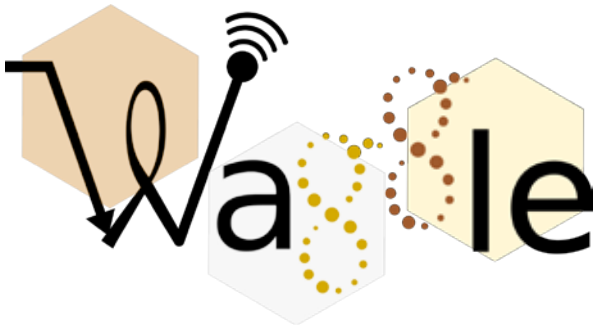


Intelligent Sensors for the Internet of Things: Parallel Computing on Chicago Street Poles

Pete Beckman

Senior Scientist, Argonne National Laboratory

Co-Director, Northwestern / Argonne Institute for Science and Engineering (NAISE)

Senior Fellow, University of Chicago Computation Institute

Collaborators: Charlie Catlett, Rajesh Sankaran, et. al.


Argonne National Laboratory
$675M /yr budget
3,200 employees
1,450 scientists/eng
750 Ph.D.s

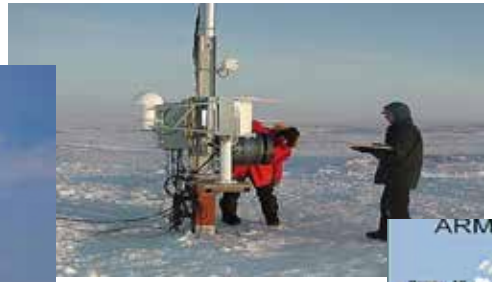
Argonne: Develops new sensors

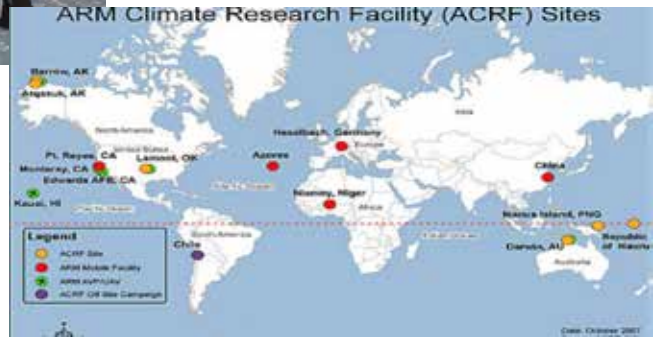
Runs large sensor networks

Climate modeling and simulation

- **… chemical, biological, nuclear and explosive materials**

Atmospheric Radiation Measurement Climate Research Facility





Internet of Things… Sometimes Silly

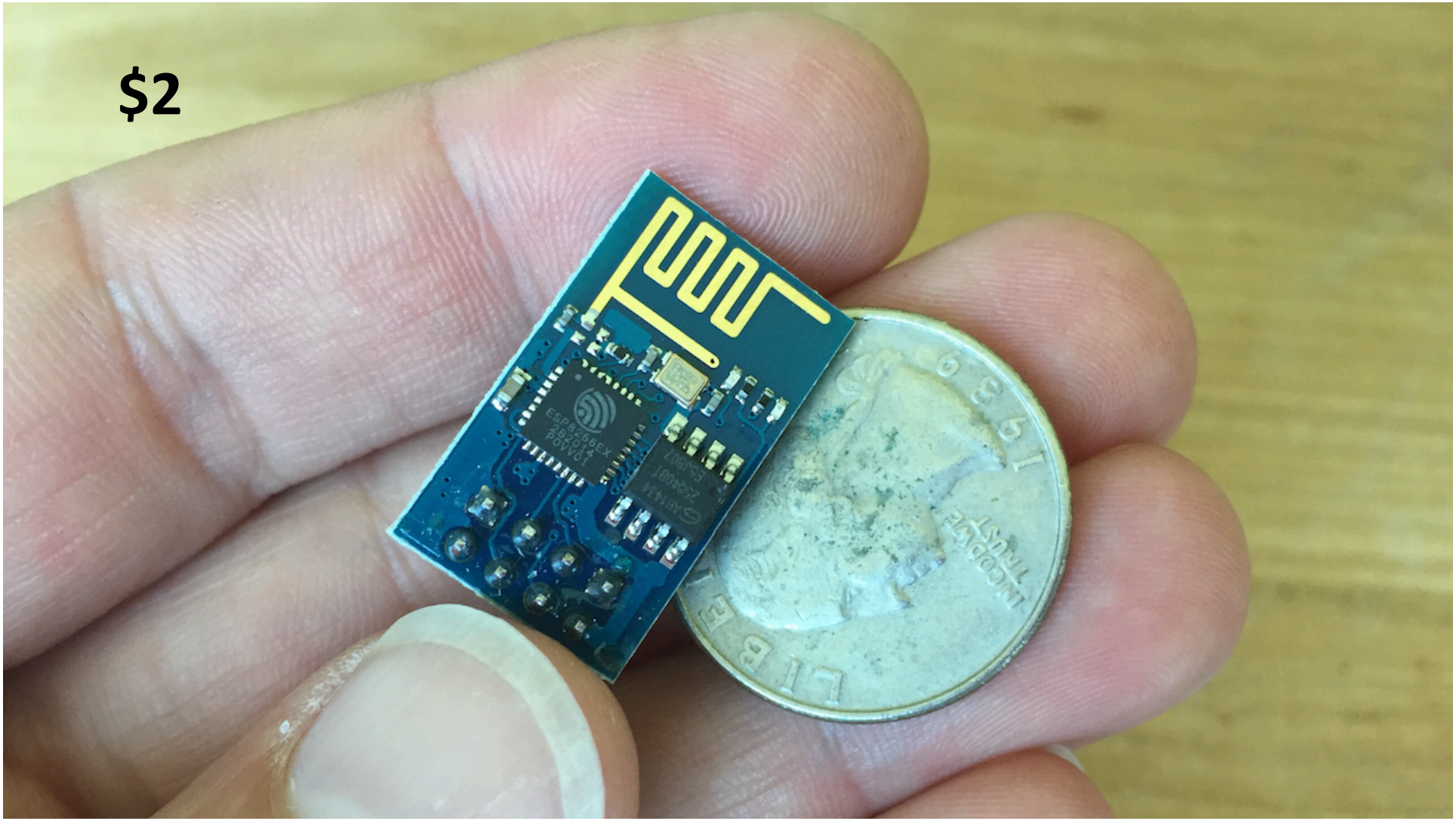
University of Cambridge, 1991

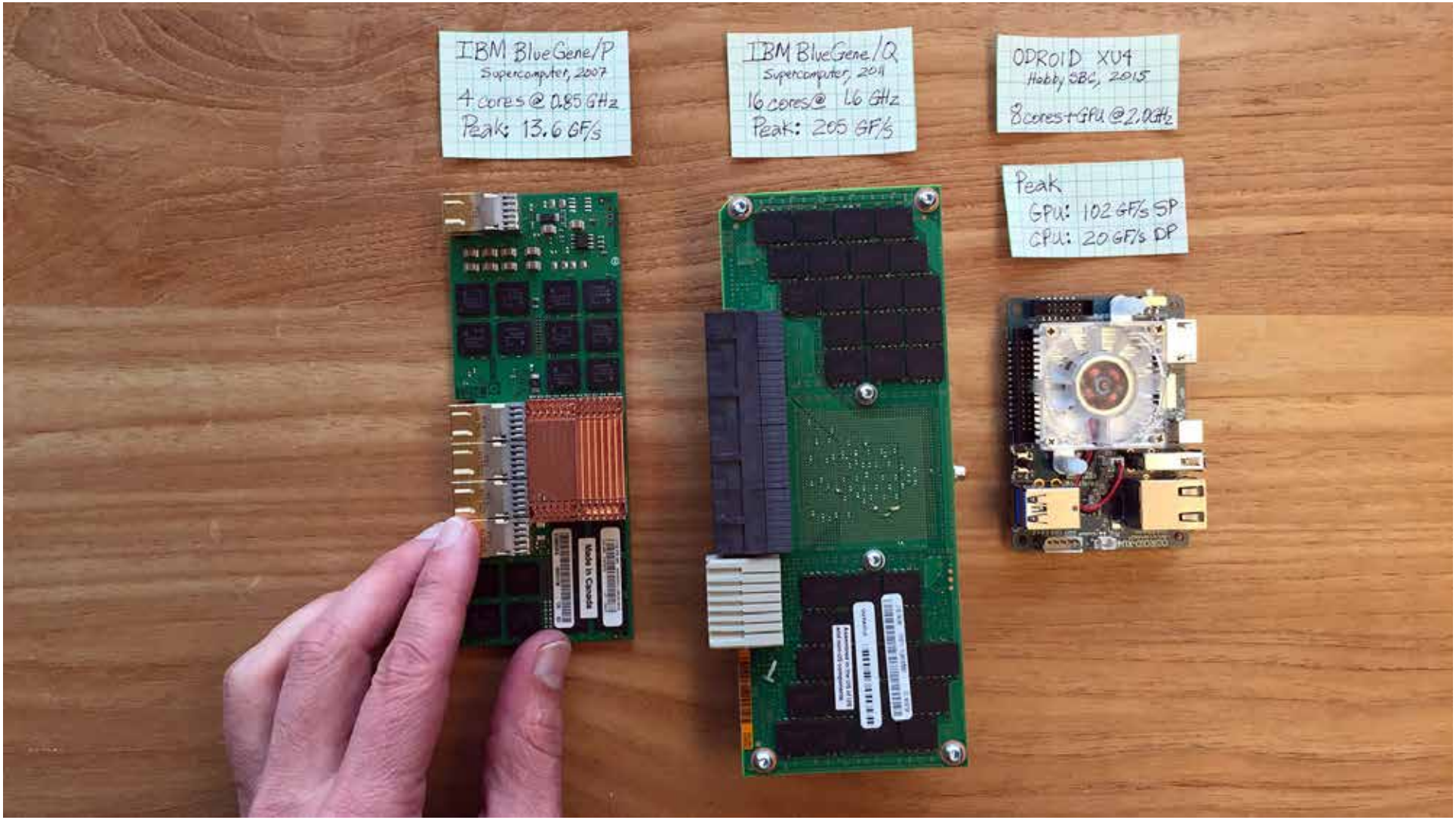
Amazon Dash

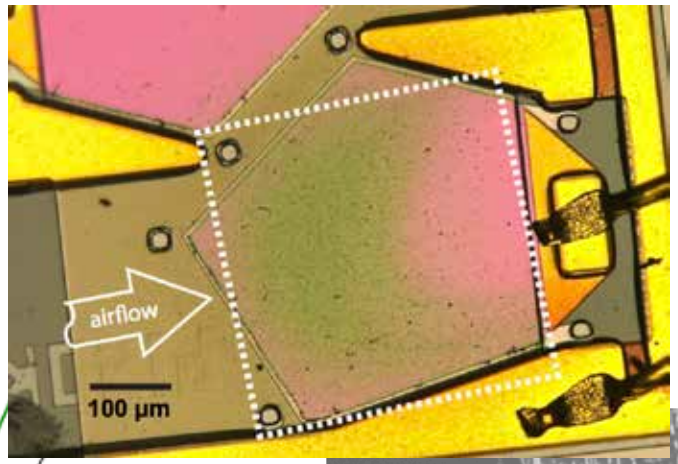
IoT: Canonical and GE's FirstBuild Collaborate on Smart Refrigerator

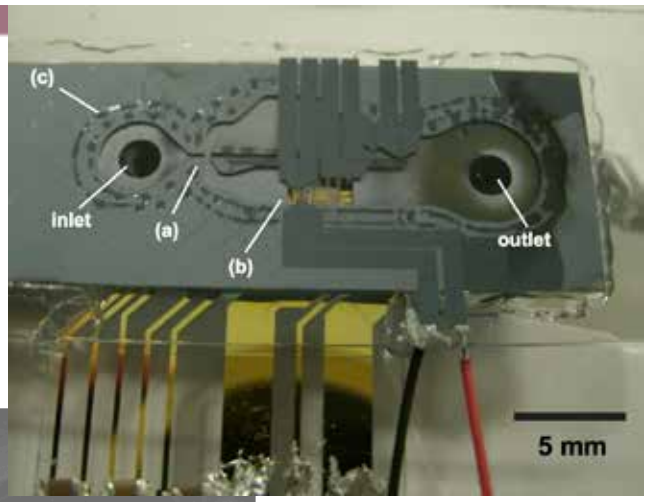
By Canonical on 11 May 2015

