Array of Things

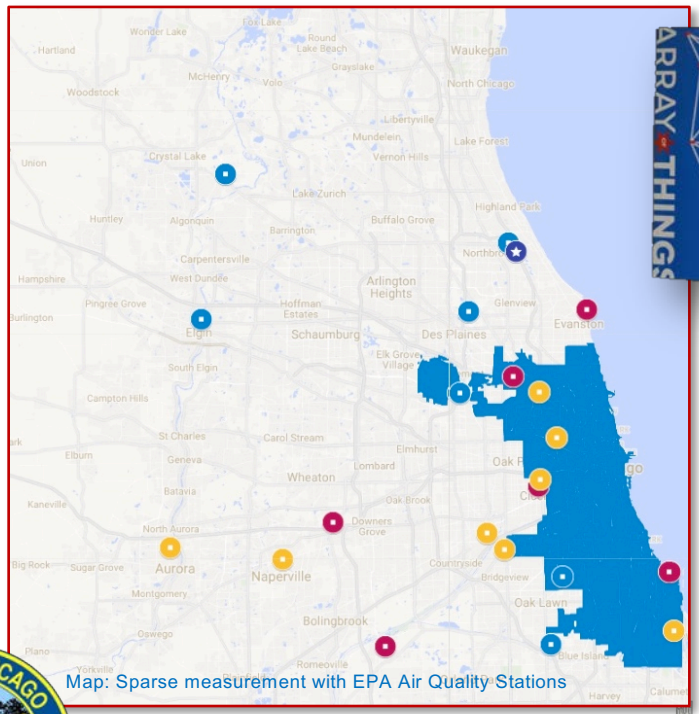
A New Approach to Measuring Cities.

Charlie Catlett
University of Chicago and
Argonne National Laboratory

Collaborators:
Pete Beckman (ANL/NU)
Rajesh Sankaran (ANL)
Kate Kusiak Galvin (UC)
Mike Papka (ANL/NIU)
Kathleen Cagney (UC)
Mark Potosnak (DePaul)
Doug Pancoast (SAIC)
Dan Work (Vanderbilt)

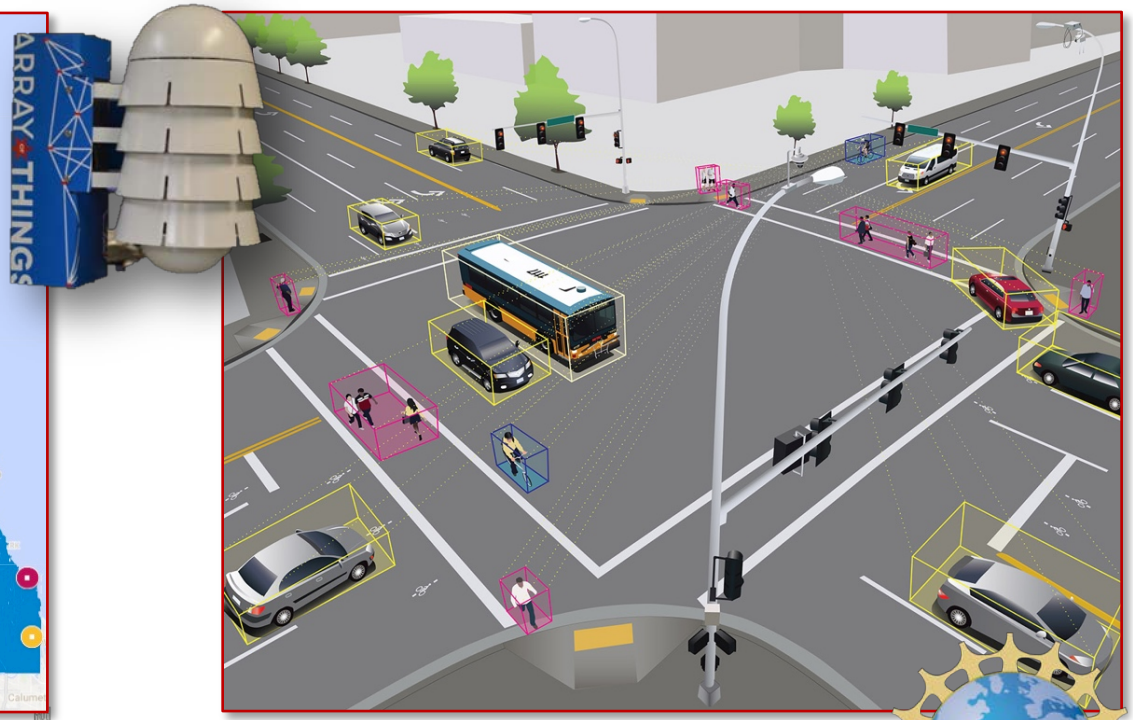
Array of Things (AoT): Beyond Passive Measurement

Goal 1: Exploit new sensor technologies to increase measurement resolution.



Map: Sparse measurement with EPA Air Quality Stations

Goal 2: "Edge Computation" to support intelligent and autonomous measurements and actions.



AoT is an NSF-funded Major Research Instrumentation project to create an urban cyberinfrastructure "instrument" comprising hundreds of autonomous, remotely programmable devices in partnership with the City of Chicago.

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AoT Configuration (FY18-19)

Environment

- Ambient, UV, IR light
- Visibility
- Magnetic Field
- Vibration
- Sound pressure
- Temperature
- Relative humidity
- Barometric pressure

Air Quality

- PM 1, 2.5, 10, 40
- Carbon monoxide
- Ozone
- Sulfur dioxide
- Nitrogen dioxide
- Hydrogen sulfide
- Total reducing gases
- Total oxidizing gases

Edge Computing

Computer Vision: Flooding, traffic flow, safety (bike helmet use, pedestrian patterns…), use patterns of public spaces, cloud cover

Computer Audio: Noise components, sound events

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All data is *open* and *free*.

