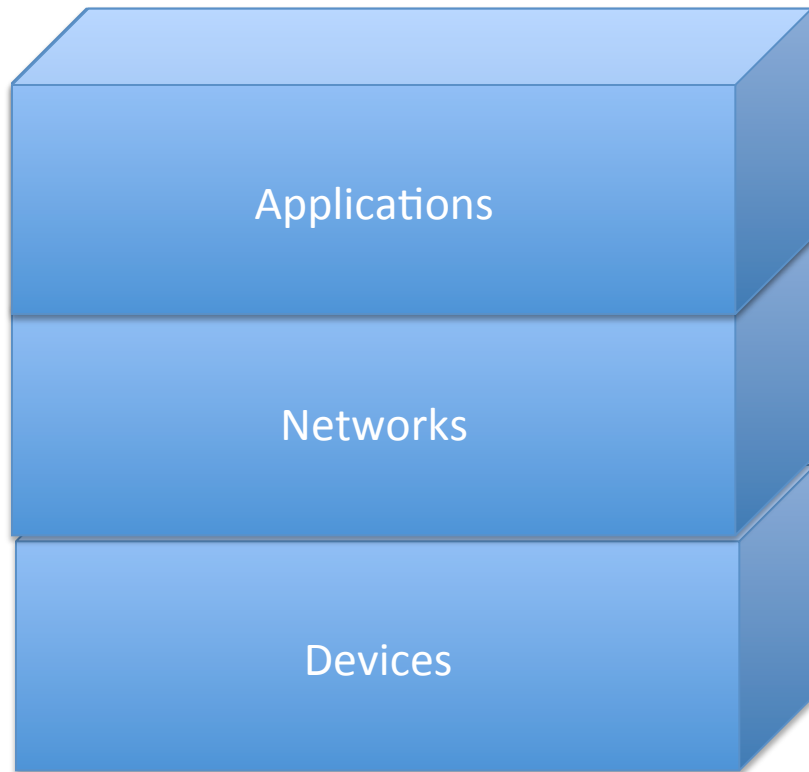Within minutes first responders arrive without any need for manual action by the person in distress

Emergency validated via mobile device; alert is sent to the dispatch center and a first response unit is sent to the resident in distress.

What We Learned (and are learning) from these experiences

Applications

Networks

Devices

What can go wrong?

- **Infrastructure component errors/failures**
  - Device Failures, Network Failures, Congestion and Overloads

- **Data Interpretation errors/uncertainty**
  - Uncertainty in Processing (e.g. speech/image processing)
  - Contextual errors (e.g cclusions to a light sensor)

- http://scale.ics.uci.edu
- Y. S. Uddin et al "The SCALE2 Multi-network Architecture for IoT-based Resilient Communities". in 2016 IEEE International Conference on Smart Computing (SMARTCOMP), 2016

SCALE Resilient Multinetworking: Infrastructure Resilience

Resilient Overlay Networking (GeoCRON)
Route around failures in underlying infrastructure by creating geo-aware overlays and passing message to a known reachable intermediate peer, which then forwards to destination (cloud server)

SDN Enabled Edge Server
OpenFlow capable switch will redirect the sensing data to local server when there are network failures that leave the cloud server unreachable.

Local Adhoc Mesh Network
SCALE client nodes are connected with to neighbors to form a local wireless mesh network to buffer sensing data and exchange traffic for local data analysis and aggregation.
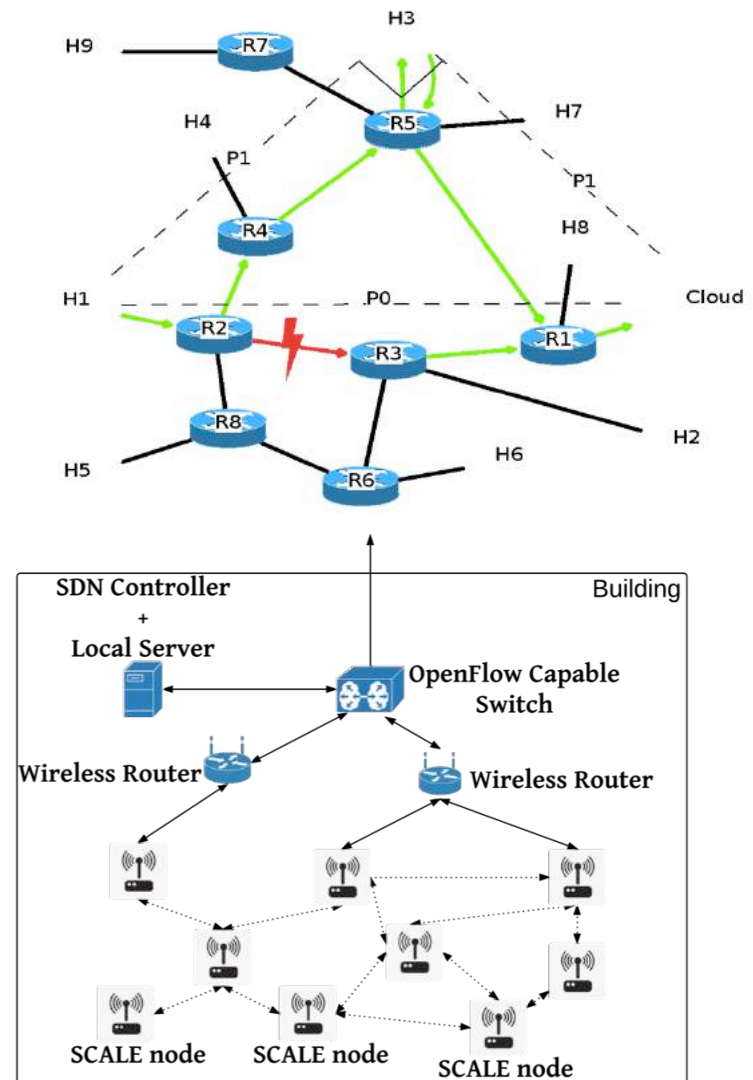
Techniques for Information Dependability

Data Interpretation errors/failures - Uncertainty in Processing (e.g. speech/image processing), Contextual errors (e.g occlusions)
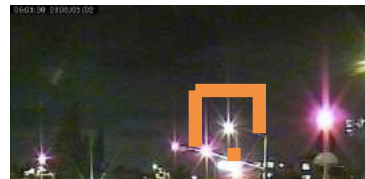
Smart Video Surveillance
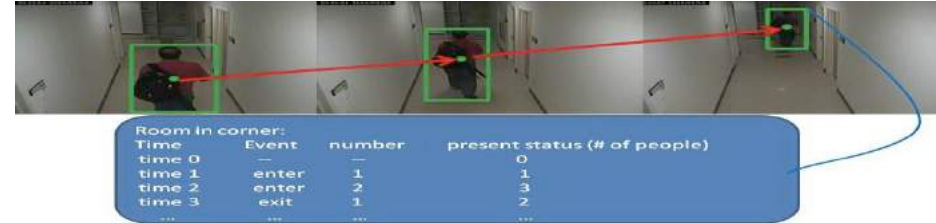
Data Cleaning via *Entity Resolution/ Dismabiguation*

