xGFabric: Coupling Sensor Networks and High-performance Computing Facilities with Advanced Wireless Networks for Near Real-Time Simulation of Digital Agriculture

Rich Wolski

UCSB Computer Science and
Institute for Energy Efficiency
September 9, 2025

IoT is a Contact Sport

PPPL — Princeton Plasma Physics Laboratory

Computer Science — UC Santa Barbara

University of Nebraska–Lincoln

Brookhaven National Laboratory

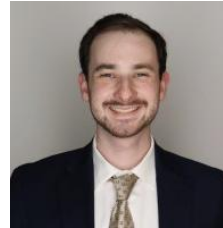the INSTITUTE for Energy Efficiency — UC Santa Barbara

University of Notre Dame

UC LREC

Liubov Kurafeeva
Graduate Research Assistant
UCSB

Alan Subedi
Graduate Research Assistant
UNL

Ryan Hartung
Graduate Research Assistant
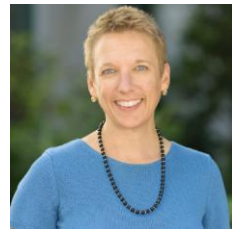ND

Michael Fay
Graduate Research Assistant
UNL

Avhishek Biswas
Graduate Research Assistant
UNL

Shantenu Jha,
PPPL/Princeton/Rutgers
