www. chameleoncloud.org

Infrastructure for Edge to Cloud AI Research

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MultiCore World, 02/17/25

CHAMELEON: AN EDGE TO CLOUD TESTBED

- Chameleons like to change – testbed that adapts to your experimental needs
  - **From bare metal reconfigurability/isolation** -- KVM cloud – to containers for edge (**CHI@Edge**)
  - Capabilities: power on/off, reboot, custom kernel boot, serial console access, etc.
- From large to small – diversity and scale in hardware:
  - **Supercomputing datacenters** (UC/ALCF, TACC, NCAR) over 100G network – to **edge devices**
  - **Diverse:** FPGAs, GPUs, NVMe, NVDIMMs, Corsa switches, edge devices via CHI@Edge, etc.
  - **Distributed: CHI-in-a-Box** sites at **Northwestern and UIC** – and now also **NRP**!
- Based on mainstream open source – proud to be cheap!
  - 50% leveraging and influencing **OpenStack** + 50% "special sauce" (incl. fed id)
- Promoting digital artifact sharing
  - Integration with **Jupyter** for non-transactional experiment packaging
  - **Trovi** for experiment sharing and discovery, **Chameleon Daypass** for access sharing
  - Reproducibility and education: digital sharing killer apps!


Chameleon
700+
Papers published
1,200+
Unique projects
11,000+
Users
9

CHAMELEON HARDWARE

Coming soon: Dell XE9640,
2x Intel 9468 CPU / 4x Nvidia H100

CHI@UC
Skylake, CascadeLake, IceLake, AMD nodes, and GigaIO
GPUs (A100, V100, RTX6000), FPGAs (Xilinx Alveo U280)
Storage (NVMe SSD, NVDIMM)
Network (Corsa SDN, 25G Ethernet, 200G InfiniBand)

CHI@Edge
Raspberry Pi, Jetson Nano, Jetson Xavier NX, AGX Orin
+ User-added devices

Chicago
Austin

CHI@TACC
Haswell, SkyLake, CascadeLake, Fugaku (ARM64 + HBM),
AMD nodes, and LIQID/GigaIO disaggregated hardware
GPU (K80, M40, P100, MI100), FPGAs (Altera)
Storage (NVMe, SSD, NVDIMM)
Network (Corsa SDN, 25G Ethernet, 200G InfiniBand)