- Face Recognition is challenging in a resource-constrained environment
- Connect the problem of person identification with entity resolution using RelDC (a graph-based entity resolution framework)
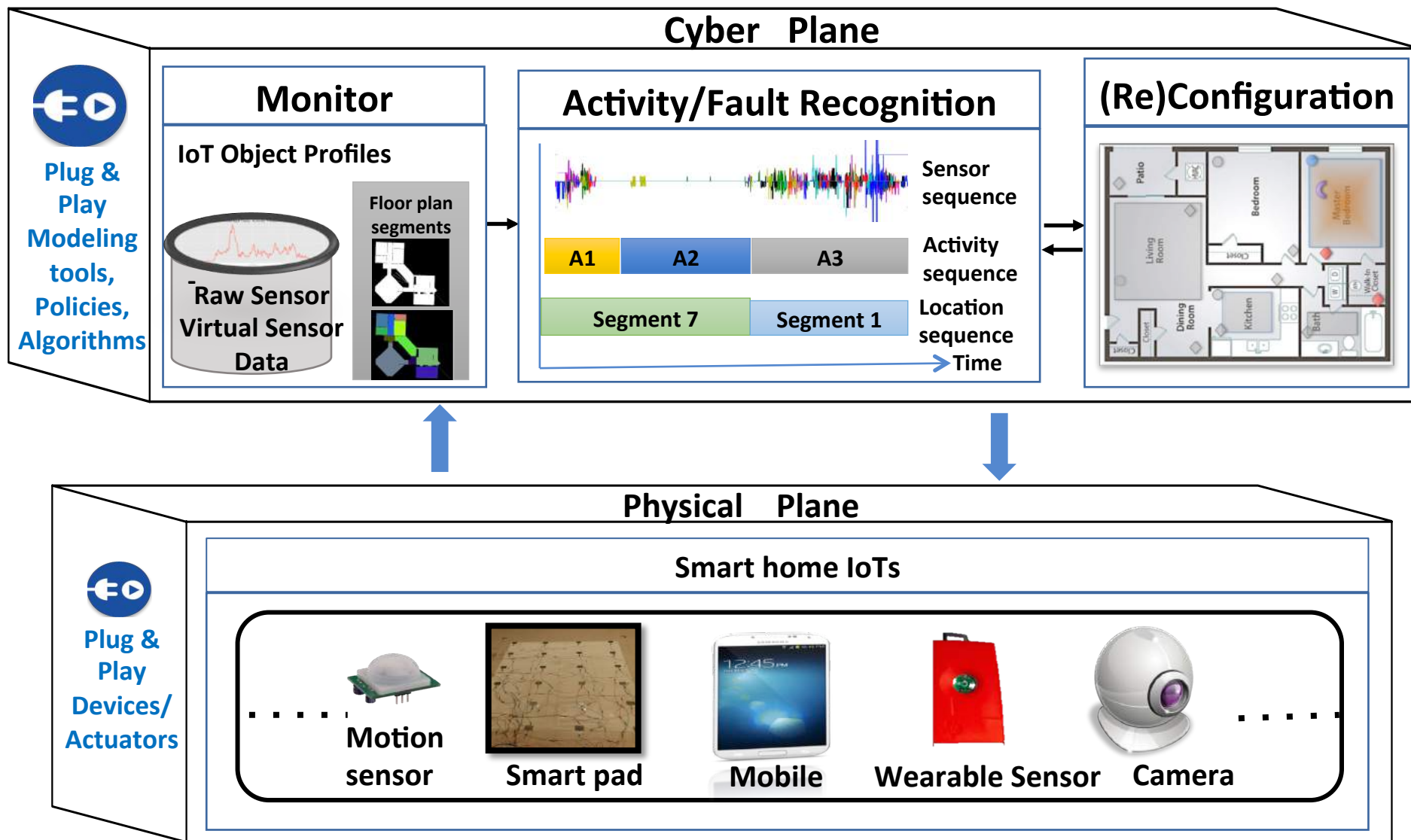
Semantics-based Actuation for *Event Detection*

- Balance event capture vs. accuracy
- Implement a lightweight, real-time scheduler applied in zoom-enabled camera network

Recalibration for perturbations

SCALE Architecture

Cyber   Plane

Monitor

IoT Object Profiles

Raw Sensor
Virtual Sensor
Data

Floor plan
segments

Activity/Fault Recognition

Sensor
sequence

| A1 | A2 | A3 | Activity sequence |

| Segment 7 | Segment 1 | Location sequence |

Time

(Re)Configuration

Plug & Play Modeling tools, Policies, Algorithms

Physical   Plane

Smart home IoTs

Motion sensor   Smart pad   Mobile   Wearable Sensor   Camera

Plug & Play Devices/ Actuators

TIPPERS *(Testbed for IoT-based Privacy-Preserving PERvasive Spaces)* - *A DARPA Brandeis Project*

Sharad Mehrotra, Nalini Venkatasubramanian, Alfred Kobsa
University of California Irvine

Raj Rajgopalan
Honeywell Research

+ a large team of TIPPERS researchers & developers at UCI CS + Calit2 + Honeywell

Bren Hall: TIPPERS Instrumented Building

- 6 Story Building
- 90,000 sq. ft classroom
- 125 Faculty Offices
- 90 Research Labs
- Lecture Halls
- Departmental Offices

Diverse set of sensors installed

New opportunity, new trend
MIXING building data with individual centric data

TIPPERS Sensors & Higher Level Observations

IoT data management & middleware technology t empower applications on sensor data.