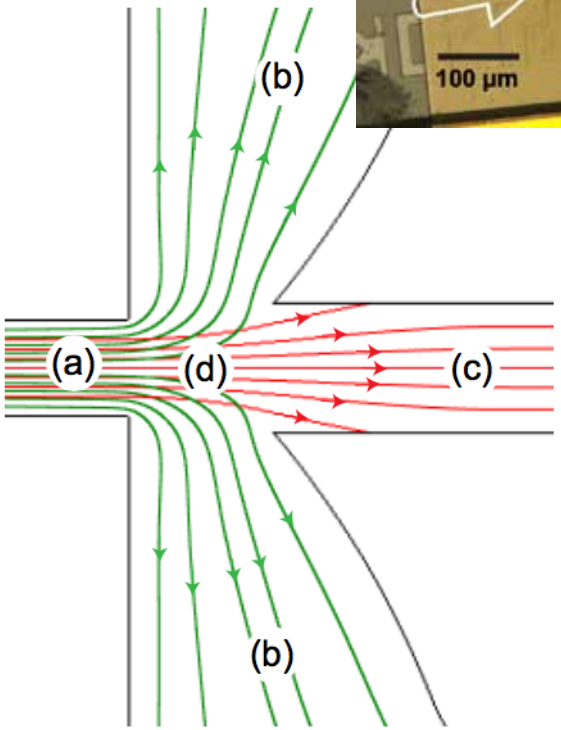
"ChillHub is a refrigerator with two USB ports and built-in Wi-Fi connectivity. In addition, ChillHub has an open-source iOS-compatible app […] Ubuntu is the favored platform for developers of all kinds – particularly those innovating around the Internet of Things."

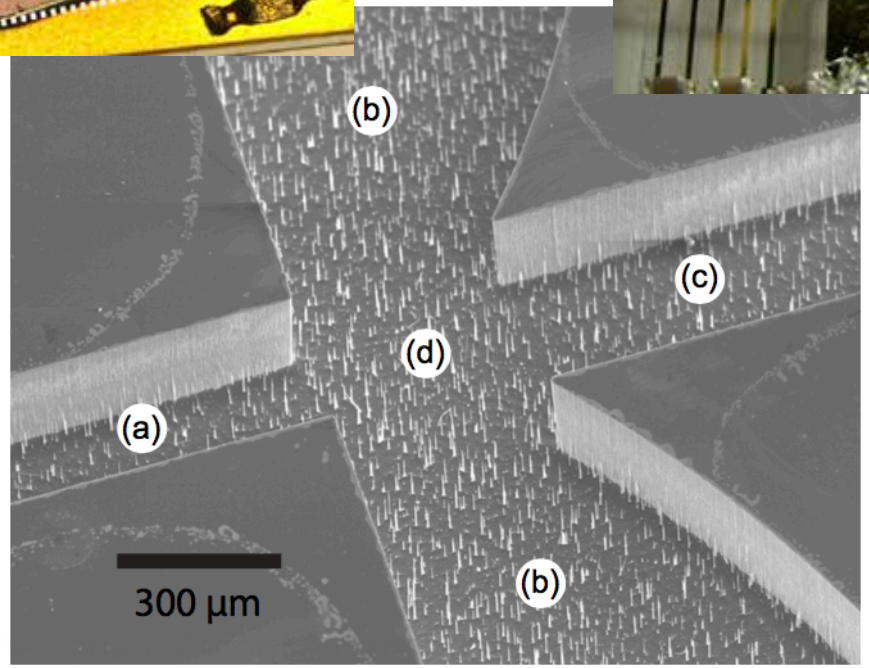

$2


IBM BlueGene/P
Supercomputer, 2007
4 cores @ 0.85 GHz
Peak: 13.6 GF/s
IBM BlueGene/Q
Supercomputer, 2011
16 cores @ 1.6 GHz
Peak: 205 GF/s
ODROID XU4
Hobby SBC, 2015
8 cores + GPU @ 2.0 GHz
Peak
GPU: 102 GF/s SP
CPU: 20 GF/s DP





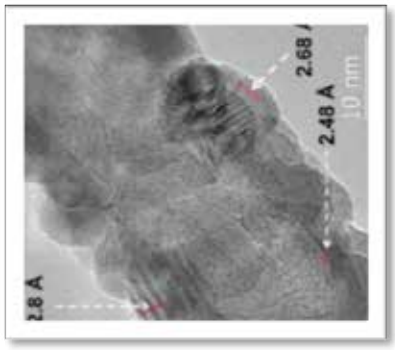




Courtesty
Igor Paprotny, UIC

Disruption: Intelligent, Attentive Sensors

- **Sensors**:
  - Explosion of nano & imaging tech
- **CPUs**:
  - Powerful, low-power, embedded with network
- **In-situ/Edge Computing:**
  - Data in flight, can't store it all
  - Sensors+CPUs = new programming model for *in-situ computation*
- **Open Source:** Reusable, extensible software communities



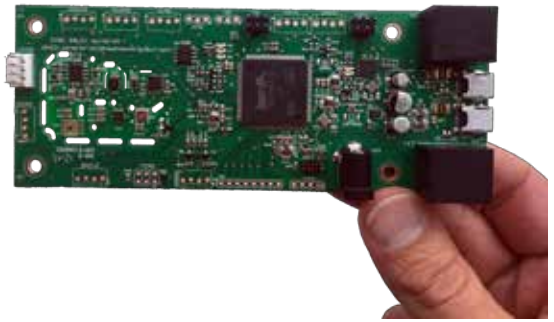
CNM carbon nanotube methane sensor

Opportunity: Predictive Models:

Smart Sensors + Supercomputers = predictions and analysis

Introducing Waggle (www.wa8.gl)
Argonne investment in new science platform

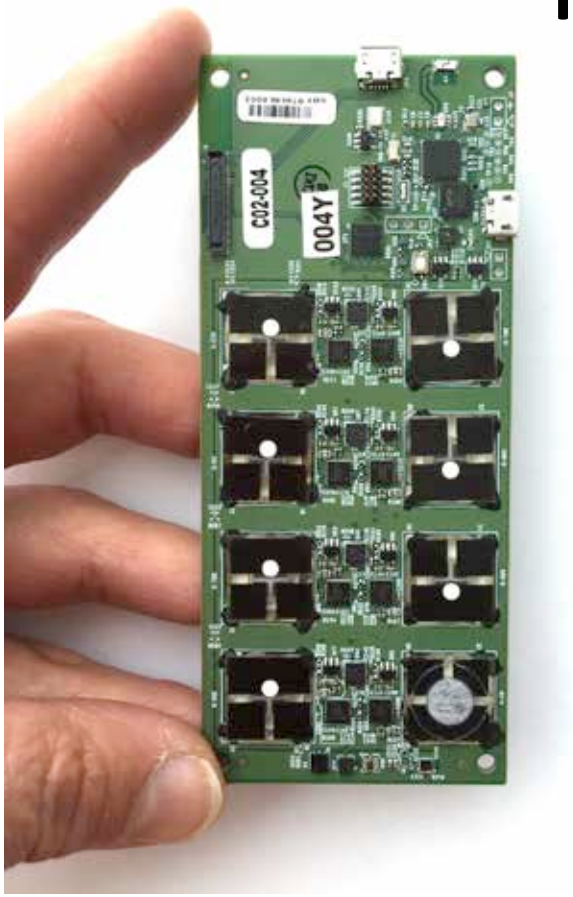
- ***Powerful CPU***, accurate sensors
- ***In-Situ Analysis*** for adaptive feature detection, attentive control
- "Deep Space Probe" design for resilience
  - (safe mode, multiple kernels, heartbeats)
- Scalable to 100Ks of nodes; streaming data to supercomputer predictions
- Scalable/hackable Open Source platform adaptable for new science & sensors
  - host active education community



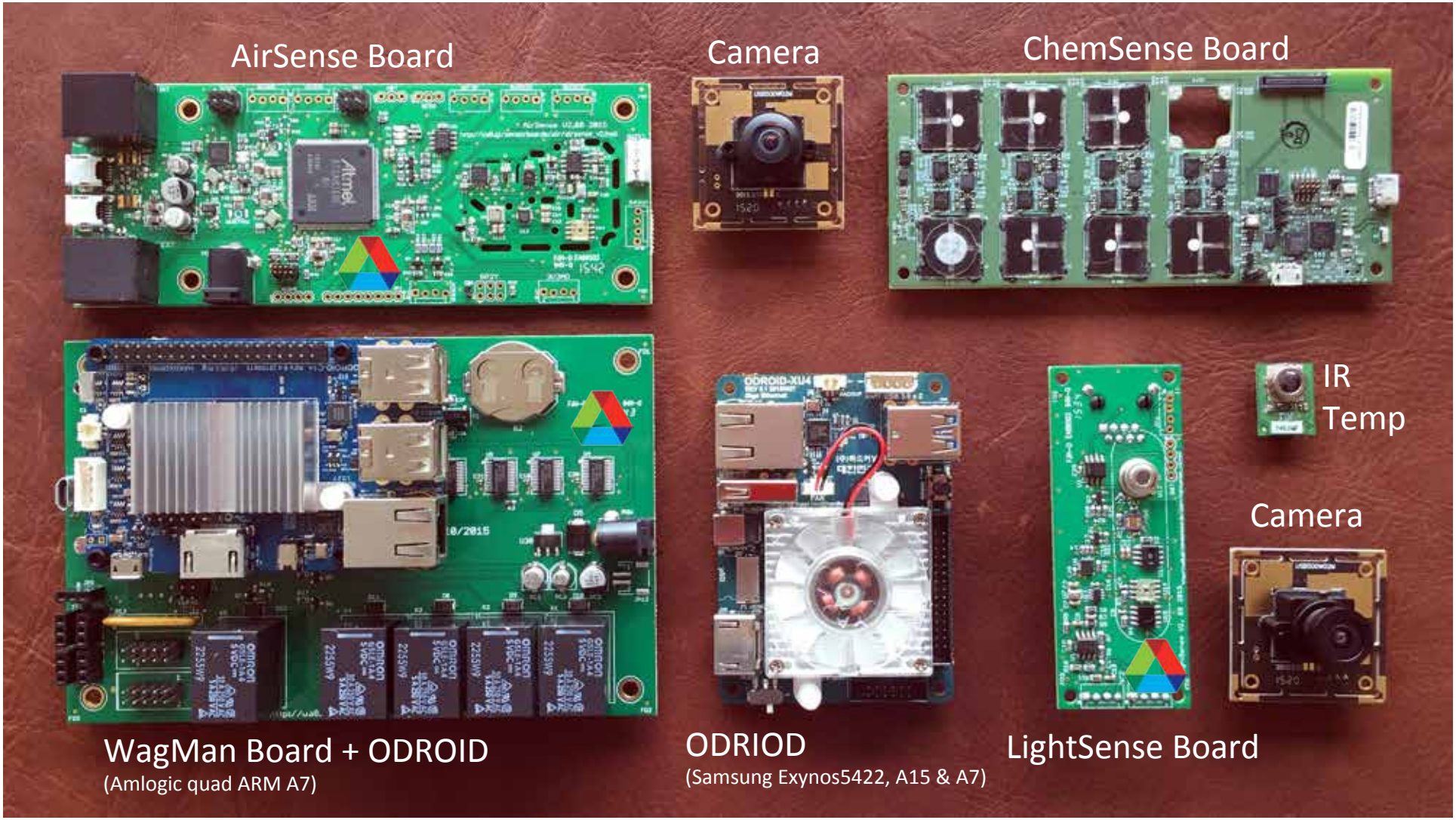
Pete Beckman: Argonne National Laboratory

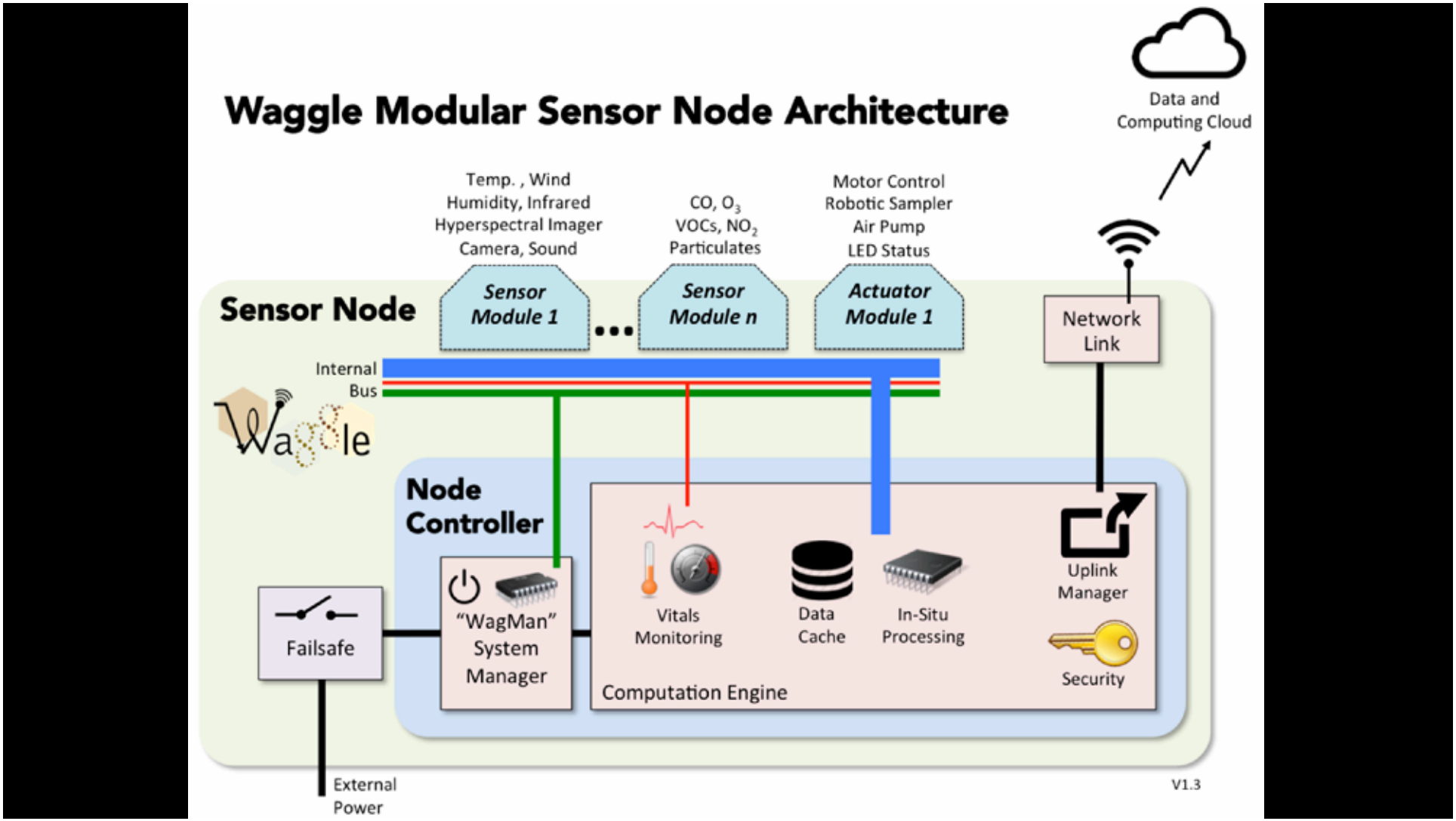
New Advanced Sensors

(via a partnership with Intel & SPEC)

