Sage Digital Continuum

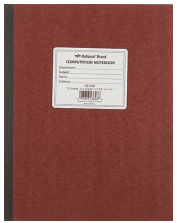
AI@Edge: The Next-generation of Environmental Sensing and IoT Systems

Collaborators: Pete Beckman, Ilkay Altintas, Charlie Catlett, Scott Collis, Nicola Ferrier, Eugene Kelly, Jim Olds, Mike Papka, Dan Reed, **Raj Sankaran**, Sean Shahkarami, Joe Swantek, Valerie Taylor, Doug Toomey, Frank Vernon, Rommel Zulueta, Ren Cooper, Josh Auld, Aymeric Rousseau, and many many more….

Northwestern University · The University of Chicago · Northern Illinois University · UIC University of Illinois Chicago · Argonne National Laboratory · Colorado State University · UC San Diego · George Mason University · The University of Utah · SAGE sagecontinuum.org · Array of Things · ARM · neon National Ecological Observatory Network · HPWREN SDSC San Diego Supercomputer Center · Lincoln Park Zoo For Wildlife. For All. · OHAZ · Berkeley Lab

Historical scientific study and analysis …

Instrument



Data

Katherine Johnson (née Coleman)

Analysis

Katherine Johnson (née Coleman), one of the first African-American women to work as a NASA scientist - played a key role in the mathematical calculations for John Glenn's orbital mission and made sure that the equations controlling Glenn's capsule were programmed accurately, ensuring a safe lift off and splashdown.

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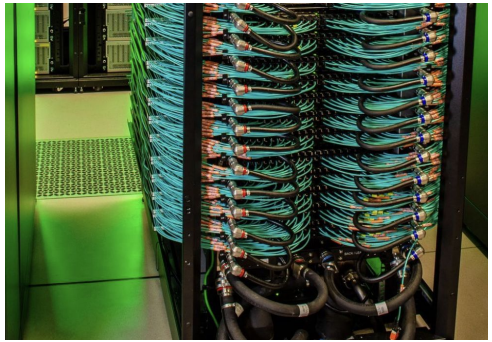
The Digital Continuum

Instrument → HPC/Cloud

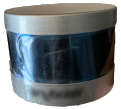


IoT Facilities Analysis

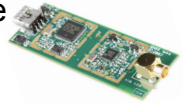
Analyse full resolution data, find highest valve data for the science

AI@Edge: Digital Continuum

Sensors


LIDAR

Software Defined Radios




Hyperspectral Imaging

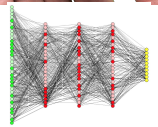
Facilities

Actuators


Servos


Dynamic adaptation

Edge Computing



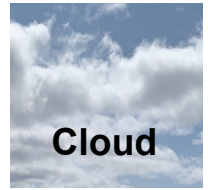
Scientific Data Analysis & Control

Artificial Intelligence
Deep Learning
Inference
Lightweight Training
Autonomous Action

Advanced Networking

New inference (model)
Adaptive controls / steering

Computation



Predictive Sim
Digital Twins
Data Analysis
Machine Learning

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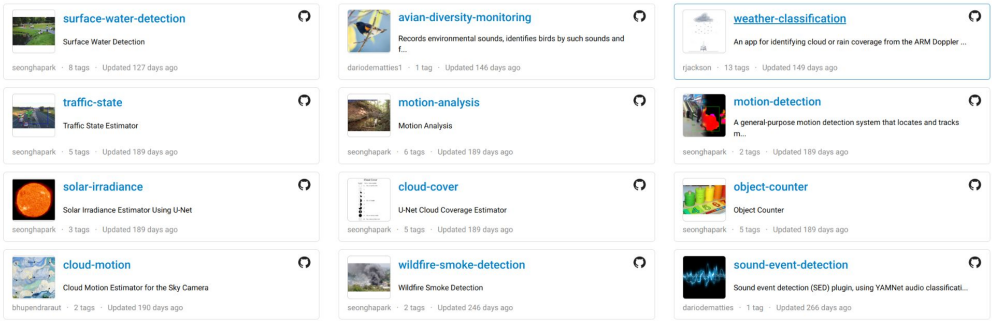
Sensor/Actuator and ***the software*** is the key!



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Waggle

Wild Node

Sage Blade

Sensors/Actuators are easily interfaced to edge-computing platforms...

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Wild Node

surface-water-detection
Surface Water Detection
seonghapark · 8 tags · Updated 127 days ago

avian-diversity-monitoring
Records environmental sounds, identifies birds by such sounds and f...
dariodematties1 · 1 tag · Updated 146 days ago

weather-classification
An app for identifying cloud or rain coverage from the ARM Doppler ...
rjackson · 13 tags · Updated 149 days ago

traffic-state
Traffic State Estimator
seonghapark · 5 tags · Updated 189 days ago

motion-analysis
Motion Analysis
seonghapark · 6 tags · Updated 189 days ago

motion-detection
A general-purpose motion detection system that locates and tracks m...
seonghapark · 2 tags · Updated 189 days ago

solar-irradiance
Solar Irradiance Estimator Using U-Net
seonghapark · 3 tags · Updated 189 days ago

cloud-cover
U-Net Cloud Coverage Estimator
seonghapark · 5 tags · Updated 189 days ago

object-counter
Object Counter
seonghapark · 5 tags · Updated 189 days ago

cloud-motion
Cloud Motion Estimator for the Sky Camera
bhupendraraut · 2 tags · Updated 190 days ago

wildfire-smoke-detection
Wildfire Smoke Detection
seonghapark · 2 tags · Updated 246 days ago

sound-event-detection
Sound event detection (SED) plugin, using YAMNet audio classificati...
dariodematties · 1 tag · Updated 266 days ago

Blade

Edge apps are executed in the edge-computing platforms...

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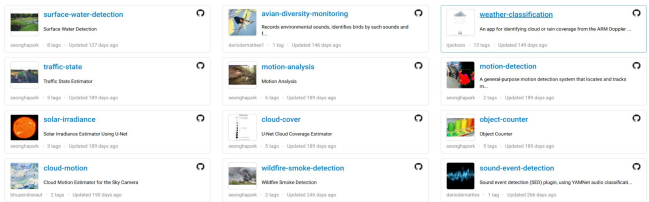
Waggle is an AI@Edge platform to bring sensors, actuators, and computing together…



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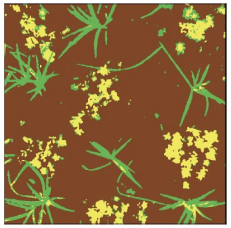
We call it "Software Defined Sensor"

Your software container running here

Analysis produces live results

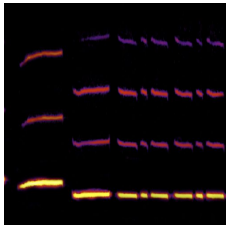
AI-Based Measurement & Anomaly Detection

Plant Species

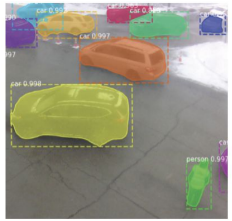


Pedestrian Flow

Birdsong

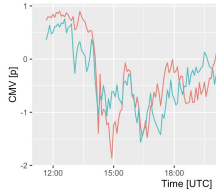


Traffic Flow



Wildlife

Cloud Motion Vectors



Wildfires: detecting smoke

Flooding / surface water

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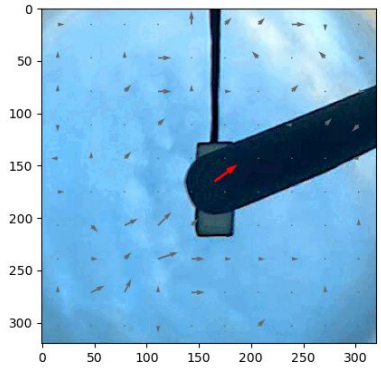
Why Live on the Edge?

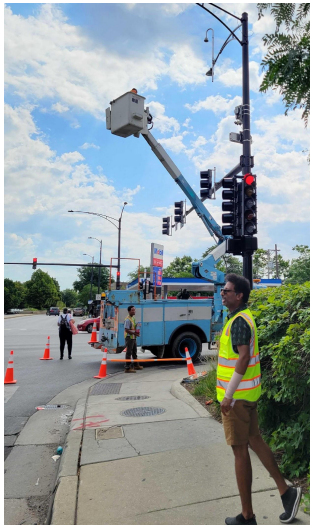


Analyse full resolution data, find highest valve data for the science

- **More data than bandwidth**
  - Imaging, LIDAR, SW defined radios, radar, audio, hyperspectral, large facilities, …
- **Latency is important**
  - Quick local decision, experimental control & actuation; adaptive sensing
- **Privacy/Security requires short-lived data: process and discard**
  - Compromised devices have no sensitive data to be revealed
- **Resilience requires distributed processing, analysis, and control**
  - Predictable service degradation, autonomy requires local (resilient) decision-making
- **Quiet observation and energy efficiency**
  - Vigilant low-power sensors, transmit only essential observations

What Makes AI@Edge Unique (hard)?