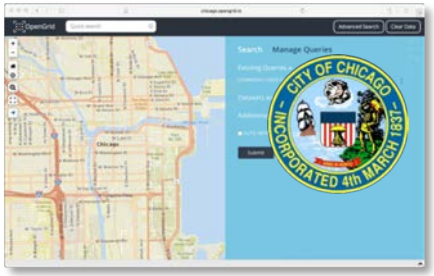
https://aot-file-browser.plenar.io/

Cellular Data Network

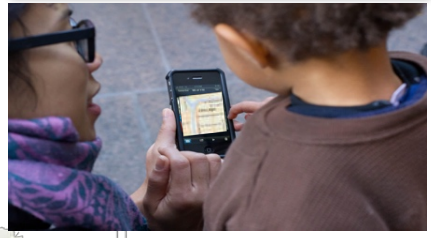
Open / Free Data

Download: Scientific Analysis

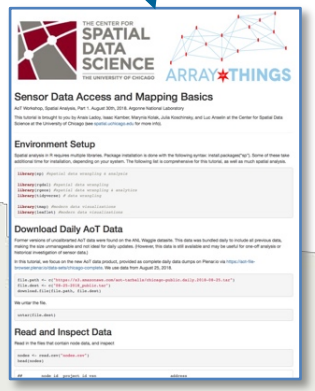
Portals: Data Discovery



Real-Time Access: New Applications



Tools and Tutorials



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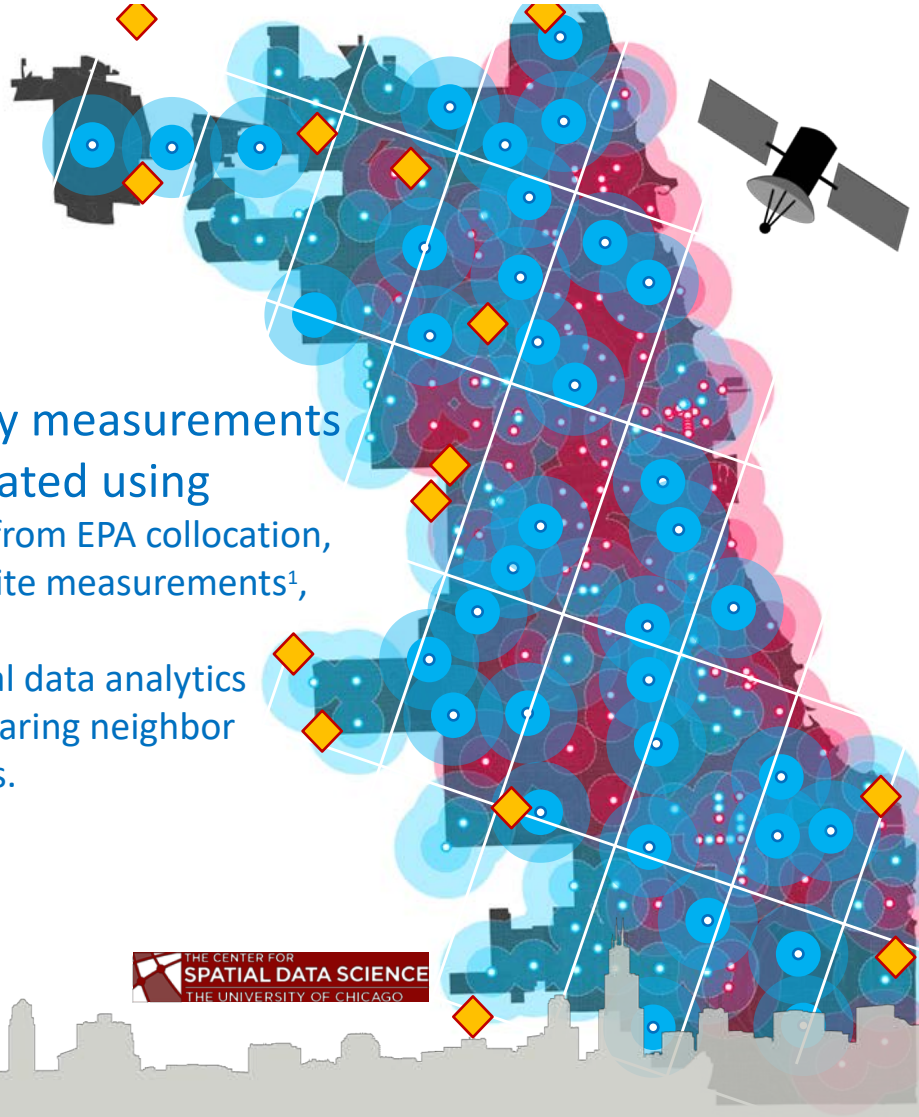
Calibration and Validation

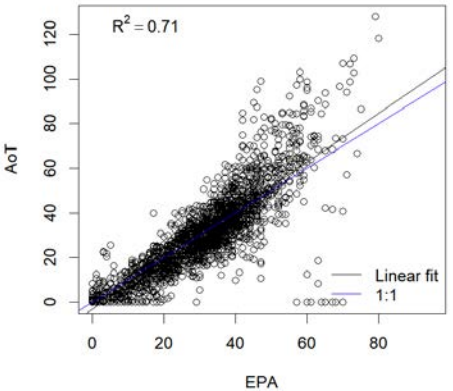


Air quality measurements are evaluated using

(1) data from EPA collocation,
(2) satellite measurements[1], and
(3) spatial data analytics comparing neighbor nodes.