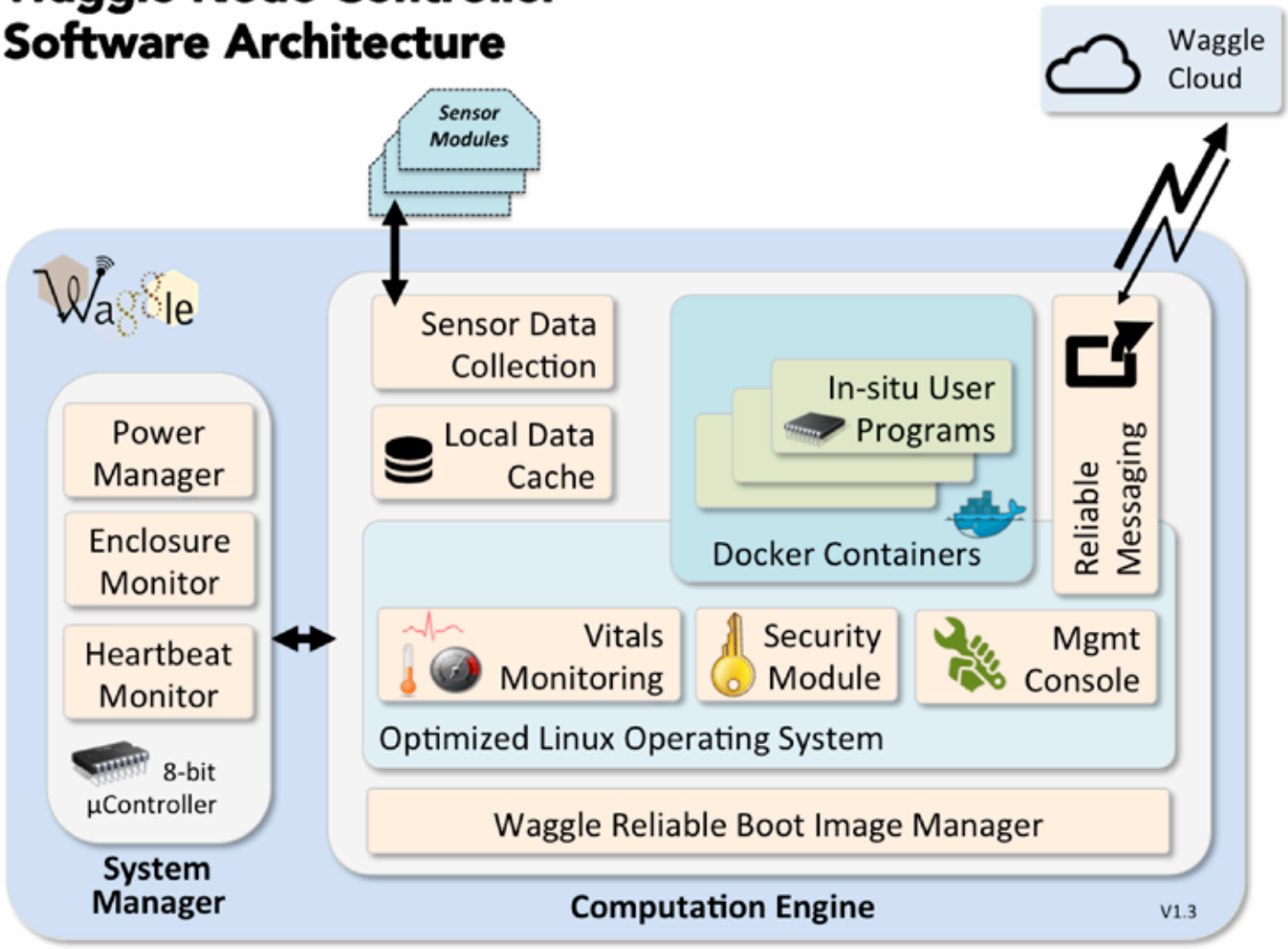


- NO2 (Nitrogen Dioxide): <2 ppb
- O3 (Ozone) < 5 ppb
- CO (Carbon Monoxide) < 1 ppm
- SO2 (Sulfer Dioxide) < 15 ppb
- H2S (Hydrogen Sulfide) < 2 ppb
- TOX (total oxidizing index) < 1 ppm CO equiv
- TOR (total reducing index) < 2 ppb NO2 equiv
- Future:
  - HCHO (Formaldehyde)
  - VOC (Volatile Organic Compound)
  - CH4 (Methane)


AirSense Board
Camera
ChemSense Board
IR
Temp
Camera
WagMan Board + ODROID
(Amlogic quad ARM A7)
ODRIOD
(Samsung Exynos5422, A15 & A7)
LightSense Board

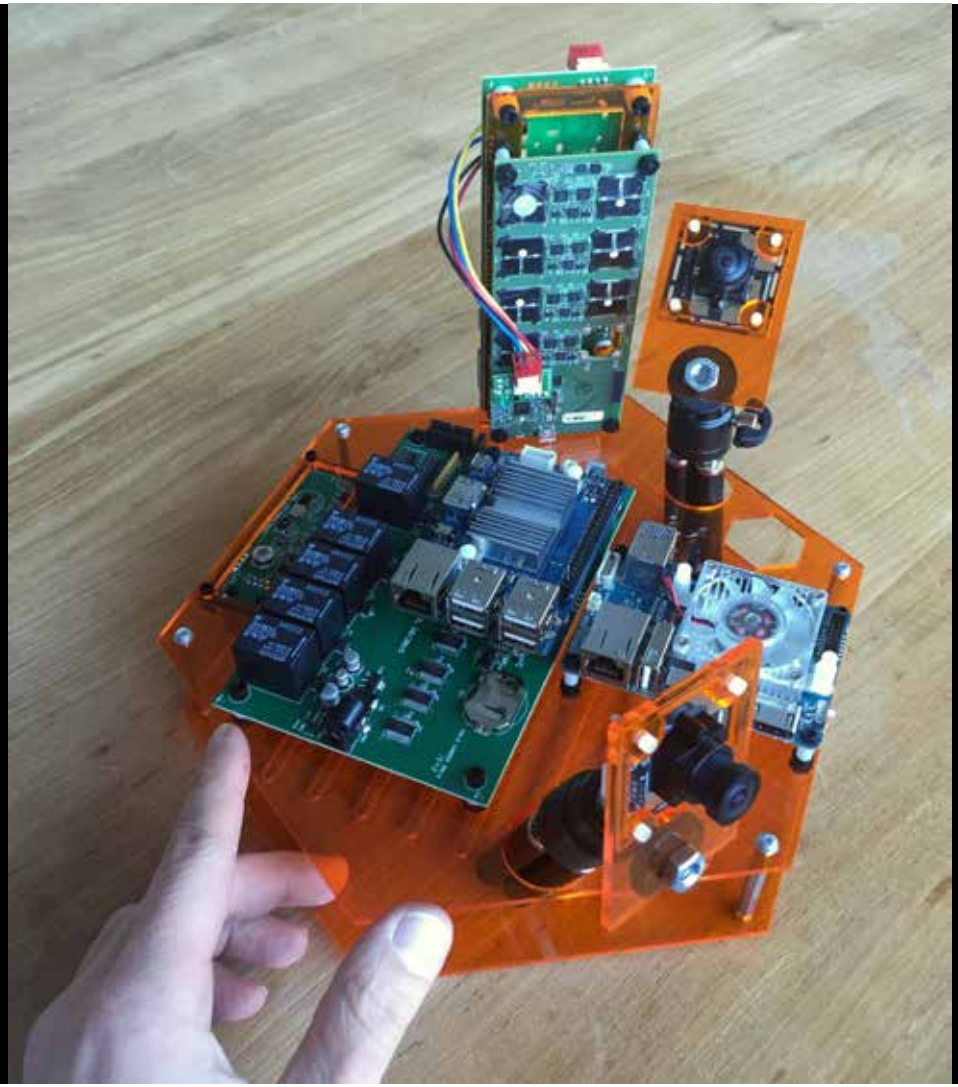

Waggle Modular Sensor Node Architecture
Data and
Computing Cloud
Temp. , Wind
Humidity, Infrared
Hyperspectral Imager
Camera, Sound
CO, O_3
VOCs, NO_2
Particulates
Motor Control
Robotic Sampler
Air Pump
LED Status
Sensor Node
Sensor Module 1
Sensor Module n
Actuator Module 1
Network Link
Internal Bus
Waggle
Node Controller
Failsafe
"WagMan" System Manager
Vitals Monitoring
Data Cache
In-Situ Processing
Computation Engine
Uplink Manager
Security
External Power
V1.3