Presence Table (**75 million rows since 1/2/17**)

Person	Confidence	Location	Timestamp
56abe584a4ca a171fc8c9681	0.85	2099	2016-01-29-14:20:10
56abef30b4cd c315ae69819a	0.8	2085	2016-01-29-08:20:10
…	…	…	

Energy Usage Table

ID	Confidence	Resource	Usage (MilliWatts)	Timestamp
56abe584 a4c9681	0.85	Room 2099	1000	2016-01-29-14:20:10
56abef30 b4cdc31	0.8	Room 2085	1200	2016-01-29-08:20:10
…	…	…		

Using: Wi-Fi AP, BLE Beacon

Transformation/ semantic interpretation

Using: WeMo Power Outlet Meter

Physical Sensors

64 access points producing Connectivity data continuously

100s covering 2nd floor → Several hundreds soon

Few so far, but soon to be 100s

WifiAccess Point

Beacon

Mobile Phones

HVAC Data

40 covering all corridors and entry/exits

Few machines on 2nd floor

50 On 2nd floor, ISG area → several hundreds

216 temperature points 116 HVAC points, vent control data

Video Camera

PC Based Sensor

Power Outlet

TIPPERS System

A data management middleware that supports:
- ***dynamic representation*** of the smart space by Integrating diverse sensors
- ***Semantic abstraction*** of sensor data to represent data at the conceptual level
- ***Policies for capture, analysis, sharing, and retention*** of data
- ***Plug-n-Play architecture*** to support integration of different privacy technologies
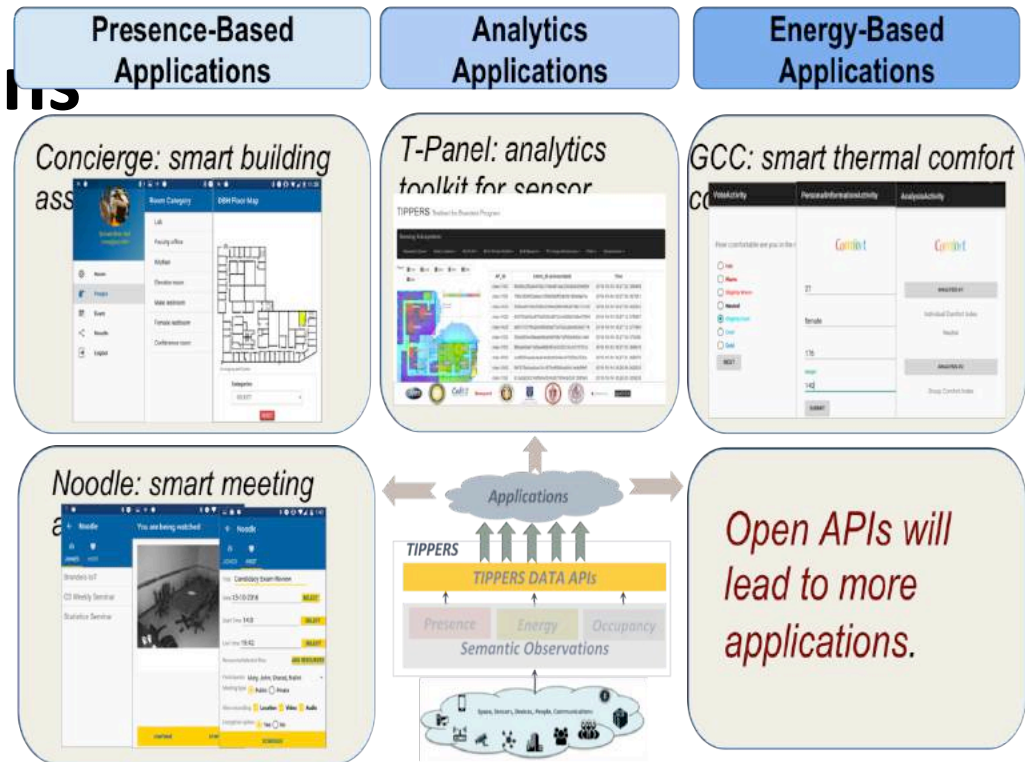 - encrypted data representation, differential privacy, and CMU's IoT and IRR technologies

Testbed: **Applications**

Users

- Faculty, staff, students, building admins, people admins, visitors

Services

- ***Real-time awareness*** of resources, people, events
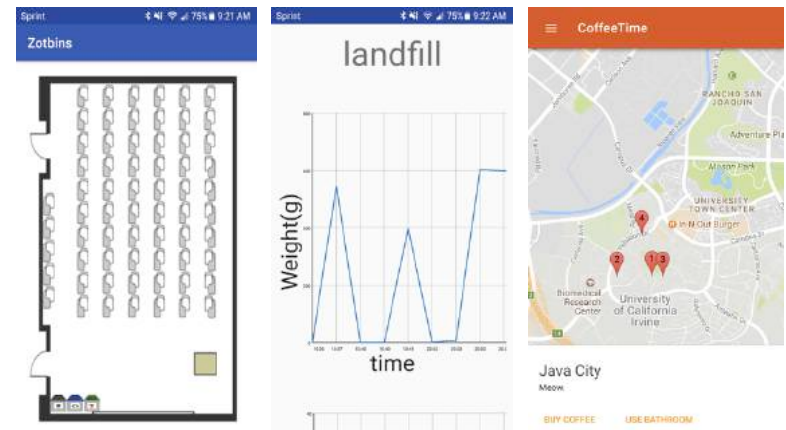
- ***Analytics on historic data***

Presence-Based Applications

Analytics Applications

Energy-Based Applications

Concierge: smart building assistant

T-Panel: analytics toolkit for sensor

GCC: smart thermal comfort

Noodle: smart meeting app

Applications

TIPPERS

TIPPERS DATA APIs

Presence   Energy   Occupancy

Semantic Observations

Open APIs will lead to more applications.

Self-Awareness app (SAPP)

114.07   History   7   181
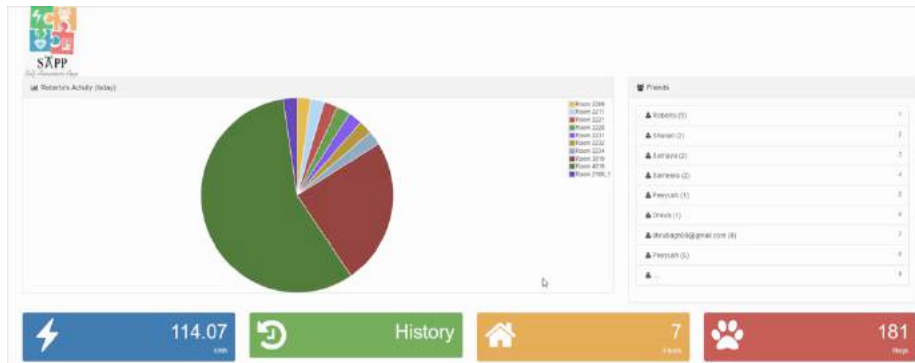
Hackathon apps: ZotBins and CoffeeTime

Zotbins

landfill

Weight(g)

time

CoffeeTime

Java City
Meow

BUY COFFEE   USE BATHROOM

SAFIRE (Situational awareness for Firefighters – 2011)
Sensing -> Sensemaking for the Fire Practice

SAFIREStreams

SpCO, light, inertial, RFID, heart rate, ..