Storage
~0.5 PB

Network
100Gbps public network

Storage
~3.5PB

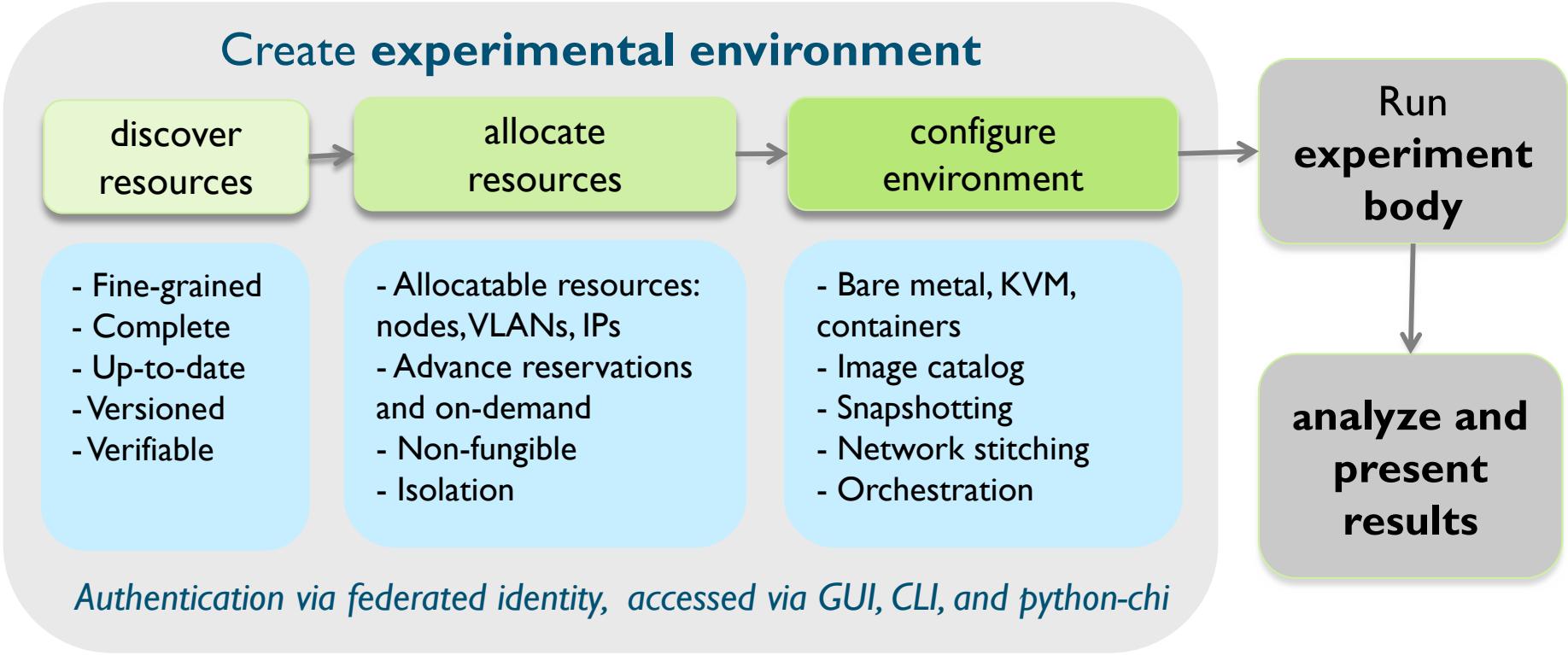
Commercial Clouds via **CloudBank**

FABRIC, FAB and other partners

Chameleon Volunteer Sites

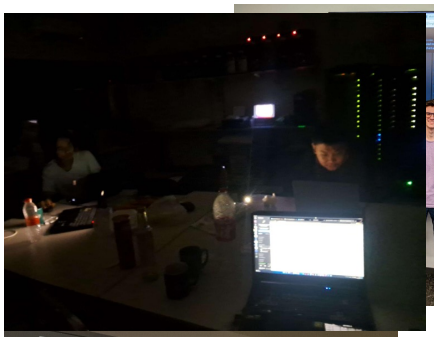
CHI@NCAR

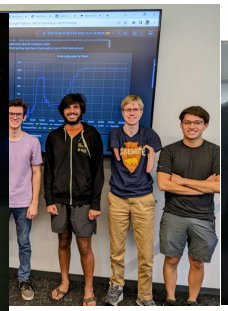
EXPERIMENT STRUCTURE

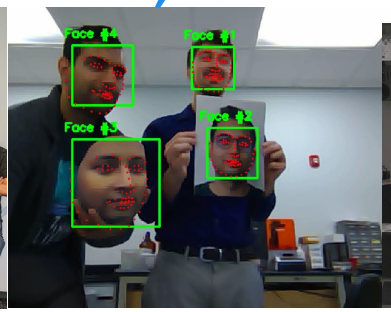


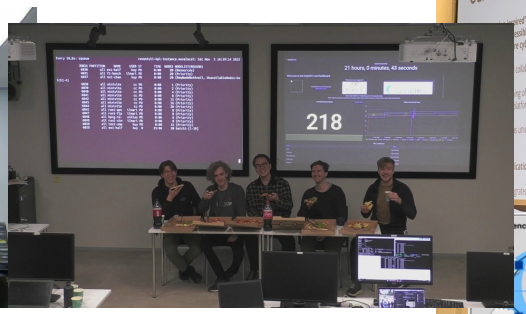
Paper: "Lessons Learned from the Chameleon Testbed", USENIX ATC 2020

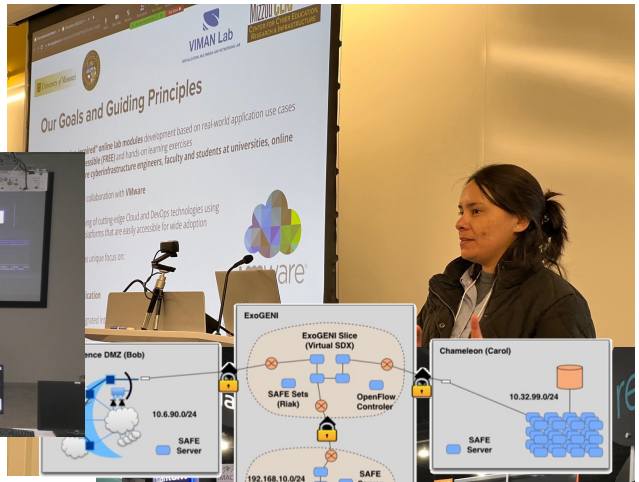
NOT JUST A TESTBED, A COMMUNITY

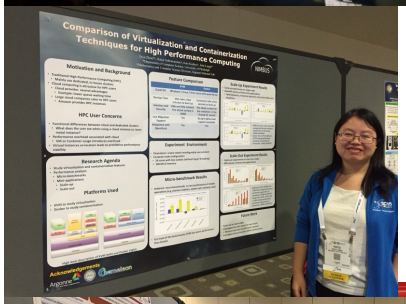




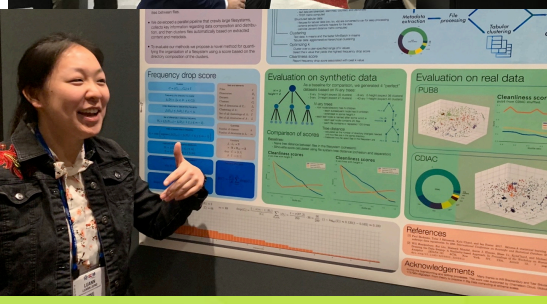


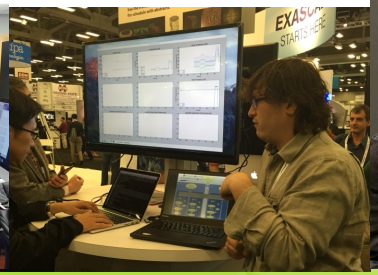






Supporting research projects in architecture, operating systems design, virtualization, power management, real-time analysis, security, storage systems, databases, networking, machine learning, neural networks, data science, and many others.