- *Extreme cybersecurity*
  - Devices have little physical security – enhanced cybersecurity is required: no open network ports, edge apps run in restricted environment, fully encrypted network links.
- *Autonomy:* Operates disconnected for weeks
  - Local decisions: computing tasks, experimental control, data preserved
- *Multi-tenancy:* AI@Edge is multipurpose – shared across several projects / goals.
- *Secure Edge Apps*: Managed builds -> provenance, policy management, cybersecurity



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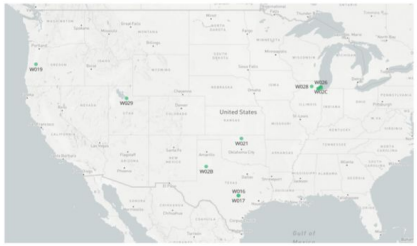
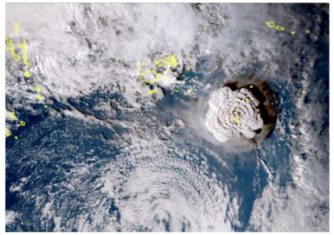
2022 Hunga Tonga Eruption



		UTC		
		First Peak	Second Peak	Third Peak
GC Distance	Node Location	1/16		1/17
10357KM	Billings (W021)	6:58		19:08
10039KM	Austin (W016)	7:14	23:33	19:23
9851KM	Lubbock (W02B)	7:21	23:41	19:31
8964KM	Eugene (W019)	8:16	23:56	20:26

Chicago area nodes registered little to no changes in atmoshperic pressure readings.

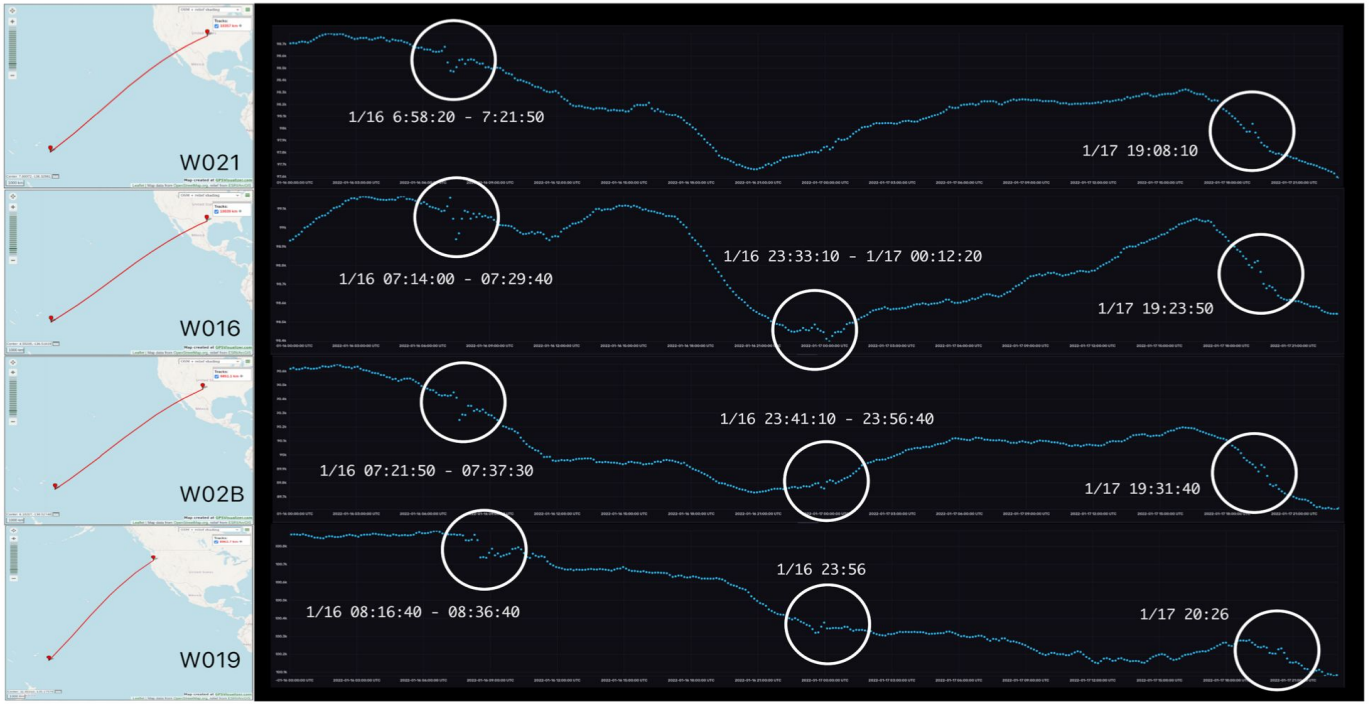


Billings, OK
10357KM

Austin, TX
10039KM

Lubbock, TX
9851KM

Eugene, OR
8964KM



Preliminary data graphs from Sage Nodes not yet curated for peer review. http://sagecontinuum.org/
Pressure data measured by BOSCH BME680 Sensors. Individual sensors were not calibrated post install. (1/27/2022)

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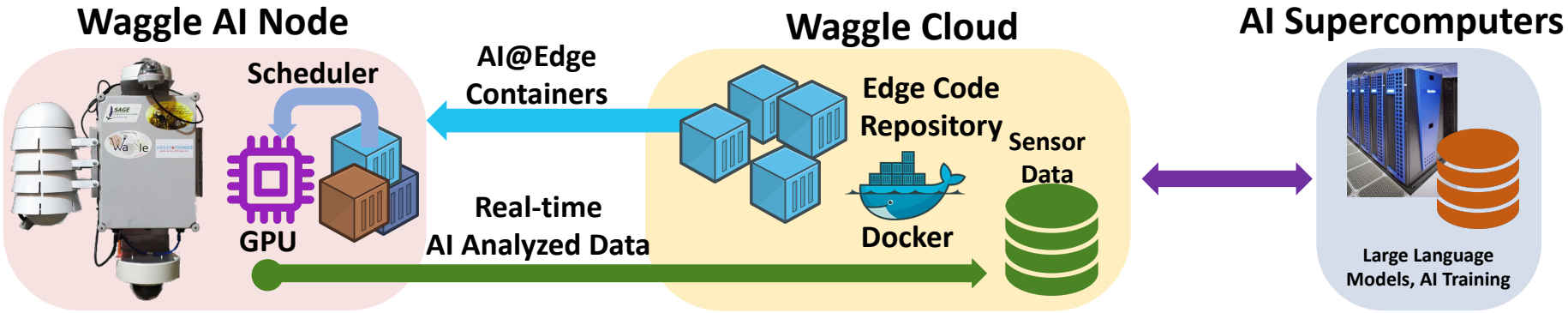
Sage Architecture

Open *Architecture* and Software Stack for AI@Edge Computing & Sensing



AI toolchain for secure, real-time, distributed AI

Built on industry components…

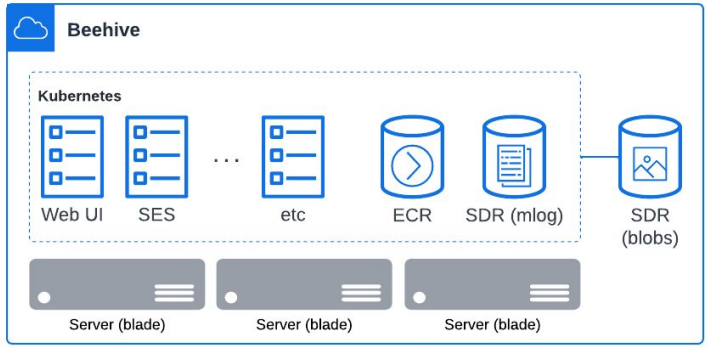
TensorFlow docker SAGE sagecontinuum.org TensorRT NVIDIA CUDA K3S PYTORCH TensorFlowLite OpenCV ROS Waggle

Sage Software Architecture

Sage Nodes

OpenCV docker PYTORCH TensorFlowLite K3S ROS

Cloud Infrastructure



AI@Edge "Plugin" from Edge Code Repository (ECR) (the "App Store")

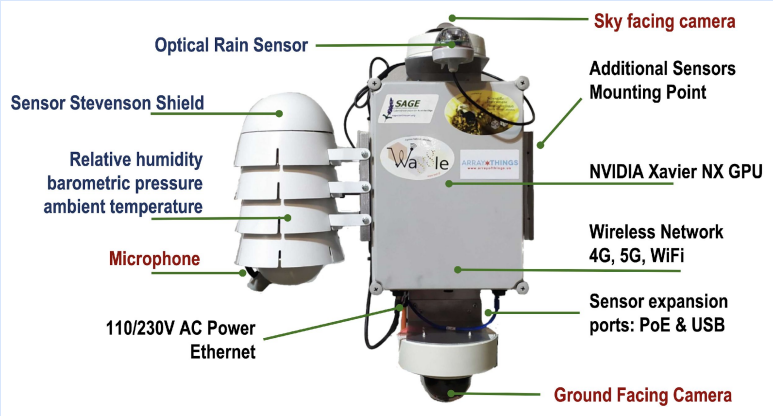
- Built upon standard AI Stack
- Containers on Kubernetes
- Multi-tenancy
- "Goal-based" Scheduler
- Local control for actuation
- Extreme cybersecurity
- Publish data to Beehive

Beehive manages

- Sage Edge Scheduler (SES)
- Sage Data Repository (log entries)
- Sage Data Repository (binary files)
- User Interface components

Sage delivering AI@Edge: Two Forms

Wild Sage Node



Ready for mounting ***outside***, any PoE sensor can be easily added

Sage Blade

(Sage software stack + pure commodity server)