Tracking the Polar Vortex

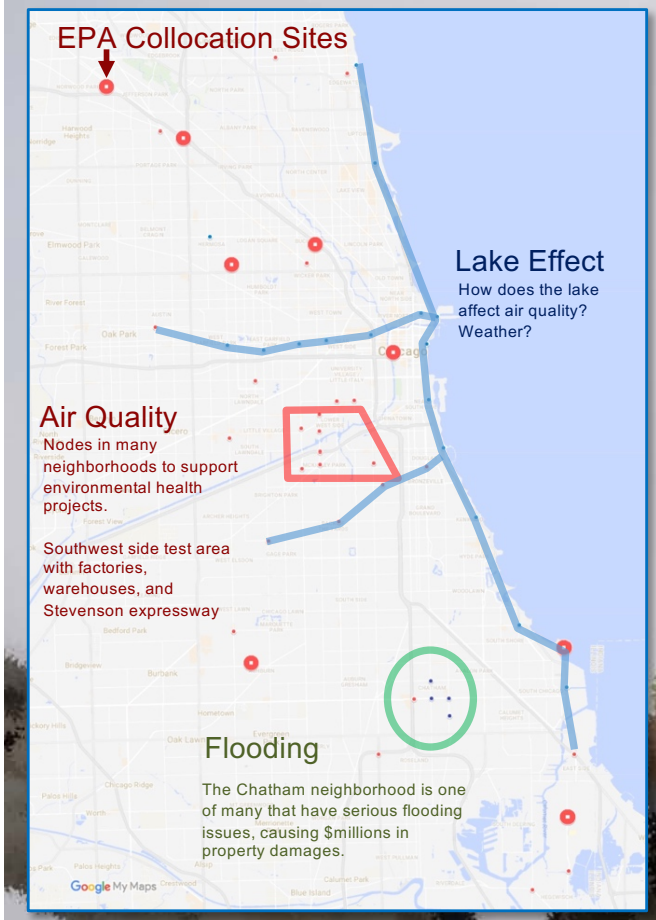
Ozone [ppb] Mar 01 - Jul 01

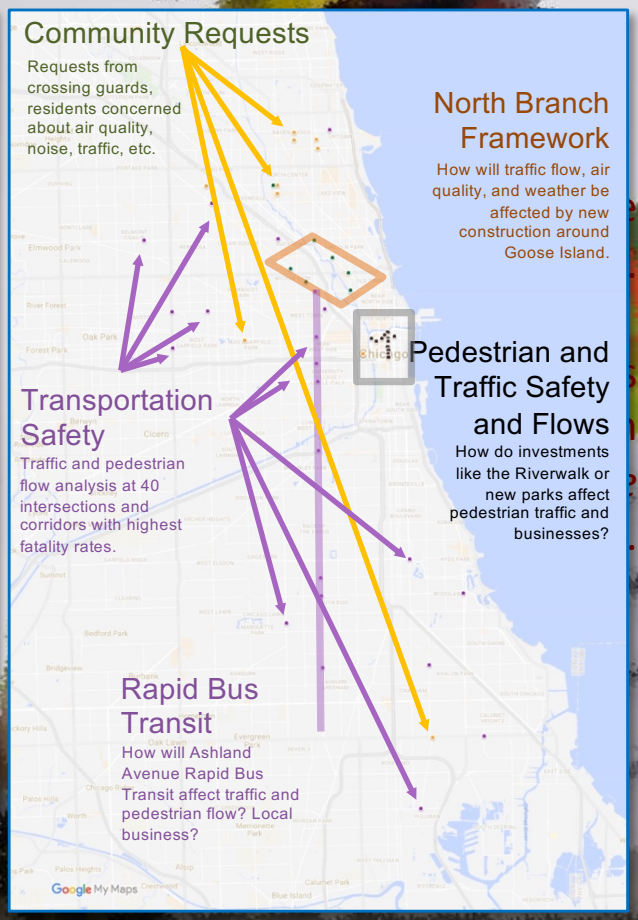


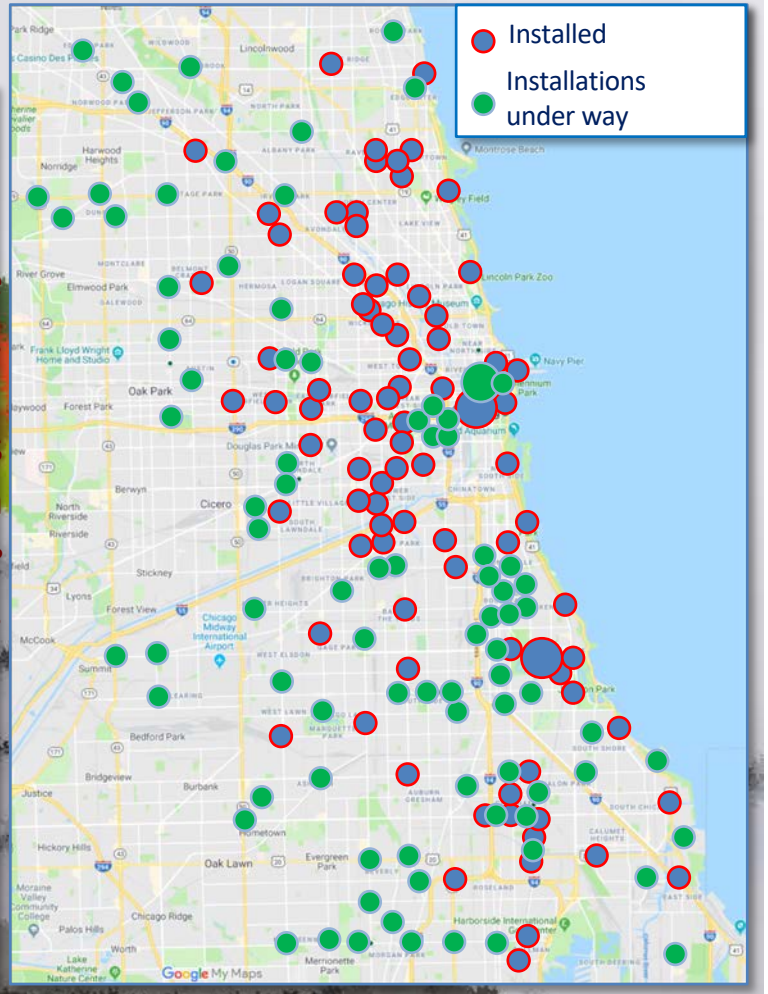
[1] Today using gas measurements from the Tropomi satellite (EU on Copernicus Sentinel-5), daily measurements). By 2020 the geosynchronous NASA TEMPO satellite will provide higher spatial resolution, hourly data.

Array of Things Chicago Deployment

CDOT
CHICAGO DEPARTMENT OF TRANSPORTATION





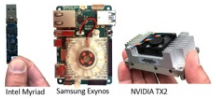


Science Examples

Sample from 25 science abstract presentations at AoT User Workshop (August 2018).

AoT Computer Science Research Challenges

- From this morning:
  - OS scheduling
  - Resource management
  - Programming models
  - Data movement
  - Heterogeneous computing
- **Improved ML/computer vision**
  - Sampling questions
    - Sampled vs Continuous data?
    - For each application: what do we need, what is enough?
      - Traffic engineering convention: 15 minute block vs all day but lower frequency?



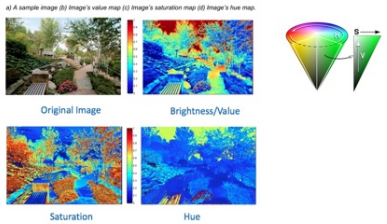
Nicola Ferrier (UChicago/ANL)

Takeaways

- Mobility is changing in fundamental ways
- Programmable cameras (w/ privacy by design) are the most flexible instruments for tracking these changes
  - AoT instrument computer vision capabilities can evolve as quickly as mobility technologies
- AoT offers a chance to see things at city scales, i.e., understand generalizable results
- AoT offers chance to validate data-driven mobility experiments

Dan Work (Vanderbilt)

Using AoT camera data to quantify naturalness and disorder in the environment



Marc Berman (UChicago)

Berman et al., (2014) PLoS ONE

Innovation: AoT and Social Sciences

- Intersection of activity space approaches with AoT data opportunities
  - NIA appreciated unique nature of these data
  - Nodes proximal to sampled neighborhoods
- New ways to examine inequality in exposure and resources
  - Public spaces and "stickiness"
  - Nature of street activity
  - Real-time assessment of emotional states and environmental exposures
- Attention to variation in the micro-environment
- Longitudinal assessment of neighborhood social and physical context

Kate Cagney (UChicago)

AoT and Urban Health and Well-Being Research

COMPASS data set

EHR data set

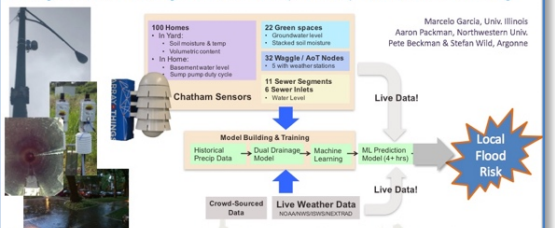
Sampled genetic data

+ AoT microenvironmental data set =

Novel Discovery Opportunities

David Liebovitz (UChicago)

Linking real-time monitoring with model development for prediction of urban flooding

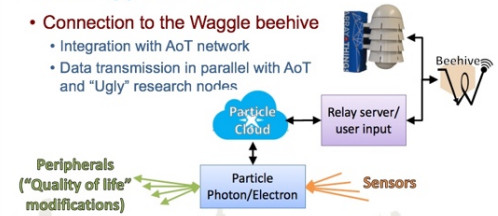


Aaron Packman (Northwestern)

Northwestern University

microWaggle: Architecture

- Connection to the Waggle beehive
  - Integration with AoT network
  - Data transmission in parallel with AoT and "Ugly" research nodes

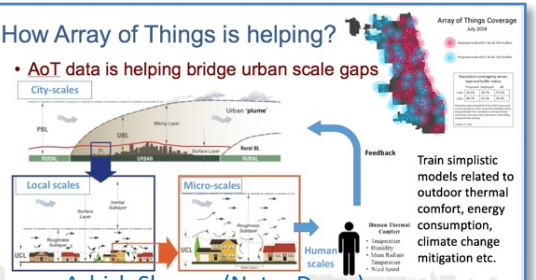


Vivien Rivera (Northwestern)

Northwestern University

How Array of Things is helping?

- AoT data is helping bridge urban scale gaps

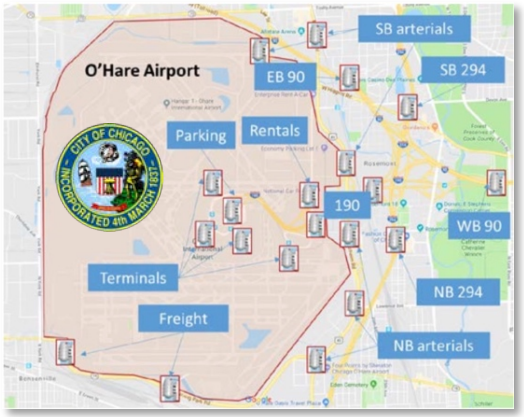


Ashish Sharma (Notre Dame)

Example Projects Leveraging AoT & Waggle

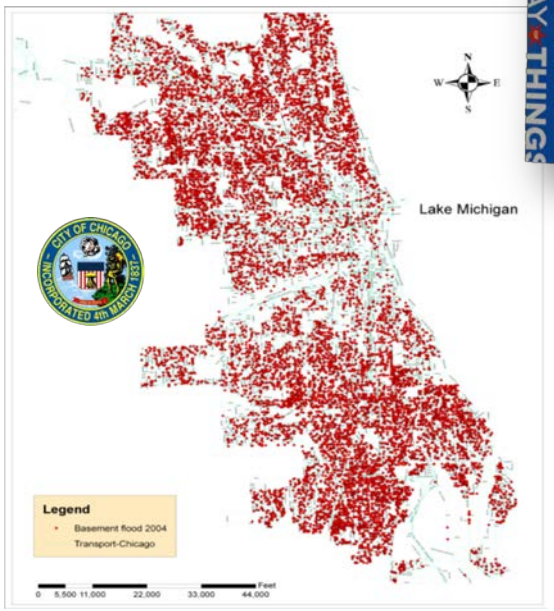
Illinois Department of Transportation

Quantify the impact of at-grade crossings on roadway operations. Edge-enabled image processing to measure key factors such as crossing start/end, duration of impact (traffic returns to steady-state), number of vehicles affected, emergency vehicles affected, etc..