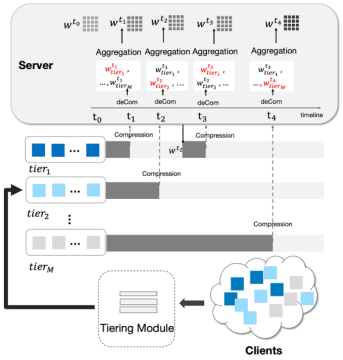




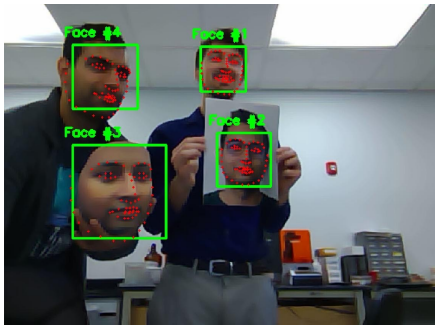
Chameleon www.chameleoncloud.org

Check out user experiment stories on our blog:
https://www.chameleoncloud.org/blog/category/user-experiments/

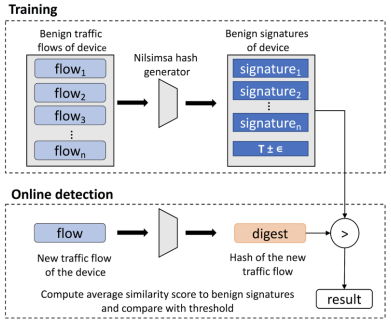
FROM CLOUD TO EDGE WITH CHAMELEON



federated learning



biometrics



network traffic fingerprinting for IoT devices

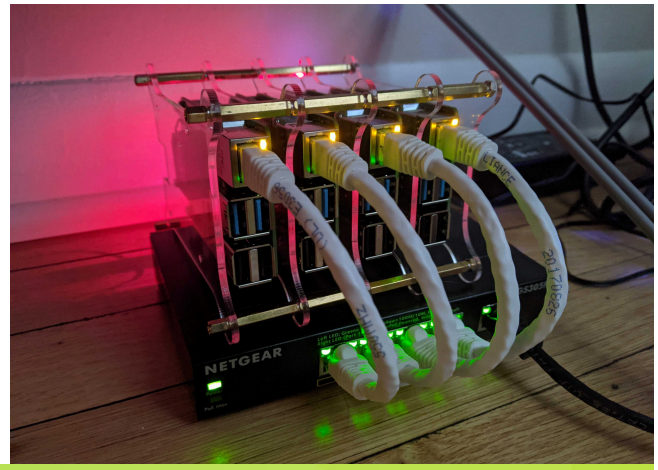
- Increasingly more Chameleon project applications working on IoT/edge
- Simulation/emulation don't always provide the answer: What are the impacts of this approach on power management on edge device? How will the performance transfer to edge? Can we measure the impact of distribution/networking for edge/cloud applications?
- **Goal: "realistic edge to cloud experiments from one Jupyter notebook"**

PROGRAMMABLE WITH CHI@EDGE

A lot like a cloud!
All the features we know and love – but for edge!
"Edge to cloud from one Jupyter notebook."

Not at all like a cloud!
Location, location, location!
IoT: cameras, actuators, SDRs!
Not server-class!
And many other challenges!

- CHI@Edge: all the features you love in CHI, plus:
  - Reconfiguration through non-prescriptive **container deployment** via OpenStack interfaces (using K3 under the covers)
  - Support for "standard" **IoT peripherals** (camera, GPIO, serial, etc.) + easy for you to add support for your own peripherals
  - **Bring Your Own Device (BYOD): Mixed ownership** model via an SDK with devices, virtual site, and **restricted sharing** – building on OpenBalena



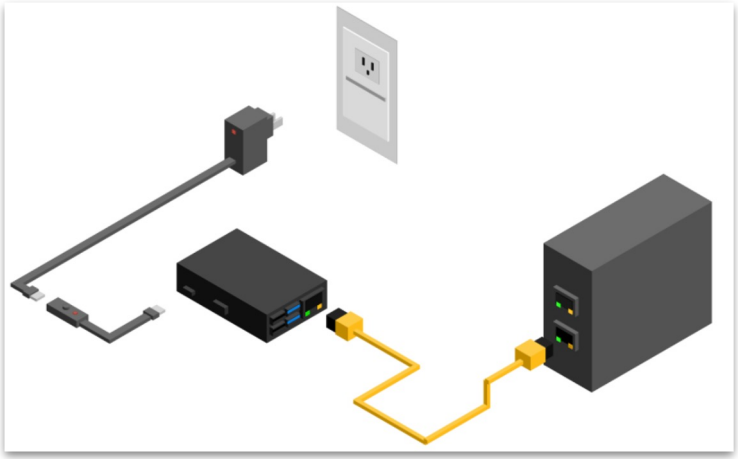
Paper: "Chameleon@Edge Community Workshop Report", 2021