Rugged server for instrument huts, new sensors easily added

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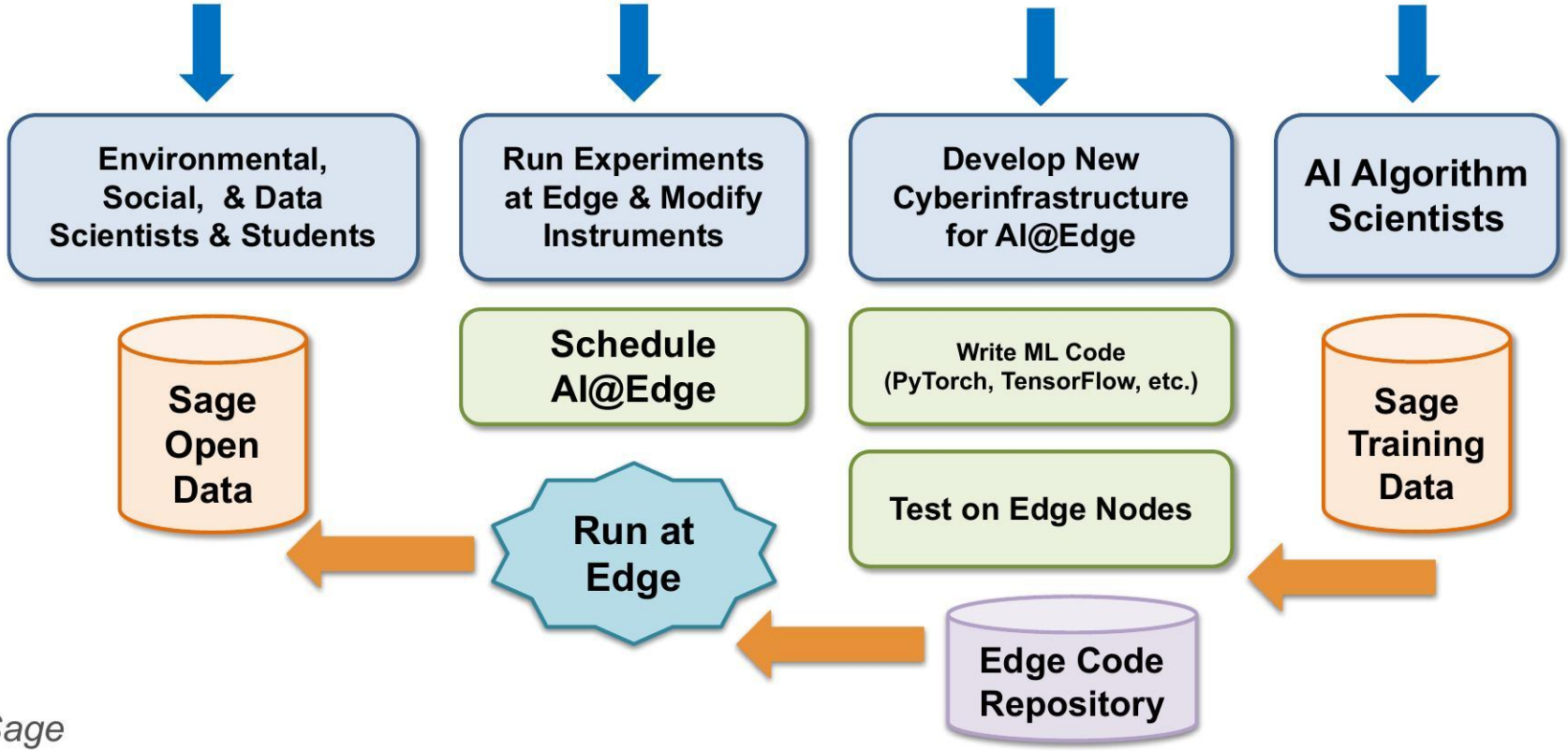
SAGE sagecontinuum.org

"Waggle" is the core node platform that can be adapted for other uses.

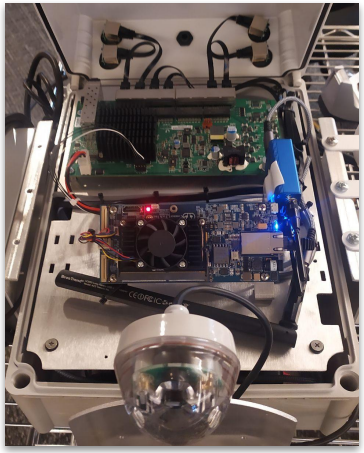
There are many ways to use Sage

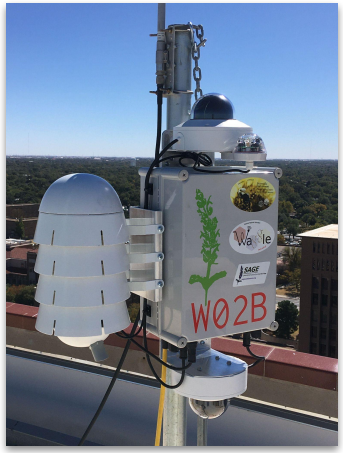


Sage

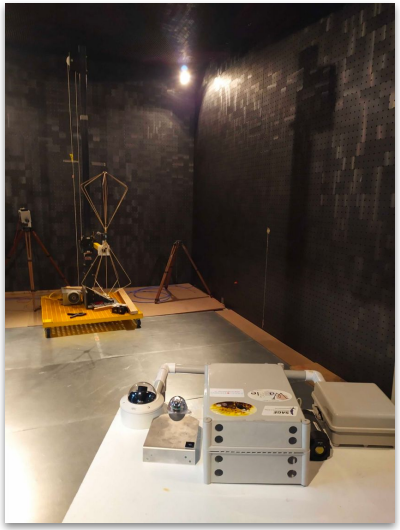
Getting the devices to the field…

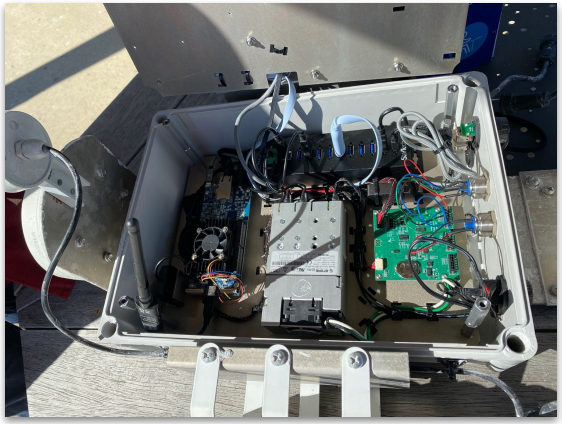
https://bit.ly/Sage-UrbanInstall-Chicago

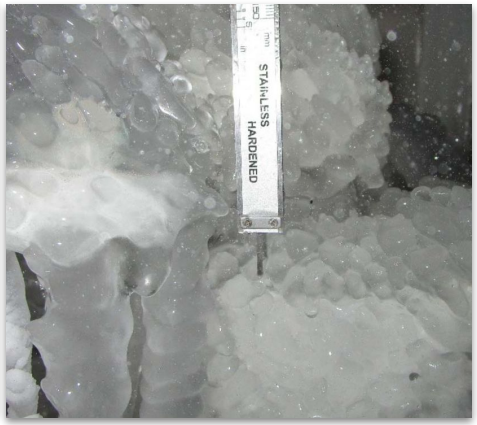




Design Qualification - Electrical and Environmental Testing…

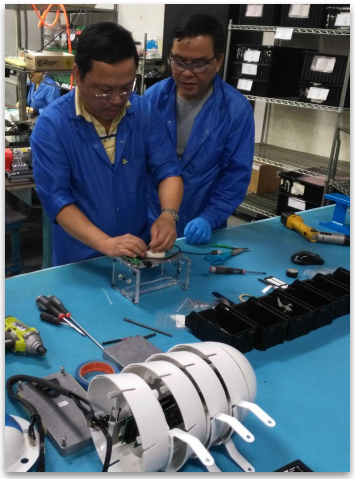


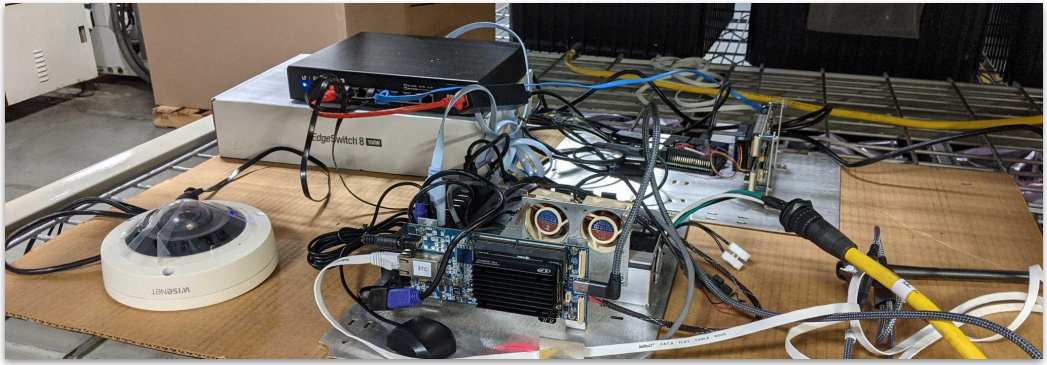


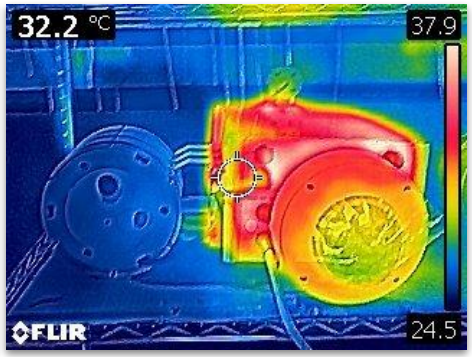


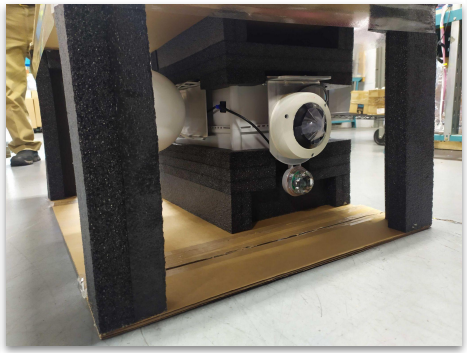
Electrical, EMI, and physical environmental tests to qualify the design.

