

How cities can become smarter: Sensors, Edge Computing, and The Array of Things

Charlie Catlett

*Senior Research Scientist, Discovery Partners Institute,
University of Illinois*

*Senior Computer Scientist, Argonne National Laboratory
Senior Fellow, Mansueto Institute, University of Chicago*

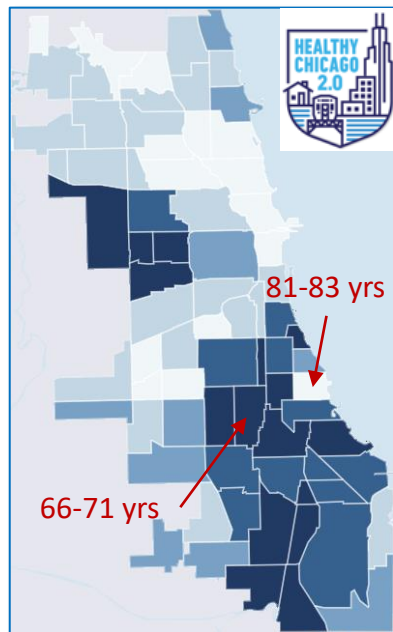
*Urban Futures Summer Workshop
Microsoft Research
July 2020*



Collaborators:

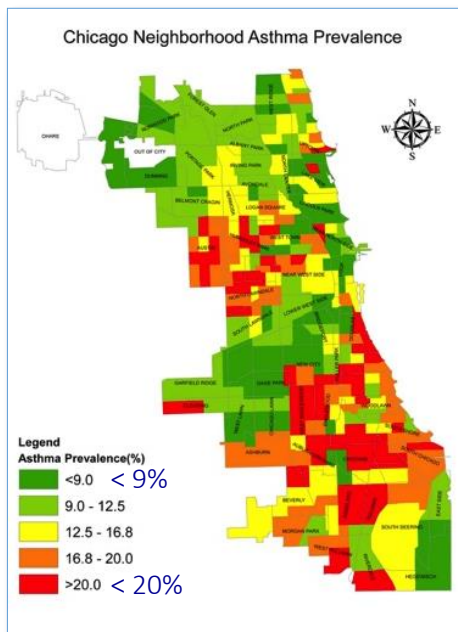
Pete Beckman (ANL/NU)
Nicola Ferrier (ANL/UC)
Jim Olds (GMU)
Dan Reed (Utah)
Ilkay Altintas (UCSD)
Carleton Nolan (Chicago CIO)
Mike Papka (ANL/NIU)
Kathleen Cagney (UC)
Howard Nusbaum (UC)
Marc Berman (UC)
Mark Potosnak (DePaul)
Douglas Pancoast (School of the Art
Inst of Chicago)
Daniel Work (Vanderbilt)
...and many more

Cities: Collections of Neighborhoods



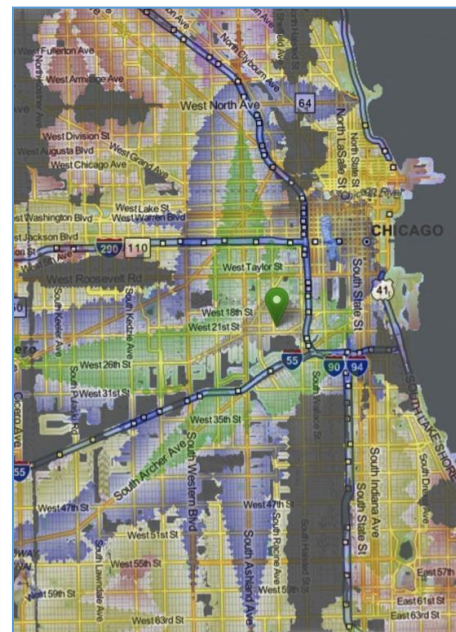
Life expectancy

<https://www.chicagohealthatlas.org/>

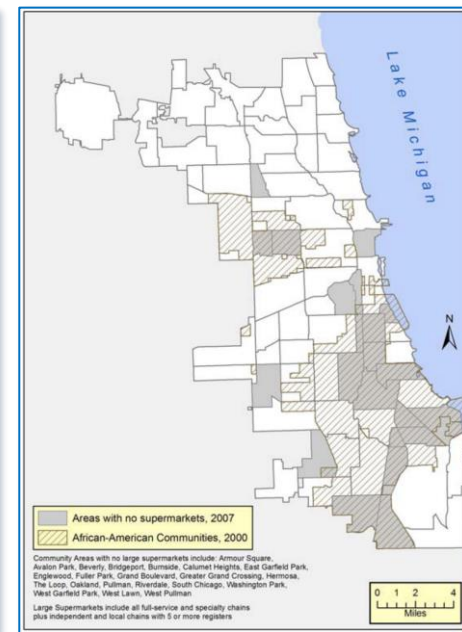


Asthma

<http://www.mentalmunition.com/2011/09/south-side-children-have-greatest.html>



Access to services



Access to healthy food

"Food Deserts in Chicago, A Report of the Illinois Advisory Committee to the United States Commission on Civil Rights. 2011

Beginning in 2013 we asked scientists, residents, and city department heads and workers...