FROM EXPLORATION TO OBSERVATION: THE FLOTO PROJECT CASE STUDY

- Why broadband monitoring?
  - Technical questions: what happens in conditions of oversubscription?
  - Policy questions: can we characterize the “digital divide” in our society?
  - Modeling questions: what assumptions about broadband are realistic?
- Measuring broadband – different approaches/applications depending on context, objective, use case, etc.
  - Netrics: open-source library of standard network diagnostic tools (ndt7, speedtest, ping, traceroute, etc.) for continuous, longitudinal network measurement
  - Others: e.g., residential versus rural broadband and other use cases
- **Can we use CHI@Edge as a large observatory instrument for broadband monitoring?**
- **Approach:** connect a “measurement box” to the router and run tests
- Collaboration with Nick Feamster & his UChicago team

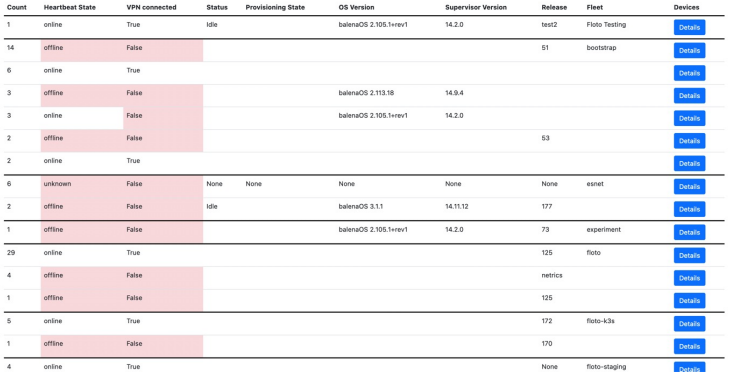
THE DEVICES

- Raspberry Pi 4 (8GB)
- Additional Components
  - MicroSD Cards (32GB)
  - CAT 6 Ethernet Cable
  - Power Cord
- Optional: PoE+ HATs to enable deployment in locations with scarce power sources
- Inventory: 1,000 devices finished arriving at the end of June’23
- Allocations via a device request form

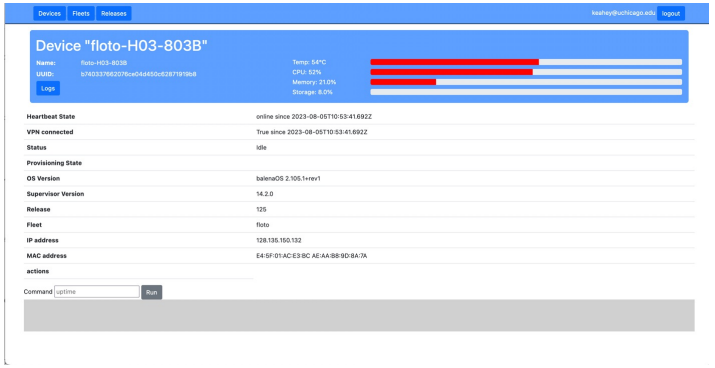


DEVICE MANAGEMENT LAYER

- Onboard, offboard, and repurpose devices
- Devices self-enroll
  - 0 touch device enrollment (after imaging)
  - Alternatively, flash with our image to enroll your own device
- Configuration management
  - Update and deploy without physical access, stateless, vetted images, includes software and device configuration, can be pinned to releases
  - OpenBalena + “special sauce”
- Robust remote management features
  - View status and statistics, create and manage deployments, trigger appropriate actions (e.g., send mail), dashboard and CLI interfaces
- HA control plane, federated identity login, etc.