Manufacturing, testing, and off they go!

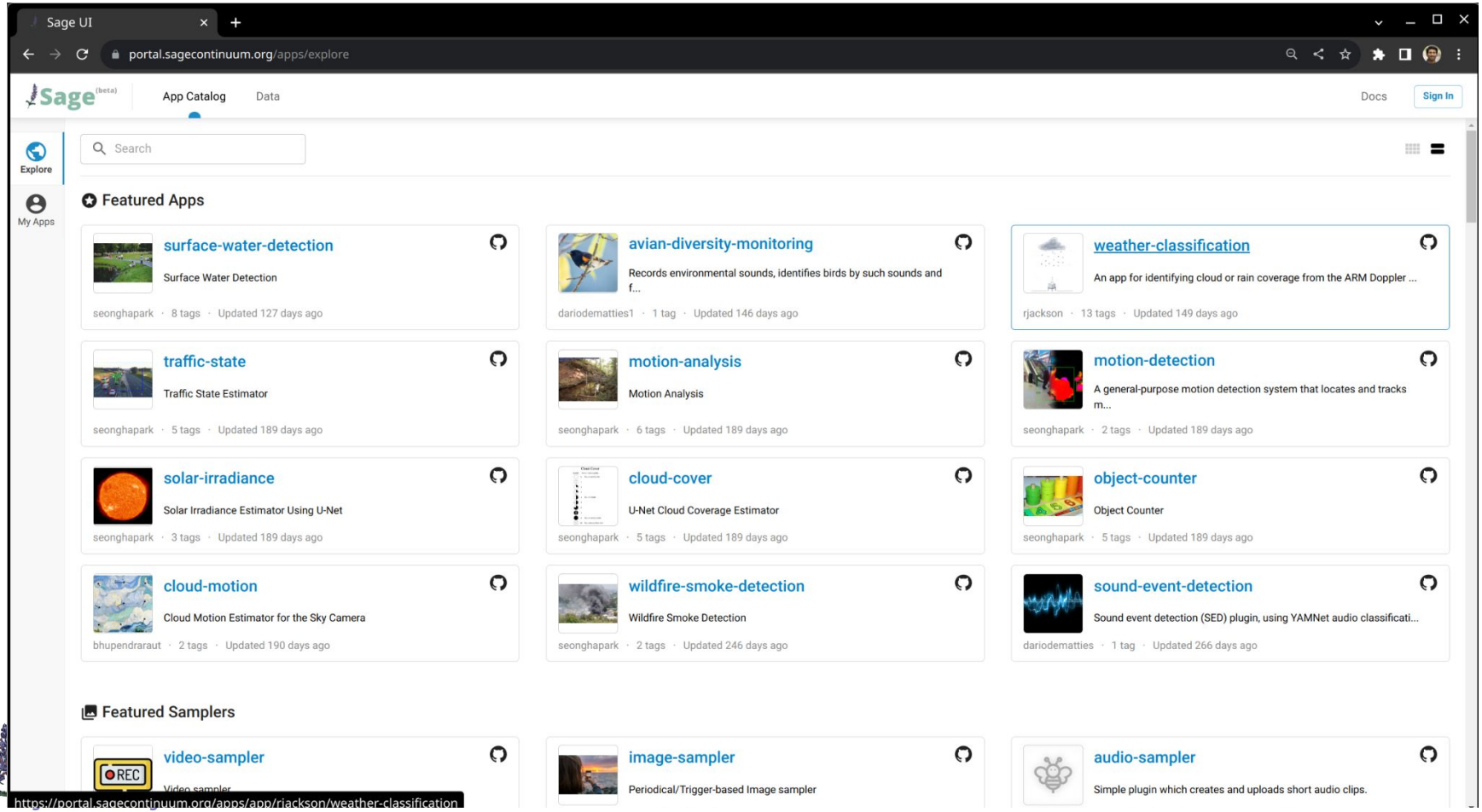






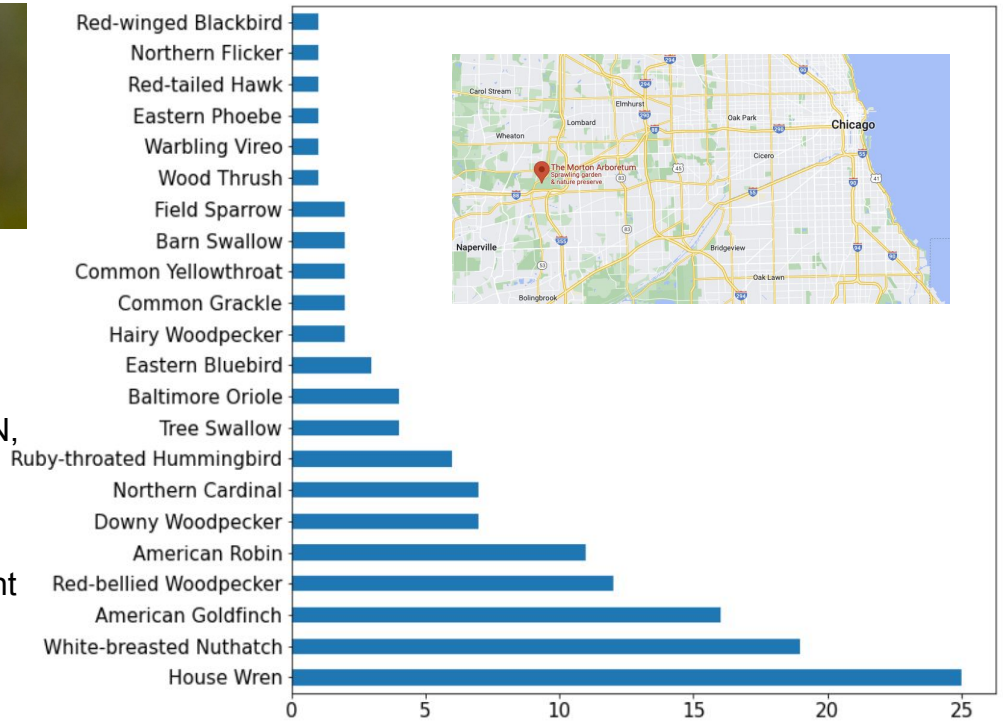


A repository for edge codes? A scientific *Play Store* or *App store*?



Avian diversity monitoring

- Bird diversity changes as a metric to track the current environmental conditions
- We automate Avian Diversity Monitoring by using a DNN, called BirdNET [1], capable of identifying 984 North American and European bird species by sound. Weekly cumulative detections of non-migratory species occurrence was highly correlated with human point count observations
- It will be possible to get exposure to many organisms occupying diverse areas without needing to detect them during demanding and expensive human fieldwork

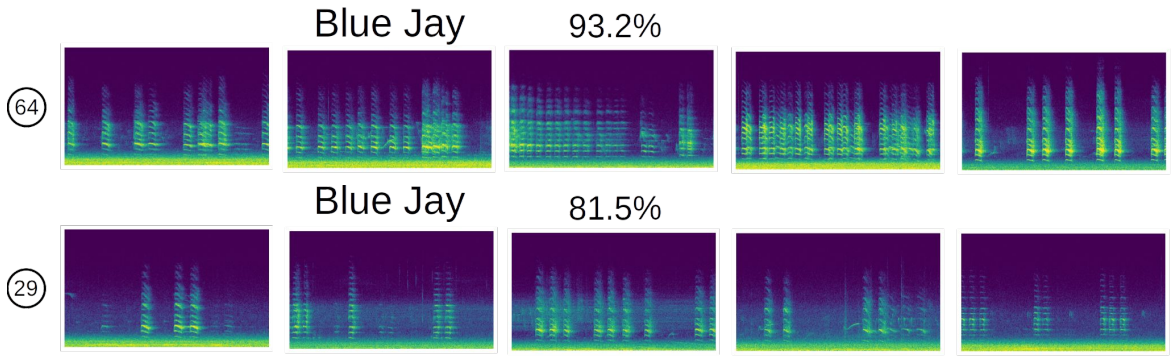


Morton Arboretum Avian Detection, June 28, 2021 (24 hour)

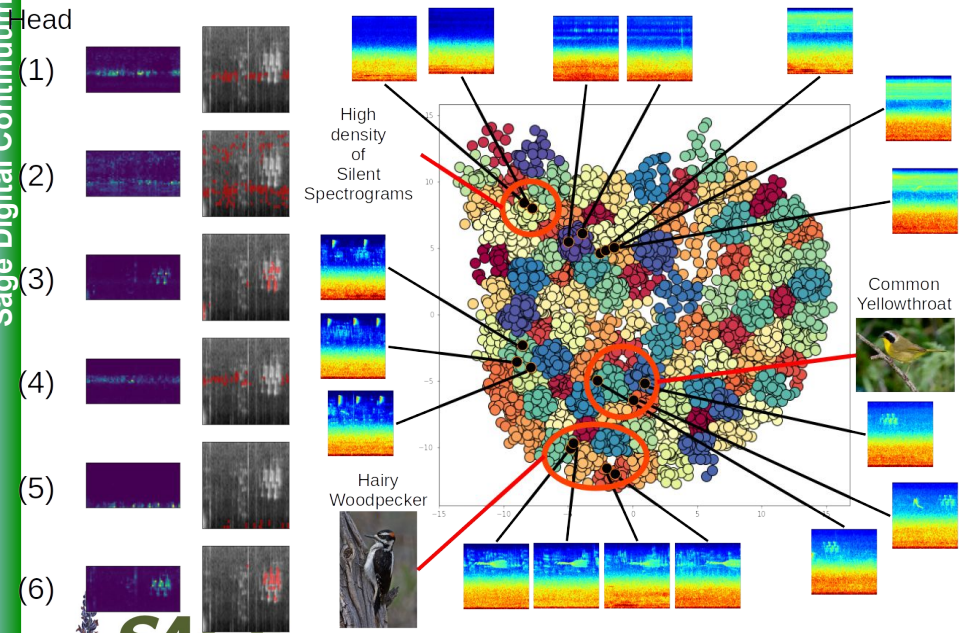
[1] Stefan Kahl, Connor M. Wood, Maximilian Eibl and Holger Klinck. BirdNET: A deep learning solution for avian diversity monitoring. Ecological Informatics Volume 61, March 2021.

