ICICLE: Intelligent Cyberinfrastructure for Next-Generation AI Applications using Computing Continuum

Talk at Multicore World Conference (Feb '26)

by

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https://twitter.com/mvapich

Brief Self-Introduction

- Working in the HPC (high-performance networking and middleware) for the last 33+ years

- Have been leading the MVAPICH MPI library project (http://mvapich.cse.ohio-state.edu) since 2001
  - Originally started with InfiniBand, supports all HPC interconnects now
  - Includes OSU MPI Micro-Benchmark suite (OMB)
  - **Registered users spanning over 3,500 organizations in 93 countries**
  - **More than 2.0 million downloads from the project site**
  - **Also part of Spack, OpenHPC, Redhat, SUSE, and vendor stacks**
  - **Enabling many TOP500 clusters during the last 25 years**

- Designing and developing *converged software stack for scale-up and scale-out in a vendor agnostic manner* for DL, ML, and Big Data
  - MPI-driven distributed training and inference (http://hidl.cse.ohio-state.edu)
    - **Delivers better performance than NVIDIA/NCCL and AMD/RCCL**
  - MPI-driven Spark and Dask support (http://hibs.cse.ohio-state.edu)

- **Director of the NSF-AI Institute ICICLE (http://icicle.ai)**

- **Focusing on designing intelligent cyberinfrastructure for computing continuum to democratize AI**
  - **Three use-inspired science cases (Digital Agriculture, Animal Ecology and Smart Food Security)**
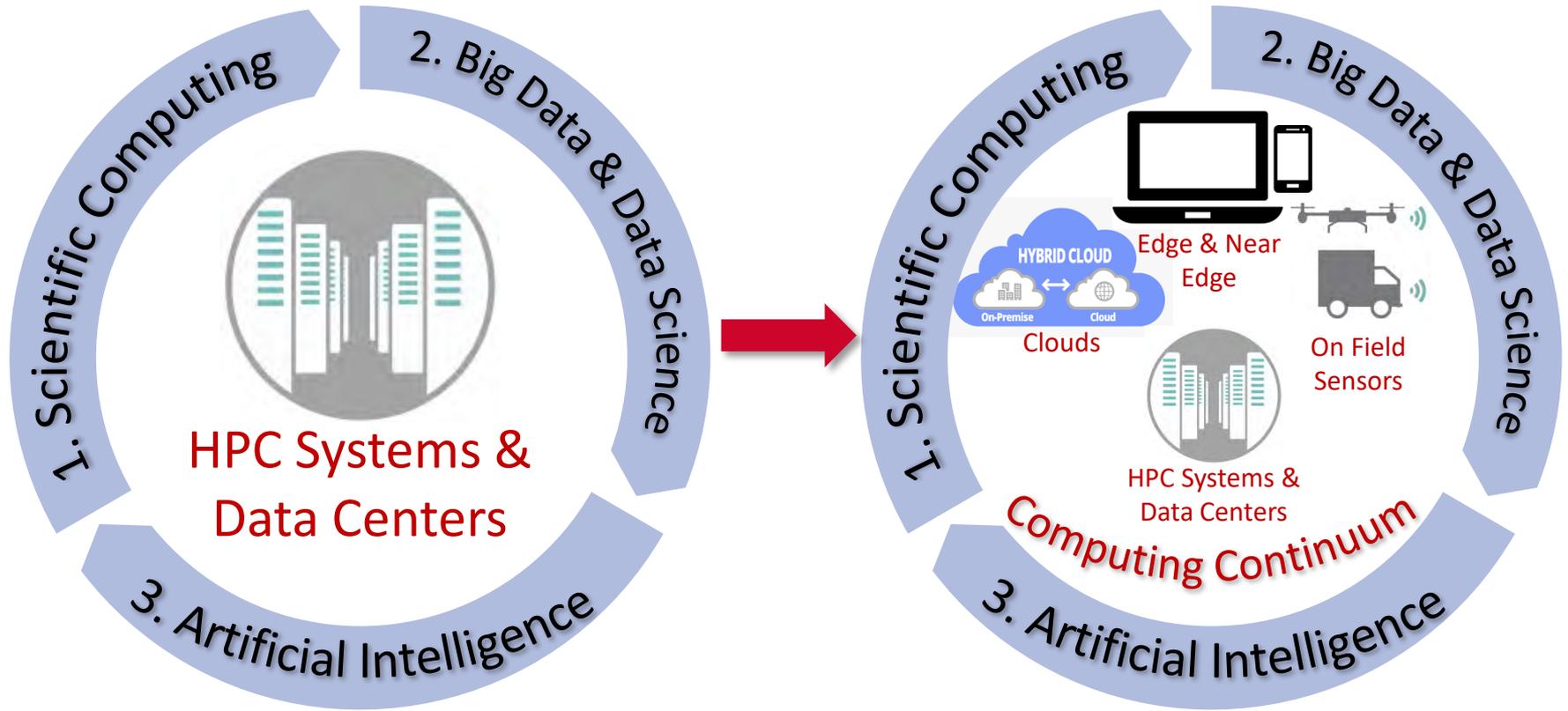
Credits to all ICICLE Team Members!!