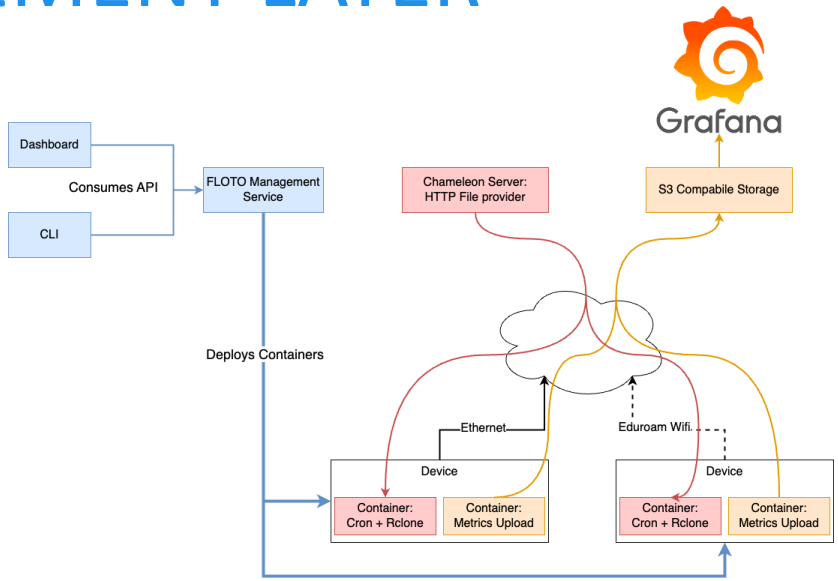


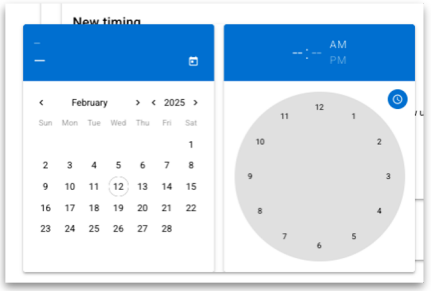
Count	Heartbeat State	VPN connected	Status	Provisioning State	OS Version	Supervisor Version	Release	Fleet	Devices
1	online	True	Idle		balenaOS 2.105.1+rev1	14.2.0	test2	Floto Testing	Details
14	offline	False					51	bootstrap	Details
6	online	True							Details
3	offline	False			balenaOS 2.113.18	14.9.4			Details
3	online	False			balenaOS 2.105.1+rev1	14.2.0			Details
2	offline	False					53		Details
2	online	True							Details
6	unknown	False	None	None	None	None	None	esnet	Details
2	offline	False	Idle		balenaOS 3.1.1	14.11.12	177		Details
1	offline	False			balenaOS 2.105.1+rev1	14.2.0	73	experiment	Details
29	online	True					125	floto	Details
4	offline	False					netrics		Details
1	offline	False					125		Details
5	online	True					172	floto-k3s	Details
1	offline	False					170		Details
4	online	True					None	floto-staging	Details



APPLICATION MANAGEMENT LAYER

- Supports deployment of applications on device fleets via a system container
- Applications are packaged as Docker containers and reviewed
- Users can reserve overlapping or non-overlapping timeslots for application deployment so as not to conflict with other deployments
- Generic data streaming implemented as a “system application”
- Multi-container applications deployed via docker-compose syntax





DATA COLLECTION AND ANALYTICS

- Software on devices uploads results directly to cloud storage
- Data curation and analysis pipelines process raw data for investigation
- Raw and processed data available for use (after anonymization)
- Current, small scale, using AWS Lambda for analysis
- After scale up, use Apache Kafka as message broker, data consumers will subscribe to real time topics for up to date results
- Grafana dashboards with time-series visualizations to monitor data in near real-time

Paper: "Discovery Testbed: An Observational Instrument for Broadband Research", eScience'23

INSTRUMENT ADAPTABILITY

What knobs can I turn on this instrument?

- Deployment scope: deploy the devices in a different area
- Application: adapting "sensing abilities" programmatically
- Hardware: combine devices with different IoT gadgets (e.g., GPS)
- Data aggregation: different methods for different applications
- Data: ask different questions of the data

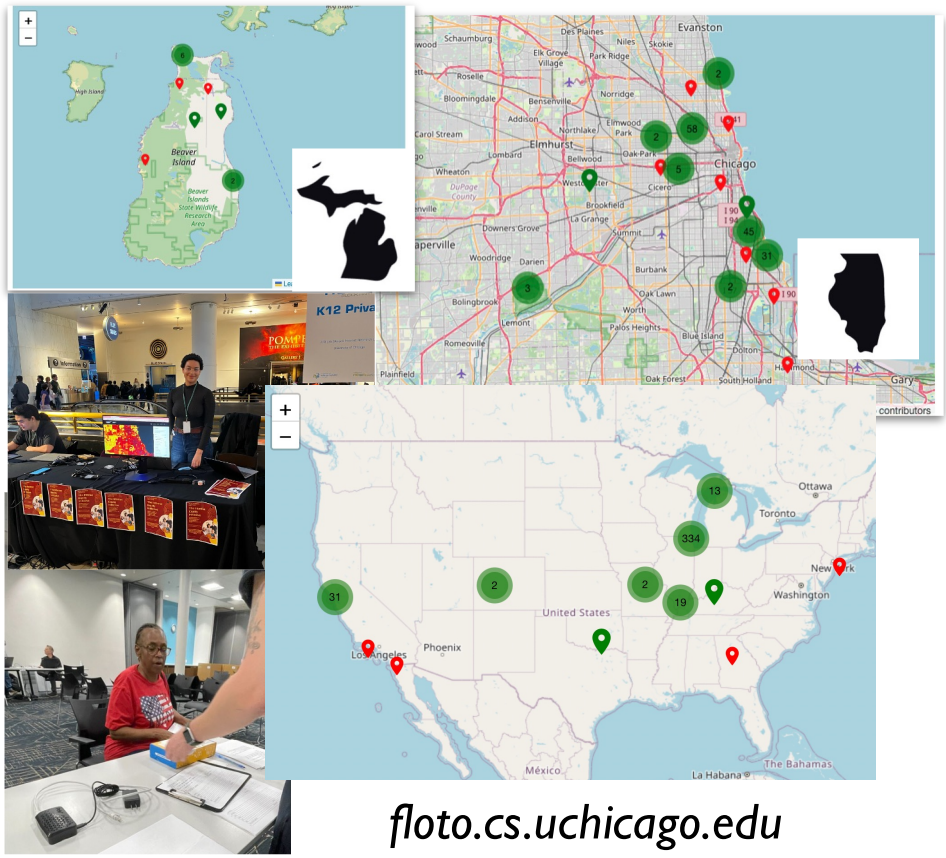
FLOTO: DEPLOY DEVICES IN DIFFERENT AREAS

~500 devices deployed across multiple states
Notable deployments:

- Chicago (180+ devices)
- Milwaukee (200+ devices)
- Marion County, IL; Beaver Island, MI -- and others

