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

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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

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Internet of Things...
Sometimes Silly

University of Cambridge, 1991

Amazon Dash

“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.”

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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

**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

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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)
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AirSense Board

Camera

ChemSense Board

WagMan Board + ODROID (Amlogic quad ARM A7)

ODROID (Samsung Exynos5422, A15 & A7)

LightSense Board
Waggle Modular Sensor Node Architecture

**Sensor Node**
- Temp., Wind Humidity, Infrared Hyperspectral Imager
- Camera, Sound

**Sensor Module 1**
- CO, O₃ VOCs, NO₂ Particulates

**Sensor Module n**
- Motor Control
- Robotic Sampler
- Air Pump
- LED Status

**Actuator Module 1**
- Network Link

**Node Controller**
- Vitals Monitoring
- Data Cache
- In-Situ Processing

**“WagMan” System Manager**
- Computation Engine

**Failsafe**
- External Power

**Data and Computing Cloud**
Waggle Node Controller
Software Architecture

Sensor Modules

Sensor Data Collection
Local Data Cache

In-situ User Programs
Docker Containers

Optimized Linux Operating System
Waggle Reliable Boot Image Manager

Power Manager
Enclosure Monitor
Heartbeat Monitor

8-bit μController

System Manager

Computation Engine

Vitals Monitoring
Security Module
Mgmt Console

Waggle Cloud
Reliable Messaging
WaggleKit: A Developer Kit for Smart Sensors and in-Situ Parallel Processing
In-Situ/Edge Computing Analysis and Feature Recognition

Parallel programming with OpenCL

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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
Green Roof Instrumentation

Lead: Cristina Negri

National Laboratory
A Science-Driven Instrument: The Array of Things

PI: Charlie Catlett, Argonne/UChicago

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)
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 cities¹

<table>
<thead>
<tr>
<th>Population (Millions)</th>
<th>GHG Emissions (MtCO₂e)</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>
</tr>
<tr>
<td><strong>3. 50 Largest Cities: 500</strong></td>
<td><strong>3. 50 Largest Cities: 2,606</strong></td>
<td><strong>2. 50 Largest Cities: 9,564</strong></td>
</tr>
</tbody>
</table>

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.

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)
Partnerships: PDT, Surya, Chicago Department of Innovation and Technology, Chicago Department of Transportation
Array of Things
Alpha Prototype
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**
Open Source to Create a global community

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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 progm 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 resolution: What is possible?

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Waggle Team & Collaborators

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