Introduction

The Array of Things – “AoT” – is a national, open instrument to support research, development, prototyping, education, and demonstration of IoT, Smart City, and related systems at urban-scale. The name blends the concept of an array telescope and the Internet of Things.

AoT builds on over $2M of early IoT research investment at Argonne National Laboratory and an additional $4M of grant funding from the National Science Foundation (ACI-1532133), the University of Chicago, and other sources.
NSF Funded - MRI: Development of an Urban-Scale Instrument for Interdisciplinary Research

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Peter Beckman (University of Chicago, Northwestern University, and Argonne National Laboratory)
Michael Papka (Northern Illinois University, University of Chicago, and Argonne National Laboratory)
Daniel Work (University of Illinois at Urbana-Champaign)

• **Industry and Government Project Partners:**
  - City of Chicago, BigBelly, Cisco, Intel, Microsoft, Motorola Solutions, PositivEnergy Practice, Qualcomm, Schneider Electric, UILabs, and Zebra Technologies

• **Science Collaborators:**
  - Argonne National Laboratory
  - Arizona State University
  - Clemson University
  - DePaul University
  - Institute for Advanced Architecture of Catalonia / FabLab Barcelona
  - Illinois Institute of Technology
  - Massachusetts Institute of Technology
  - Northern Illinois University
  - Northwestern University
  - School of the Art Institute of Chicago
  - University of Chicago
  - University College London
  - University of Strathclyde
  - University of Illinois at Chicago
  - University of Illinois at Urbana-Champaign
  - University of Michigan
  - University of Texas Austin
  - University of Washington
Open Source Platform for Embedded Sensing/Systems

- **Privacy.** Secure design with privacy policy “baked in” to prevent collection, storage, or transmission of data about individuals.
- **Transparency.** All policies, hardware and software specifications, designs, and source code are open source, published.
- **Public-Private Partnerships.** Low-cost, open, networked, programmable “nodes” that collect, process, and publish real-time data on environment, infrastructure, and activity.

http://wa8.gl
Array of Things - Components

Light sensors and skyward camera
Array of Things - Components

Experimental Chemical sensors

Intel designed, SPEC sensors
Array of Things - Components

Air sensors
Array of Things - Components

Compute

ODROID – hardkernel.com
Outdoor – Test Node
Testbed Deployments - Today
Waggle Node Controller Software Architecture

http://wa8.gl
Waggle Sensor and Cloud Architecture
### Why Instrument Cities?

#### The 50 Largest Cities, C40 Cities, and Top 10 GHG Emitting Cities

<table>
<thead>
<tr>
<th>Population (Millions)</th>
<th>GHG Emissions (M tCO₂e)</th>
<th>GDP (billion $ PPP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. China: 1,192</td>
<td>1. USA: 7,107</td>
<td>1. USA: 14,204</td>
</tr>
<tr>
<td>2. India: 916</td>
<td>2. China: 4,058</td>
<td></td>
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<tr>
<td>3. 50 Largest Cities: 500</td>
<td>3. 50 Largest Cities: 2,606</td>
<td>2. 50 Largest Cities: 9,564</td>
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</tbody>
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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.
Why Instrument Cities?

Most areas of urban inquiry require dramatic increases in temporal and spatial resolution. *New sensor, computing, and communication technologies provide a means to drive sensor costs down to support much more dense deployment, both fixed and mobile.*

Questions:

- What is the impact of the Urban boundary layer on regional climate?
- What are the dynamics of urban air pollutants and how can traffic flow be modified to improve air quality?
- How might diverse data sources including ambient sensors provide data relevant to predictive analytics w.r.t. disease, public safety/sentiment, energy and emissions, etc.?
- How can new, lower cost sensors fill in the gaps?
- How can new sensors and embedded technologies be rapidly tested and deployed?
- How can applied mathematics and diverse data sources improve insight and measurement?
What Drives the Location of Nodes?

People
(A Challenge/Concern of Residents, Visitors, Businesses)

Science
(Scientists pursuing related research)

Policy
(Related Government policy or action plans)
Proposed AoT testbed locations at Northern Illinois University, allow for year around testing and development in preparation for Chicago deployment.
Timeline

2013
• Argonne Seed Funding

2014
• Resilient Design Field Testing
• Argonne Prototype Funding

2015
• Sensor Evaluation
• Argonne Proof of Concept Funding
• UChicago Innovation Fund; Argonne match

2016
• Deployment and Field Test (50 nodes)
• NSF Concept Funding
• NSF Deployment Funding
• Expanded AQ measurement; Calibration (+150 nodes)

2017
• Full-scale Instrument (+300 nodes)
Science Driver Exemplars

**Climate, Environmental, and Life Sciences**
- Urban Weather and Climate
- Urban CO2 Measurement

**Smart Urban Infrastructure Systems**
- Multimodal Traffic Monitoring and Resilience
- Urban Traffic Emissions
- Smart Urban Hydrology
- Infrastructure Status Monitoring

**Education, Health, Social and Behavioral Sciences**
- Activity Space, Delineating Neighborhoods, and Neighborhood Context
- Urban Built Environment and Community-Based Services Data
- Voluntary Health and Activity Tracking

**Computer Science and Cyber-Physical Systems**
- Privacy Conscious Visual Datamining
- Data Fusion
- Information-Rich Geocache and Content Delivery
- Mobile Device Sensor Integration
- Privacy and Security on Local Infrastructure
Example Applications

http://kentwa.gov/stormwater/
Example Applications (Testbed)
Example Applications (Testbed)
Student Engagement

Students from Northern Illinois University and North Central College construct prototype nodes for deployment at the University of Chicago.

Northern Illinois University student tests and debugs AoT test node.
World-wide Interest in Instrumented Cities

- Agreed to partner to test and extend the open source platform.
  (participated in September 2015 Kick-off Workshop)
- Expressed interest in testing.
- Initial discussions and partner universities/labs.

Science Collaborators: Argonne National Laboratory, University of Chicago, Arizona State, Clemson, DePaul, IaaC/FabLab Barcelona, GaTech, IIT, MIT, Newcastle University, NYU, NIU, Northwestern University, Notre Dame, Portland State, Purdue, School of the Art Institute of Chicago, National Applied Research Laboratories (Taiwan), University of Amsterdam, University of Bristol, University of Calabria, University College London, Radboud University, University of Strathclyde, UI-C, UIUC, University of Michigan, University of Texas Dallas, University of Texas Austin, University of Washington

Government Partners
DOE, NSF, State Dept., City of Chicago

Private Partners
MacArthur Foundation, Bloomberg Philanthropies, Motorola Foundation

Industry Partners
BigBelly, Cisco, Intel, Intersection (Sidewalk Labs), Microsoft, Motorola Solutions, Schneider Electric, Zebra Technologies
Array of Things

- Array of Things: Charlie Catlett (Argonne/Chicago)
- Waggle: Pete Beckman (Argonne/NWU)
- Funding: Argonne National Laboratory, University of Chicago, National Science Foundation (ACI-1532133)
- NIU support via College of Liberal Arts and Science and Division of Research and Innovation Partnerships
Thank You!

Questions?

Rendering of AoT deployment in Chicago – Doug Pancoast (SAIC)