Temperature humidity, visibility,

Ambient CO

Image/Video

Audio/speech

Sensor Data Ingest Unit

Sensor Data Collection

Multimedia Data Collection

Sensor Stream Processing Module

Virtual Sensors for Media Level events

Sensor Fusion

Multisensor Event Extraction

Visualization & Decision Support Services (Alerts, Queries, Replay, Triggers)

Available GIS layers

Firefighter Status Dashboard

Mapping and Localization

Receive /display alert messages.

Raw Data DB
Raw Sensor data (sensors, speech, video)

Event DB
Semantically Enriched Event Data

Sensor/Incident Storage& Archival

Weather
HAZMAT
CAD Systems
Demographics
Occupancy
Floor plans

Ebox External Data Access

Goal: Reliable Timely SA over Unpredictable Infrastructure

Smart Fire Fighting for Smart Buildings (2018)

- **Smart FF** fuses sensor data and computing power/analytics
  - Sensors in buildings, on FF or their apparatus, IoT devices, smartphones, security cameras, social media, etc.
  - Building management systems (BMS) grant access to data, devices, and infrastructure

- **Goals** involve many stakeholders:
  - Minimize injuries/death to building occupants
  - Improve FF safety/health
  - Enhance operational efficiency & effectiveness
  - Minimize property loss and business interruption

- **Data-driven** approach to FF:
  - Targeted inspections for prevention
  - Post-incident forensics e.g.insurance
  - Real-time data provides situational awareness to Incident Commander (IC)
  - Create an *Electronic knoxbox* and *analytics sandbox* functionality…
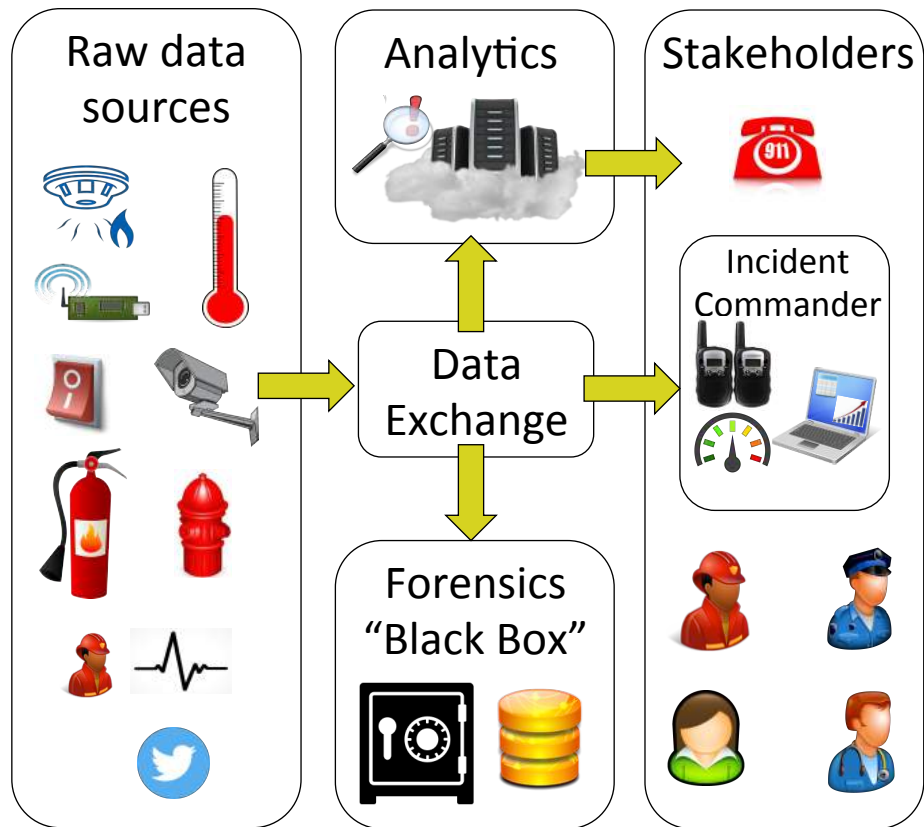
SciFIRE: Fire Data Exchange to enable IoT Dataflows for Smart Firefighting
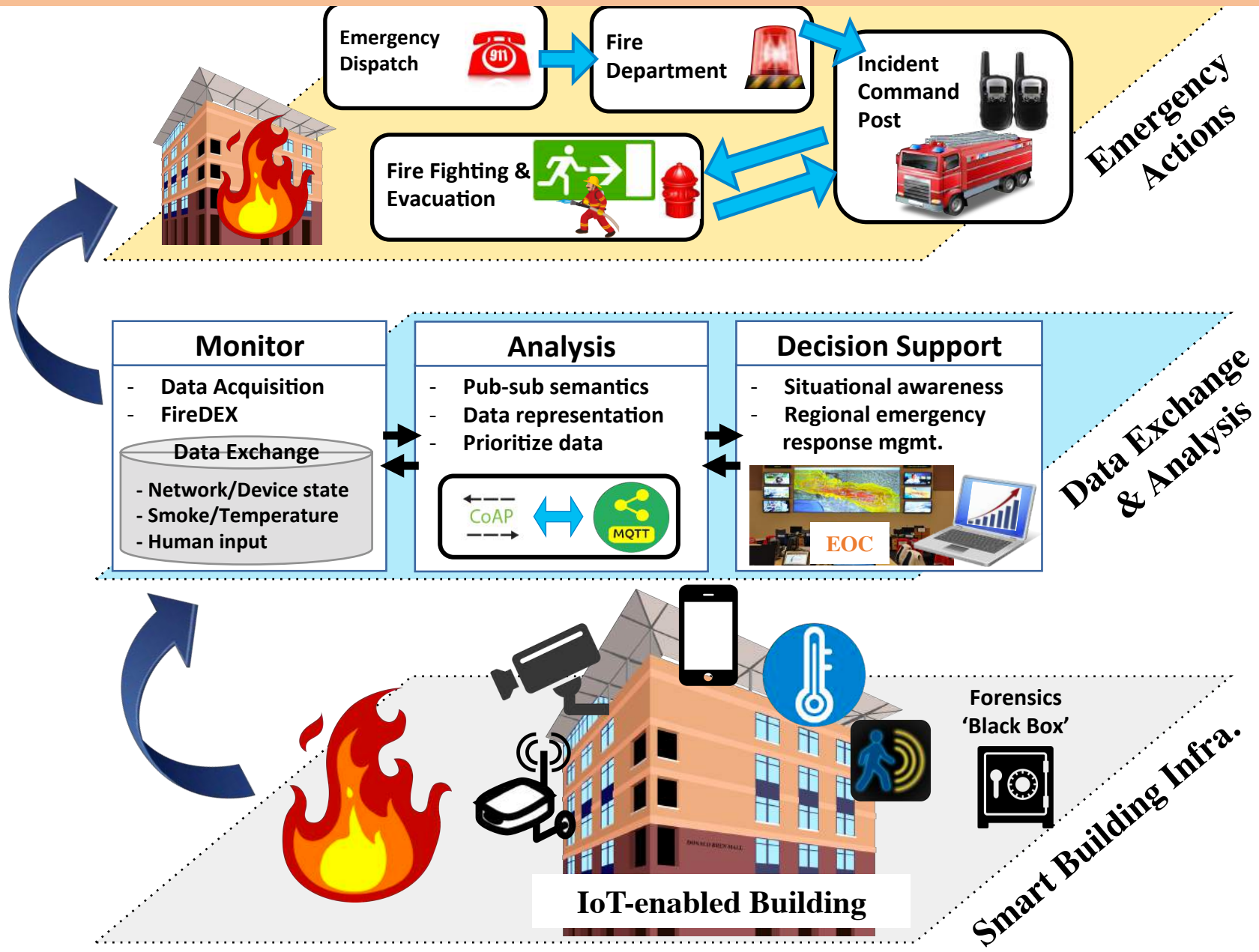
Mobile and in-situ sensing in a fire scenario