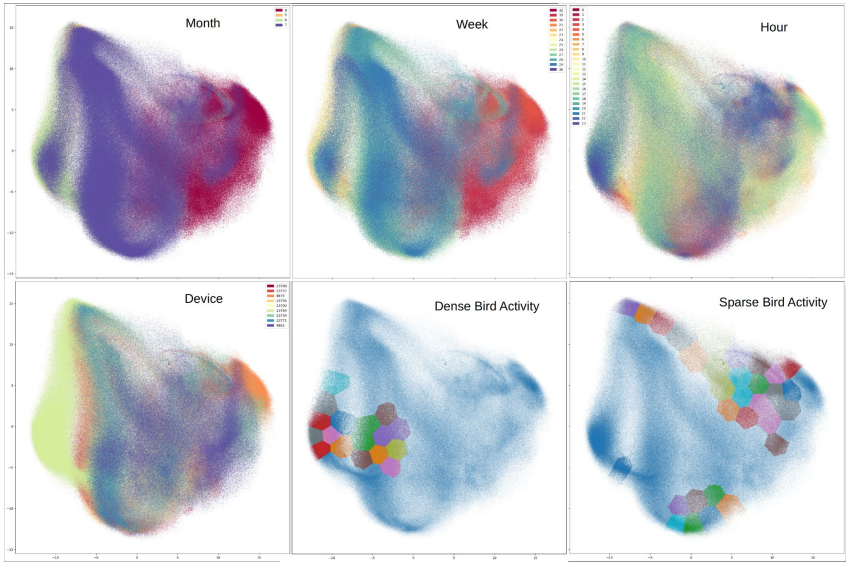
Research Credit: *Dario Dematties, Bhupendra Raut, Nicola Ferrier*

Self-supervised Avian Diversity Monitoring Joint-Embedding Architecture



(a) (b)





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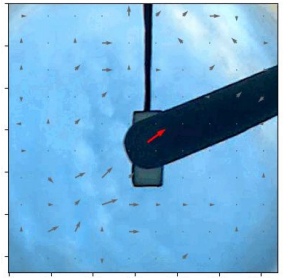
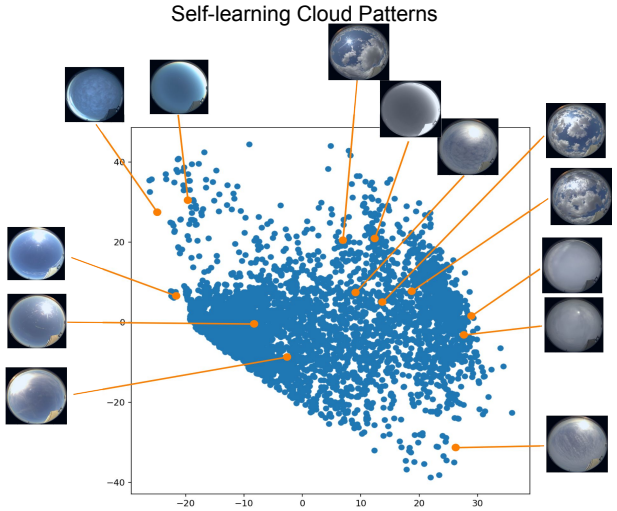
Dario Dematties and Samir Rajani, Northwestern University

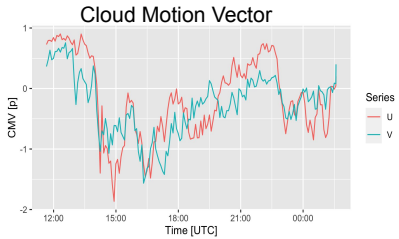
Edge computing for understanding climate

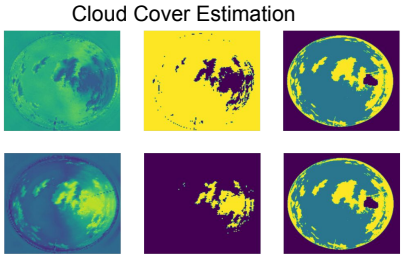
Sage Digital Continuum



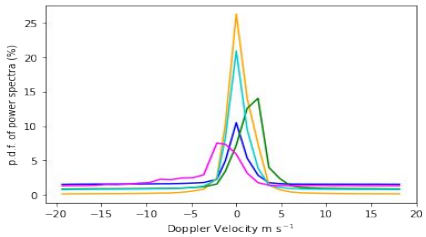
Analyzing cloud patterns

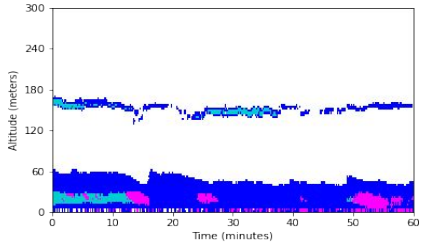




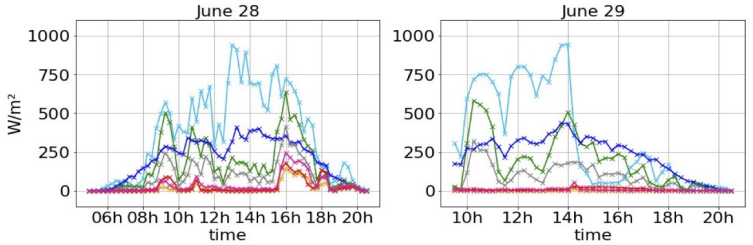


Automated LIDAR particle identification





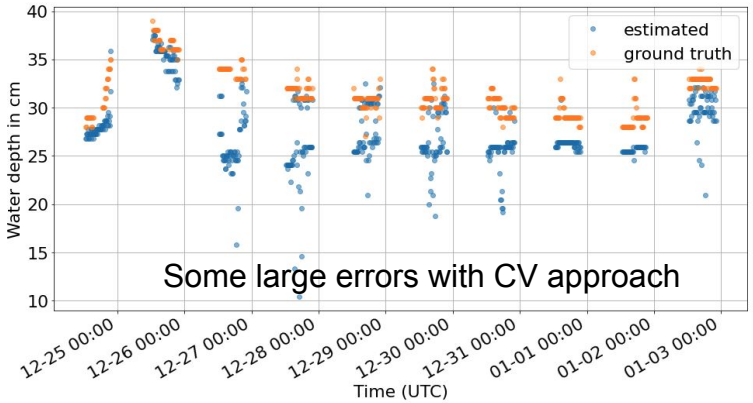
Solar energy estimation



Measuring Water and Snow Depth

We are evaluating multiple approaches to estimate the water (or snow) level from images of rulers (in of a stream at a NEON site)

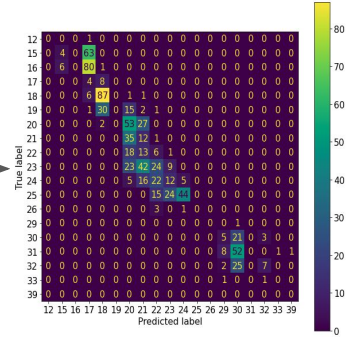
- Computer vision (CV) based
- Machine Learning algorithms
  - U-Net, ResNet
  - Self-supervised Learning

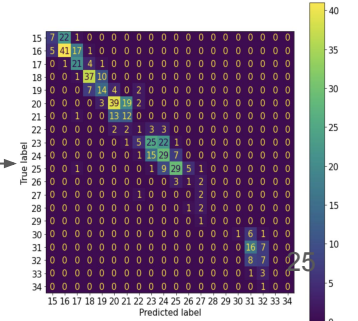


Human annotation using Labelbox

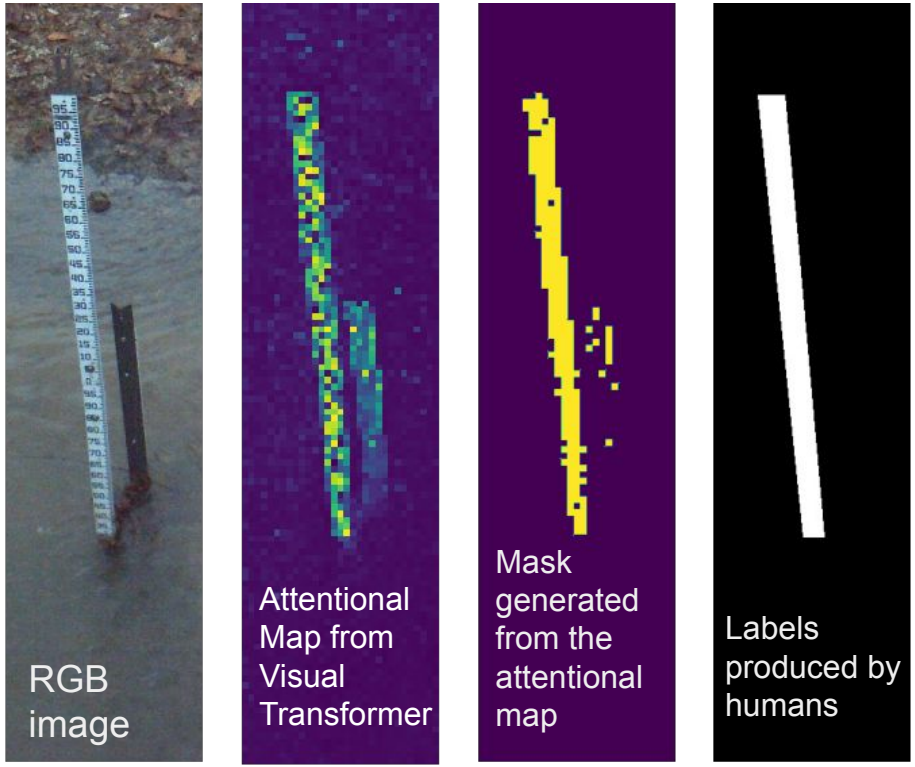
U-Net (segmentation)