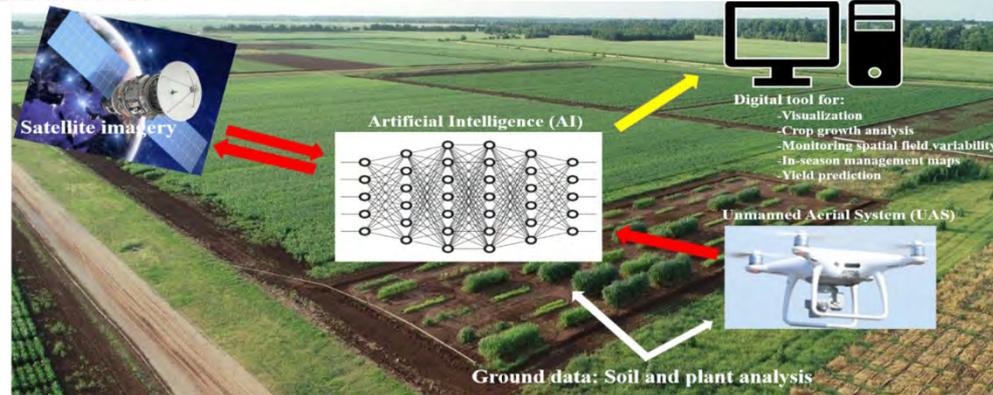**ICICLE Members Attending All-Hands-Meeting In-Person (Jan 2025)**

Computing has been evolving over the last three decades with multiple **phases:**

- **Phase 1 (1975-):** Scientific Computing/HPC

- **Phase 2 (2000-):** HPC + Big Data Analytics

- **Phase 3: (2010-):** HPC + AI (Machine Learning/Deep Learning)

Emergence of the Computing Continuum

AI-Driven Digital Agriculture

Data Movement and Control in Computing Continuum

Emerging Computing Continuum

On Field Sensors

Edge & Near Edge

Clouds

HYBRID CLOUD
On-Premise ↔ Cloud
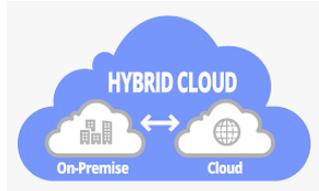
HPC Systems & Data Centers

Data Movement and Control

How to Create Intelligent Cyberinfrastructure for Computing Continuum in the Modern AI Era
&
Democratizing AI?

Computer Science Challenges from Use-Inspired AI Workflows

| Efficient data collection and cleaning | High-performance and scalable schemes for model training | Running inference in edge-to-center/ cloud computing continuum | Plug-and-play models/ data commons | End-to-end AI/ML workflows with configurable components | Intelligent resource scheduling | Efficient conv AI support and scientific agents | Efficient privacy preserving techniques | Flexible unified reference architecture |

enables

New workflows in:

Mobility

Materials and Manufacturing

Biotechnology

AI Systems and Testbeds

How to Create Intelligent Cyberinfrastructure for Computing Continuum in the Modern AI Era & Democratizing AI?

http://icicle.ai

One of the 29 NSF-AI Institutes
(each one $20M USD over 5 years)

ICICLE is the only one focusing on
Intelligent Cyberinfrastructure

Objectives: Intelligent CyberInfrastructure for Computing Continuum

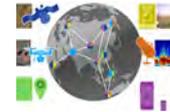Use Inspired Science Domains

Digital
Agriculture

Smart
Foodsheds

Animal
Ecology

ICICLE: Intelligent CyberInfrastructure with Computational Learning in the Environment

Systems AI Foundational Research for CI

Intelligent Cyber Infrastructure

CI for AI	AI for "CI for AI"

On Field
Sensors

Edge & Near Edge
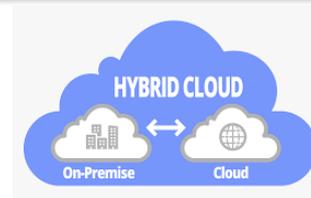
Clouds

HPC Systems & Data
Centers

Emerging Computing Continuum

Participation (Current):
16 Organizations, 23 faculty, 29 staff, (36 PhD, 15 MS, 25 undergrad, 9 K-12) students & many Collaborators