“What do you want to measure?”

SENSORS

Environment

- Solar load on buildings
- Traffic safety
- Idling trucks
- Construction effects
- Noise pollution/sources
- Urban heat island
- Mold exposure

Air Quality

- Asthma rates
- Traffic impact on AQ
- Industrial air pollutants
- Fossil fuel emissions
- Hydrogen sulfide
- Fuel leaks
- Flammable hazards

OBSERVATIONS

Activity

- Flooding
- Traffic flow & safety
- Pedestrian flow & safety
- Use patterns of public spaces
- Sources of noise pollution & noise events

Array of Things current sensor configuration includes sensors that were selected and developed based on five years of input from, and collaboration with, city officials, policymakers, residents, scientists, and students.



2018 Array of Things International Student and User Workshop

Array of Things Measurements

(First units built and deployed in 2016)



Environment

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

Air Quality

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

Edge Computing or “AI at the Edge” Research:

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

Computer Audio: Noise components, sound events

The “Array of Things” (AoT) was an NSF-funded Major Research Instrumentation project in partnership with the City of Chicago, led by the University of Chicago and Argonne National Laboratory. The underlying hardware and software used is Argonne’s Open WAGGLE platform. (wa8.gl)



Northwestern
University



THE UNIVERSITY OF
CHICAGO

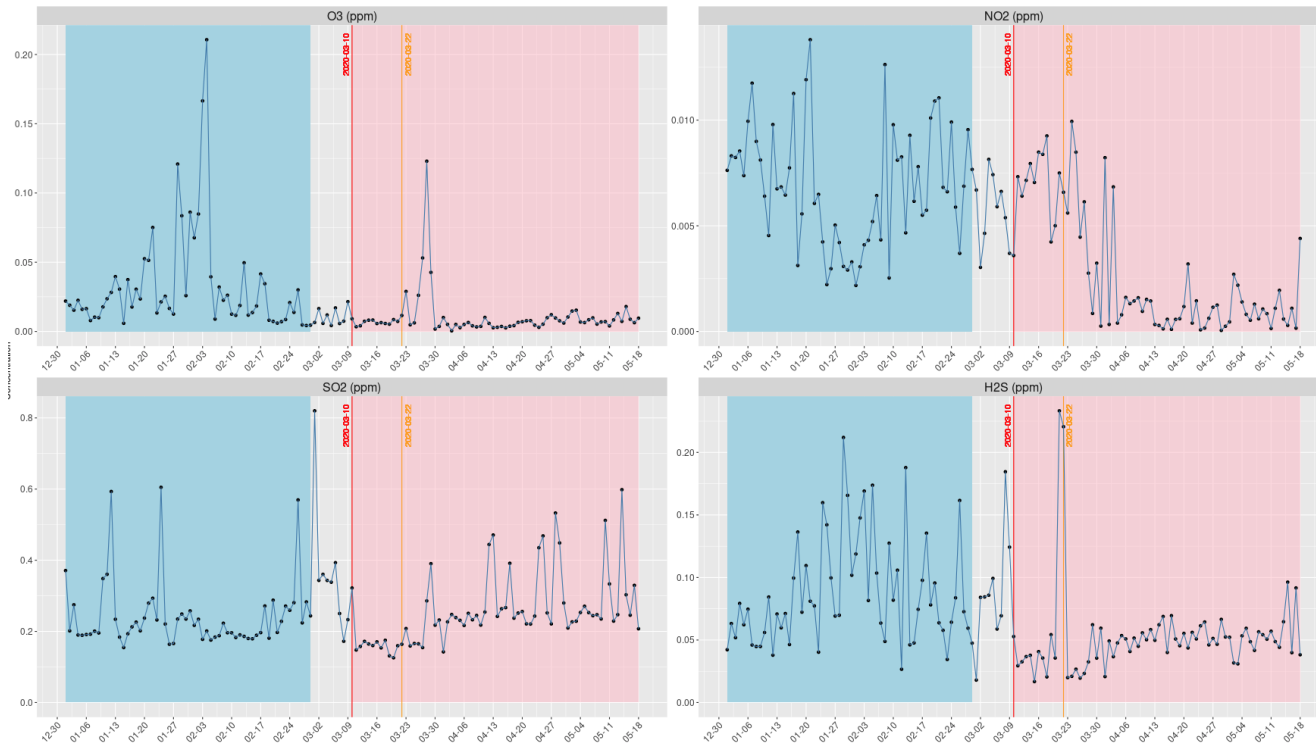
Argonne
NATIONAL LABORATORY



Array of Things and Air Quality

Selected Baseline Period: from 2020-01-01 to 2020-02-29
Selected COVID-19 Period: from 2020-03-10 to 2020-05-18

<https://aot-air-quality-change-report.norc.org/>



Next steps on AQ – smaller, less expensive, ideally with edge AI

English, N., et al. (2020). "Making Sense of Sensor Data: How Local Environmental Conditions Add Value to Social Science Research." *Social Science Computer Review*: 0894439320920601.

Jacob, R. L., et al. (2017). Early results from the Array of Things. *AGU Fall Meeting Abstracts*.

Jacob, R. L., et al. (2015). "Informing urban decision making with an array of things." *AGUFM 2015: NH53A-04*.

Jain, R., et al. (2018). "Representation and Evolution of Urban Weather Boundary Conditions in Downtown Chicago." *Journal of Building Performance Simulation* (to appear).

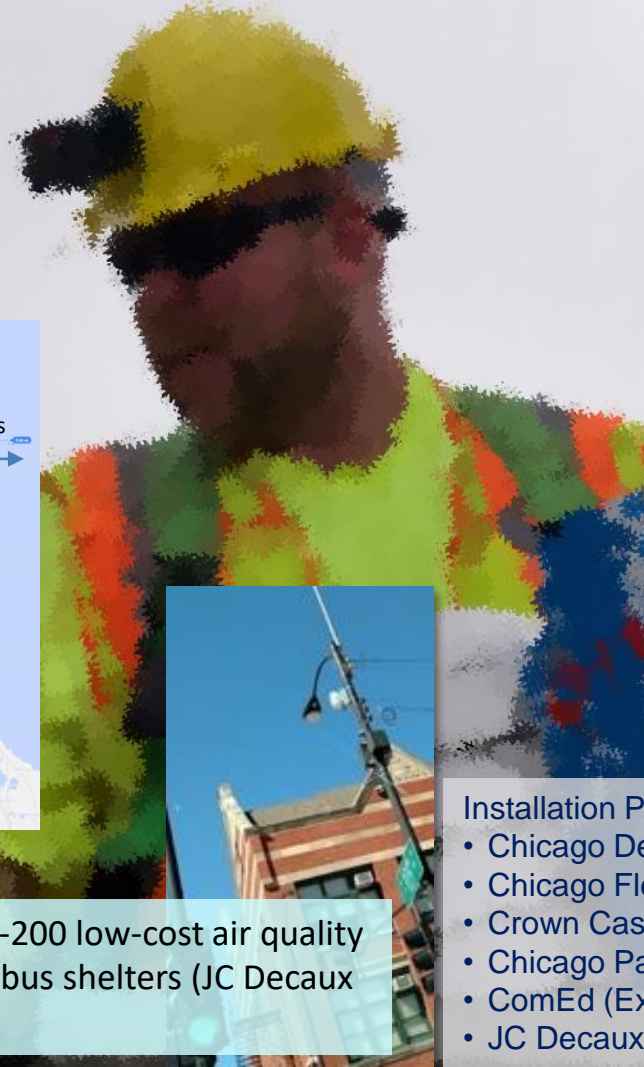
Potosnak, M. J., et al. (2018). Array of Things: Characterizing low-cost air quality sensors for a city-wide instrument. *American Geophysical Union (AGU) Fall 2018 Meeting*, Washington, D.C., USA.