Chief Instigator, xGFabric

Ozgur Kilic
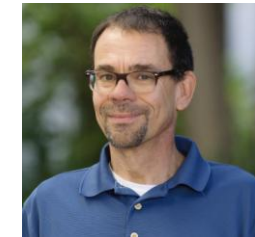Research Scientist
BNL

Chandra Krintz
Professor
UCSB

Andre Merzky
RADICAL-Group
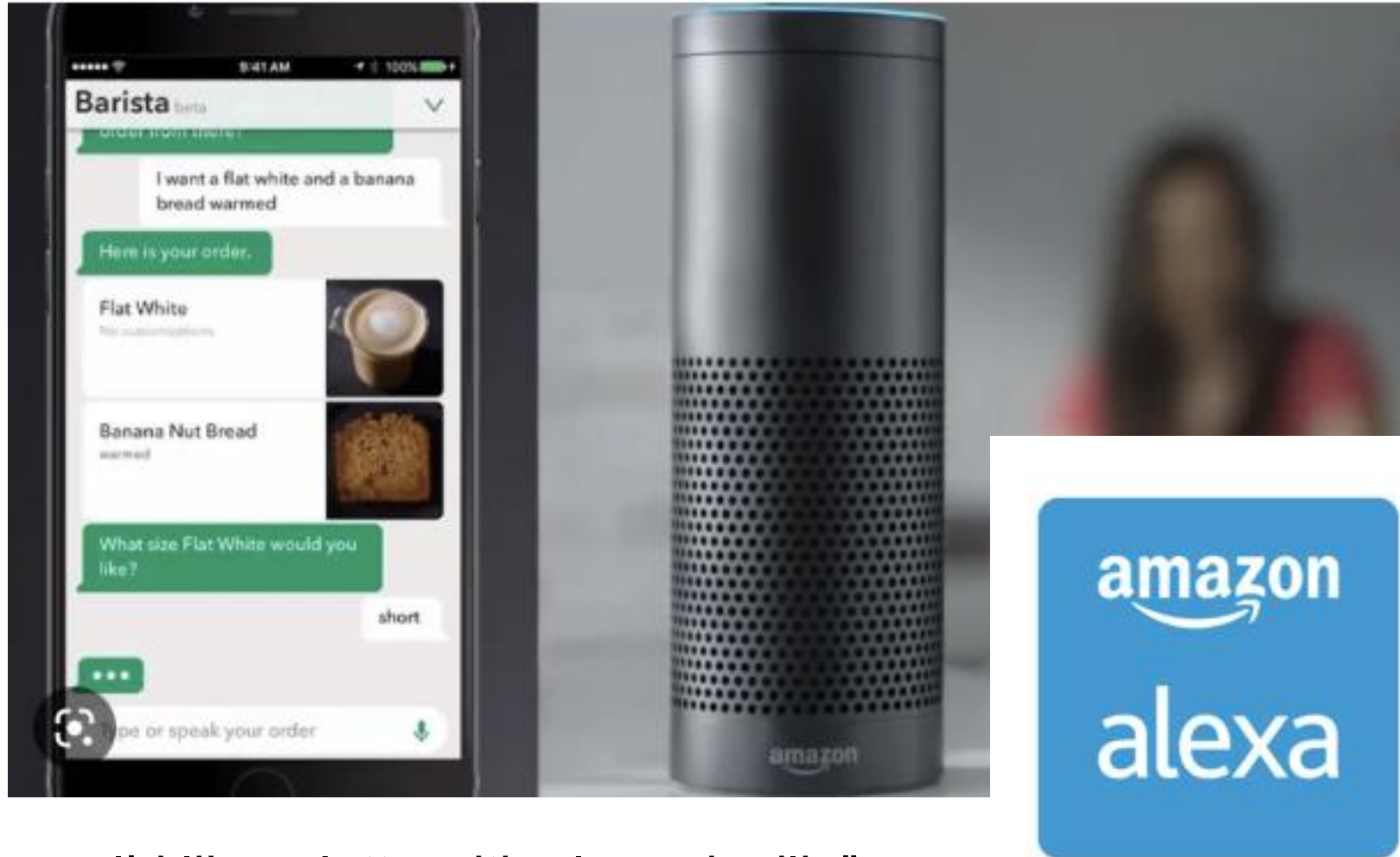Rutgers

Douglas Thain
Professor
ND

M. Can Vuran
Dale M. Jensen Chair
UNL

Rich Wolski
Duval Chair Energy Efficiency
UCSB

UCSB

IoT: How do we get from this?


- "Alexa, I'd like a latte with almond milk."

To this?

- "Alexa, what aquafer is keeping these plants alive, how deep is it at this moment, and can I use it to grow crops?"

UCSB

xGFabric: Converging IoT and HPC using 5G/6G

- End-to-end software platform for coupling IoT sensing to HPC and vice versa
- Leverages 5G/6G software controllable networking at the edge
- *How do we put modeling and intelligence "in the loop?"*
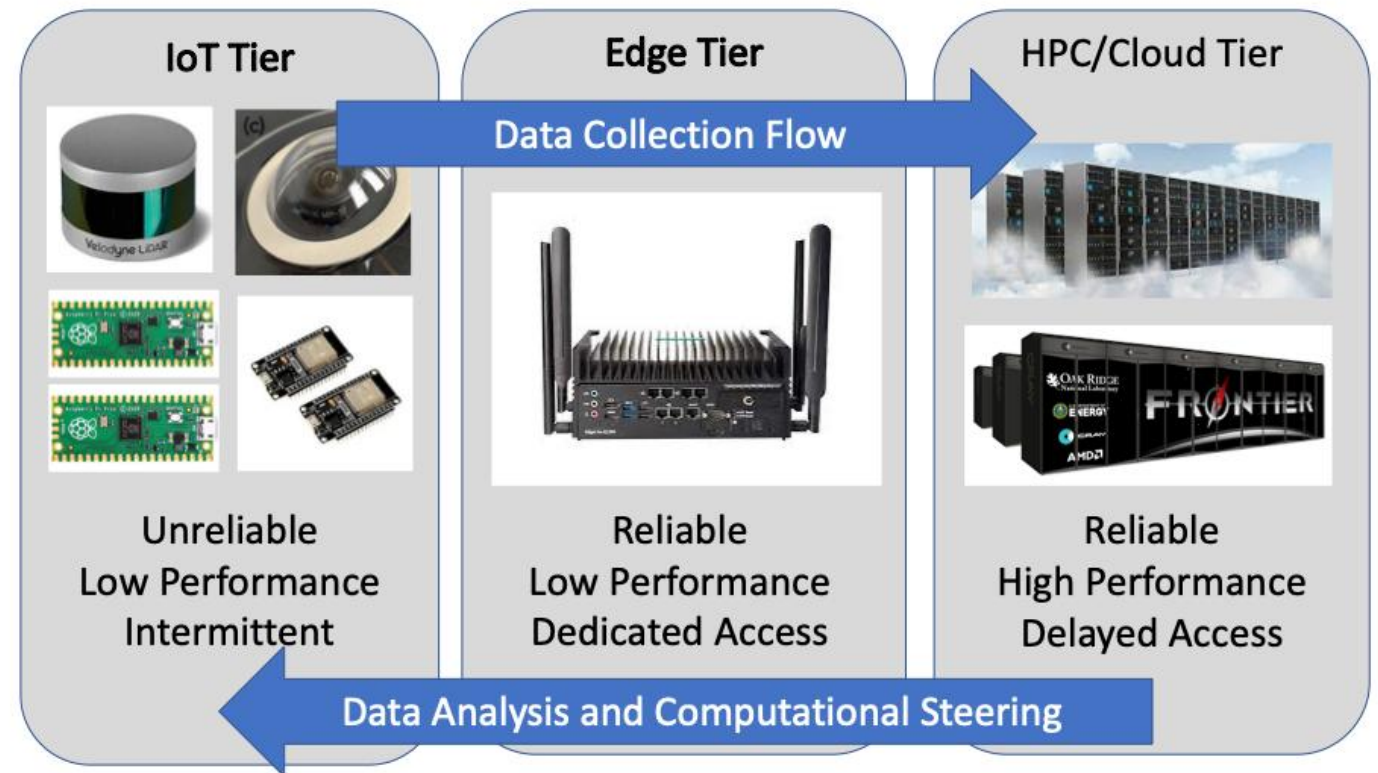
Research Challenges