Govt. Agencies & National Labs

Research Institutes

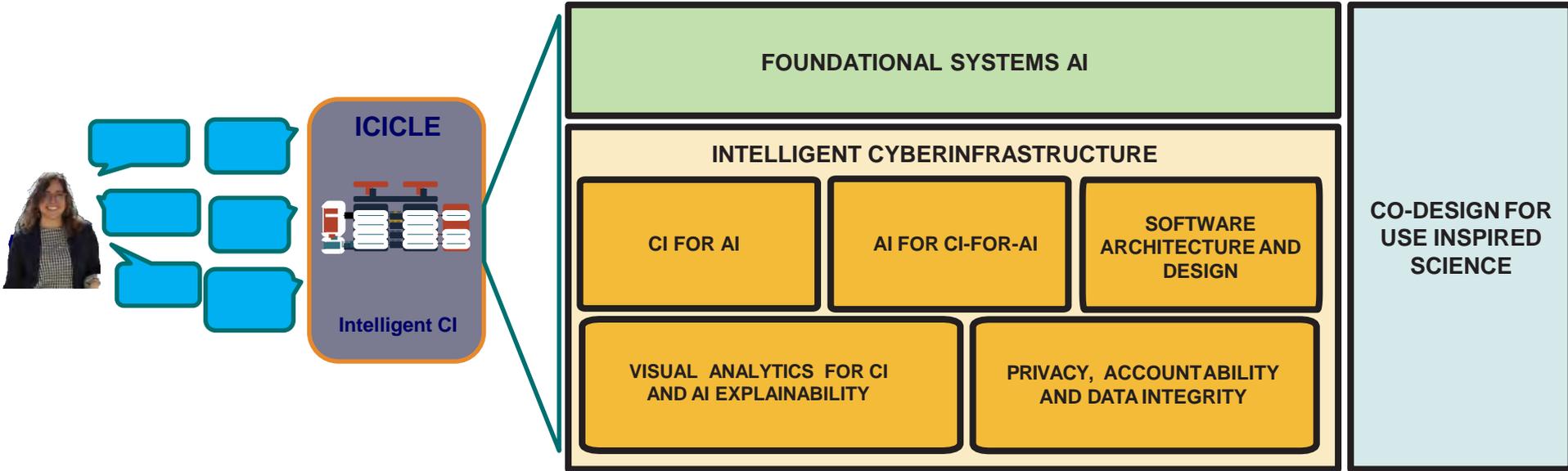**International**

Industry

NSF & USDA Funded AI Institutes

Hospitals & Universities

Research Plan: Overall Vision

Research Challenges

Thrust: Foundational Systems AI

Components address CI complexity and heterogeneity for plug-and-play

Knowledge Graphs
- Multimodal KG to encode & reason rich data modalities (e.g., camera trap)
- Auto construction
- Interplay with LLM and knowledge-based QA

Model Commons
- MINT to support ICICLE use cases, KG, and models
- Precise profiling
- Flex composition
- Versioning and provenance

Adaptive AI
- Context-aware
- Efficient update
- User-friendly adaptation process
- Adaptation of foundation models, conversational AI

Federated Learning
- Heterogeneity
- Context-aware
- Privacy-preserving and robustness
- Going beyond classification (GNN, foundation models)

Conversational AI
- KG- and model-commons-aware
- LLM-powered
- Grounding LLMs to the context
- Hallucination reduction
- Complex reasoning

Thrust: CI4AI

Provides necessary CI to deploy AI throughout computing continuum and make it plug-and-play!

High Perf. Training
- High-performance communication libraries
- Gradient sparsification
- Exploiting data-, model-, pipeline-, and hybrid-parallel paradigms

High Perf. Data Management
- Unified storage of data, model and hyperparameters
- Data location transparency with migration
- Leveraging new hardware

Edge Intelligence
- Performance characterization of edge
- Optimize ML/DL inference on edge devices
- Profiling edge devices to improve quality of service

AI-Adaptive Edge Wireless
- High-throughput, reliable communications
- Predictable Wireless Comm. via Rateless-Coding & Multi-Modal/Path
- AI-adaptive edge wireless prototypes.

Control and Coordination
- Functional/Performance Interface Design
- Intelligent Resource Management with Tapis
- Hardening and Optimizing for Production-ready Service

Thrust: AI4CI

Enhances CI with AI for adaptive and field-optimized machine learning!

KGs & Model Commons for CI
- Investigate and survey existing datasets for CI optimization
- Create new CI components to serve CI data and models for other ICICLE CI and AI4CI components
- Edge-specific CI dataset distributed as KGs

Intelligent Modeling and Optimization
- Collection of baseline performance
- Exploration of analytical metrics
- Use and refinement of hybrid models in a design-space explorer for code optimization

Applications
- Application Selection and Performance Profiling
- Building Performance Models
- Designing Features for Applications, Frameworks, and Hardware

Middleware
- Develop a set of intelligent linear algebra kernels for sparse-matrix operations
- Leverage data sparsity in all computational kernels.
- Cross-layer Optimizations