Silva, M. P., et al. (2018). "Neighborhood scale heat mitigation strategies using Array of Things (AoT) data in Chicago." *AGUFM 2018: PA21D-0986*

Chicago AoT Deployment



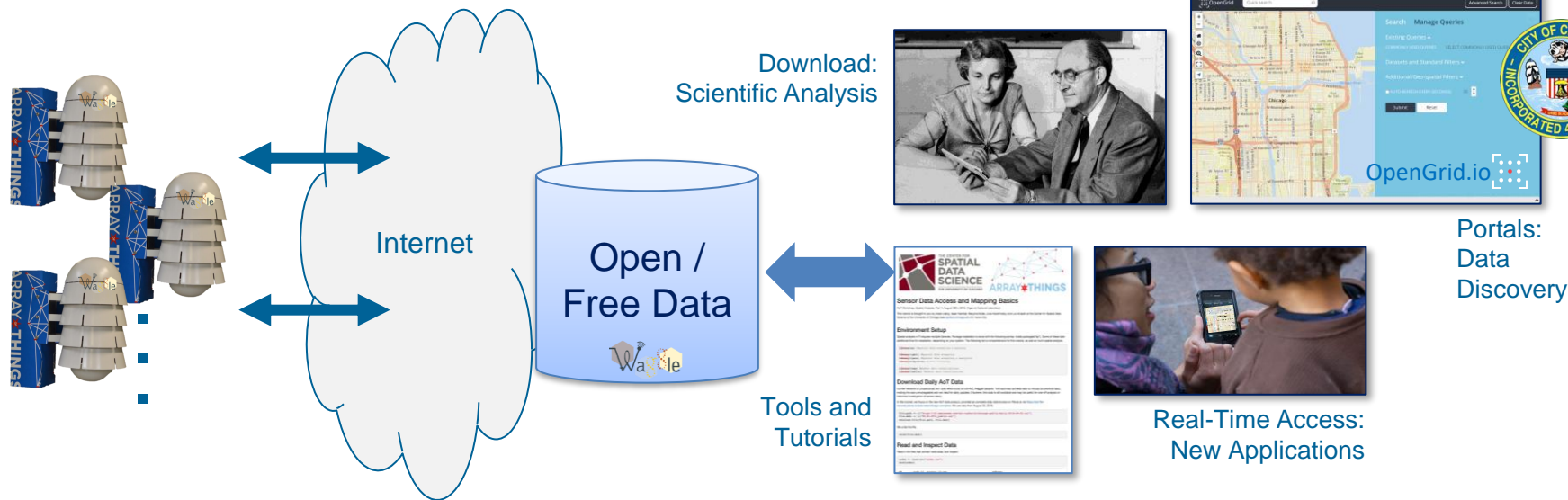
Next: Exploring 1-200 low-cost air quality units to place on bus shelters (JC Decaux operates 2100)



Installation Partners include:

- Chicago Department of Transportation (CDOT)
- Chicago Fleets & Facilities Management
- Crown Castle Communications
- Chicago Park District
- ComEd (Exelon)
- JC Decaux

All Data is *Open and Free*



- **Nodes transmit sensor readings several times per minute.**
- **Only a limited volume of images and sound samples are transmitted*.**
- **Results of (pre-approved) image or sound processing (e.g., number of pedestrians or vehicles), done using AI-at-the-edge, are transmitted and published.**
- **For more information, policies, data tutorials, and data links, go to <https://www.arrayofthings.org>**

*Several times per hour a sample image and sound clip are sent to a protected, controlled-access training library, which is only available to research teams under a data use agreement. See Privacy Policies at www.arrayofthings.org



Northwestern
University

THE UNIVERSITY OF
CHICAGO

Argonne
NATIONAL LABORATORY

Array of Things Operating Policies

August 15, 2016

Contents

Array of Things Governance Policy and Process	1
1. Purpose and Scope	1
1.1. Guiding Principle	1
1.2. Program Overview	1
2. Technical Objectives	2
2.1. Support for Evolving Technologies Over Time.....	2
2.2. Support for Software and Services Projects.....	3
3. Governance Bodies	3
3.1. Program Operators	3
3.2. Executive Oversight Council	3
3.3. Technical Security and Privacy Group	4
3.4. Scientific Review Group	4
4. Governance Policy and Processes	4
4.1. Policy	4
4.2. Transparency	4
4.3. Node Locations	5
4.4. Node Security	6
4.5. Node Capabilities.....	6
4.6. Education	6
4.7. Updates	6
Array of Things Privacy Policy	7
5. Purpose and Scope	7
6. Guiding Principle	7
7. Personally Identifiable Information	7
8. Information Collection, Use, and Sharing	8
9. Updates	8



Governance*



Guiding principles:
privacy, transparency, and openness



Elissa Tenny
President, School of the
Art Inst. of Chicago



Ari Scharg
Partner, Edelson



Brenna Berman
CEO, CityTech



Carleton Nolan
CIO, City of Chicago



Aaron Koch
Chicago Director,
Trust for Public Land



Pete Beckman
Scientist,
Northwestern



Don DeLoach
Chair, Midwest IoT Council



Dan Reed
Provost, Univ of Utah



Karen Weigert
VP, Slipstream



Steven Philpott
Community Organizer



Danielle DuMerer
CIO, Shedd Aquarium



Glenn Eden
VP, Weber Shandwick
Chairman, Choose Chicago



Charlie Catlett
Scientist, UChicago



Lynn Osmond
President/CEO, Chicago
Architecture Foundation

*How do we ensure that residents are enthusiastic, not just accepting (and certainly not opposed!)?