- Distributed multi-scale end-to-end system of computing, storage, networking, and power infrastructure

- New computer science
  - Energy efficiency
  - Longevity (extended life cycle)
  - Resilience
  - Security
  - Cost
  - Programmer Productivity
  - Dynamic adaptivity

- New multi-disciplinary research in
  - **Agriculture**
  - Ecology
  - Climate resilience
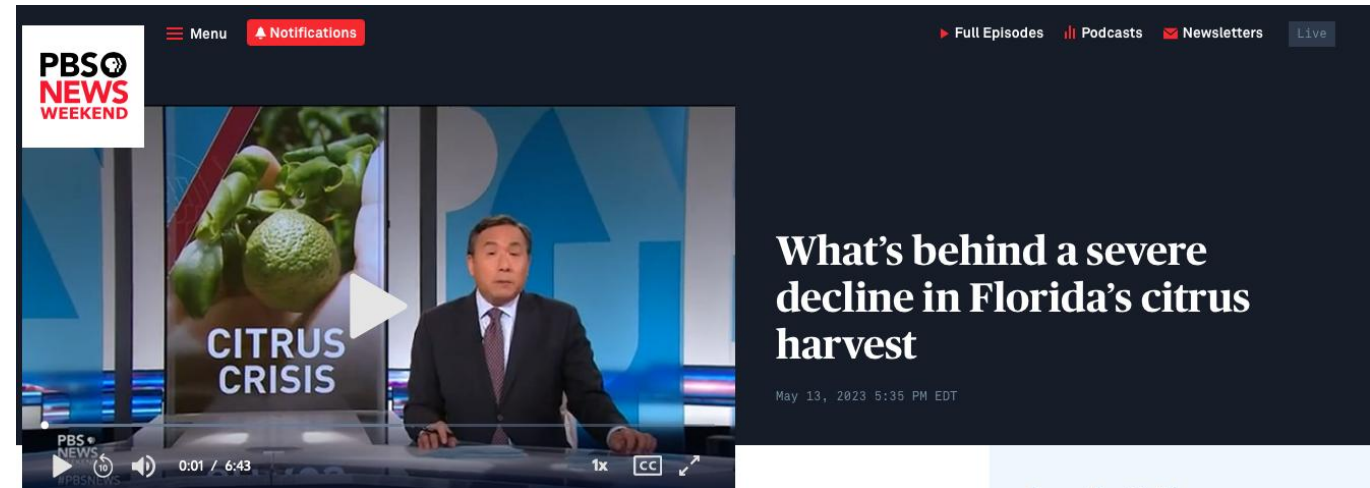
UCSB

Example:
Pest Remediation

USDA Animal and Plant Health Inspection Service
U.S. DEPARTMENT OF AGRICULTURE

Asian Citrus Psyllid
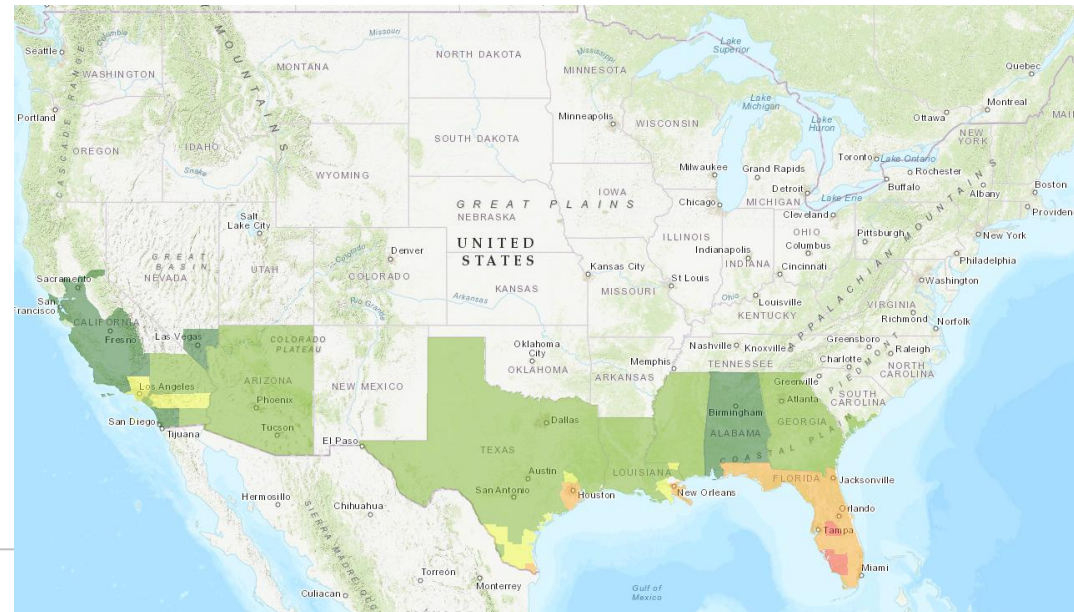
The Asian citrus psyllid threatens America's citrus. Don't risk citrus, don't move citrus.