ResNet32 based Regression



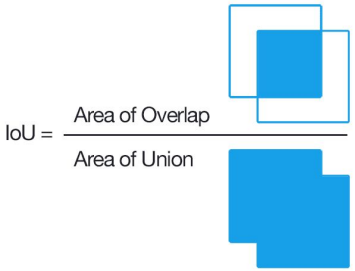


Measuring Water and Snow Depth

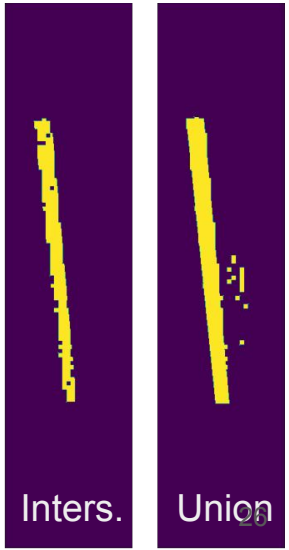


Self-supervised Segmentation

- Exploring visual transformer ML
- ML model was trained using only images from IMAGENET (no labels and no NEON data)
- An Intersection over Union score > 0.5 is normally considered a “good” prediction.



Intersection/Union (IoU) = 0.729



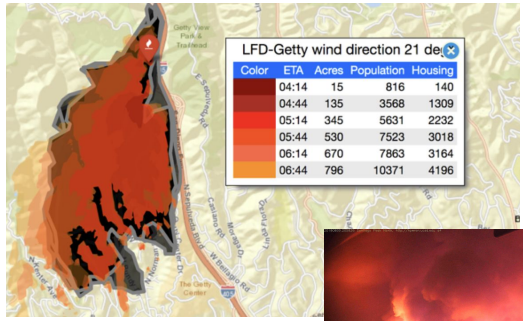
Ilkay Altintas, UCSD, Co-PI for SAGE

Wildfire Detection and Prediction

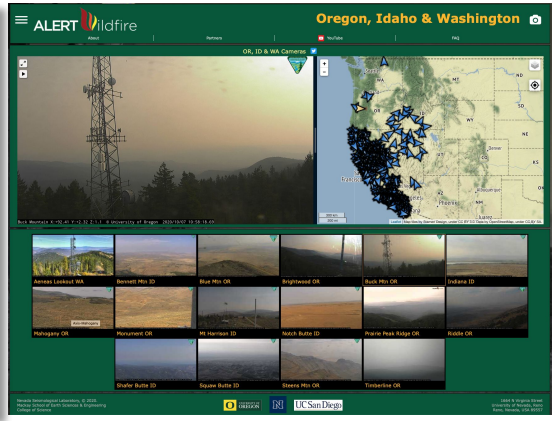
Exploring wildfire detection at the edge linked to HPC simulations

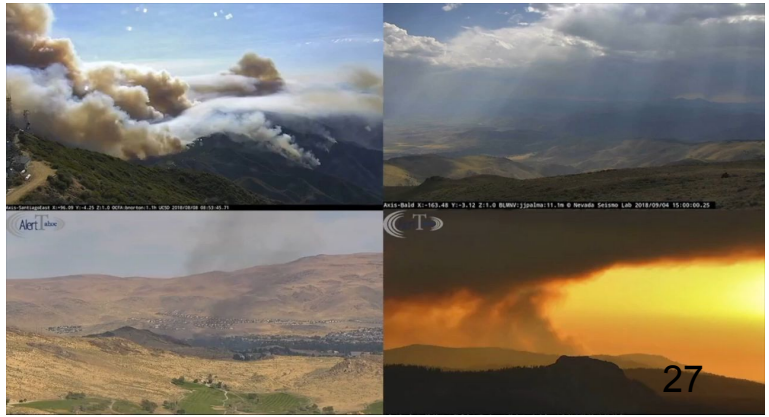
https://bit.ly/Sage-AlertWildFire

ALERTWildfire: A unique wildfire detection and monitoring system

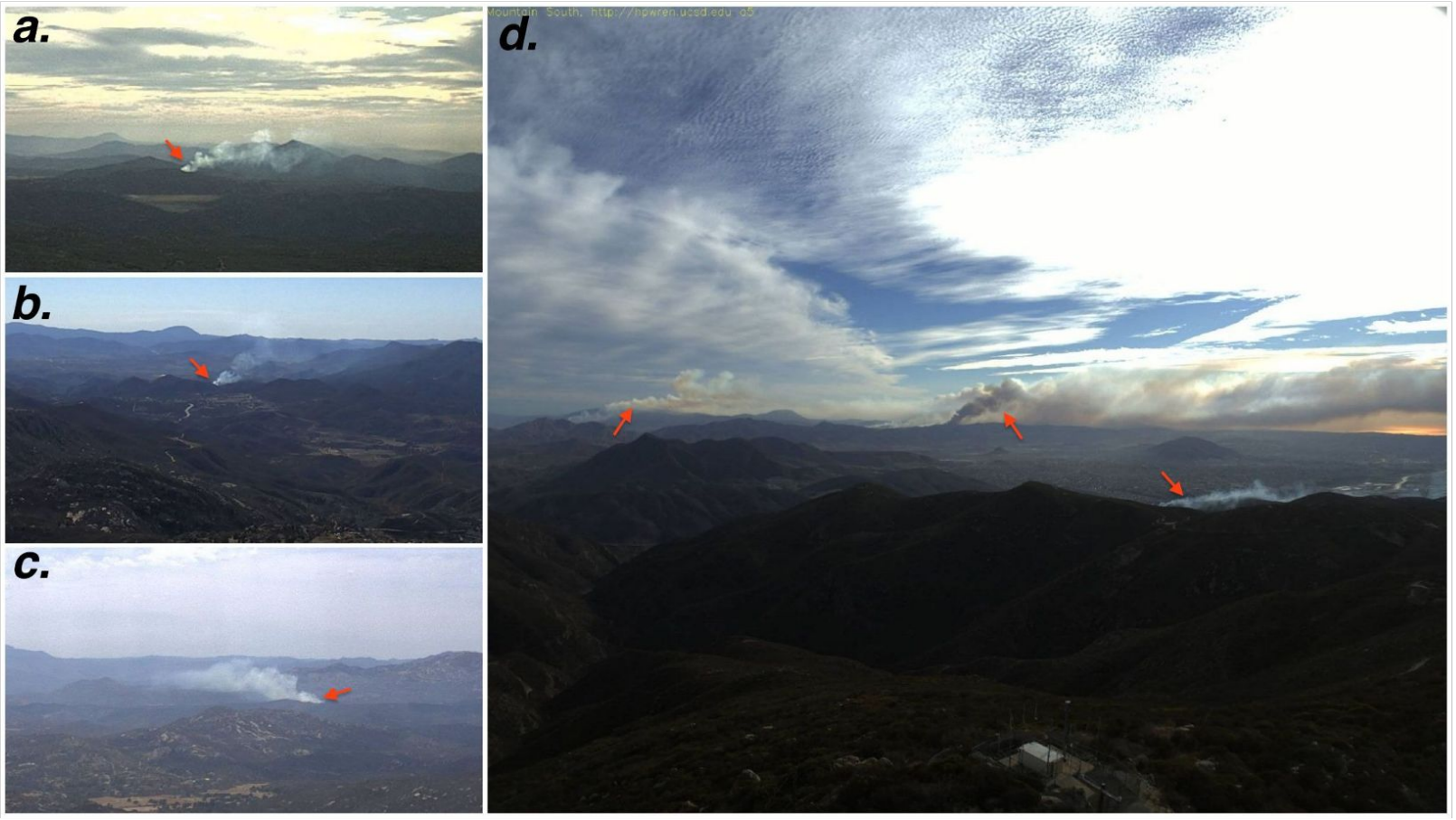


Collaboration: Doug Toomey, UOregon



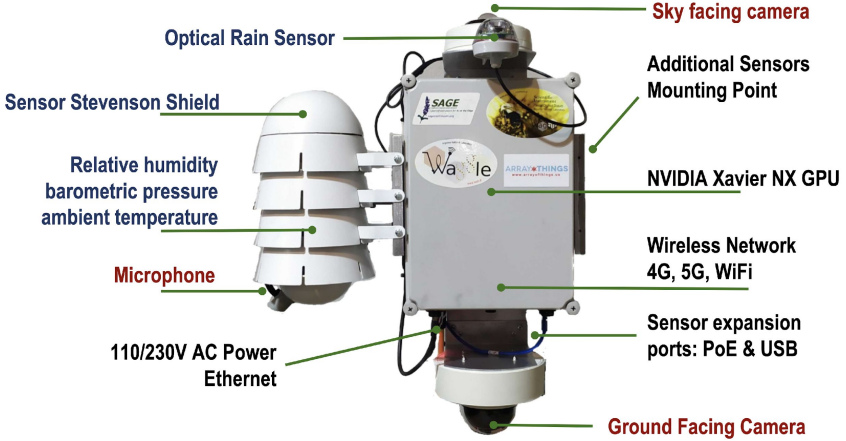


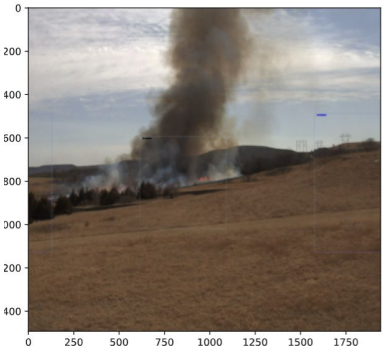
Early Detection and Monitoring of Wildfire

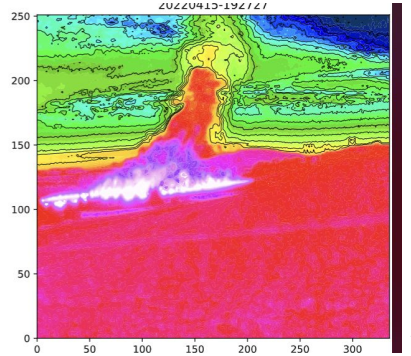


Sage Co-PI: Eugene Kelly, Colorado State
eugene.kelly@colostate.edu

NEON Mobile Deployment Platform (MPD) with Sage Konza Prairie for controlled burn: April 2022.