As a distributed community, we rely on trust and deep partnerships to bring infrastructure where it is needed most

- Building trust with communities
- Managing devices remotely (with many participants)
- Coordinating large-scale distribution



floto.cs.uchicago.edu

FLOTO: RUN A DIFFERENT APPLICATION

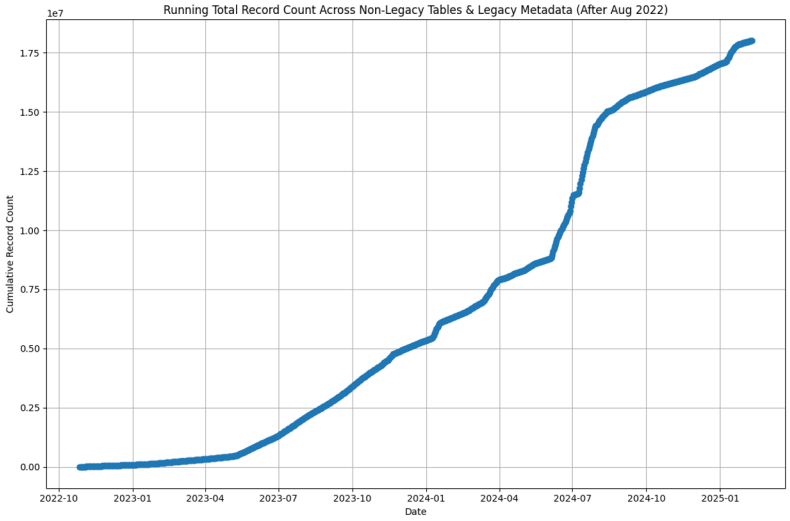
Applications Deployed on FLOTO to Date:

Each application provides different methods for broadband measurement depending on research interest

- **Netrics**: Broadband performance measurements to study access networks
- **RADAR Toolkit**: QoE measurements for telehealth applications
- **NetUnicorn**: Data pipeline experiments
- **Georgia Tech**: IPv6 Performance Studies
- **M-Lab**: Measurement Swiss Army Knife (MSAK) integration
- **ARA**: Monitoring 5G wireless performance in rural areas

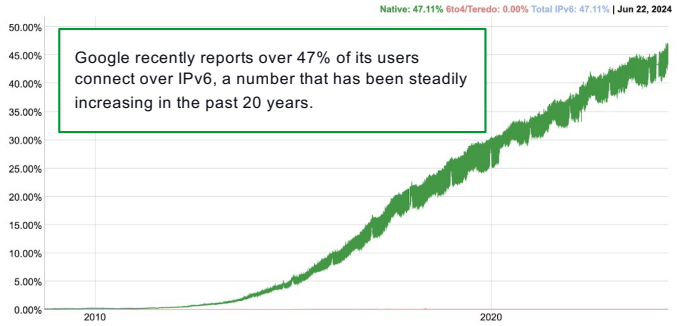
FLOTO: MINE THE DATASET

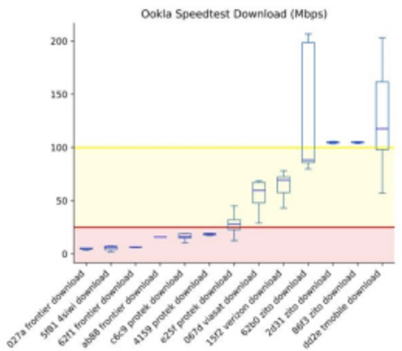
- ~18M million measurements collected since Oct. 2022
- What Measurements? Time series speed tests, latency, DNS performance, network paths on fixed connection (no WiFi bias)
- Spans 17 different network providers
- Multiple access technologies (fiber, cable, satellite, fixed wireless)
- Data is publicly available via project website
- Proposed as NAIRR dataset for working with projects like e.g., anomaly detection

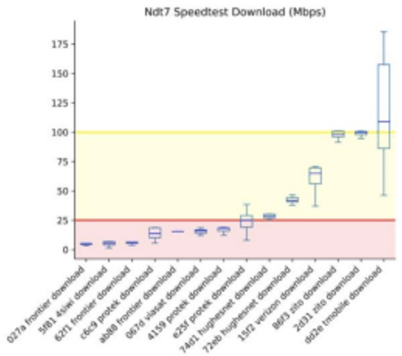


FLOTO: CASE STUDIES

- Computer Science questions: IPv4 versus IPv6
  - Objective: Understand how Internet speed varies between IPv4 and IPv6’
  - Method: sequential speed tests comparing IPv4 and IPv6 results under similar conditions
  - Early Findings: IPv4 and IPv6 speeds degrade differently under various conditions, influenced by the ISP (SIGMOD paper in preparation)
- Policy questions: Marion County
  - Objective: Improve internet infrastructure and performance in Marion County, Illinois
  - Method: Deploy FLOTO devices to collect and analyze broadband performance data
  - Finding: 32% of sampled households below the federal threshold -- data used to support grant applications for fiber broadband expansion