Quantify air, road, rail, public transit traffic into and surrounding O'Hare International Airport, in concert with transportation modeling and data from diverse sources.

Integrate data with Argonne coupled multiscale urban modeling capabilities to evaluate policy and infrastructure interventions, including normal and emergency operations (weather, threats, attacks).



Detect pre-flooding and flooding events such as street floods that lead to basement flooding (map shows 2004 basement flood reports).

A growing number of projects funded by industry, state, and federal sources to leverage Waggle *edge computing capabilities* for computer vision and hearing.

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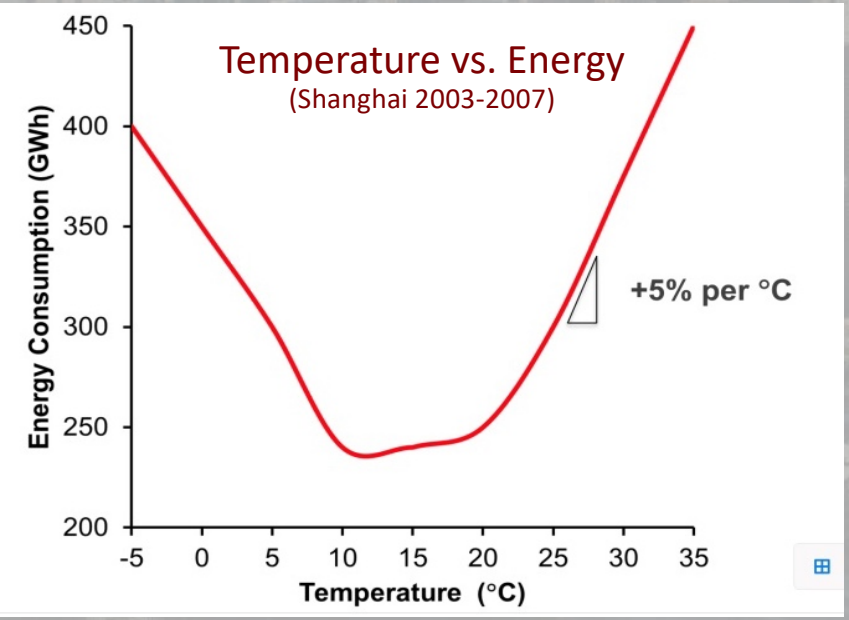
Multiscale Coupled Urban Systems

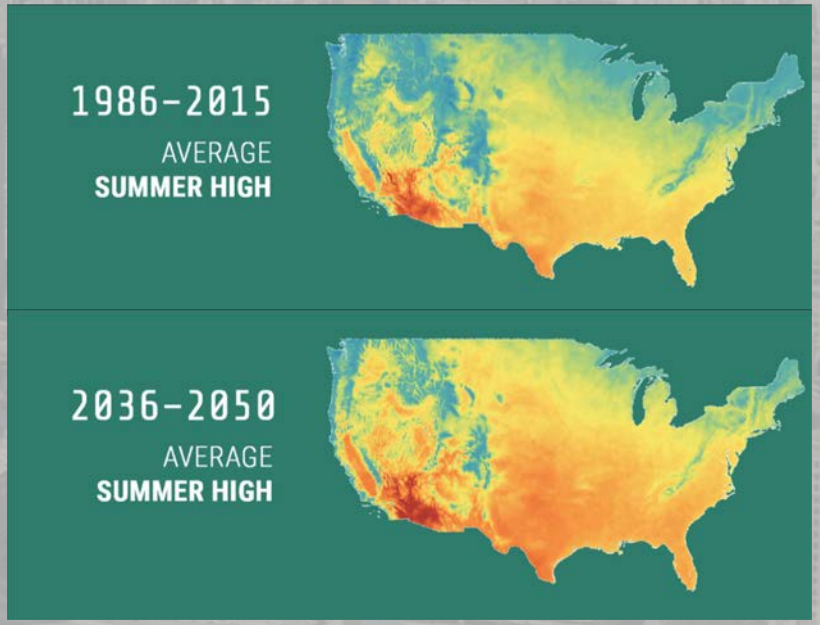
Transforming Urban Design and Optimization through Exascale Simulations

EXASCALE COMPUTING PROJECT

- **Use Exascale platforms to simulate the coupled urban microclimate and buildings system, evaluating city-scale energy performance in extreme weather events.**



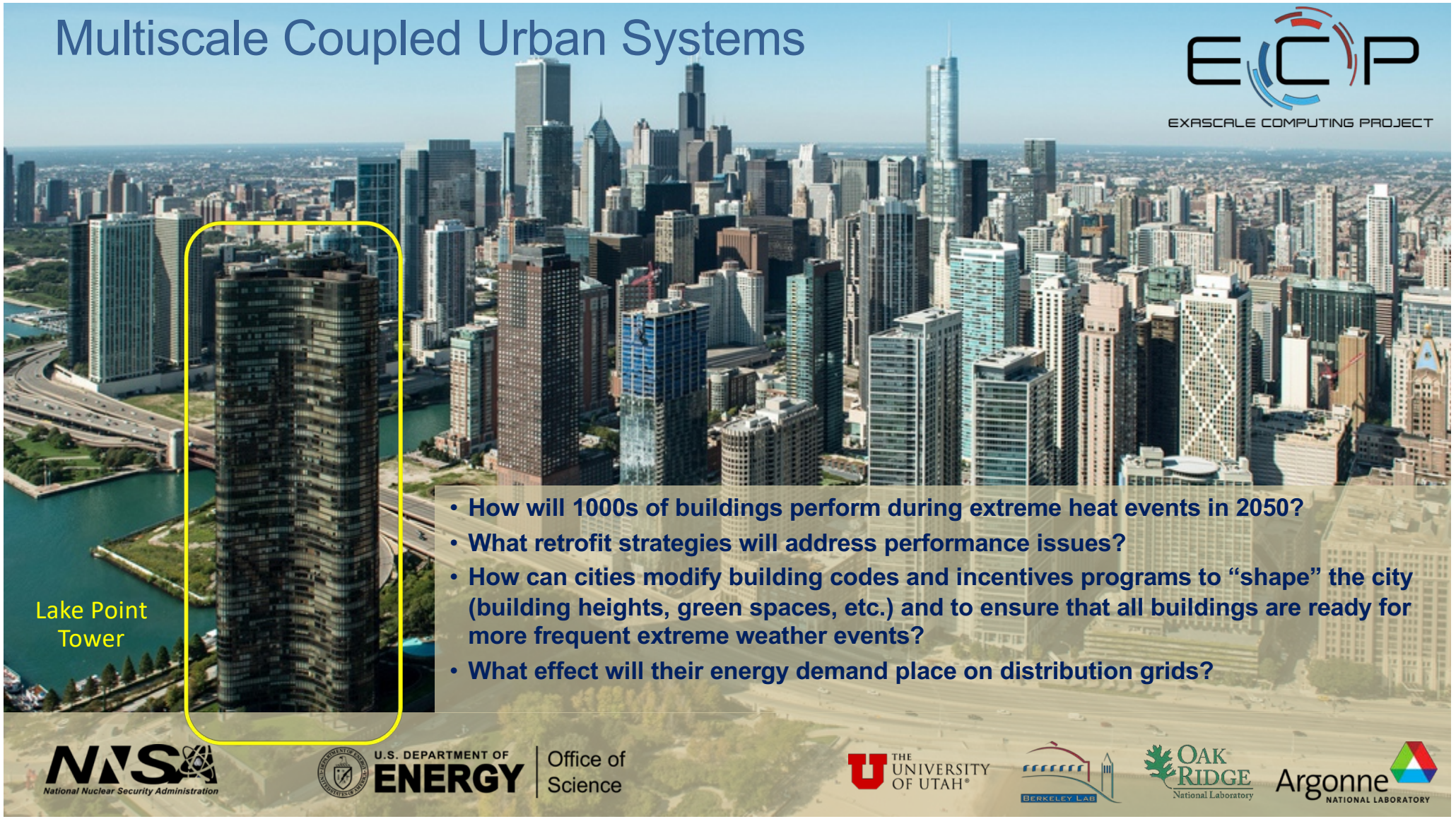
H. Yi-Ling et al, Influences of Urban Temperature on the Electricity Consumption of Shanghai, Advances in Climate Change Research, Vol. 5, Issue 2, 2014.