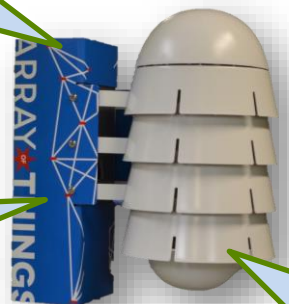
Edge Vision: Cameras and AoT@Edge



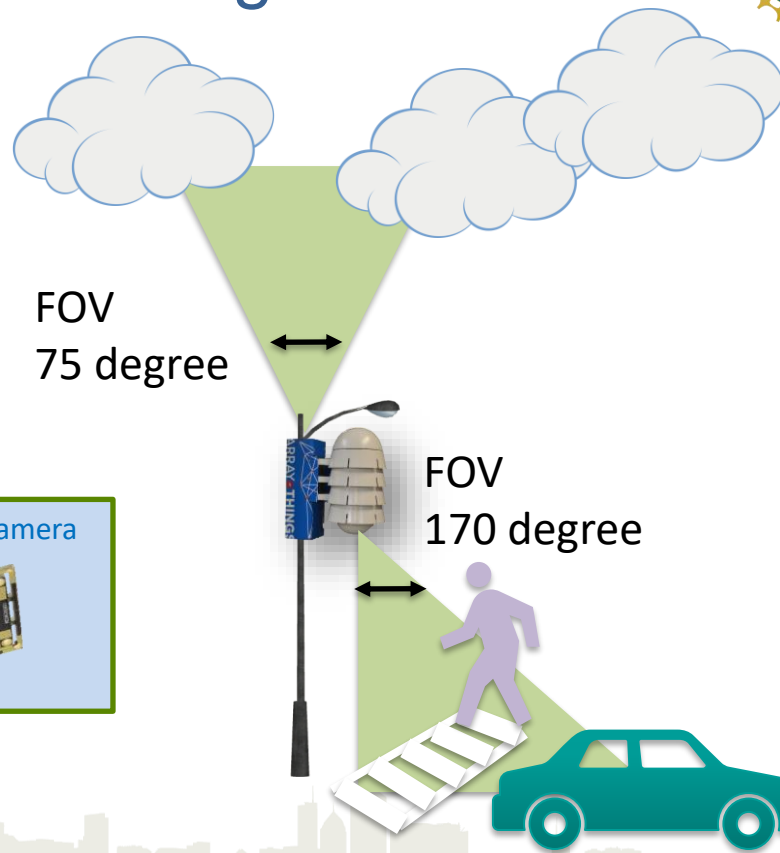
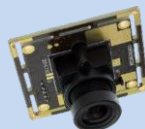
8 M Pixel Camera



Edge Processing Unit



5 M Pixel Camera

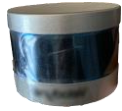


Northwestern University

THE UNIVERSITY OF CHICAGO

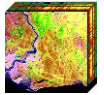
Argonne NATIONAL LABORATORY

Sensors



LIDAR

Software Defined Radios



Hyperspectral Imaging

Facilities



Actuators



Servos

Dynamic adaptation



AI at the Edge

Why AI@Edge?

- Privacy
- Real-time decisions—adaptive and goal-oriented computing
- Latency
- Bandwidth limitations