Systems
- Resource allocation optimizer for ML training
- Develop an optimizing middleware for ML inference placement based on our use cases.
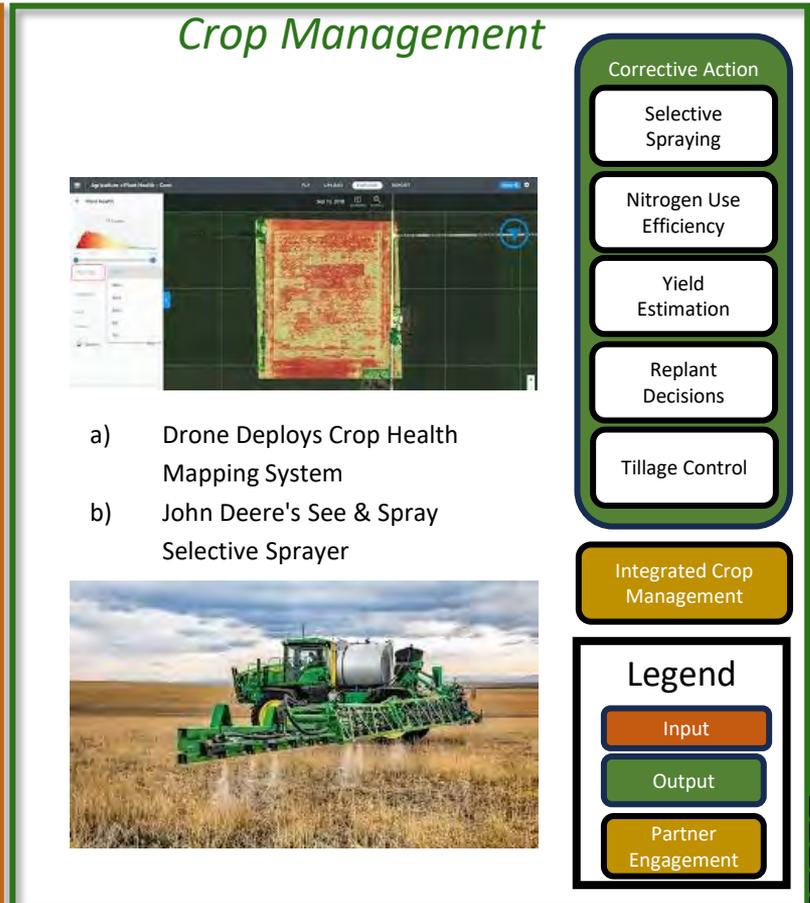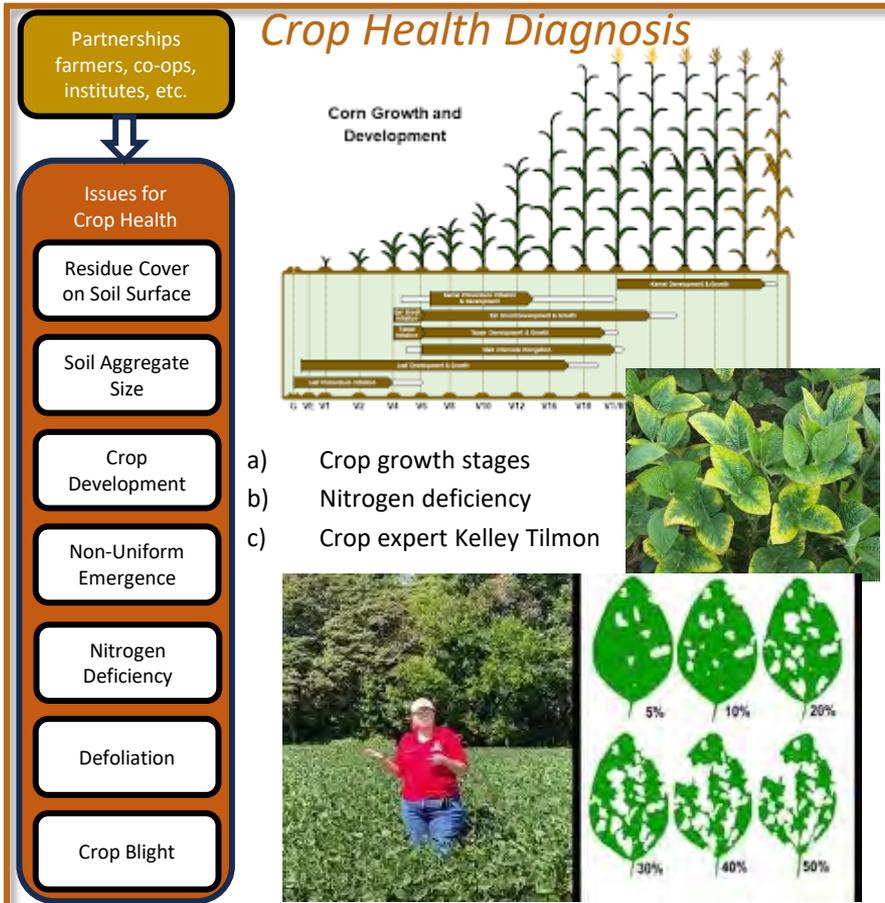- Intelligent Wireless Communications

Thrust: Privacy, Accountability and Data Integrity (PADI)

- PADI contributes to
  - ICICLE vision as *transparent and trustworthy* infrastructure for AI-enabled future
  - An ethically aligned infrastructure and workforce through an *AI ethics framework*
- PADI advances both technical and non-technical innovations and best practices that collectively contribute to a trusted environment
  - e.g., where stakeholders (farmers, industry partners, etc.) are comfortable contributing data and AI models for ICICLE AI research (and more broadly for AI research).
- PADI addresses both research questions and issues of practice (project norms and practice)