Umair Irfan, Eliza Barclay, and Kavya Sukumar, Weather 2050, Vox.com, Nov. 26, 2018

National Nuclear Security Administration | U.S. DEPARTMENT OF ENERGY | Office of Science | The University of Utah | Berkeley Lab | Oak Ridge National Laboratory | Argonne National Laboratory

Multiscale Coupled Urban Systems



- How will 1000s of buildings perform during extreme heat events in 2050?
- What retrofit strategies will address performance issues?
- How can cities modify building codes and incentives programs to “shape” the city (building heights, green spaces, etc.) and to ensure that all buildings are ready for more frequent extreme weather events?
- What effect will their energy demand place on distribution grids?

ECP EXASCALE COMPUTING PROJECT

NNSA National Nuclear Security Administration | U.S. DEPARTMENT OF ENERGY | Office of Science | THE UNIVERSITY OF UTAH | BERKELEY LAB | OAK RIDGE National Laboratory | Argonne NATIONAL LABORATORY

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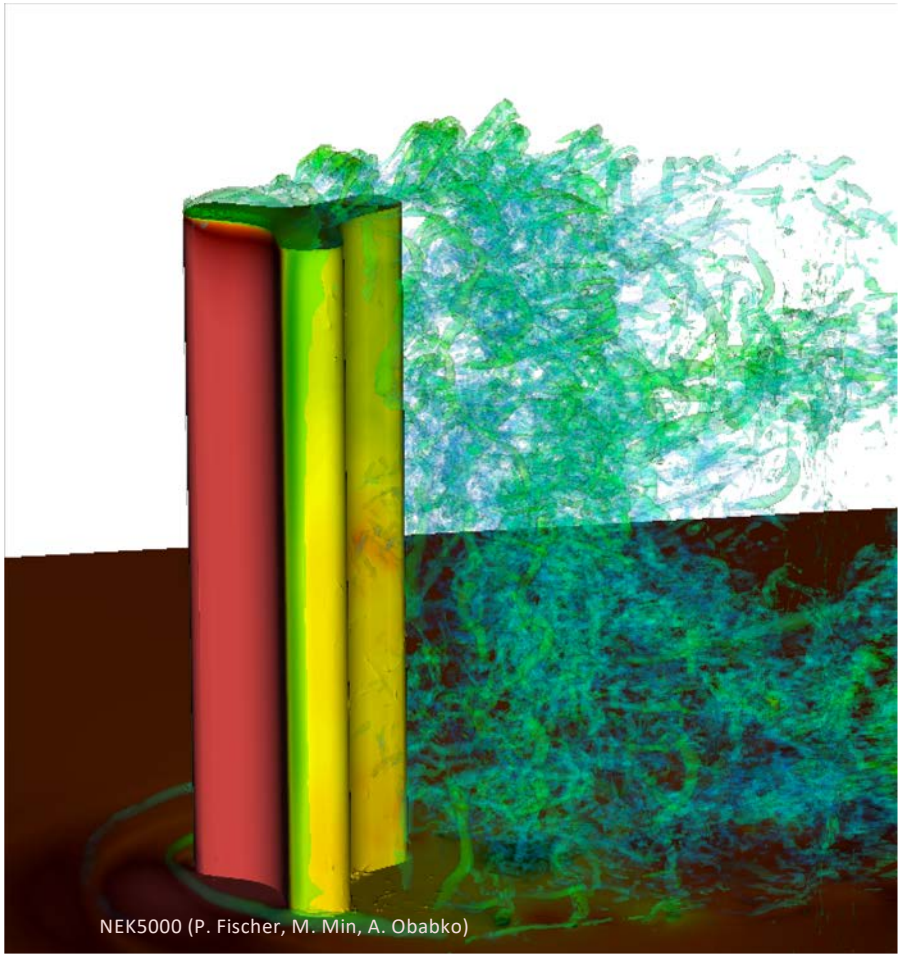
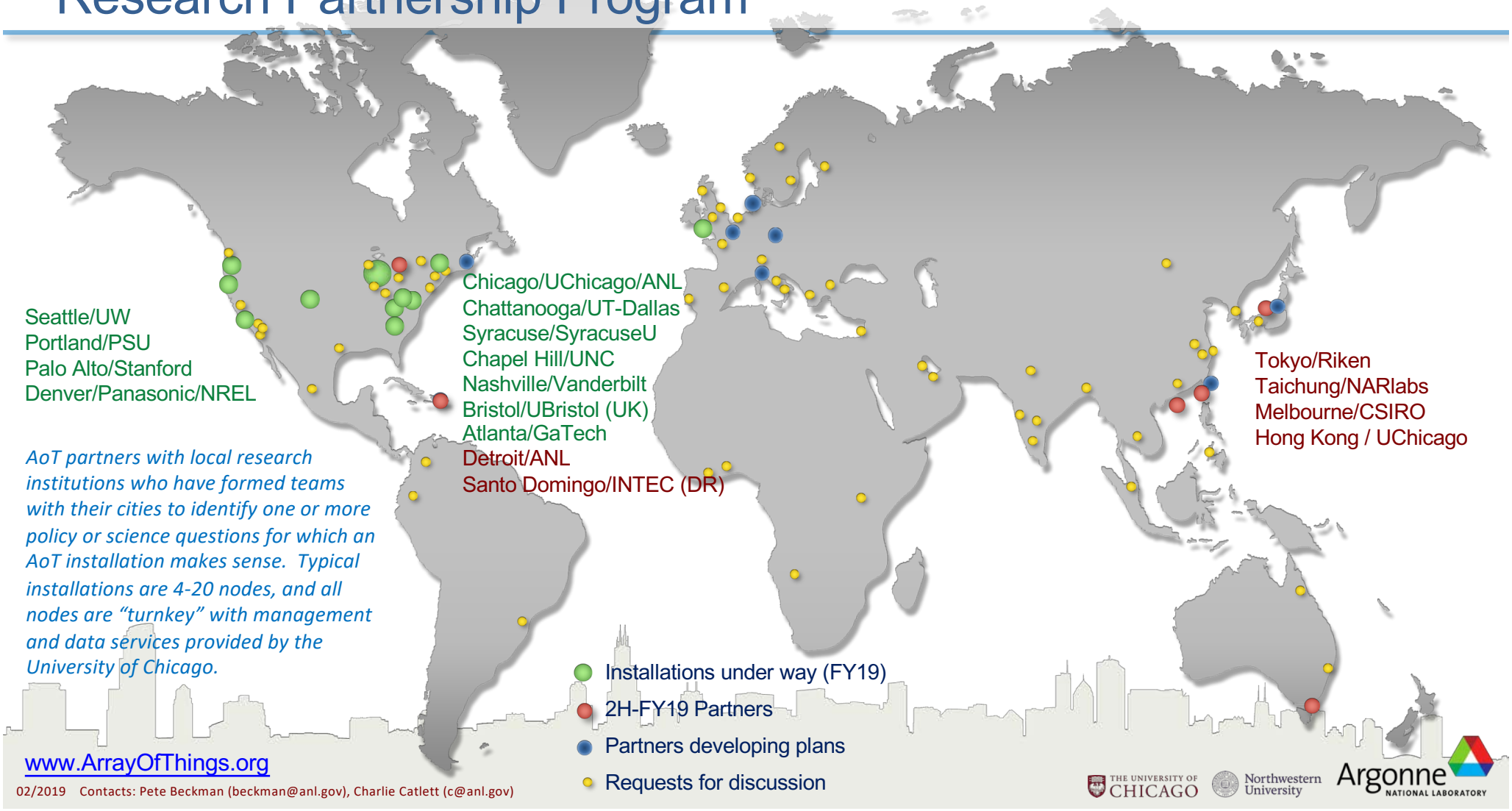
Transforming Urban Design and Optimization through Exascale Simulations