Edge computing and deep learning with feedback for continuous improvement

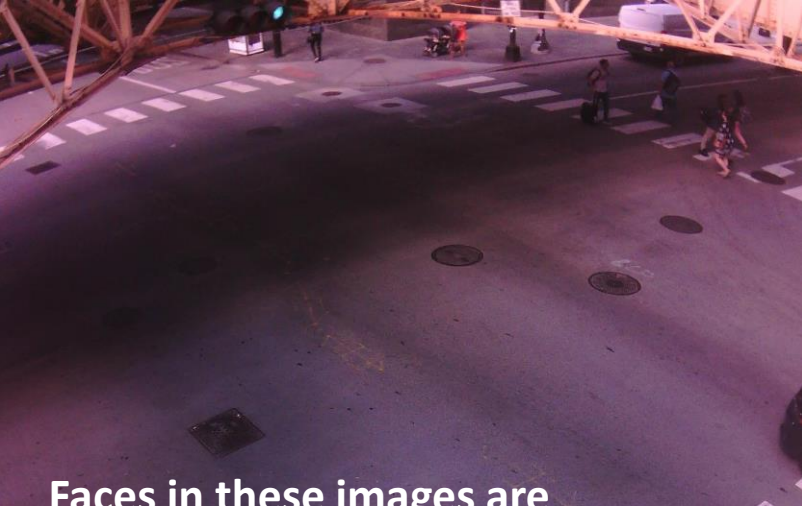
Reduced, Compressed data

New inference (model)
Adaptive steering

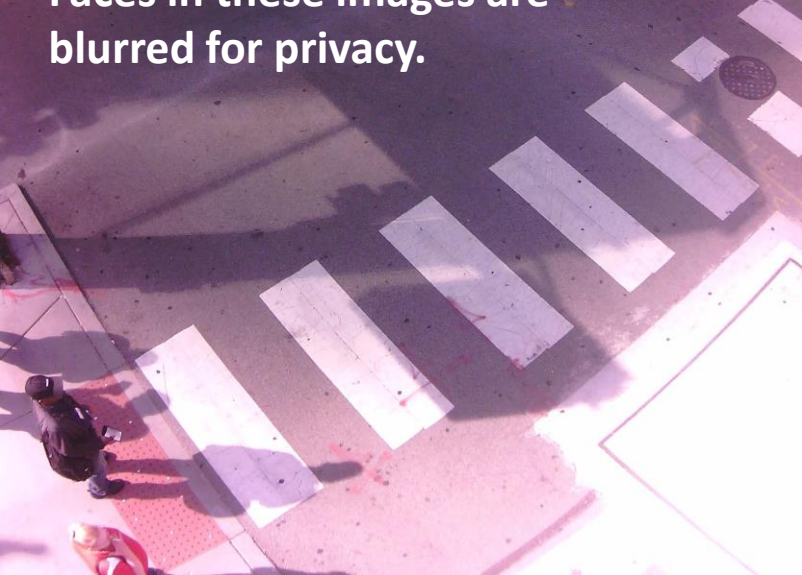
HPC



Deep Learning Training
Simulation / Forecast



Faces in these images are blurred for privacy.

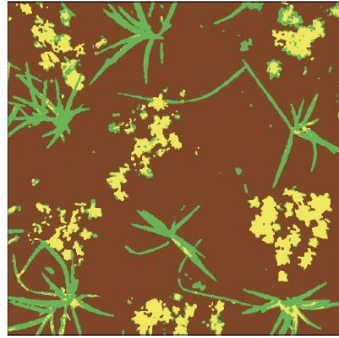


Many Science Problems....

Wildfires: detecting smoke



Plant Species



Pedestrian Flow



Drone detection



Snow Depth



Urban flooding



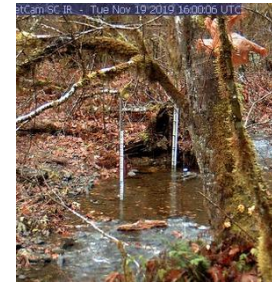
Traffic Flow and vehicle type



Wildlife



Cloud Coverage



Water Depth

Replicable Experiments: Measuring the Use of Public Places

Chicago, IL



Nashville, TN



Atlanta, GA



DeKalb, IL



Paris, France



Taichung City, TW



Bristol, UK



New York City, NY



For example, new techniques using AI@edge for privacy, scene characterization (natural/urban; ordered/disordered) and understanding how different urban/natural environments impact health, cognition, crime, and other social and behavioral factors.