Some Highlights

- **Digital Agriculture**

- Animal Ecology

- Food transportation and security

- CI and AI

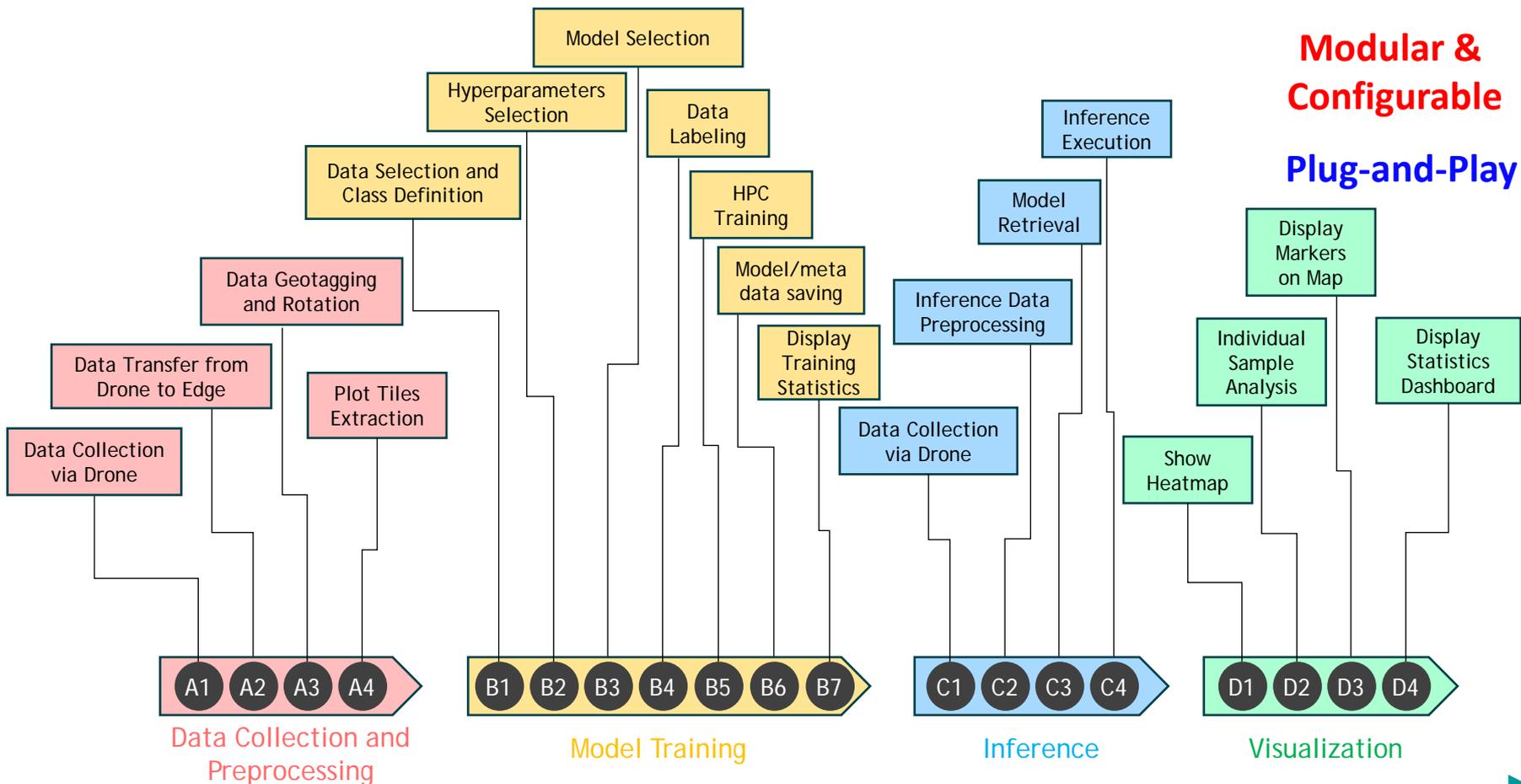- Software Release and Training Catalog

- Current Collaboration

Smart CI for Democratized Digital Agriculture

Crop Health Diagnosis

Partnerships farmers, co-ops, institutes, etc.

Issues for Crop Health

- Residue Cover on Soil Surface
- Soil Aggregate Size
- Crop Development
- Non-Uniform Emergence
- Nitrogen Deficiency
- Defoliation
- Crop Blight

Corn Growth and Development

a) Crop growth stages
b) Nitrogen deficiency
c) Crop expert Kelley Tilmon

5% 10% 20%
30% 40% 50%

Crop Management

a) Drone Deploys Crop Health Mapping System
b) John Deere's See & Spray Selective Sprayer

Corrective Action

- Selective Spraying
- Nitrogen Use Efficiency
- Yield Estimation
- Replant Decisions
- Tillage Control

Integrated Crop Management

Legend

- Input
- Output
- Partner Engagement

FndAI
CI4AI
AI4CI4AI
SoftArch
VA
PADI

ICICLE == DEMOCRATIZATION

Overview of ICICLE Workflow for Digital Agriculture

Modular & Configurable

Plug-and-Play

1 On Field Data Collection and Transfer

Ground-based

Aerial

Wired

Wireless

Authentication and Security

2 Model Training and Fine Tuning

At Edge For Light Weight Tasks

On HPC and Cloud for Complex Tasks

HPC

Data Repository

Model Repository

3 Postprocessing

Model Distillation

Intelligence Payload (Compressed Model)

JSON

Inference Postprocessing

Targeted Application Prescription (Shapefile)

4 Downstream Use Cases

Smart/Precise On-Farm Application and Seeding

Click here to watch the Demo

ARA-to-ICICLE: Remote Data Sourcing for Agricultural AI Processing

Sarath Babu[†], Vincent Lee[†], Yatish S. M. [§], Joscif Raigne[†],
Matt Lieber [§], Martin Kandes[‡], Hongwei Zhang[†], and Hari Subramoni [§]

[†]Iowa State University, USA
[§]The Ohio State University, USA
[‡]San Diego Supercomputer Center, USA

Some Highlights

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- Software Release and Training Catalog

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Biodiversity

Open Questions in Biodiversity

1. What are the rates of diversity change and species extinction now and how is human-induced climate change impacting biodiversity?
2. How many species cohabitate with Pere David Deer?
3. Where do rare, endangered species like Himalayan wolves live? Where will they live in 5 years?
4. What abiotic conditions have first-order affects at each crop growth state?