Sage Digital Continuum

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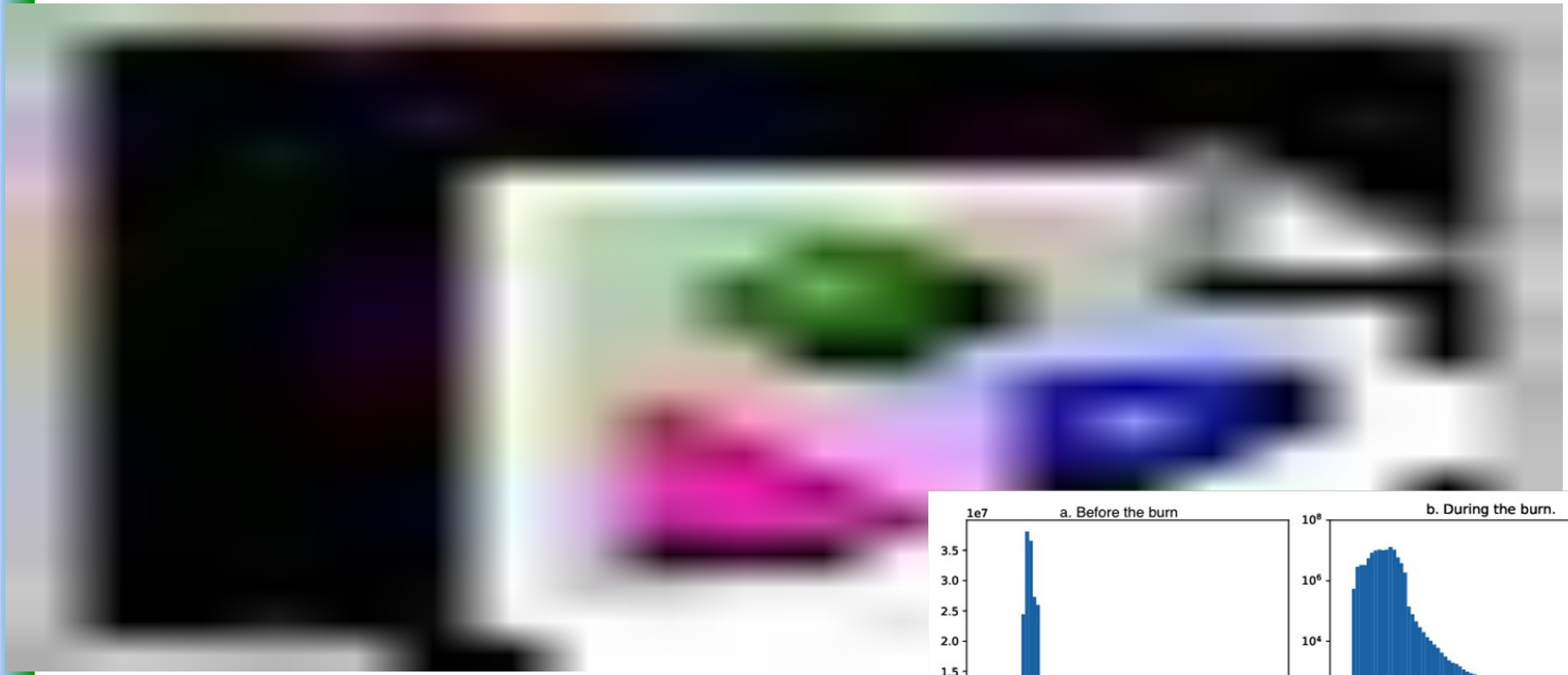
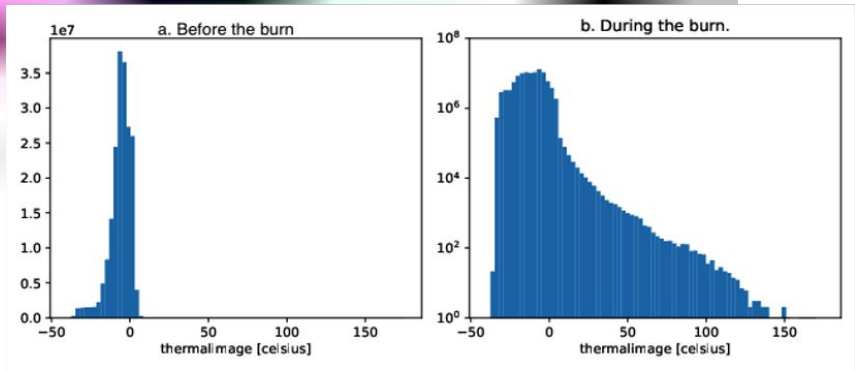
Konza Burn Experiment with thermal IR imaging





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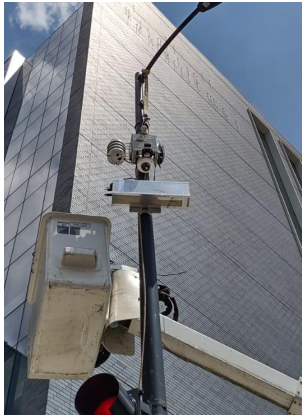
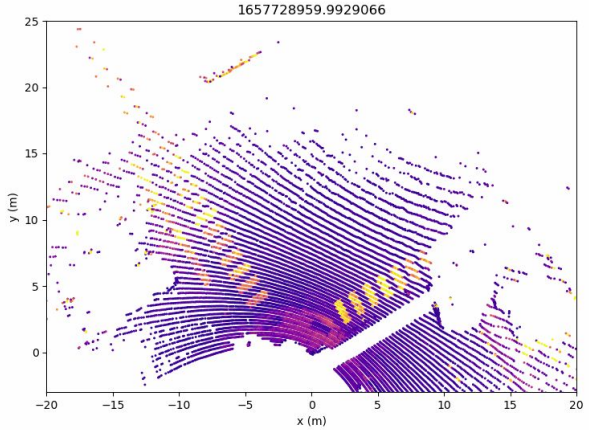
https://bit.ly/Sage-KonzaBurn2022

DOE NNSA (NA-22): Safer Cities

Domain Awareness Waggle Network (DAWN - ANL) -- with PANDA (LBNL)



Integration of radiological and contextual sensors into a remotely-programmable and configurable platform



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CROCUS - Waggle Supported Urban Integrated Field Laboratory

With the partnership of academic and community organizations and civic and industry champions (DOE BER)

Scientific Achievement

Community Research on Climate and Urban Science (CROCUS) is using Argonne's Waggle system to study urban climate change and its implications for environmental justice in the Chicago region through novel observational science and create highly accurate climate models. Waggle is enabling integration and deployment of novel sensors, and aggregation of sensor data for analysis and modelling.

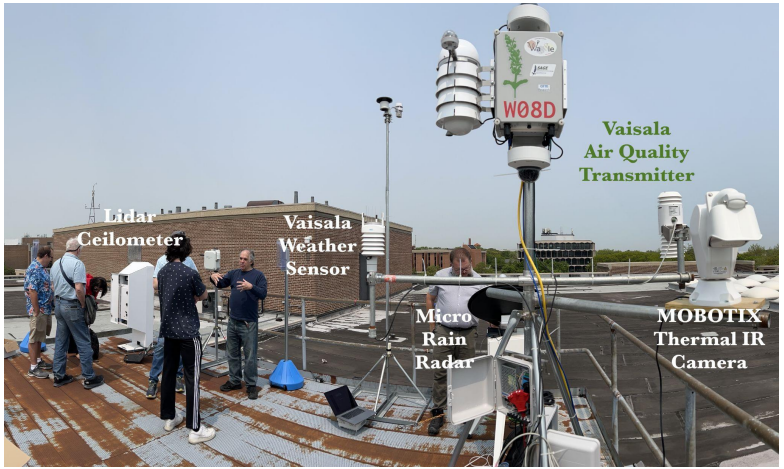
Significance and Impact

The information generated by the sensors will lead to new insights on current and future urban climate challenges and will inform future actions for mitigating and adapting to climate change at the street, neighborhood, and regional levels. Waggle has reduced the barrier to entry to deploy and analyze data from advanced sensors including Doppler LiDARs, RADARS, and Ceilometers.