Augmenting in-situ sensing with mobility

- Flexibility and extended sensing coverage (i.e. covers larger areas with more sensor types)

- Lower dependency on communication infra. that could be congested or destroyed in disasters

- Facilitates data exchange

SCALECycle platform

- A network-enabled multi-sensor box on a bike with GPS, battery, and various sensors (air quality, gas, camera, microphone, etc.)

- Conducted measurements in multiple testbeds: (1) UCI campus, (2) Victory Court Senior Apartments in Montgomery County, MD, and (3) NTHU (Taiwan) campus.
Collected Wi-Fi RSSI/quality and air quality. (4) Dhaka, Bangladesh – using limited dataplans

New Problems

- Fire awareness in IoT Islands

- Novel Calibration using mobile and insitu sensors
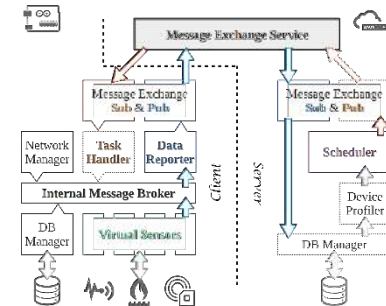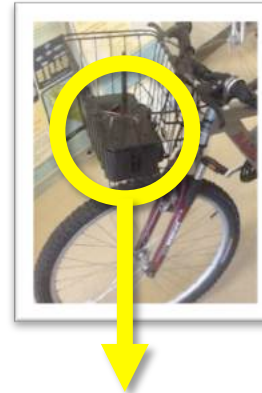
server.

Smart Buildings and Smart Firefighting

Cyber Plane

Plug & Play Modeling tools, Policies, Algorithms

Monitor
- Data Acquisition
- Fire Data Exchange

Database
- Network/Device state
- Smoke/Temperature
- Human input

Analysis
- Pub-sub semantics
- Data representation
- Prioritize data

CoAP ↔ MQTT

Decision Support
- Situational awareness
- Regional emergency response mgmt.

EOC

Physical Plane

Plug & Play Devices/ Actuators

Smart Building Infrastructure
- Floor Map
- Wifi
- Camera
- Mobile Phone
- IoT Sensors - Smoke/CO/ Explosive gas

Static Spatiotemporal Information
- Office Assignment
- Office Hour
- Class/Meeting Schedule

- A critical resource and lifeline service to communities worldwide.
- Water infrastructure has been developed **over decades (centuries sometimes)**.
- Become **large**, **complex** and **vulnerable to failures** (operational degradation, disasters).

Fire Hydrant Error

Resource Wastage

Pipe Burst, New Jersey, 2016

Community Disruption

Flint Water Crisis, Michigan, 2014

Water Contamination

Lead Test

Threat to Public Health

Community Water Infrastructures
Operational Vulnerabilities, Disaster Resilience
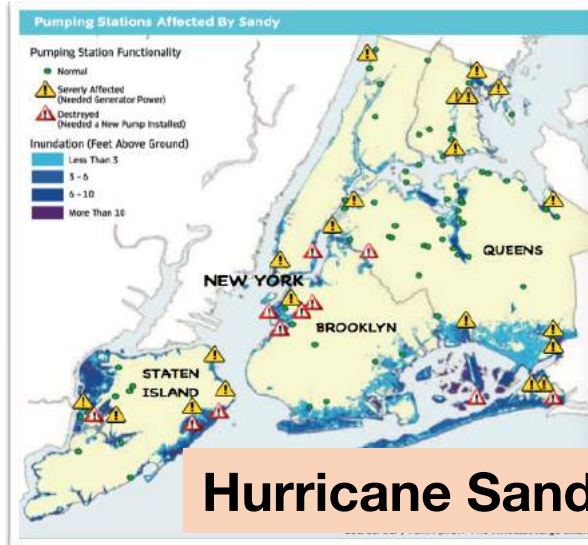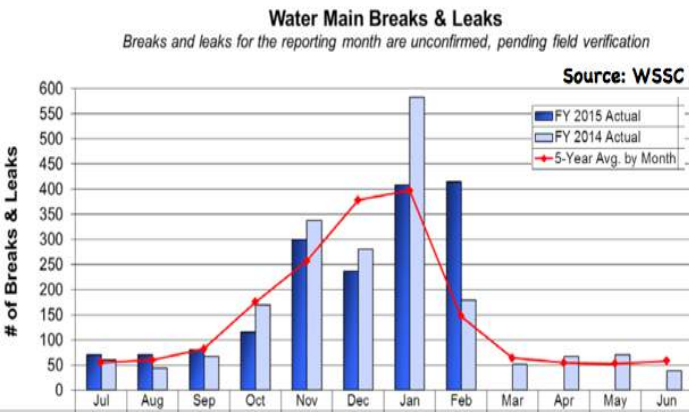
Hurricane Sandy (Oct. 25, 2012)

Water Pipe Burst Under Sunset Boulevard in L.A. (July 30, 2014)
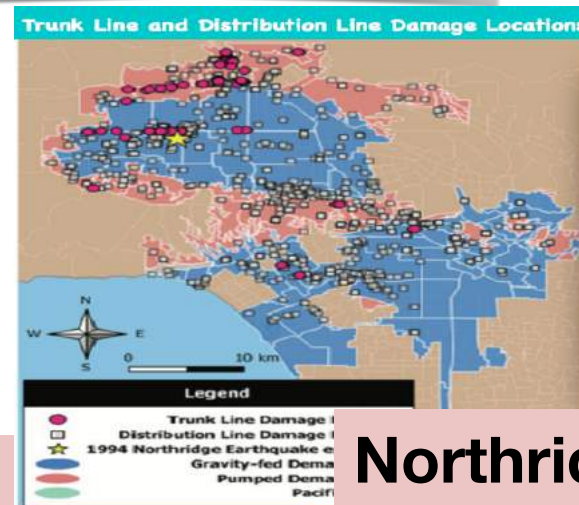
Northridge Earthquake (Jan. 17, 1994)