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Revealing uncertainty in the status of biodiversity change

T. F. Johnson ✉, A. P. Beckerman, D. Z. Childs, T. J. Webb, K. L. Evans, C. A. Griffiths, P. Capdevila, C. F. Clements, M. Besson, R. D. Gregory, G. H. Thomas, E. Delmas & R. P. Freckleton

Nature **628**, 788–794 (2024) | Cite this article

https://www.nature.com/articles/s41586-024-07236-z

Smart Fields: An Ambitious Demonstration

CI for temporal & geospatial heatmaps

Kenyan Animal Behavior Dataset (KABR) *WACV 2024*

CI for camera traps, drones, and in-field device management

Stakeholders In Biodiversity

Stakeholders with a variety of skills and objectives

ICICLE Use-Inspired Infrastructure for Animal Ecology

ICICLE Ref. Arch.

| Data Collection and Capacity Planning | → | Model Training | → | Field Deployment And Adaptation | → | Post-Study Data Analysis |
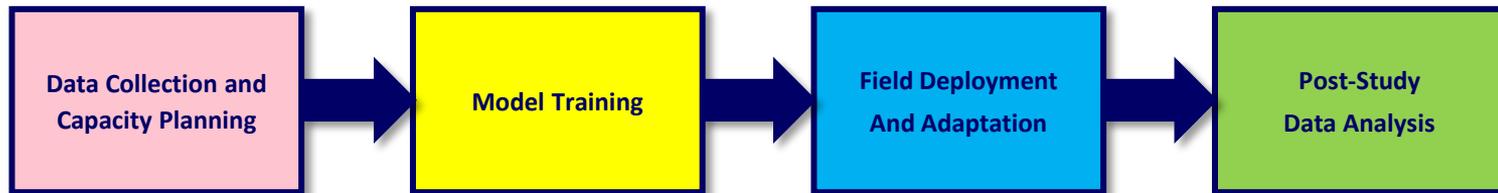
ICICLE Smart Fields seeks to orchestrate a complete end-to-end workflow that demonstrates ICICLE reference architecture and CI on real, ongoing animal-ecology studies.

- **Novel** and **adaptive pipeline that** leverages **hypothesis-driven capacity planning, adaptive data collection, and conversational AI support.**

Some Highlights

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AI/CI Powered Food Systems

Goal: Utilize AI and CI resources to increase national and regional food security.

- **Food supply chain modeling**
- **Food equity and access simulation**
- **Food logistics**
- **Data privacy protections**

Demo: GNN Food Flow Portal

Portal Demo Video: https://youtu.be/AZrqhO3LIQY?si=-ECxEzoQnFnNRaAv

Demo: Food Equity Access Simulation Technology (FEAST)