The **Asian Citrus Psyllid (Diaphorina citri Kuwayama or ACP)** causes serious damage to citrus plants and citrus plant relatives. Burned tips and twisted leaves result from an infestation on new growth. Psyllids are also carriers of the bacterium that causes Huanglongbing (HLB) disease, also known as citrus greening disease, spreading the disease to healthy citrus plants. Citrus greening is one of the most serious citrus plant diseases in the world. Once a tree is infected, there is no cure.

What's behind a severe decline in Florida's citrus harvest

May 13, 2023 5:35 PM EDT

https://www.pbs.org/newshour/show/whats-behind-a-severe-decline-in-floridas-citrus-harvest

UCSB

Citrus Under Protective Screens (CUPS), Lindcove Research Extension Center Exeter, CA

100m x 200m

Can CUPS Prevent Citrus Greening at Commercial Scale?

- Citrus trees have a lifespan of between 25 and 30 years

- 40 micron mesh must remain in tact

- What are the growing conditions?
    - Humidity?
    - UV?
    - Eto?
    - Other pests?
    - Soil moisture?

- What husbandry practices?
    - Frost prevention?
    - Fertilizers?
    - Pesticides?

UCSB

CUPS Sensing Infrastructure

- Sensing

△ CUPS-out (Davis 5ft, 30ft)

▲ CUPS-in (Davis, 5ft, 15ft)

▲ CUPS-inside-middle (Acurite, ibuttons, young trees 6x6)