Waggle Node Controller Software Architecture

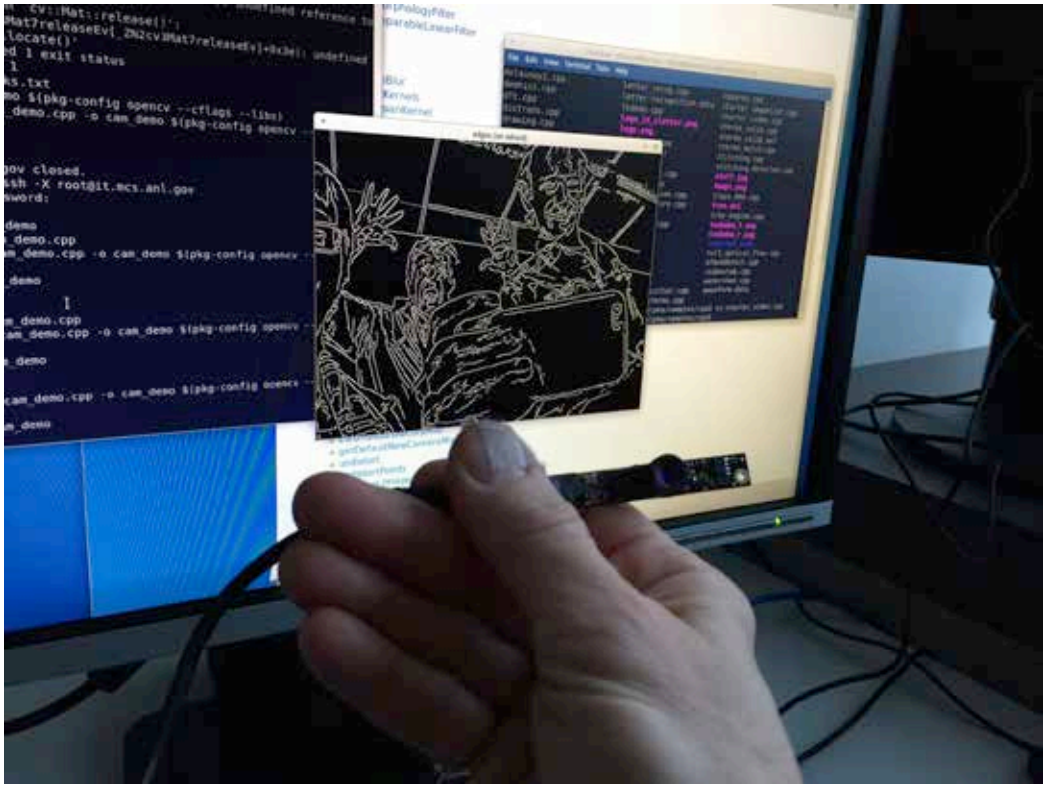


WaggleKit:

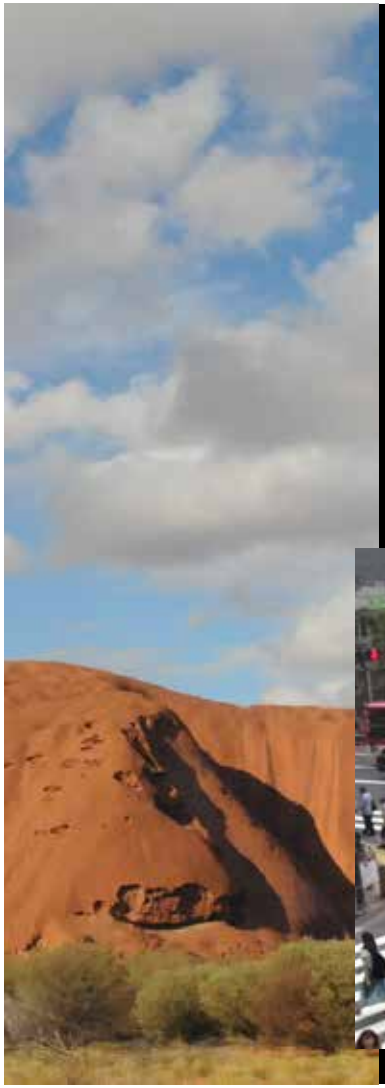
A Developer Kit for Smart Sensors and in-Situ Parallel Processing



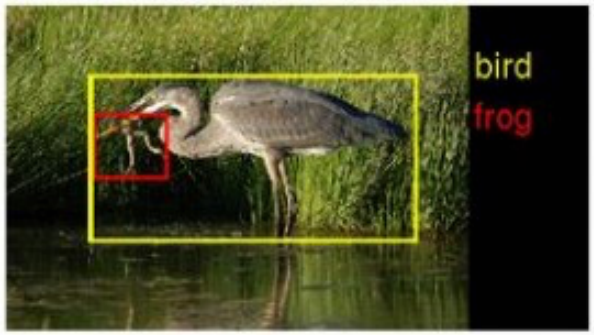
In-Situ/Edge Computing
Analysis and Feature Recognition

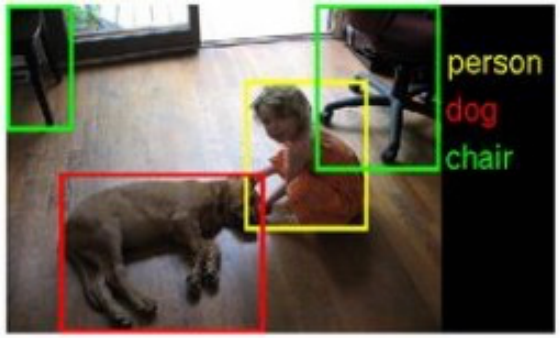


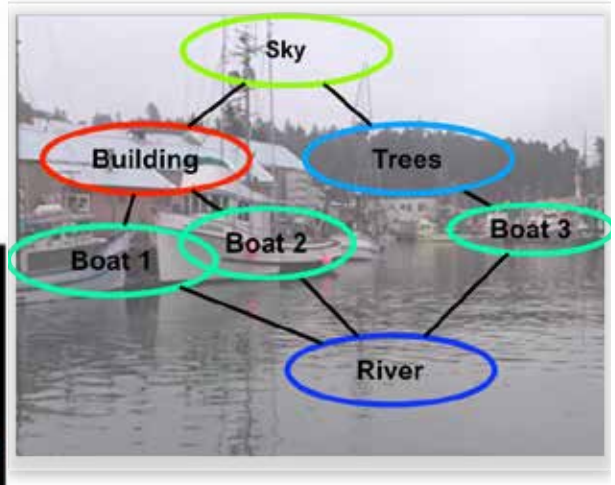
Parallel programming
with OpenCL



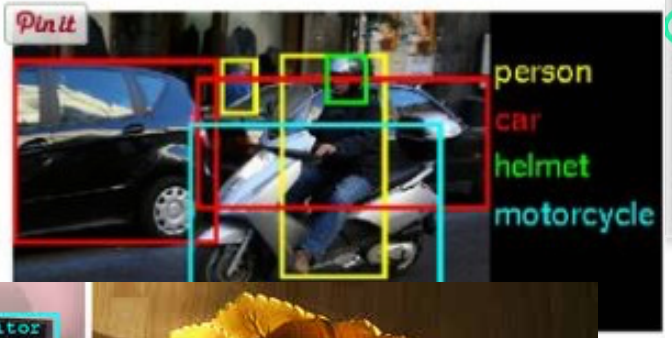

9 FT 6 IN


bird
frog

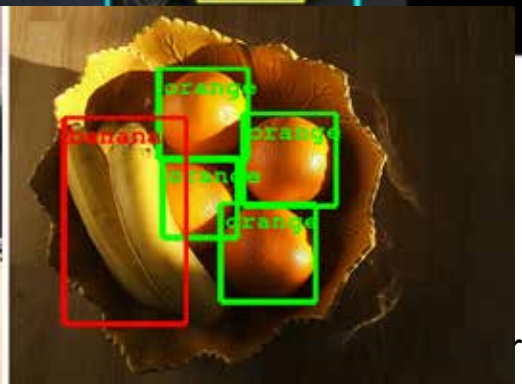

person
dog
chair


Sky
Building
Trees
Boat 1
Boat 2
Boat 3
River


person
hammer
flower pot
power drill


Pin It
person
car
helmet
motorcycle


tv or monitor
domestic cat


orange
orange
orange

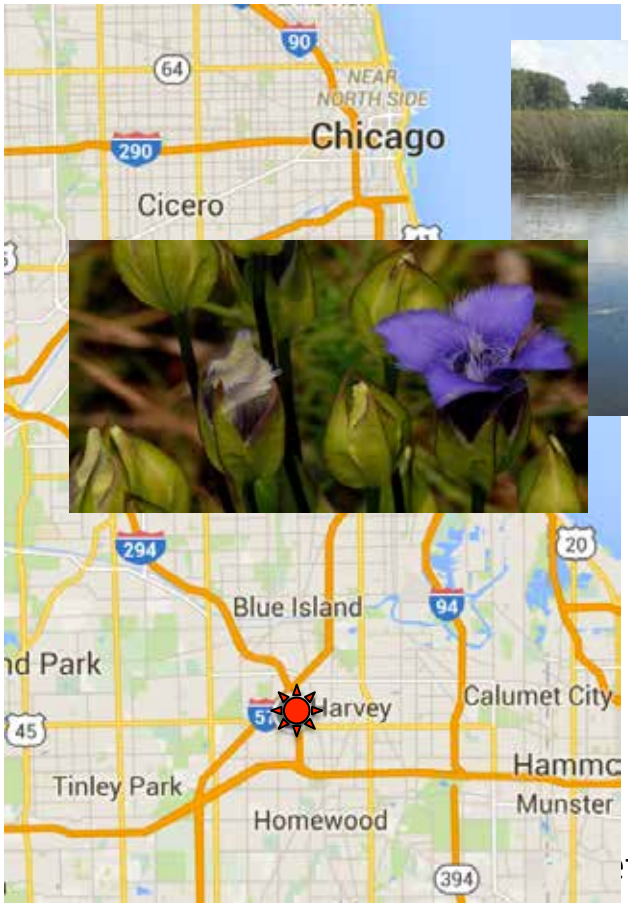

hat with a wide brim
dog

ratory

Gensburg-Markham Prairie

370 acres, owned/managed by Nature Conservancy and Northeastern IL Univ.
Registered as National Natural Landmark