Some Highlights

- Digital Agriculture

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- **CI and AI**

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CI and AI Highlights

- **Unified Reference Architecture**

- Model and Data Commons

Human Ready

AI Ready

Ease of Use

Ease of Reuse
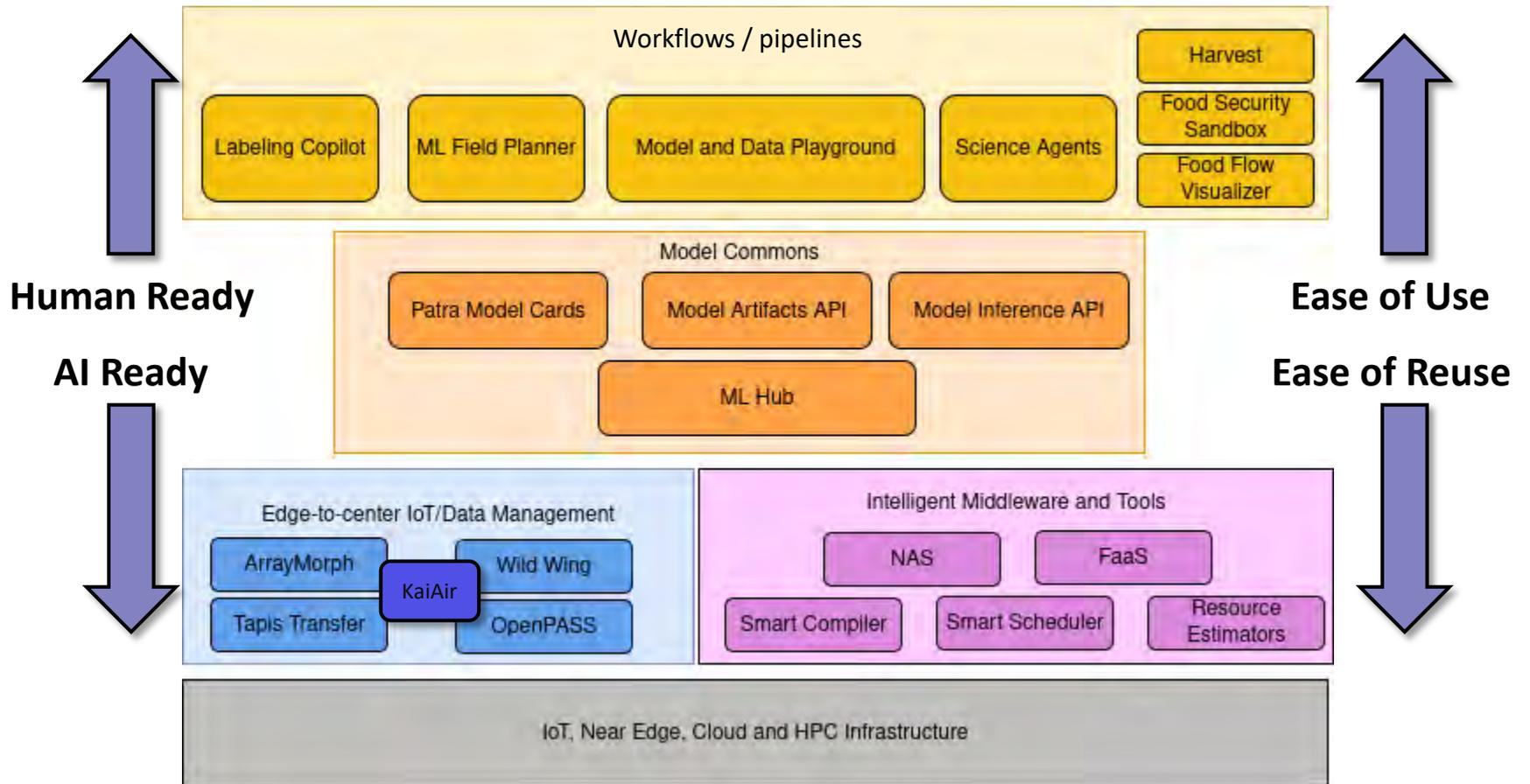
CI and AI Highlights

- Unified Reference Architecture

- **Model and Data Commons**

  - **Trustworthy AI**

Provisioning Model & Data Commons

- Modular, plug-and-play ecosystem of FAIR-compliant datasets and AI models
- Enable transparent reuse, reproducibility, and interoperability across heterogeneous platforms
- Accelerate scientific discovery while lowering barriers to scalable, domain-driven AI adoption
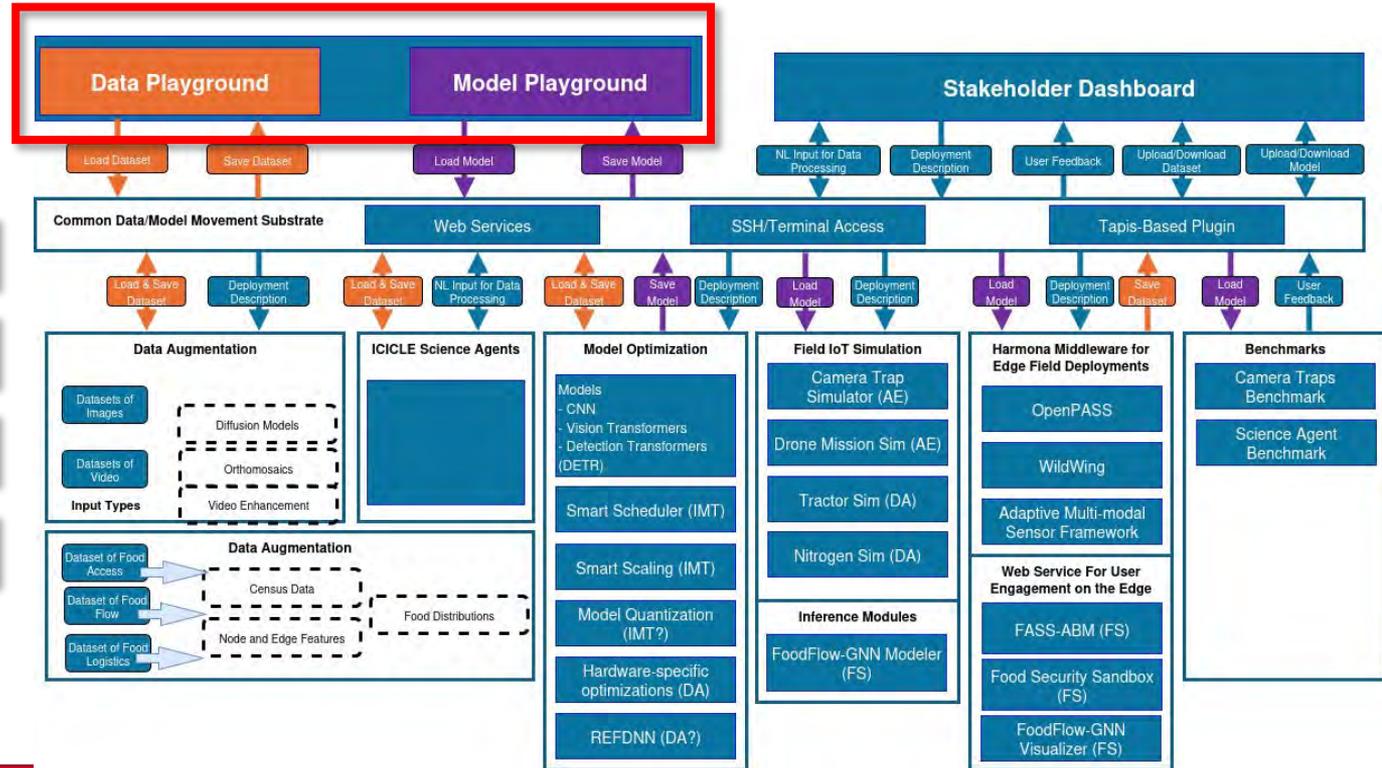
Sub-Projects

Model & Data Playground

Neural Architecture Search

Forte: Out of Distribution

LABELING COPILOT Agent

Click here to learn more about Forte and Labeling CoPilot

Some Highlights

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CI/SOFTWARE Components Released

Metrics

- Total # of Clones & Views: **6,500 +**

- **6** PyPI Packages

- **1,700** Container Downloads

- **1300k** total authentications to
    ICICLE Tapis tenant since 08/2024

- **77** unique ICICLE Tapis users

Component Thrust

- core/Software
- core/CI4AI
- core/AI4CI
- core/FoundationAI
- core/PADI
- core/VA
- useInspired/DA
- useInspired/AE
- useInspired/SF