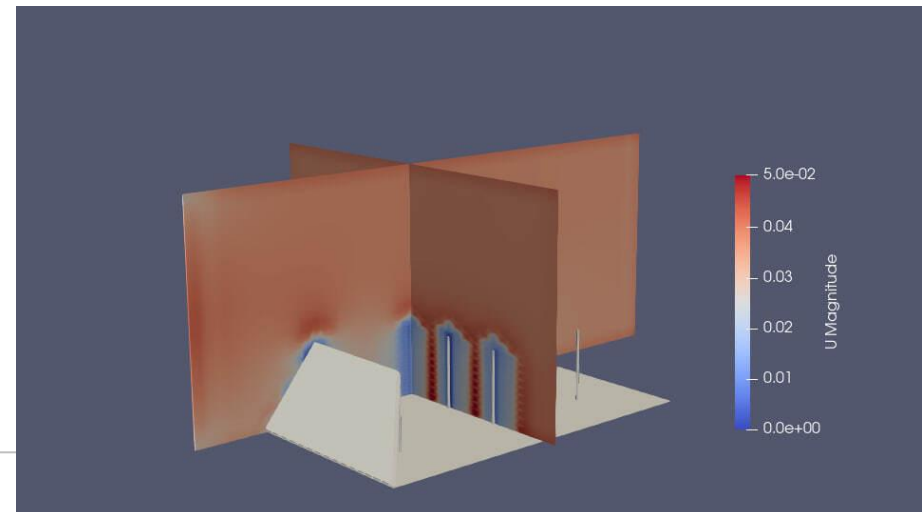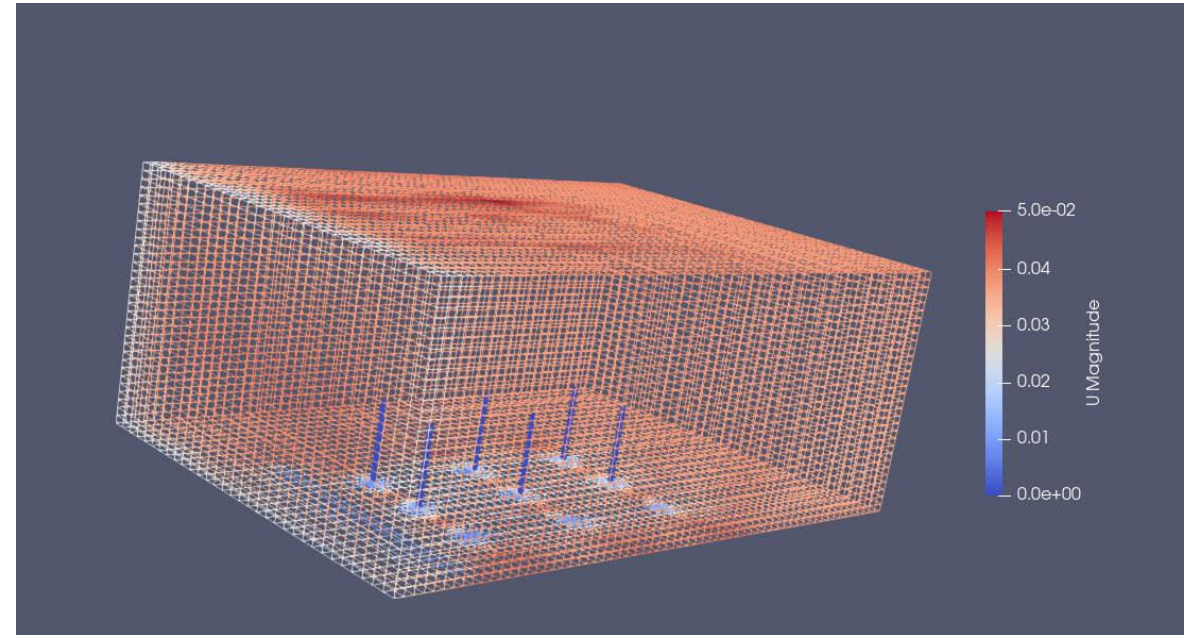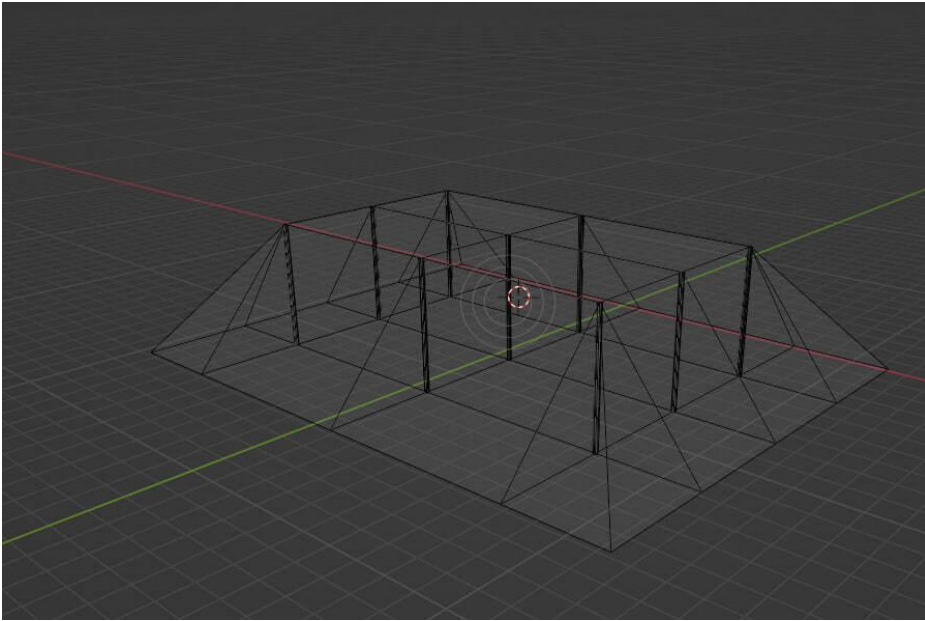▲ CUPS-inside-south (Acurite, ibuttons, young trees 6x6)

△ CUPS-outside-south (Acurite)

▲ CUPS-inside-north (ibuttons, young trees 6x6)
Not on WooFPlot (ibuttons only)