Lead: Aaron Packman@NU
Cristina Negri



Chicago Botanic Garden

Lead: Cristina Negri

Green Roof Instrumentation

National Laboratory

A Science-Driven Instrument: The Array of Things

Climate, Environmental and Life Sciences
(Robert Jacob, ANL)
Potosnak (DePaul); Niyogi (Purdue); Gilbert, Graham, Kotamarthi, (UC/ANL); Fernando (Notre Dame)

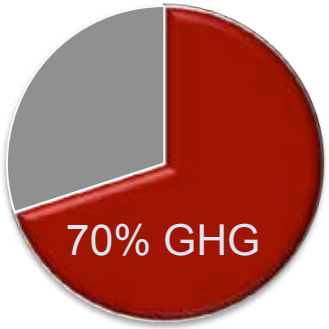
Urban Infrastructure Systems
(Danie Work, UIUC)
Markoupolou (IaaC); Negri, Snyder (UC/ANL); Buttlar, Peschel, Garcia (UIUC), Gonzales (MIT), Pancoast (SAIC), Guzowski, Rosner (UC/ANL), Claudel (UT); Liu (UMich), Chen (UW)

Education, Health, Social and Behavioral Sciences
(Kathleen Cagney, UChicago)
Diez (UCL/IaaC); Contractor (Northwestern); Epley, Gilliam, Lindau, Meltzer, Hampton-Marcel, Zarraonaindia (UC); Bellingham (Strathclyde)

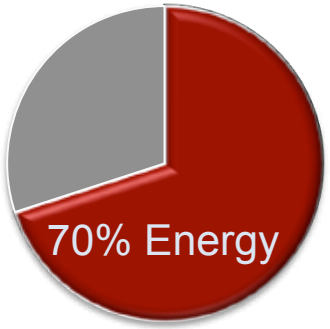
Computer Science and Cyber-Physical Systems
(Michael Papka, UC/NIU/ANL)
Derrible, Lin, Eriksson (UIC); Alok Choudhary (NU); Beckman, Sankaran, Chien (UC/ANL)

ARRAY THINGS

The Centrality of Cities



Climate Change



Energy Security

Economic Vitality

To address Climate Change and Energy Security while maintaining Economic Vitality will require understanding cities as multiscale, complex, dynamic, interconnected systems.

The Centrality of Cities

Table 3

The 50 Largest Cities, C40 Cities, and Top 10 GHG Emitting cities[4]

Population (Millions)	GHG Emissions (M tCO_2e)	GDP (billion $ PPP)
1. China: 1,192	1. USA: 7,107	1. USA: 14,204
2. India: 916	2. China: 4,058	**2. 50 Largest Cities: 9,564**
3. 50 Largest Cities: 500	**3. 50 Largest Cities: 2,606**	**3. C40 Cities: 8,781**
4. C40 Cities: 393	**4. C40 Cities: 2,384**	4. China: 7,903
5. USA: 301	5. Russian Federation: 2,193	5. Japan: 4,354
6. Indonesia: 190	6. Japan: 1,374	**6. Top 10 GHG Cities: 4,313**
7. Brazil: 159	**7. Top 10 GHG Cities: 1,367**	7. India: 3,388
8. Russian Federation: 142	8. India: 1,214	8. Germany: 2,925
9. Top 10 GHG Cities: 136	9. Germany: 956	9. Russian Federation: 2,288
10. Japan: 128	10. Canada: 747	10. United Kingdom: 2,176

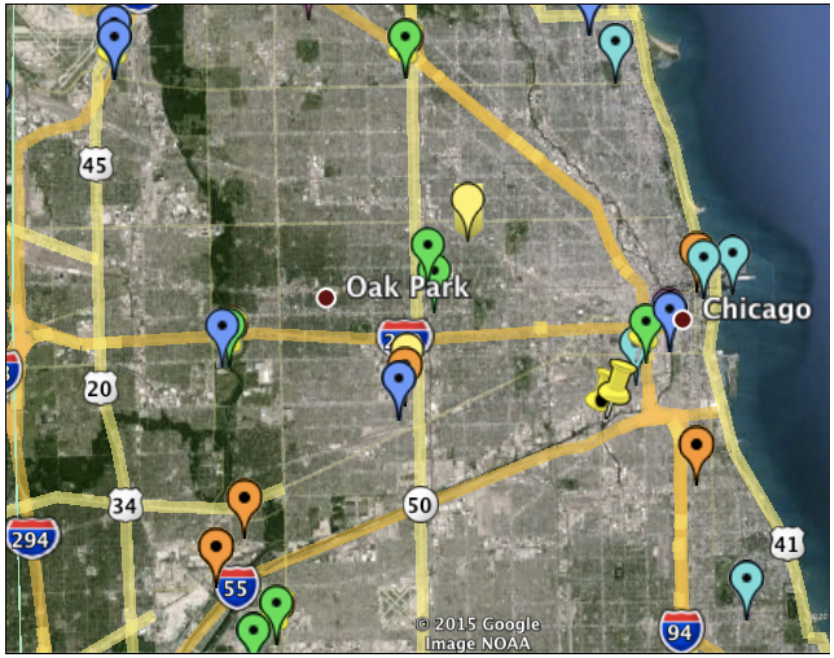
Source: See Annex D. Data for the urban agglomeration associated with each C40 city is used in calculations to maintain consistency with the 50 largest cities, 2005.

"Cities and Climate Change: An Urgent Agenda," World Bank, 2010

Sensors, Instrumentation, Measurement

Most topics of urban inquiry require data with greater in temporal and spatial resolution.

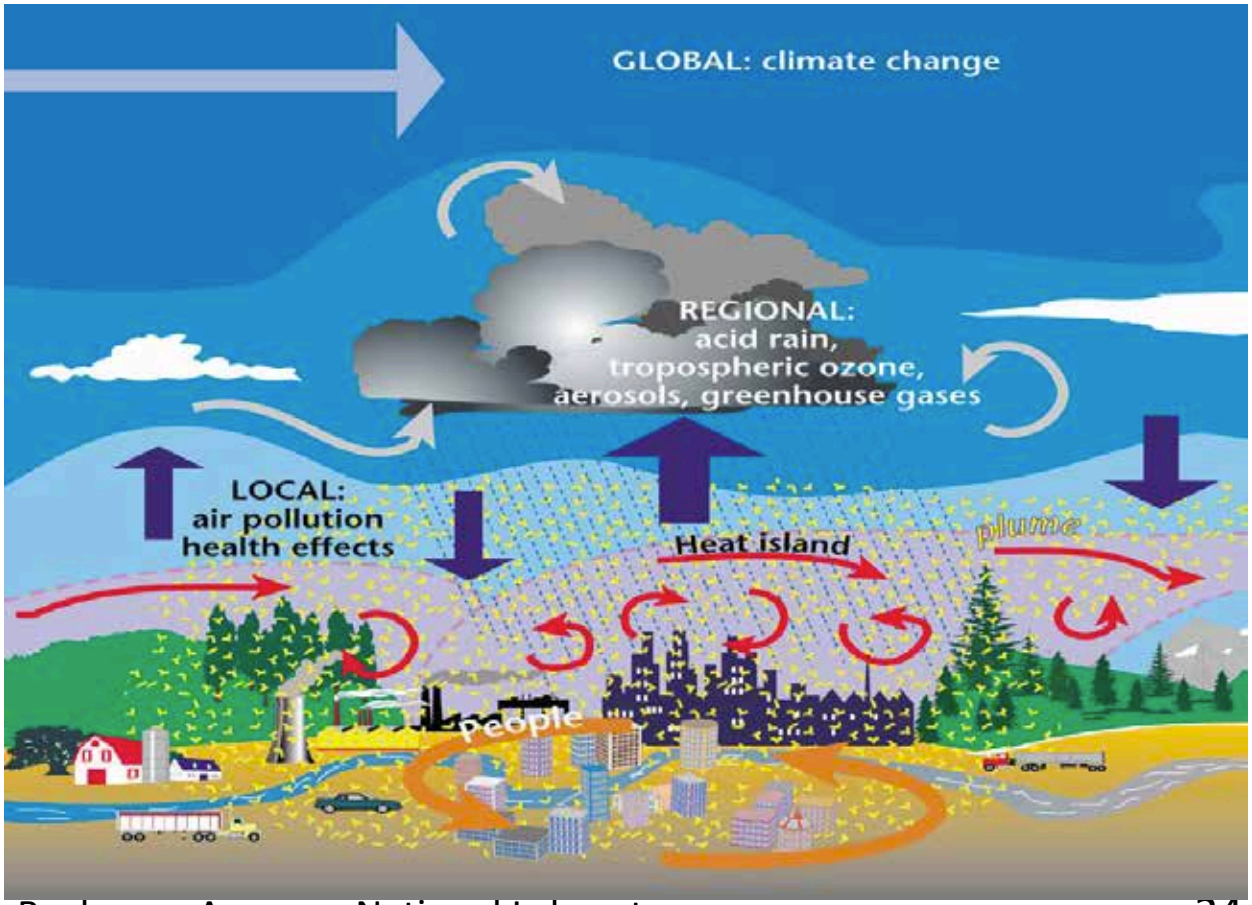
- **Energy**
  How can hyper-local weather information improve energy efficiency? Reliability?
- **Climate and Heat Islands**
  What is the impact of the Urban boundary layer on regional climate?
- **Air Quality, Transportation, and Health**
  What are the dynamics of urban air pollutants and how can traffic flow be modified to improve air quality?
- **Social Sciences**
  How might diverse data sources including ambient sensors provide data relevant to predictive analytics w.r.t. disease, public safety/sentiment?