- Addresses basic research needs driving the urban design / optimization (buildings, districts) and understanding the feedback among building heat emissions, energy use, and microclimate.
- Modeling turbulence at high fidelity also provides new scientific capability for other problems requiring such resolution, such as
  - Wind and solar energy in urban settings.
  - Optimizing building form (vortex shedding, etc.) to reduce structural loads → embedded carbon (steel, concrete).
- Current state of modeling building/district energy performance uses regional weather data. We add:
  - Heat emissions from buildings.
  - Turbulent flows at resolution commensurate with building geometries and including differential temperature at surfaces.

Research Partnership Program



AoT partners with local research institutions who have formed teams with their cities to identify one or more policy or science questions for which an AoT installation makes sense. Typical installations are 4-20 nodes, and all nodes are "turnkey" with management and data services provided by the University of Chicago.

www.ArrayOfThings.org

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How is AoT / Waggle Unique

AoT: An Experimental Instrument

- A new type of instrument / cyberinfrastructure
- Driven by science questions, including cyberinfrastructure research
- Implemented and tested in real life, at scale
- Embedding policy in infrastructure

Unique Waggle Capabilities

- Embedded in public way with tested policies & governance
- Data pipeline and APIs
- **Edge Computation**
  - Software-Defined Sensors
  - Analytics in place (intelligent data compression; responsive measurements)
- **Scaling and Replication**
  - Open hardware/software; open data pipelines
  - Commercially made
  - Four generations of field testing and improvements.

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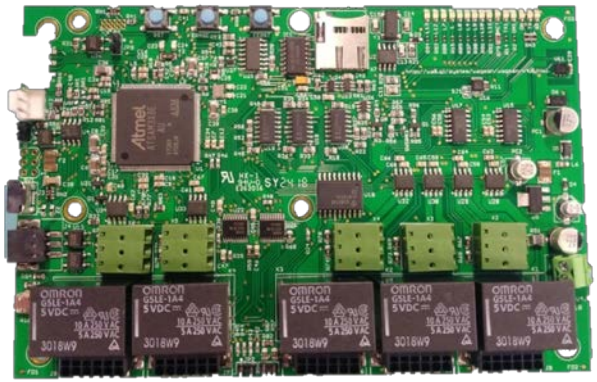
The Waggle Platform

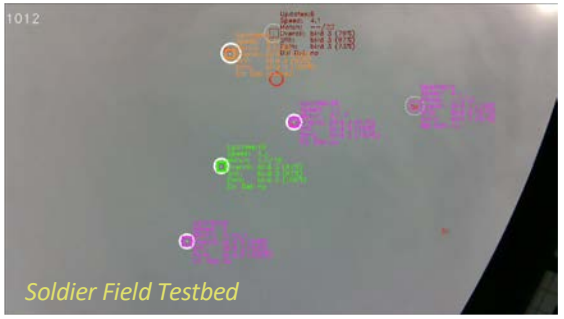
- Open source hardware, software
- Design for hosting edge computation, sensors, and actuators in harsh and/or remote locations.
- “100-year Space Craft” design principles to avoid, minimize, and/or recover from faults.
- Remotely programmable with common ML environments (TensorFlow, OpenCV, etc.).
- Open/standard architecture supports agile integration of new ML hardware.

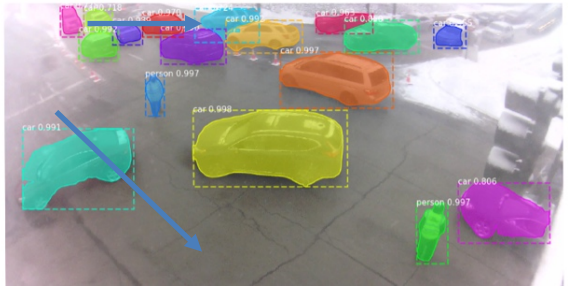


Edge Computation: “Software-Defined Sensors”

Example Application Areas:
- Drone detection (USSAF)
- Transportation analysis (DOE, IDOT)
- Multi-messenger methods to adapt sensing based on detected events/conditions (NSF)
- Pedestrian and Vehicle flows

Under Development:
- Utility grid load/failure prediction and anomaly detection (Industry)
- Pedestrian flow and interaction analysis (NSF)
- Flood detection/tracking (NSF)
- Near-miss traffic events (NSF)





Resilience in Harsh Environments

System Controller (Wagman) monitors health of computing, sensing, and other hosted devices; can force hibernation, reset, and rebuild hosted Linux systems.