UCSB SmartFarm

UCSB

Physical Models

Modeling "in the Loop"
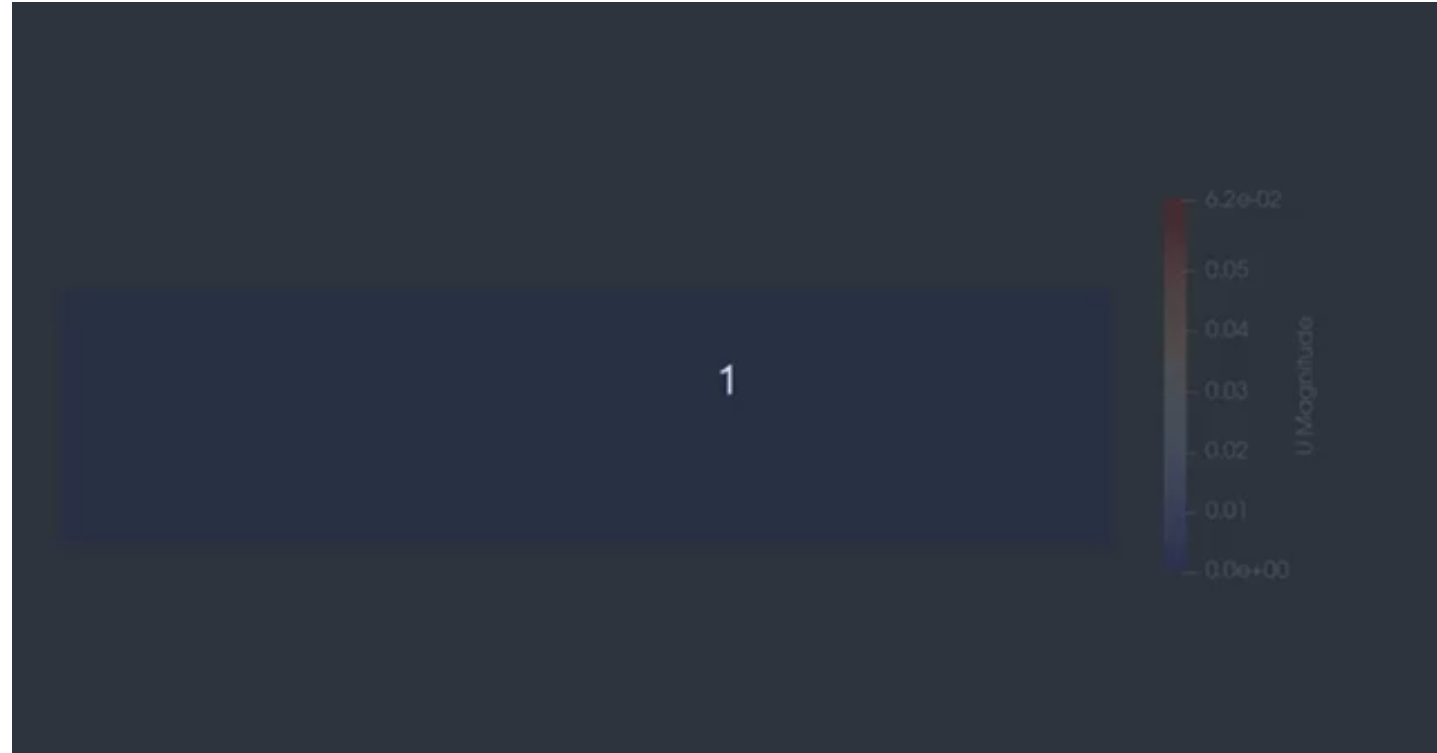
Sensing

xGFabric CUPS Application Driver

- Leverage existing CUPS sensing infrastructure at LREC

- Stream CUPS telemetry through 5G private cell at UNL

- Create telemetry data repository at UCSB

- Monitor telemetry stream for change-points (UNL+UCSB)