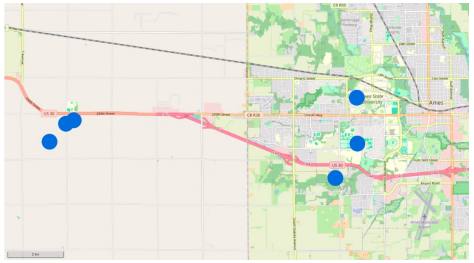


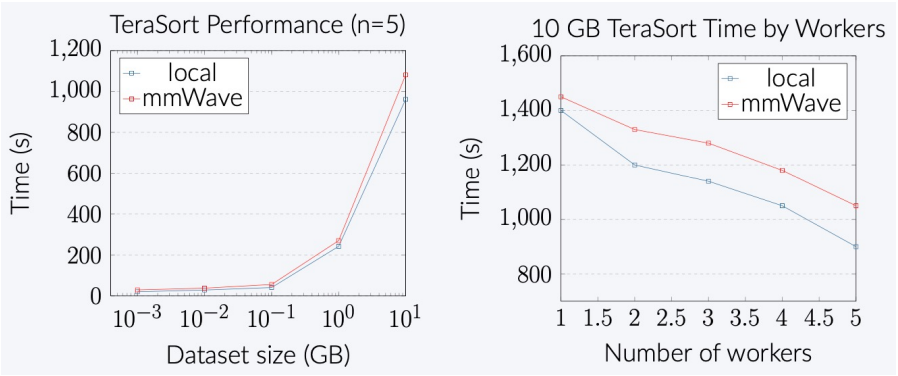




MEASURING RURAL WIRELESS

- Collaboration with ARA project
- Assessing the quality of rural 5G networks
  - Measuring device to device latency
  - Clock synchronization
  - Comparing over different network fabrics
- Deployed 6 Raspberry Pi devices with 5G connectivity in rural Iowa
- Latency measurements: GPS-based time synchronization for precise measurements (4000x more precise than NTP over 5G)
- Tested using Hadoop
- Hey presto: 5G networks can support distributed computing with performance comparable to wired connections!

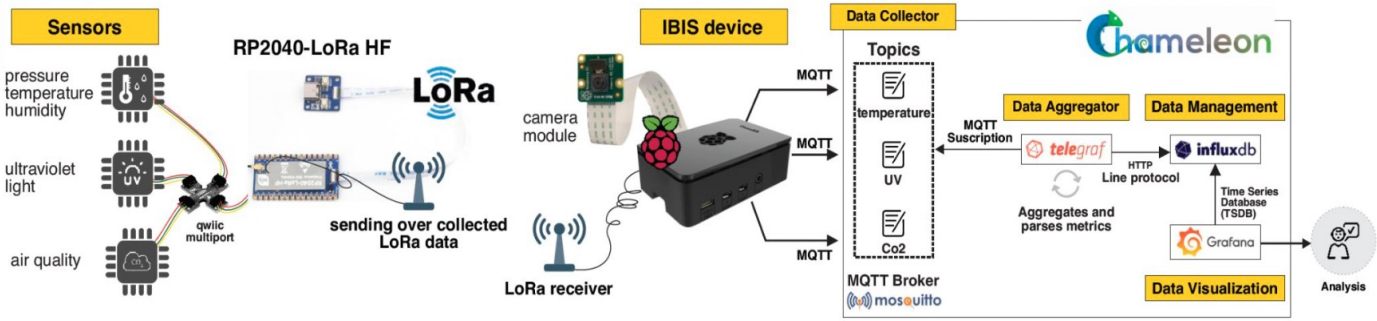




Zack Murry, University of Missouri

NCAR WEATHER SENSING STATIONS

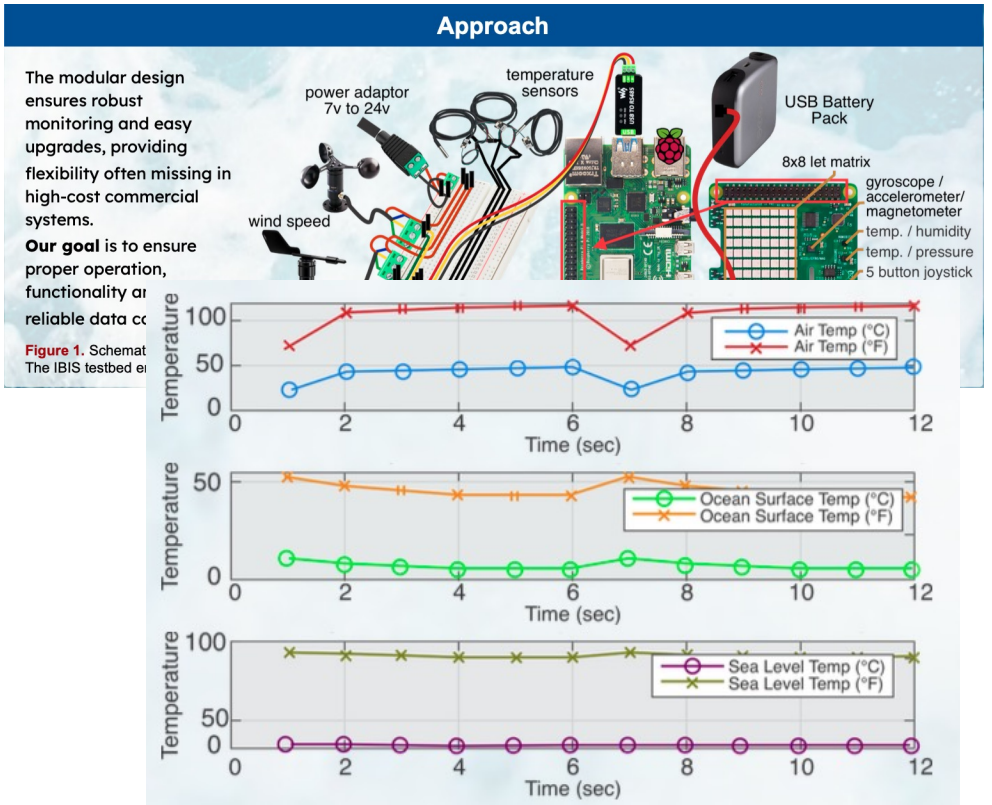
- openIoTwx: NCAR 3D printed weather stations
- Richer continuum: IBIS SBCs connecting to openIoTws via LoRa
  - Exploring power (4x factor), connectivity (cellular vs aggregation via LoRa), sensing (additional camera sensors), and processing (to e.g., reduce size of data) trade-offs
- Future challenges
  - Image-based weather prediction methods, scaling up to create dense, high-resolution weather monitoring networks, and assessing long-term reliability in diverse outdoor environments