The AquaSCALE Framework
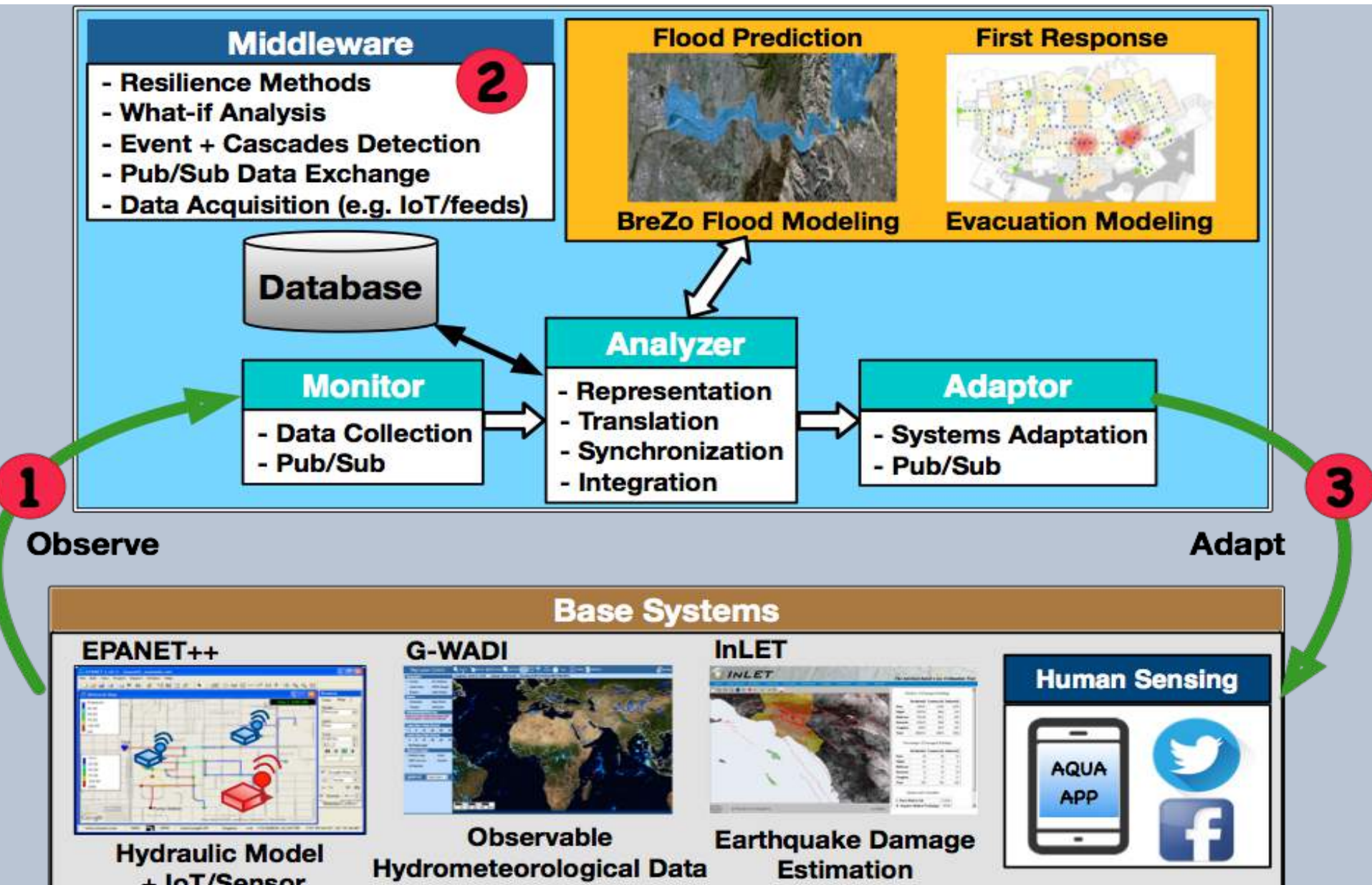
A Composite Multi-leak Identification Approach

Phase I

- **Generate the profile model offline using extensive measurements and plug-and-play machine learning.**
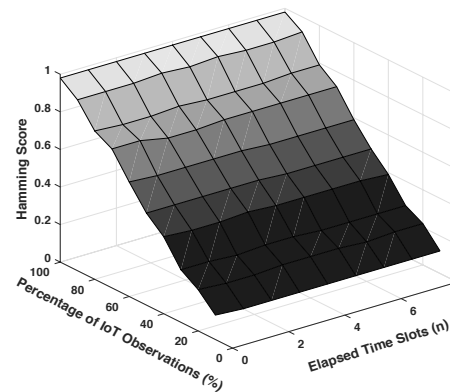- **Features include the topology of the network and changes in pressure heads and flow rates.**

Phase II

- **Aggregate multiple data sources to infer leak locations.**
- **IoT measurements and ambient temperatures are relatively periodic.**
- **Use IoT and temperature streams to infer leak events.**
- **Human inputs, though aperiodic and coarse-grained, enhance the knowledge of leaks.**
- **Incorporates additional human inputs to enforce the predicted event consistency.**
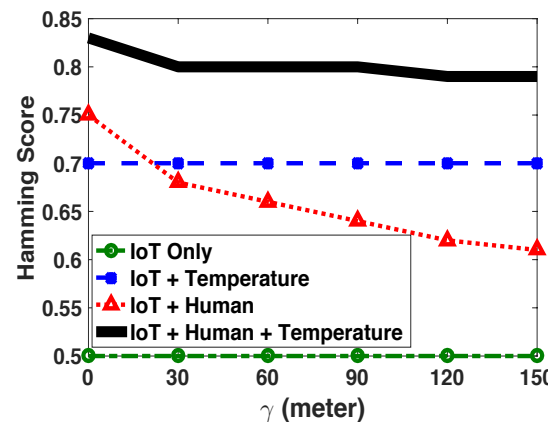
Experimental Study (WSSC)