- Run OpenFOAM Computational Fluid Dynamics simulations at ND when the system detects a statistical change in the telemetry
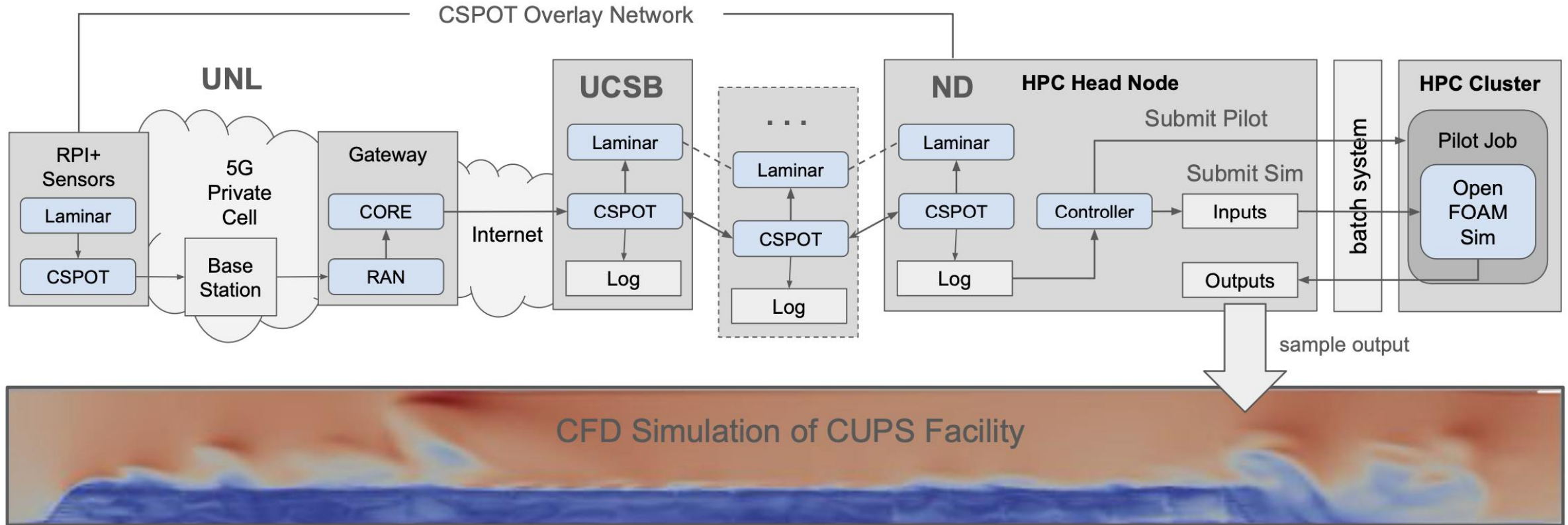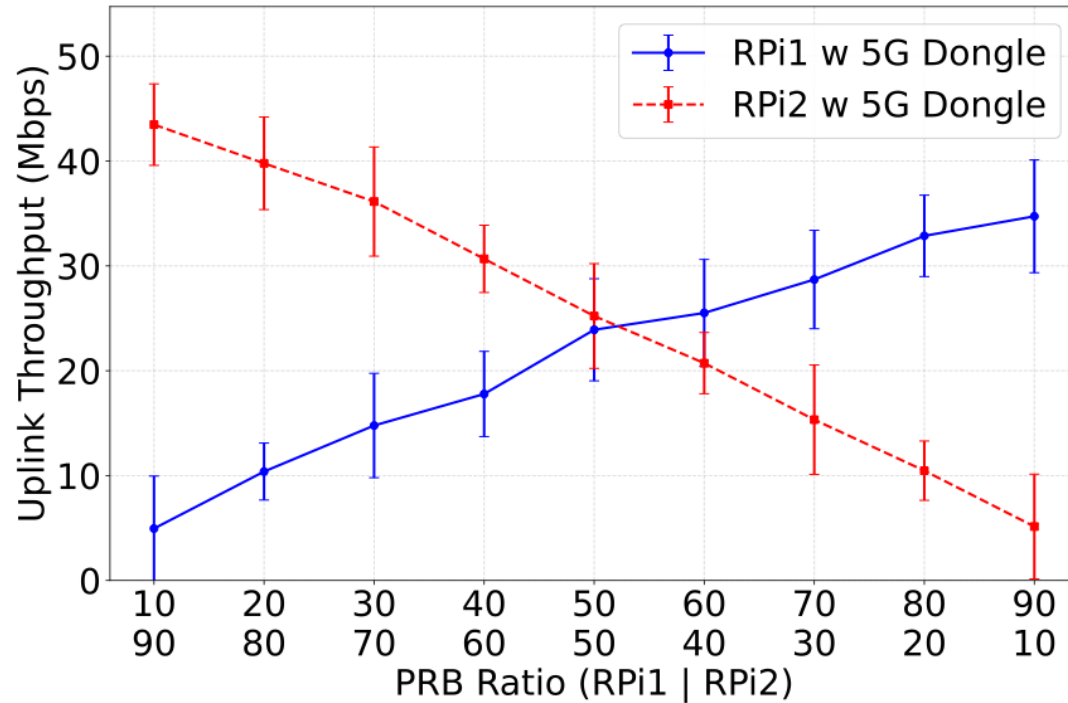
UCSB

New Full-stack Approach

- CSPOT: Universal, event-driven runtime
  - Log-based distributed microservices
  - Network transparent and agnostic

- Laminar: distributed dataflow programming for CSPOT

- Capability-based per-message authorization

- Ultra-lightweight for power efficiency
  - 2 to 4 orders of magnitude more efficient than Linux or cloud

- Integrated control of 5G/6G slicing APIs for SLA-based communication guarantees (*coming soon*)

- HPC Pilot-controlled provisioning and workflow scheduling

- *Single end-to-end platform: It is easier to scale the stack "up" to cloud/HPC than it is to miniaturize these technologies "down."*

xGFabric CUPS Deployment Architecture

CFD Simulation of CUPS Facility

Sensor Slicing using 5G Private Cell

Path	Latency Avg. (ms)	Latency SD (ms)
UNL->UCSB (5G+Int.)	101	17
UNL->UCSB (Internet)	17	0.8
UCSB->ND (Internet)	92	1

- End-to-end latency includes data persistence and delay-tolerance
- Most of UNL->UCSB is in 5G cell

- Physical Resource Block (PBR) is unit of allocation
- Linear trajectories and stable variance