William Fowler, Tufts University

SENSOR STATIONS FOR MARINE AND COASTAL ECOSYSTEMS

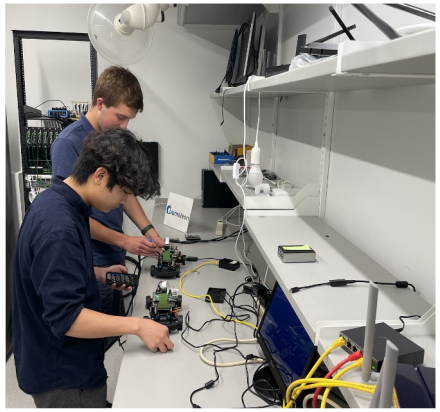
- Smart buoy system: sensor stations for oceanic data collection (water quality, water movement, water levels, etc.)
- Collaboration with FIU
- Integrated multiple environmental sensors with IBIS infrastructure
- Demo deployment with real and simulated data
- Implemented cloud-based data visualization system
- Collaboration with FIU

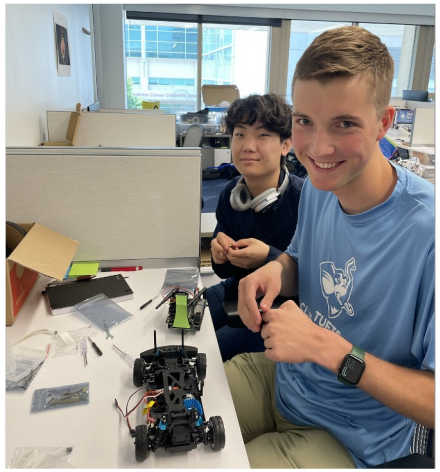


AUTOLEARN

- Chameleon notebooks based on the DonkeyCar package
- Students learn in three stages:
  - Data collection – actual/simulator – edge to cloud
  - Model training in the cloud
  - Verification via autonomous driving – actual/simulator – edge to cloud
- Supports different emphasis in teaching
  - Introduction to engineering might emphasize driving the actual car
  - Machine learning focus might use the simulator
- Individual exploration:
  - E.g., digital twin combining simulator and experimental driving

Paper: "AutoLearn: Learning in the Edge to Cloud Continuum", EduHPC'23





REU 2023 students working on hardware setup for autonomous vehicles

AND OTHERS…

- Predicting air quality with federated learning
- Soundscaping and forestry data analysis
- Precision agriculture: optimizing greenhouse environments
- Meteorologic monitoring system for ML-based weather forecasts
- And more…

PARTING THOUGHTS

- AI has opportunities at the edge
  - Bi-directional interaction with the environment, intelligent data collection and processing, federated learning, etc.
- Edge to cloud continuum
  - Hardware/capability continuum, configuration continuum, connectivity continuum, power continuum, processing continuum, etc.
  - Operations continuum – not just for specialists anymore
- CHI@Edge captures a general-purpose continuumRI instrument pattern
  - Some things are the same: e.g., management of heterogenous components at scale, interactions with datacenter
  - Some things are different: e.g., installation considerations like casing, deployment strategies

FOR BETTER OR WORSE, SCIENTIFIC INSTRUMENTS SHAPE A FIELD

research highlights

DOI:10.1145/2209249.2209271

Technical Perspective

For Better or Worse, Benchmarks Shape a Field

By David Patterson

LIKE OTHER IT fields, computer architects initially reported incomparable results. We quickly saw the folly of this approach. We then went through a sequence of performance metrics, a victim of its own success. The SPEC organization has been selecting old programs written in old languages that reflect the state of programming in the 1980s. Given the 1,000,000X improve-

Given this measurement framework, the authors then measured eight very different Intel microprocessors built over a seven-year period. The authors evaluate these eight micropro-

- The **ability** to deploy, observe, measure and record
- "**Common denominator**": the ability to create and compare
- **Evolution**: follow the debate

We're here to change

www.chameleoncloud.org