WSSC-SUBNET
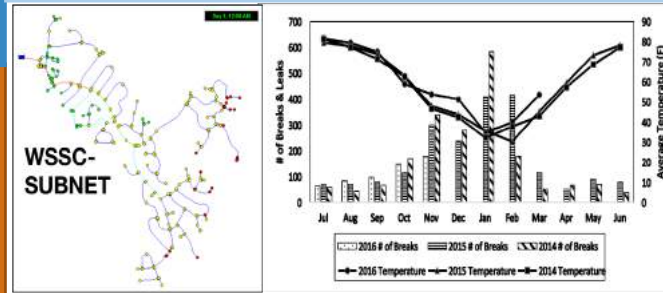
Scenario: winter at east coast
# of training samples: 20,000
# of test cases: 2,000
# of leak events ~ U(1, 5)
Freeze probability: 0.3
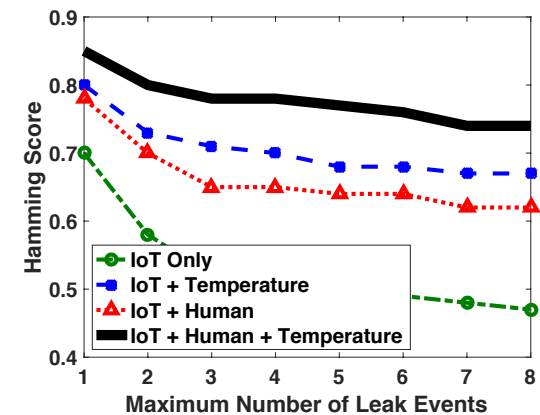Human inputs ~ Poisson Dist.
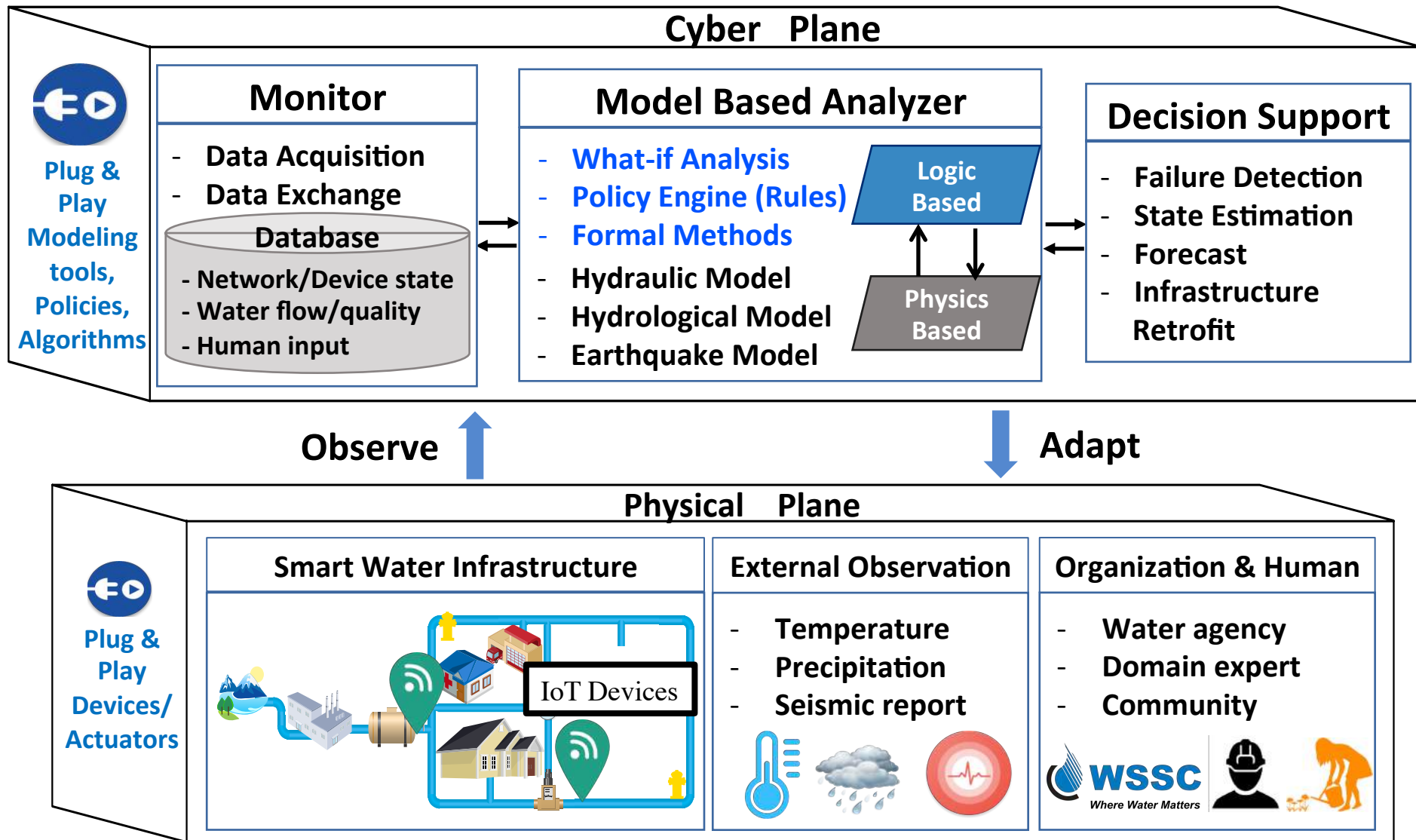Arrival rate: 1 / 15 minutes

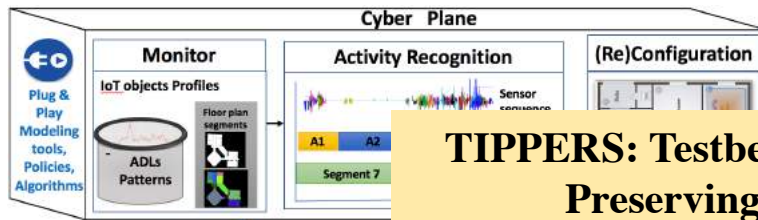**1. IoT Data**

2. IoT + Weather + Human Data

Legend:
- IoT Only
- IoT + Temperature
- IoT + Human
- IoT + Human + Temperature

x-axis: γ (meter)
y-axis: Hamming Score

3. Coarser Twitter Data

Legend:
- IoT Only
- IoT + Temperature
- IoT + Human
- IoT + Human + Temperature

x-axis: Maximum Number of Leak Events
y-axis: Hamming Score
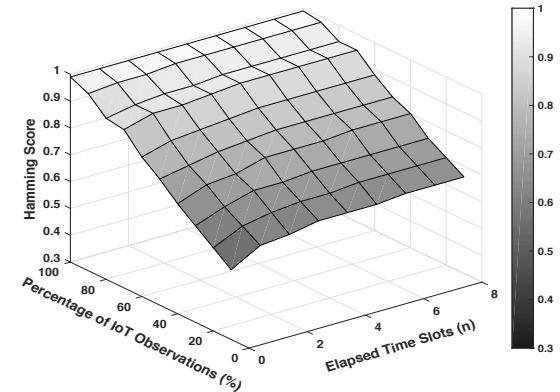
4. Increasing # of Leaks