OpenFOAM (CFD) Speedups

Mean Total Time vs Number of Cores
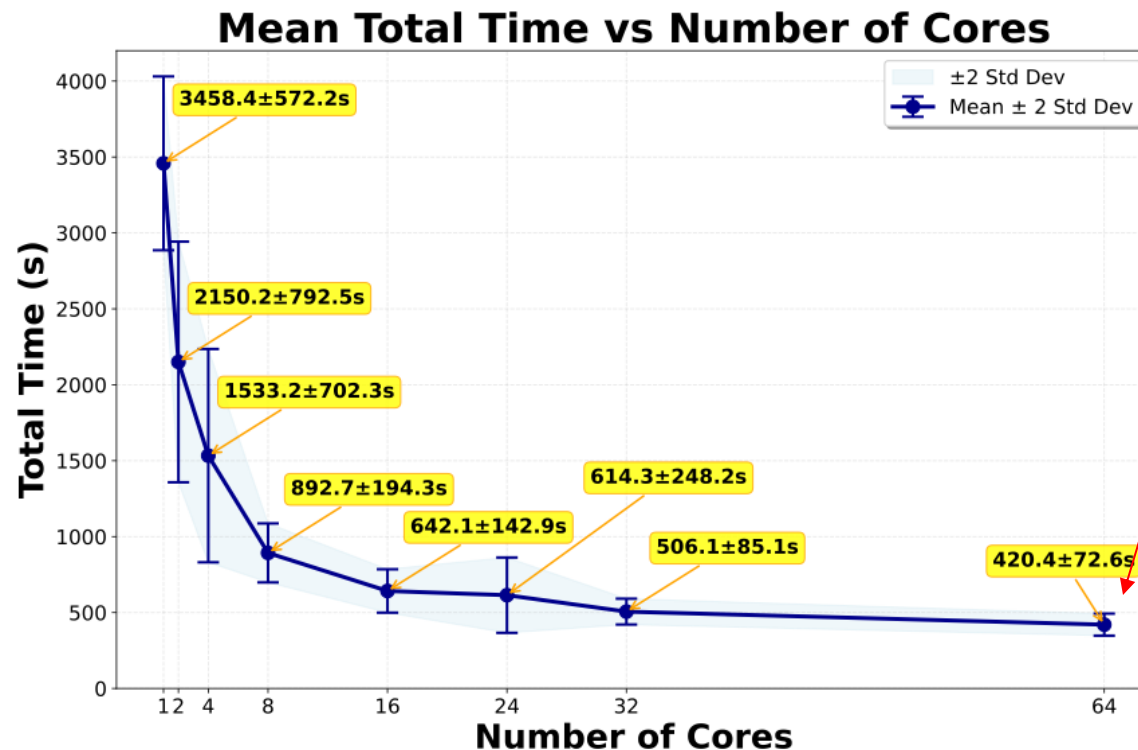
- 6.5M grid cells for 100,000 cubic meter CUPS structure

- Seven minutes on dedicated 64-core processor

- Batch queue wait times at ND range from immediate to 24-hours

- We need to do better with the computation component

Lessons from the "Trenches"

- Long-term biosurvellance and management requires new, end-to-end converged infrastructure
  - Must couple
    - Sensing
    - Modeling
    - Inference/Prediction (AI/ML)
    - Actuation
  - Must adapt and learn in response to changing conditions and technologies

- The small scale is as hard as the large scale
  - Making the large-scale work at the small scale is often harder than the other way around

- For agriculture,
  - Time constants are shortening
  - Length-scales are reducing
  - 5G/6G is making connectivity ubiquitous
  - Infrastructure needs to "close the loop"
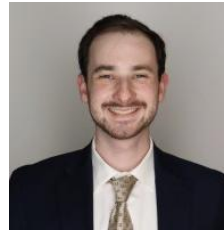
UCSB

Thanks!

Liubov Kurafeeva
Graduate Research Assistant
UCSB

Alan Subedi
Graduate Research Assistant
UNL

Ryan Hartung
Graduate Research Assistant
ND

Michael Fay
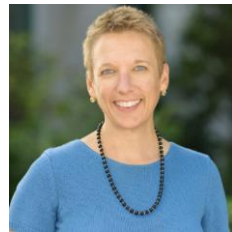Graduate Research Assistant
UNL

Avhishek Biswas
Graduate Research Assistant
UNL

Shantenu Jha,
PPPL/Princeton/Rutgers
Chief Instigator, xGFabric

Ozgur Kilic
Research Scientist
BNL

Chandra Krintz
Professor
UCSB

Andre Merzky
RADICAL-Group
Rutgers

Douglas Thain
Professor
ND

M. Can Vuran
Dale M. Jensen Chair
UNL

Rich Wolski
Duval Chair Energy Efficiency
UCSB

Project Website: https://sites.google.com/view/xgfabric
xGFabric (The Movie): https://sites.cs.ucsb.edu/~rich/talks/xGFabric-2025.mp4
Paper (to appear in XLOOP25): https://sites.cs.ucsb.edu/~rich/publications/xGFabric-xloop-2025.pdf