Marc Berman (UChicago Environmental Neuroscience Laboratory)



SAGE

A Software-Defined Sensor Network
Cyberinfrastructure for AI at the Edge

www.sagecontinuum.org



Leadership Team



Eugene Kelly



Pete Beckman



Ilkay Altintas



Charlie Catlett



Scott Collis



Valerie Taylor



Stacie Williams



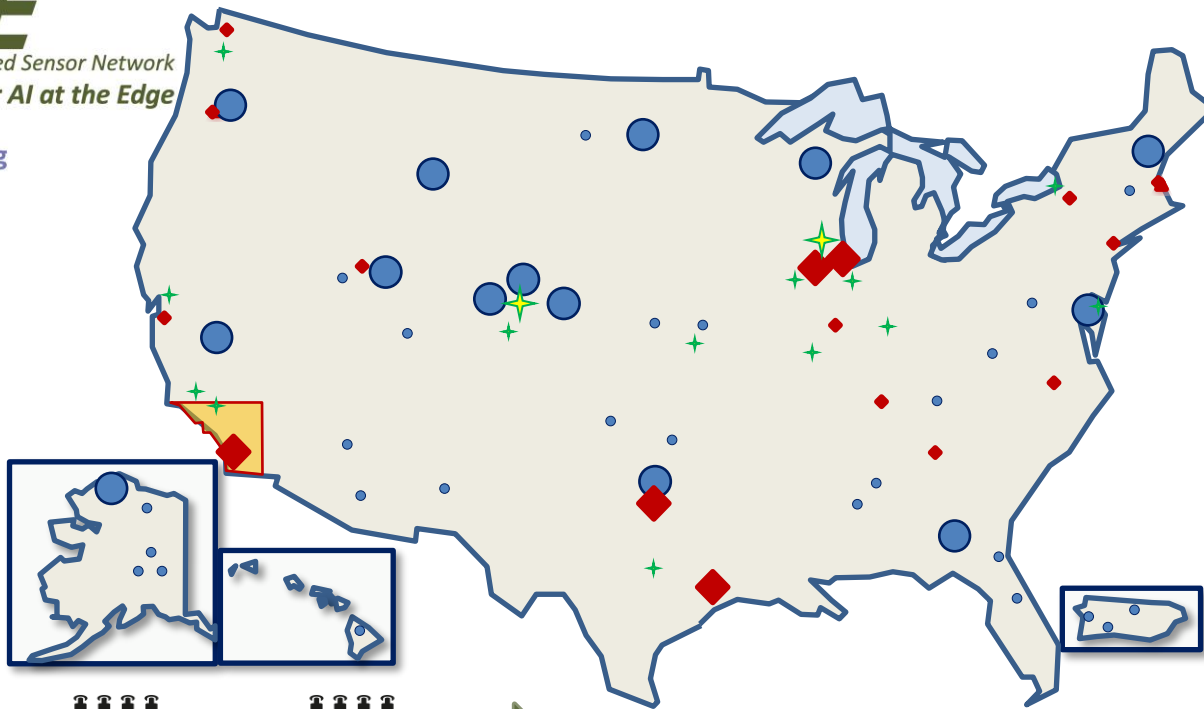
Dan Reed



Jim Olds



Irene Qualters



HPC / Cloud



NEON



WIFIRE/
HPWREN



Aot

Looking To The Future: Programming The Computing Continuum



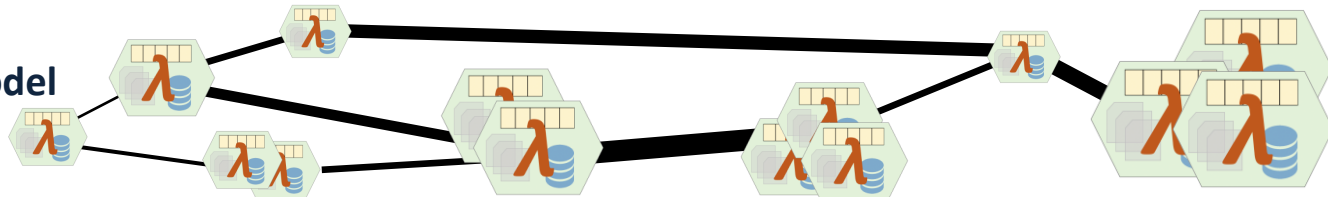
Size	Nano	Micro	Milli	Server	Fog	Campus	Facility
Example	Adafruit Trinket	Particle.io Boron	Array of Things	Linux Box	Co-located Blades	1000-node cluster	Datacenter
Memory	0.5K	256K	8GB	32GB	256G	32TB	16PB
Network	BLE	WiFi/LTE	WiFi/LTE	1 GigE	10GigE	40GigE	N*100GigE
Cost	\$5	\$30	\$600	\$3K	\$50K	\$2M	\$1000M