Map of EPA monitoring sites from EPA.

The connection between urban and regional climate

- Cities can alter their local climate through their built environment.
  - Temperature (urban heat island) and precipitation (storm splitting and initiation) are the most widely known examples.
- Cities alter the surrounding regional climate primarily through emissions carried downwind as an “urban plume”.
- Predicting urban climate change requires interactive modeling of regional and urban climate systems.



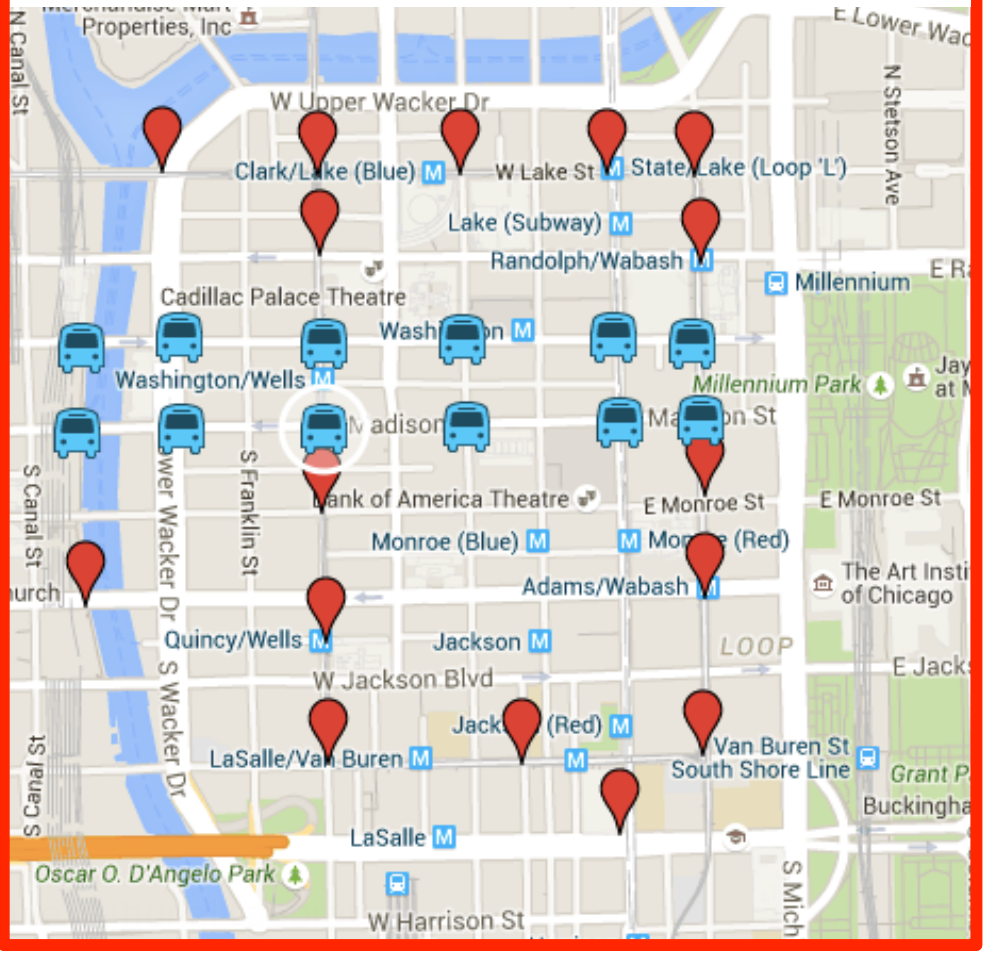
Sustainable Green Infrastructure

(air quality, heat island, social cohesion, urban flooding)

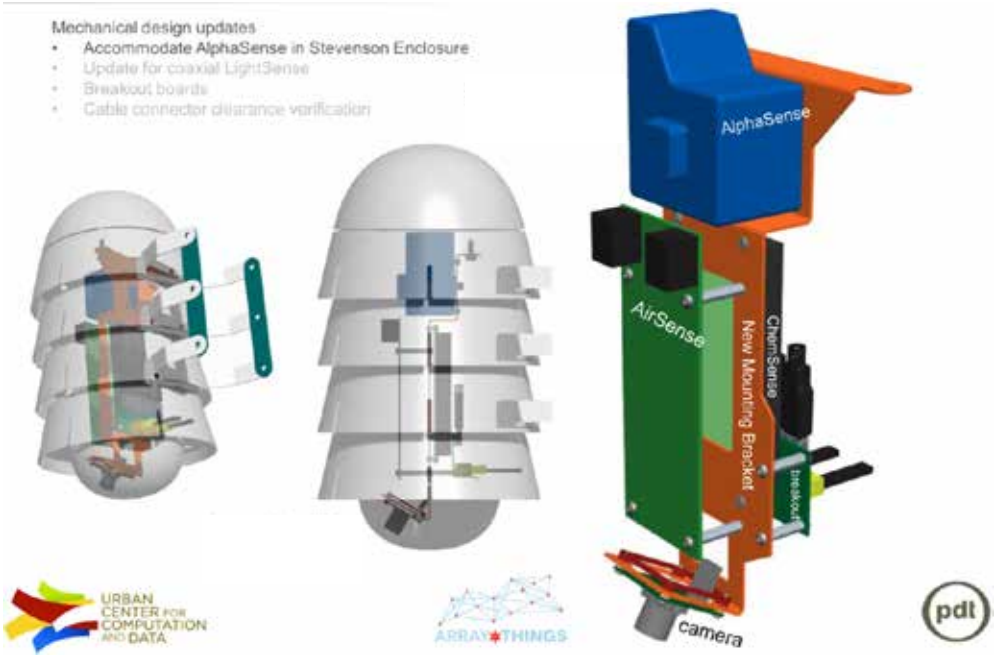
Rapid Bus Transit

(air quality, walkability, traffic congestion)

Argonne NATIONAL LABORATORY
THE UNIVERSITY OF CHICAGO




3
GERALD



Partnerships: PDT, Surya, Chicago Department of Innovation and Technology , Chicago Department of Transportation

ratory

Argonne NATIONAL LABORATORY

THE UNIVERSITY OF CHICAGO

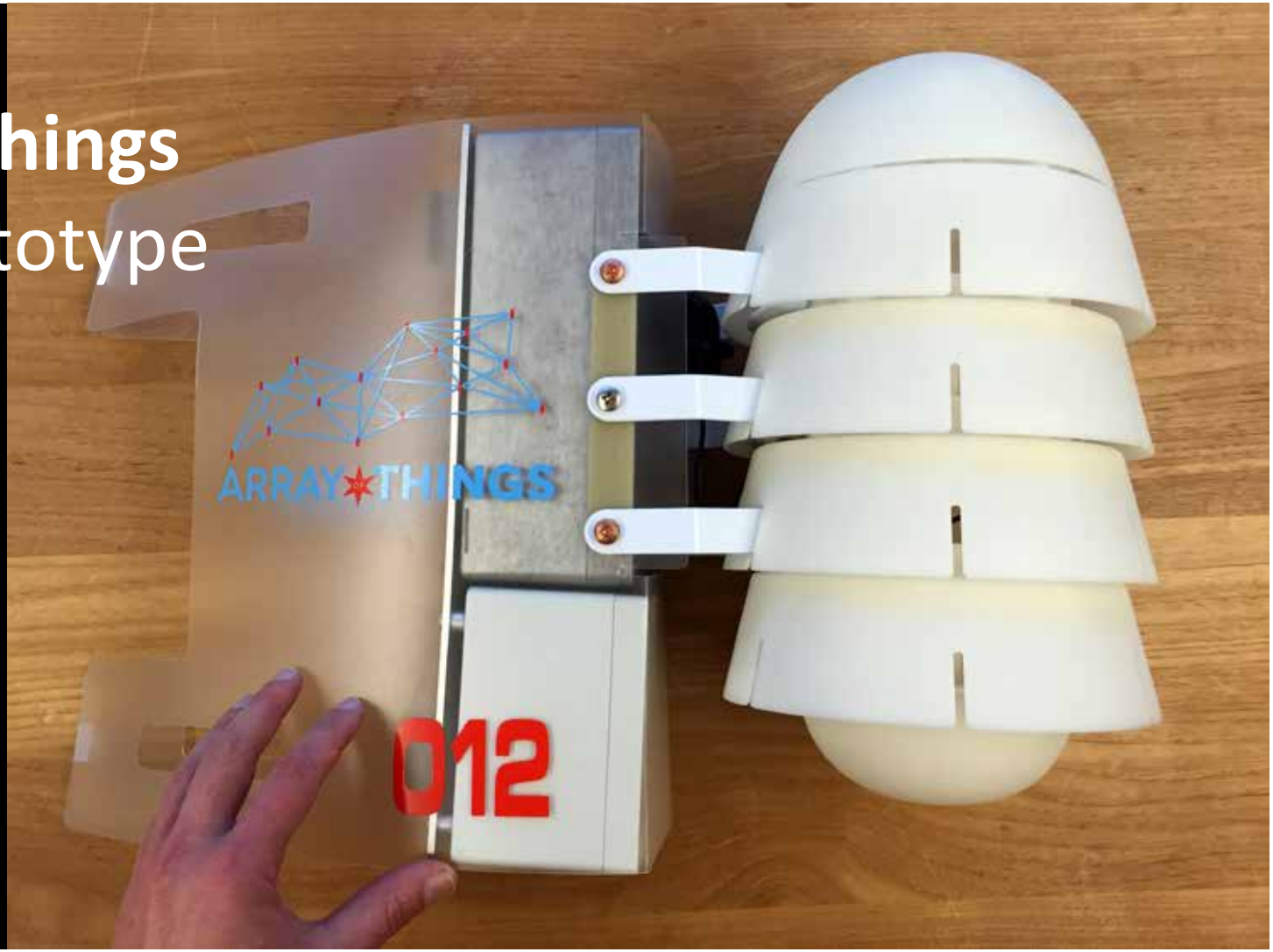
CITY OF CHICAGO INCORPORATED 4th MARCH 1837