Technical Approach

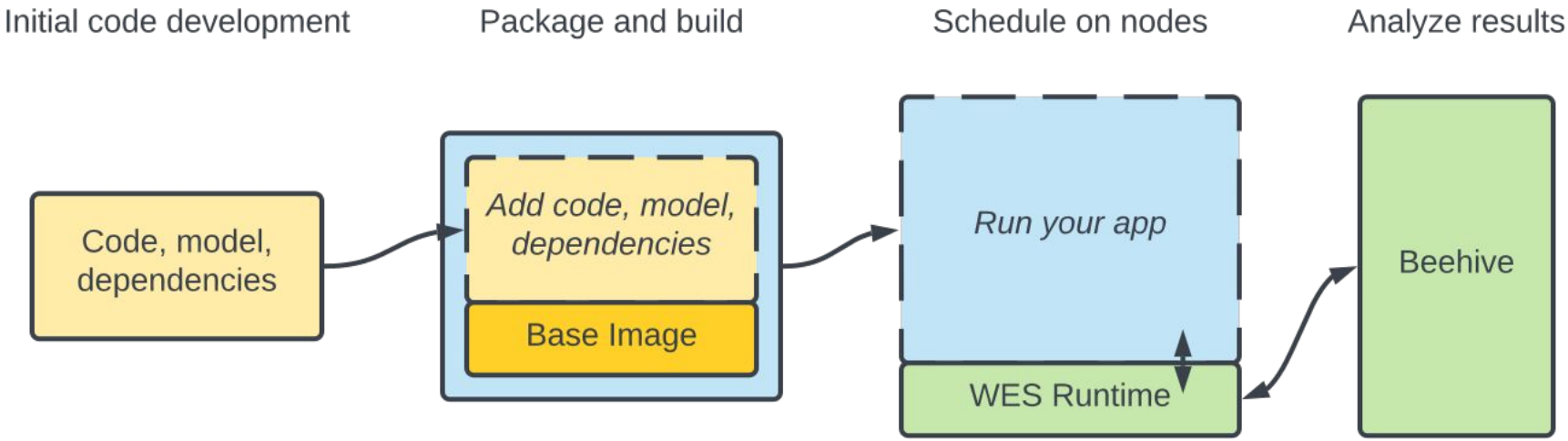
- Waggle Edge AI supports analysis on full fidelity sensor data in real-time.
- Edge analysis is enabled by goal oriented scheduling, secure application

PI(s)/Facility Lead(s): Christina Negri (PI), Pete Beckman and Raj Sankaran (Waggle/CI Leads)
Collaborating Institutions: https://www.anl.gov/crocus/collaboration
DOE Program: BER (https://ess.science.energy.gov/urban-ifls/crocus-uifl/)
ASCR PM: Hal Finkel
Code Developed or Datasets: https://github.com/CROCUS-Urban/instrument-cookbooks, https://portal.sagecontinuum.org/nodes?project=%22CROCUS%22



A Level 3 CROCUS node being deployed on the top of Bernard J. Brommel Hall at NorthEastern Illinois University (NEIU). Several advanced sensors including Vaisala Ceilometer, Metek Microwave rain radar, Vaisala Multi-Parameter Weather Sensor, MetOne Air quality Sensor, Mobotix M16 thermal camera and RGB cameras are supported by Waggle cyber-infrastructure. Real-time data from the sensors are processed by the Waggle AI Edge node (on the right), and communicated to cloud infrastructure for further analysis and developing AL/ML models.

Edge Development Process …



OpenCV TensorFlow PyTorch docker

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AI@Edge science problems for students. Get involved!

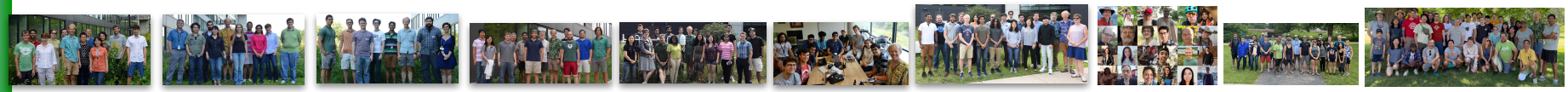
- Measuring river depth against graduated marker
- Auto-steering of PTZ cameras based on local AI
- Measuring snow depth against graduated marker
- Measuring vegetative states, growth rates
- Self-supervised learning: IR, LiDAR, audio, and RGB
- Vehicle types and flow speeds
- Quantify flower blooming (color, count)
- Outlying conditions from previous sensor data
- Calculating biodiversity based on audio
- Measuring surface water coverage
- Measuring lightning via RF (software defined radios)
- Measuring visibility across a field
- Measuring rime ice thickness
- Measuring ice coverage on a large body of water
- Measuring bird flocks and dynamics
- Measuring water flow speed
- Classifying wildlife behaviors
- Improved wildfire detection algorithms
- Wildlife tracking in open fields (speed, direction, count)
- Ultrasonic bat detection
- Measuring pedestrian movement dynamics
- Measuring land changes (riverbeds, plant coverage)
- Measuring water turbidity, debris movement, floating waste
- Measuring vehicle dynamics: identification of sliding, crashes, mishaps
- Measuring bike usage, bike lane dynamics
- Identifying urban "near misses"

Many, Many, Computer Science Challenges…

- Lightweight AI training / model adaptation at instrument edge
- Self-supervised learning with multiple instruments
- Container technology for HPC and the edge
- Cooperative sharing of edge resources
- Control loops for actuation
- Movement (drones, robots)
- Digital twin / MODEX for setting local edge goals
- Microelectronics for low-power AI@edge and analog/digital conversion
- Extending 5G and Satellite communications for next-gen instrumentation
- Large Language Models
- Federated Learning, Learning at the edge, self-supervised and other approaches
- Edge-to-cloud and cloud-to-edge

Special Thanks

Students!



2013 — 2022

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Charlie Catlett
Scott Collis
Neal Conrad
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Nicola Ferrier
Jannick Fischer
Larry Hartman
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Euguene Kelly
Yongho Kim
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Seth Magle
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Aaron Packman
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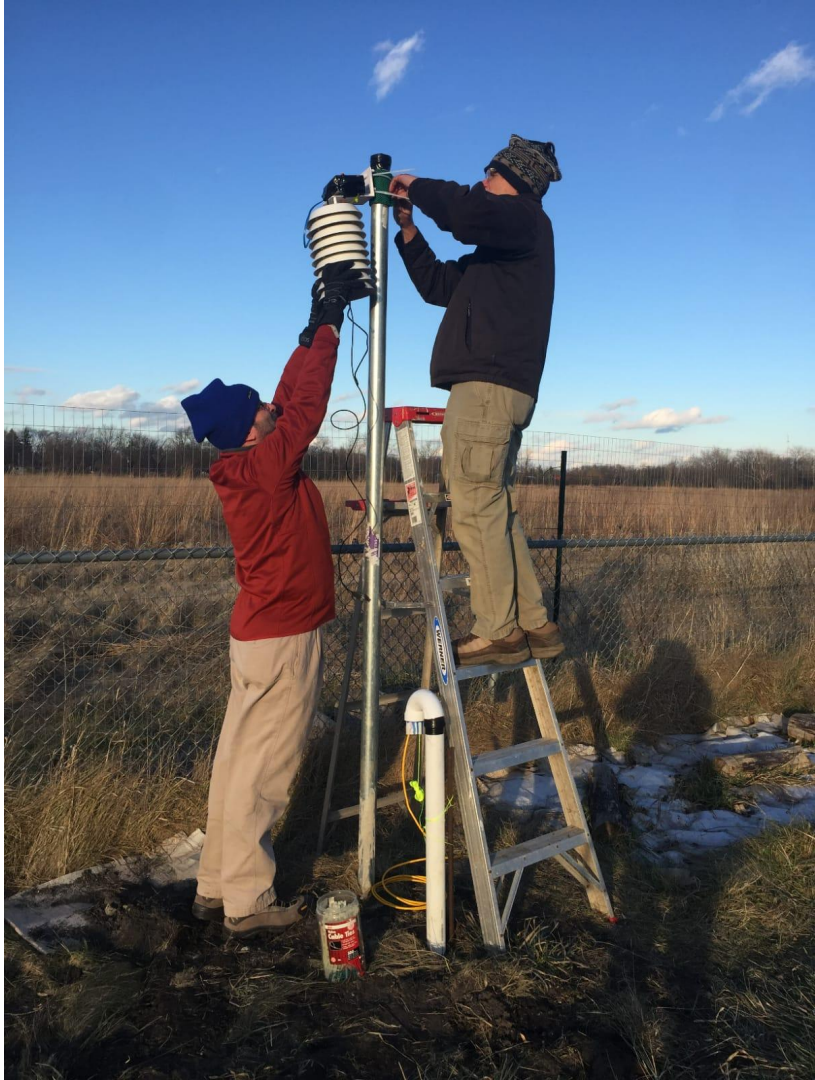
Seongha Park
Ismael Perez
Bhupendra Raut
Dan Reed
Mike SanClements
Raj Sankaran
Sean Shahkarami
Sergey Shemyakin
Joe Swantek
Helen Taaffe
Valerie Taylor
Doug Toomey
Frank Vernon
Rommel Zulueta

Questions?

Getting started with Sage! - https://sagecontinuum.org/
Sage AI@Edge Apps - https://portal.sagecontinuum.org/apps/explore
Sage Data - https://portal.sagecontinuum.org/data
Waggle Github - https://github.com/waggle-sensor
Sage Continuum Github - https://github.com/sagecontinuum

Some interesting videos -
https://bit.ly/NU-Manoomin
https://bit.ly/Sage-Deploy-Taft2022

rajesh@anl.gov



Professors Aaron Packman and William Miller, Northwestern University
Gensburg-Markham Prairie, The Nature Conservancy
Photo Credits: Liliana Hernandez-Gonzalez, Northwestern University
Dec 2015

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