Count = 10^9
Size = 10^1



Count = 10^1
Size = 10^9

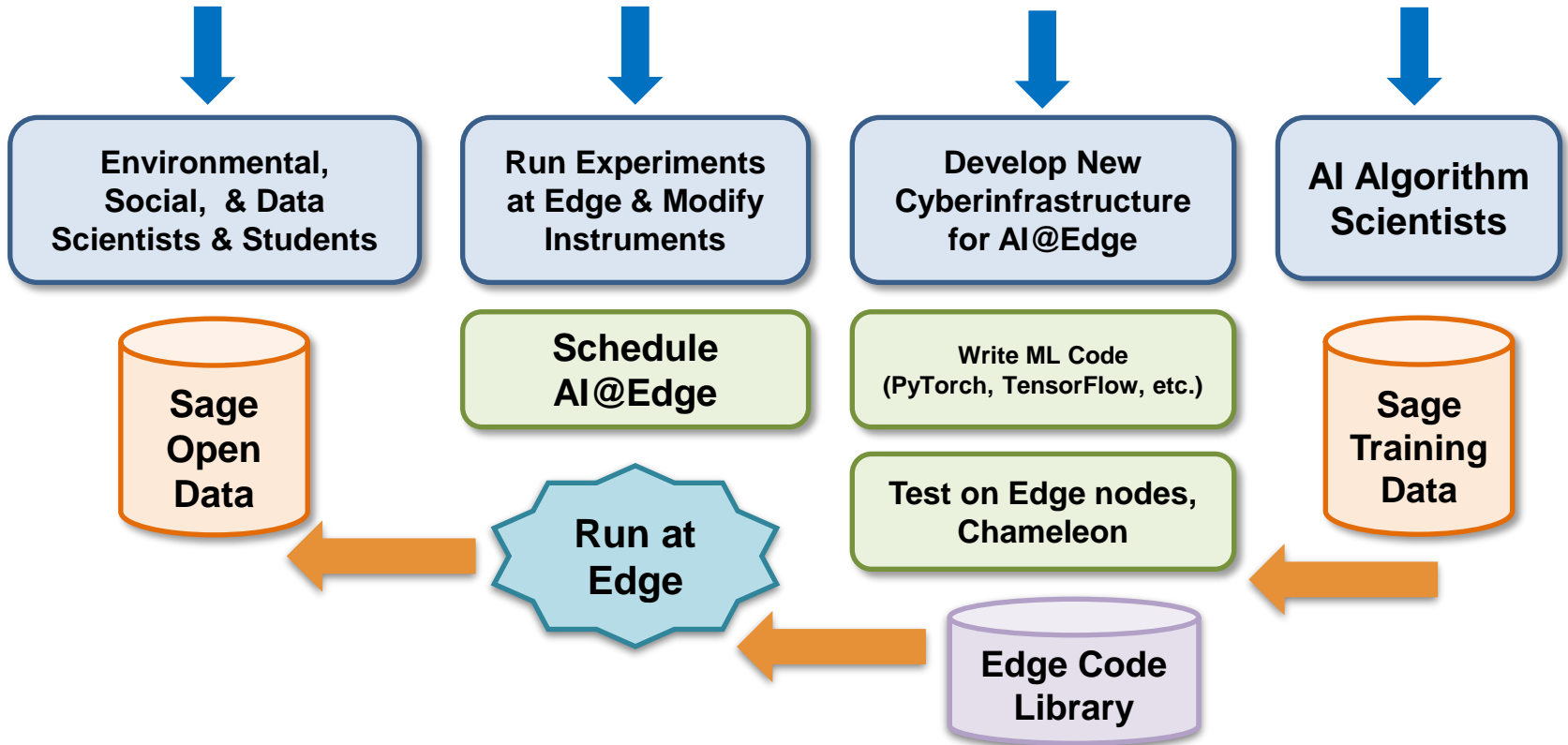
Continuum
Abstract Model
& Runtime



**The Computing Continuum will be the future facility;
it needs a run-time system and programming model**

What does AI@Edge Cyberinfrastructure need?

A User-Driven, Science Architecture:



Thank you

Charlie Catlett
ccatlett @ illinois.edu



• Discovery Partners Institute

- Identifying, Creating, Supporting Interdisciplinary Team Science

ILLINOIS



• Beyond Array of Things: SAGE

- Building on lessons learned from the Array of Things (AoT) - an NSF-funded experimental instrument to explore the use edge-computing and of lower cost sensors to create new types of urban measurements.
- SAGE: Software-Defined Sensor Network is an NSF Mid-Scale Research Infrastructure project seeking collaborators interested in AI@edge, programming and runtime environments particularly for AI/ML across the edge-to-cloud continuum, developing new types of AI-based measurements and autonomous/adaptive computing, and other areas.



Northwestern University