IoT-Enabled Smart Communities
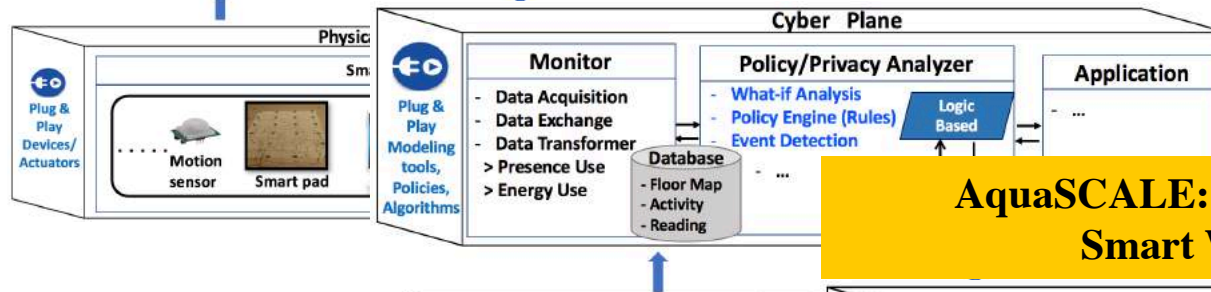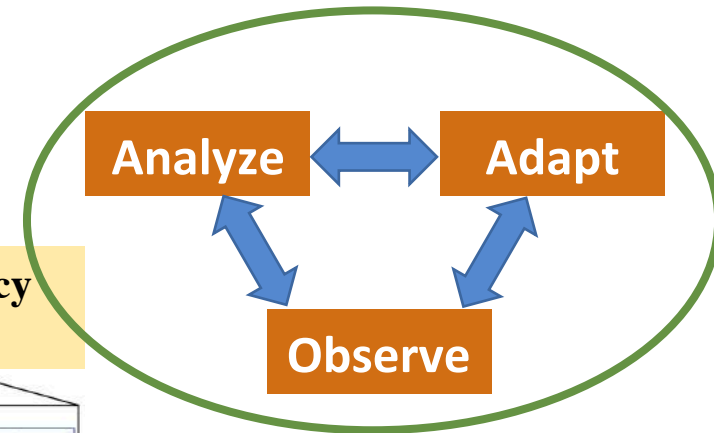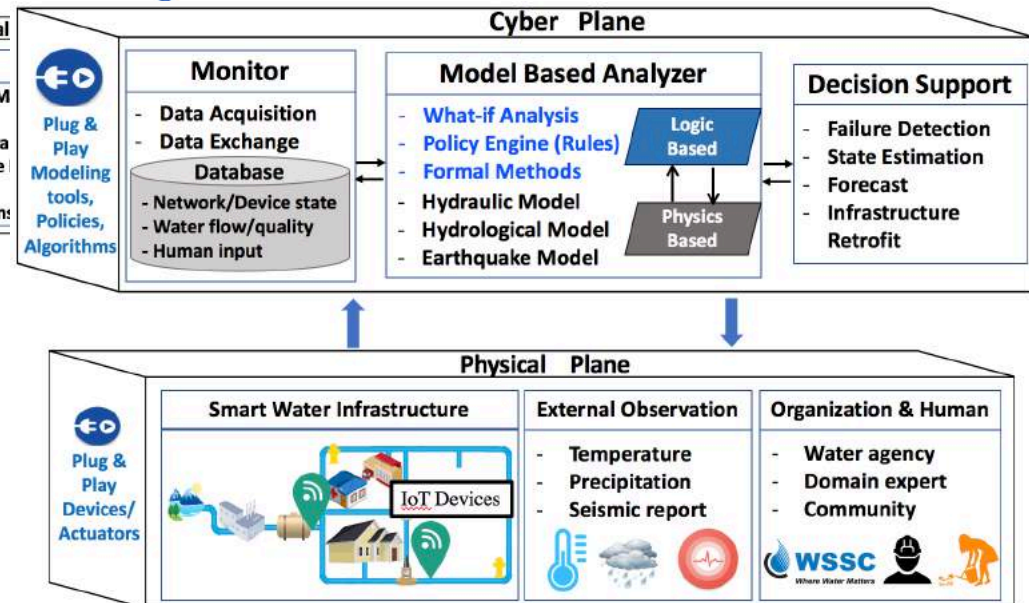
New Directions

- Decentralization
  - Pushing OAA to the edge; to the device
- Human centric approach - semantic
  - Build communities for humans (not cars or devices)
  - Semantically driven vs. device- control
  - Privacy and Security
- Open Architectures
  - Integrate and absorb
  - Standardization – Help or hindrance?
- Assured Behavior
  - Enabling safe Composition of non-functional needs
  - Designing for optimality may reduce adaptability for resilience.

References

- Websites of interest
  - Nalini Venkatasubramanian – http://www.ics.uci.edu/~nalini
  - Project SCALE – http://scale.ics.uci.edu
  - Project TIPPERS – http://tippersweb.ics.uci.edu
  - Project AquaSCALE -- http://www.ics.uci.edu/~dsm/aquascale/

- Relevant Publications

  - Y. S. Uddin, A. Nelson, K. Benson, G. Wang, Q. Zhu, Q. Han, N. Alhassoun, P. Chakravarthi, J. Stamatakis, D. Hoffman, S. Almomen, L. DArcy, and N. Venkatasubramanian.
    "The SCALE2 Multi-network Architecture for IoT-based Resilient Communities". in 2016 IEEE International Conference on Smart Computing (SMARTCOMP), 2016
  - Q. Han, P. Nguyen, R. T. Eguchi, K.L. Hsu, and N. Venkatasubramanian.
    "Toward An Integrated Approach to Localizing Failures in Community Water Networks". in 37th IEEE International Conference on Distributed Computing Systems (ICDCS), 2017
  - S. Mehrotra, A. Kobsa, N. Venkatasubramanian, S. R. Rajagopalan.
    "TIPPERS: A Privacy Cognizant IoT Environment". in First IEEE International Workshop on Security, Privacy and Trust for IoT, Sydney, Australia. 2016.
  - Zhijing Qin, Grit Denker, Carlo Giannelli, Paolo Bellavista, Nalini Venkatasubramanian
    . "A Software Defined Networking Architecture for the Internet-of-Things". To appear in IEEE/IFIP Network Operations and Management Symposium (full paper), (NOMS) 2014

EXTRA SLIDES