pdt

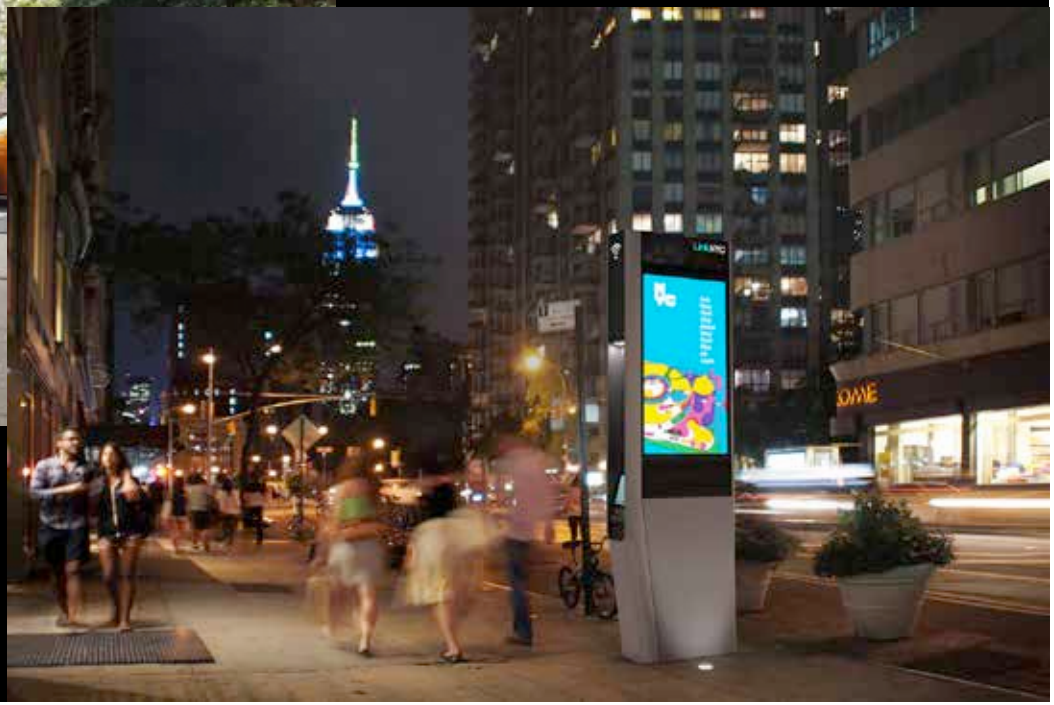
SAIC

SURYA ELECTRONICS

Array of Things
Alpha Prototype




LinkNYC
NYC
RESTAURANT
WEEK
JAN 14–FEB 8
NYCGO.COM

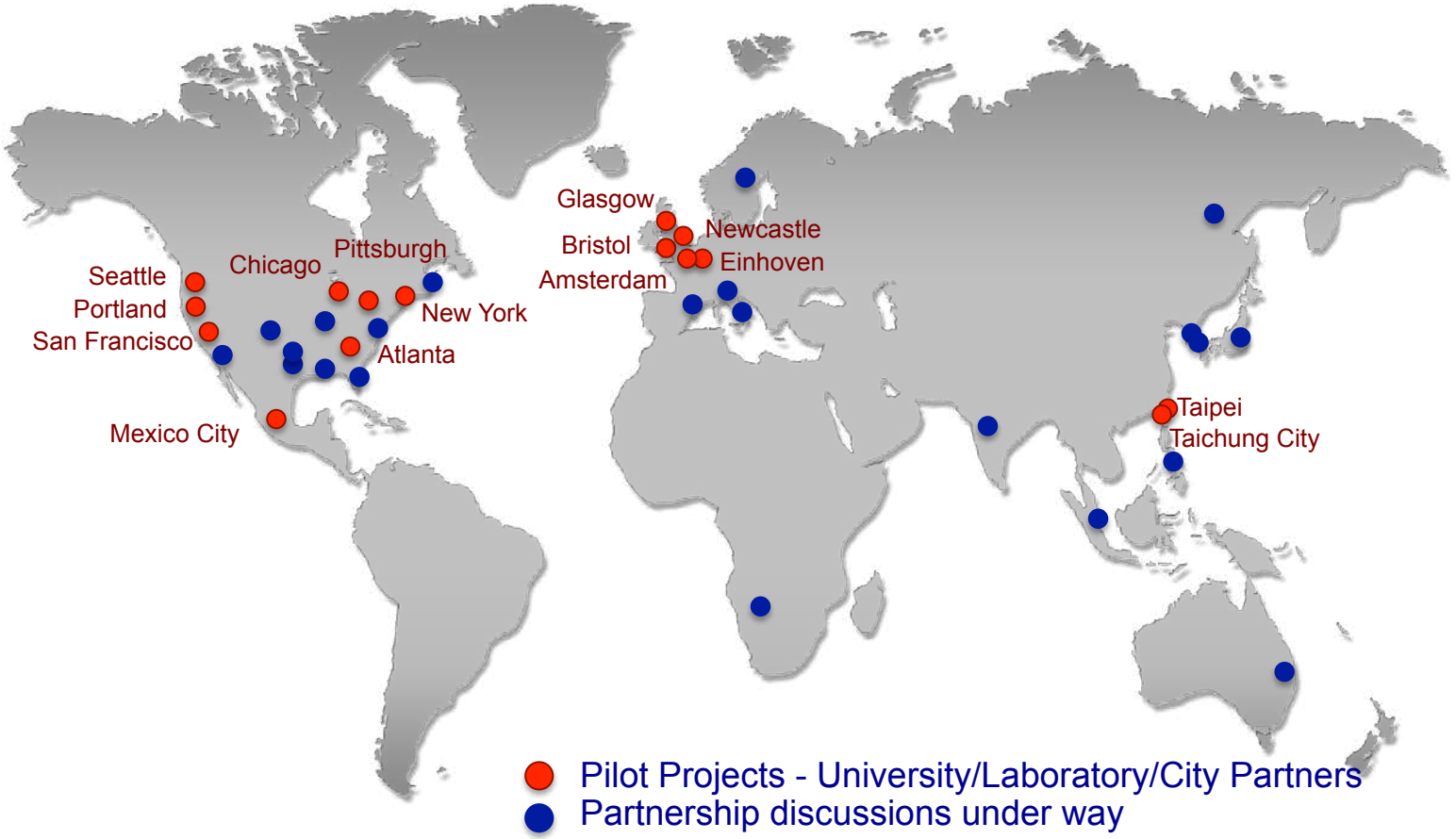

LinkNYC


BOTTLES CANS PAPER
RECYCLING ONLY
BigBelly

Students at Chicago City Colleges showing off their Arduino-enabled high-altitude balloon payload from a previous launch. They are hoping to Waggle-enable a launch this fall. **Waggle into Space**

laboratory

Open Source to Create a global community



Why HPC Geeks Should Care

- New sensors are ***programmable* parallel computers**
  - Multicore + GPUs & OpenCL or OpenMP
  - New algorithms for in-situ data analysis, feature detection, compression
  - Need new progmod for "stackable" in-situ analysis (for sensors and HPC)
  - Need advanced OS/R resilience, cybersecurity, networking, over-the-air programming
- 1000s of nodes make a **distributed computing "instrument"**
  - New streaming programming model needed
  - New techniques for machine learning for scientific data required
    - Both for within a "node" and collectively across time series
- How will **HPC streaming analytics and simulation** be connected to live data?
  - Can we trigger HPC simulations after first approximations? (weather, energy, transportation)
  - Unstructured database with provenance and metadata for QA/collaboration
- Use novel HPC hardware to solve power issue?
  - Can we use neuromorphic or FPGAs to reduce power for in-situ analysis & compression?
- We are trading precision & cost for greater spacial resoluton: What is possible?

Waggle Team & Collaborators