wa8.gl

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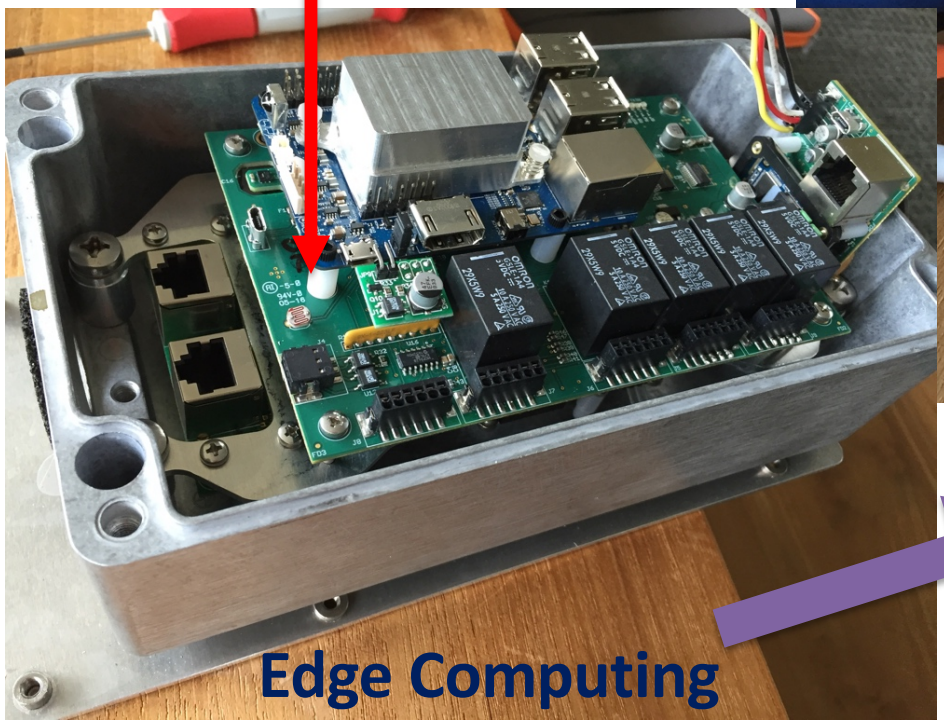
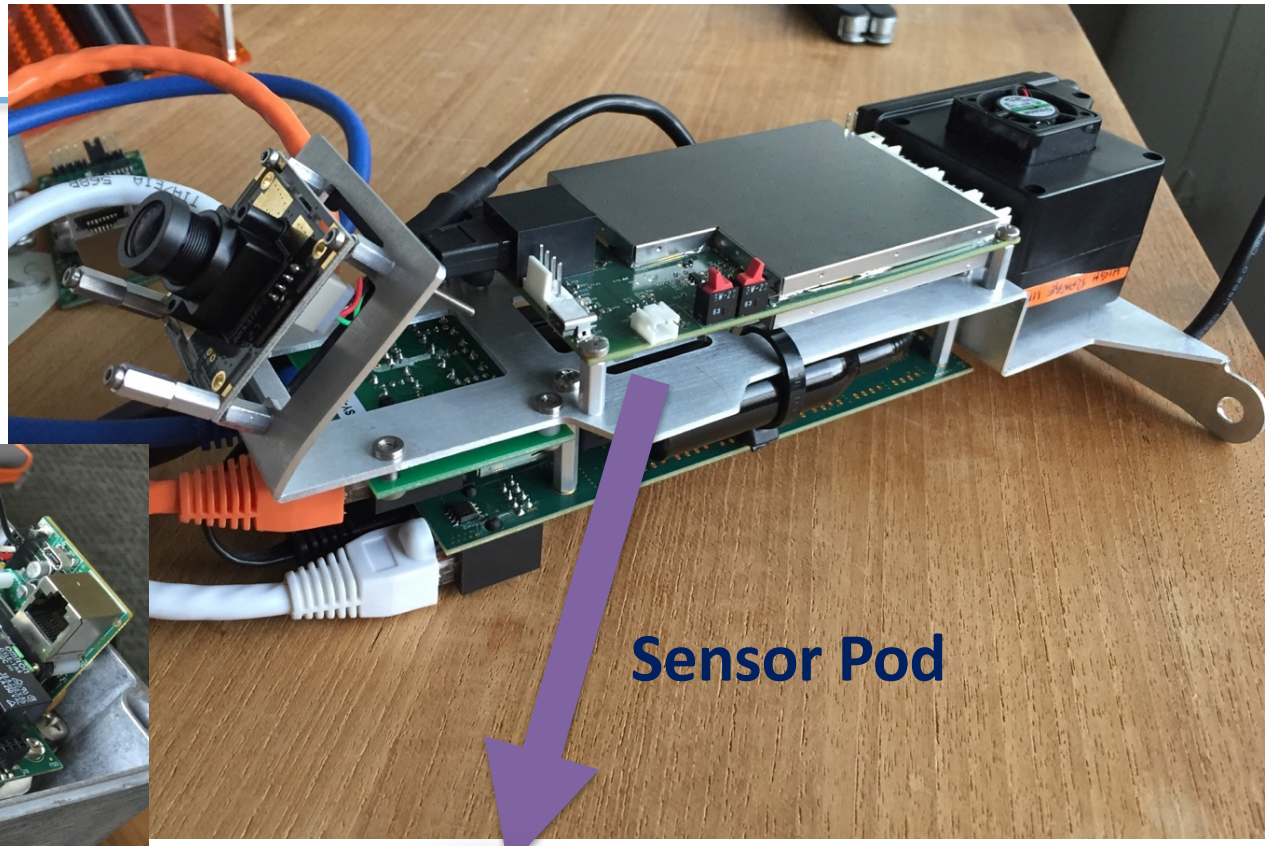
Waggle Breakdown

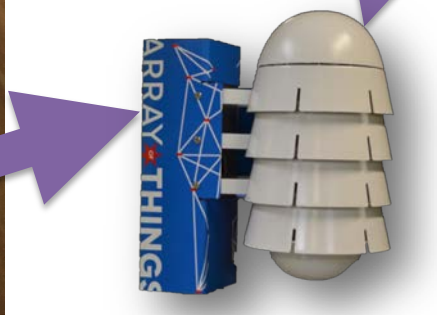
Resilient Hardware



Edge Computing



Sensor Pod



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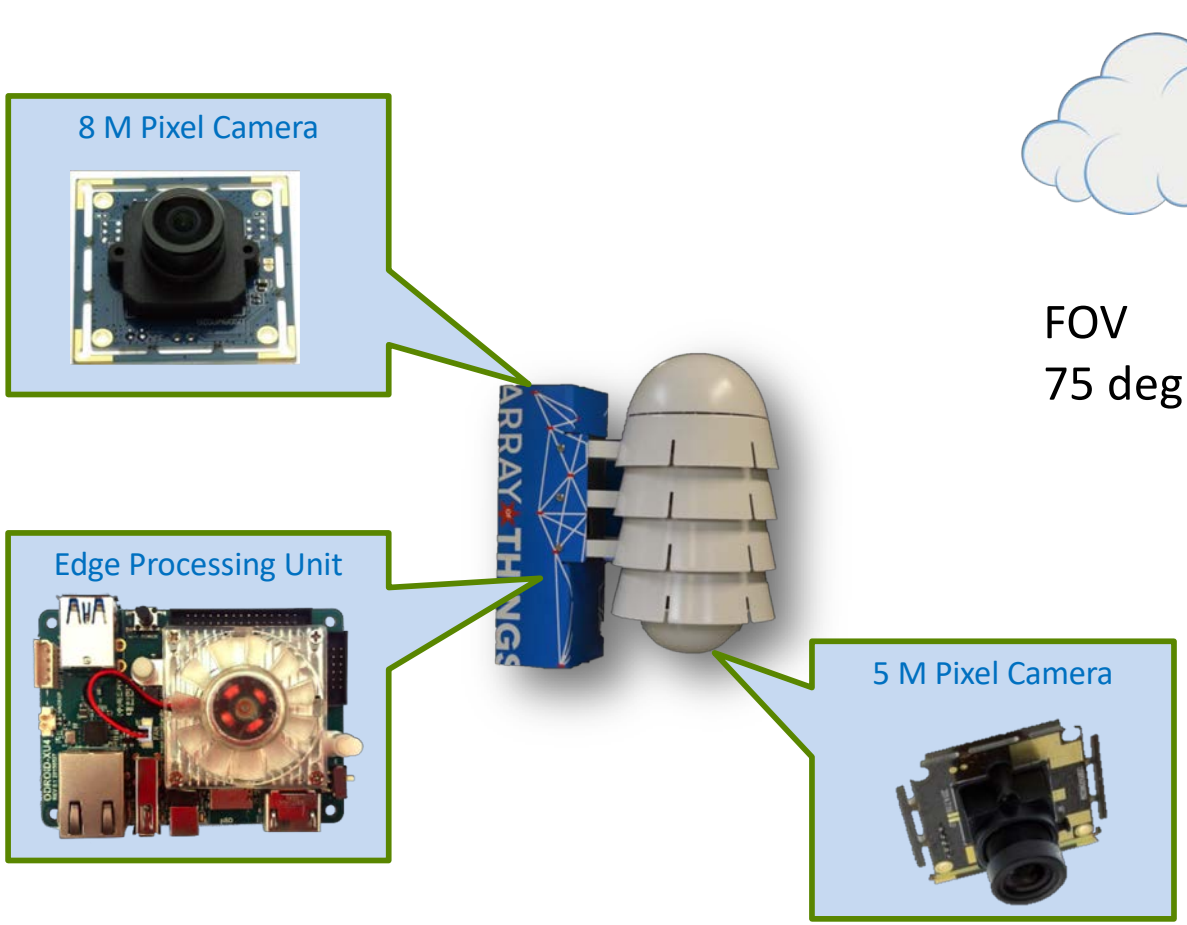
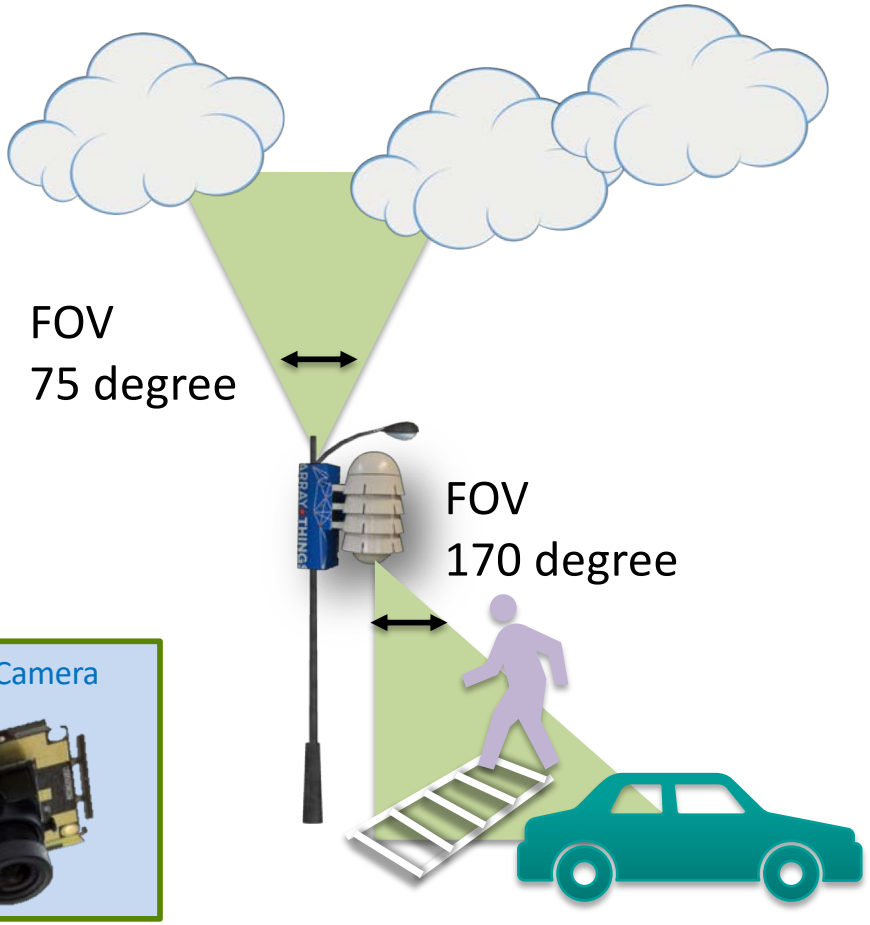
Edge Vision: Cameras on Array of Things Nodes





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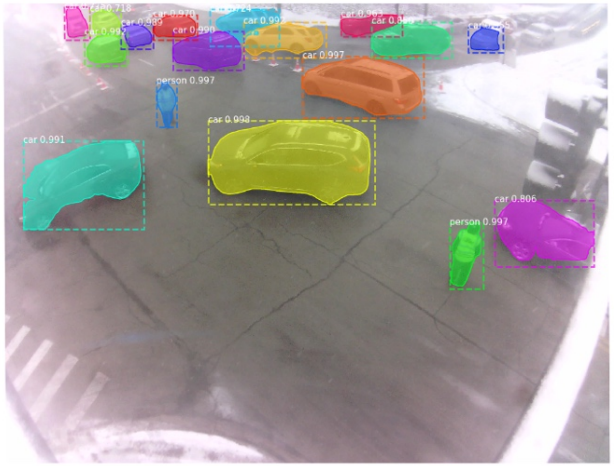
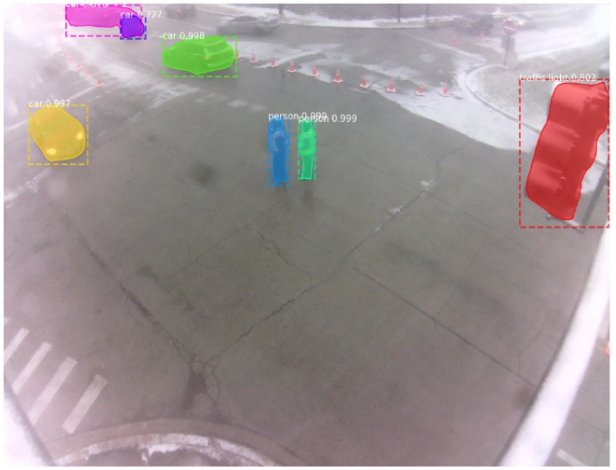
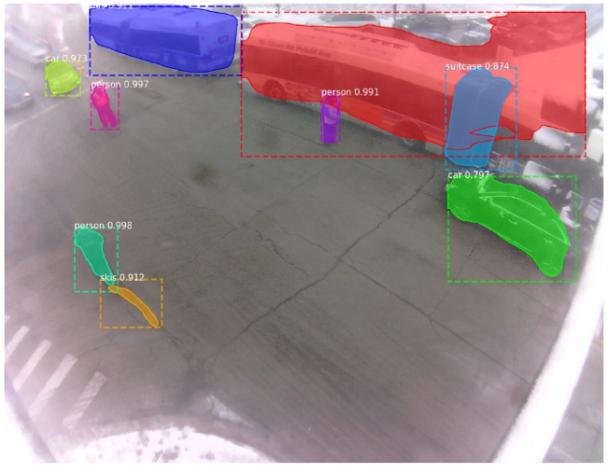
Performance for Current Processes (1 of 2)

Model: **Mask RCNN** (Region with Convolutional Neural Network) in **TensorFlow**
Training Data Set: **Coco Dataset**
Original Image Size: 2592 x 1944, Lake Shore Drive, Dec. 2017
Input Image Shape: **1024 x 1024**
Computing Device: A Laptop, 8GB memory Intel i7 CPU
Confidence threshold : 0.6
Computing Time: ~ **9** seconds







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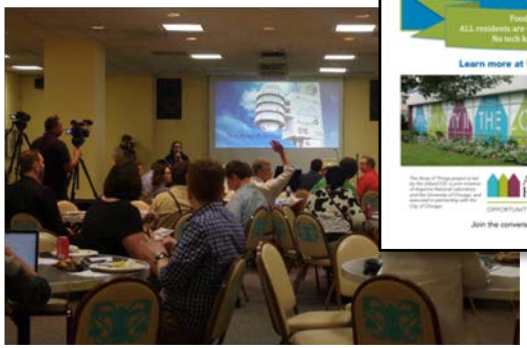
Performance for Current Processes (2 of 2)

Model: **SSD** (Single Shot MultiBox Detector) in **OpenCV**
Training Data Set: **Coco Dataset**
Original Image Size: 2592 x 1944, Damen Ave. & Lawrence Ave., Dec. 2017
Input Image Shape: **300 x 300**
Computing Device: **NVIDIA Jetson TX2 CPUs (~1.2 GHz)**
Confidence threshold: 0.6
Computing Time: ~ **230** milliseconds

Engaging Communities



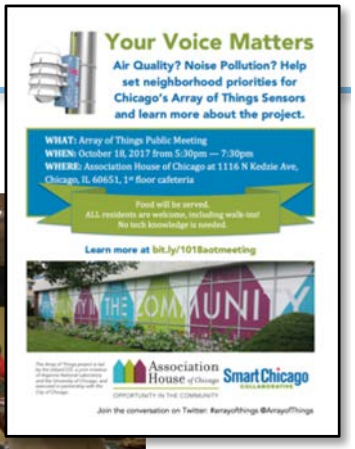


Image: Horsch Gallery

Images: Jose Osorio, Chicago Tribune

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