114 components released till date

https://componentcatalog.pods.icicleai.tapis.io/index.html

https://icicle-ai.github.io/training-catalog/

Some Highlights

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- **Current Collaboration**

Users (Registered) using Released CI Components

- **60 Organizations from 9 countries**

- **National/International Labs and Research Centers**
  - American Institutes for Research
  - Argonne National Laboratory
  - Idaho National Laboratory
  - Molecular Maker Lab Institute (MMLI)@UIUC
  - Nationwide Children's Hospital
  - Rothamsted Research (UK)
  - Science Technology an Innovation Agency at Epirito Santo State, Brazil

- **Industry/Companies**
  - Ansys Ltd (UK)
  - IBM
  - HDR Foods Corporation
  - Korean Rural Community Corporation, South Korea
  - SPC Consulting
  - Titan Technologies
  - TraceGains

First ICICLE User Group (iUG) BoF at PEARC '24

- **Universities**
  - Arkansas State University
  - California State University-Monterey Bay
  - Colorado School of Mines
  - Cornell University
  - Georgia Institute of Technology
  - Georgia State University
  - Idaho State University
  - Indianapolis University
  - Indian Institute of Technology, Bhubaneswar, India
  - McGill University, Canada
  - North Carolina State University
  - Purdue University Indianapolis
  - Texas A&M University
  - Texas Southern University
  - University of Arizona
  - University of Cambridge (UK)
  - University of Chicago
  - University of Cincinnati
  - University of Delaware
  - University of Georgia
  - University of Hawaii at Manoa
  - University of Illinois Urbana-Champaign
  - University of Maryland
  - University of North Carolina at Charlotte
  - University of Puerto Rico at Rio Piedras
  - University of Southern California
  - University of Texas San Antonio
  - UW-Madison Division of Extension Community Development Institute
  - Virginia Tech
  - Virtual University of Cote d'Ivoire, Ivory Coast
  - Washington State University

Collaboration with AI Institutes and Other Centers (National)

- **ICICLE is emerging as the nexus point for providing CI support for other AI Institutes and centers**

- Joint work under MOUs with 3 other NSF-AI Institutes
    - **AI4OPT**
    - **AgAID**
    - **AIIRA**

- Joint work with 2 other NSF Institutes/Centers
    - NSF HDR DIRSE **Imageomics** Institute
    - **Iowa State University/ARA**

Collaboration with Industry and Non-Profit

Collaboration Going-on with 4 industry and Non-Profit Organizations

- Tata Consulting Service (TCS) along Digital Agriculture

- Apple Farm Service along Digital Agriculture

- Conservation-X Labs along Animal Ecology

- The Wilds along Animal Ecology

Collaboration with International Organizations

Collaboration/Discussion going-on with four industry and international Organizations

- Tata Consulting Service (TCS), India

- Cardiff University, UK

- Univ. of Cambridge, UK

- Indian Institute of Technology, Bhubaneswar, India

Looking forward to collaboration!!

Conclusions

- Latest advances in HPC, AI, and Big Data can enable AI-driven applications in many fields (science, engineering, medicine, ..)

- ICICLE has been developing the necessary cyberinfrastructure components and solutions to be used in a configurable, adaptable, and in a plug-and-play manner

- Looking forward to collaboration with various stakeholders to democratize AI-enabled Science

Potential for the ICICLE Solutions to be applied to more Verticals

Smart Foodsheds

Digital Agriculture

Animal Ecology

Health & Medicine

Environment

Communications & Collaboration

Mobility, Machines, & Manufacturing

AI for Social Good

ICICLE: Intelligent CyberInfrastructure with Computational Learning in the Environment

Systems AI Foundational Research for CI

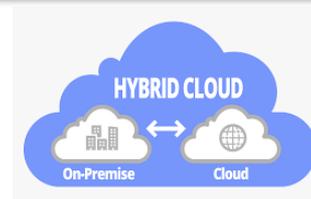Intelligent Cyber Infrastructure

CI for AI

AI for "CI for AI"

On Field Sensors

Edge & Near Edge

HYBRID CLOUD

On-Premise ↔ Cloud

Clouds

HPC Systems & Data Centers

Emerging Computing Continuum

Acknowledgments to all ICICLE Participants (Faculty, Students and Staffs)

Current Faculty
– E. Ayday, CWRU
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– P. Sharma, IU
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– Y. Cai, OSU
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– DB. Jackson-Smith, OSU

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– DK. Panda, OSU
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– S. Gao, UW-Madison
– A. Morales, UW-Madison

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– K. Pierce, TACC

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– M. Norman, UC San Diego

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– E. Goetz, OSU
– Y. Gu, OSU
– A. Jain, OSU
– D. Suresh, OSU
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Current Staff
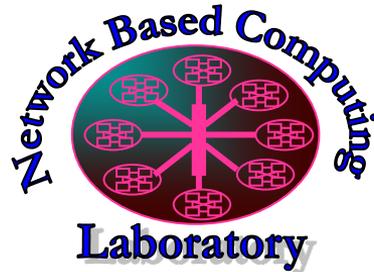– M. Lange, IC-Foods
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– M. Miller, UW Madison

Current International Students TIH - IITB
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– S. Paramane, TIH IITB

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– M. Ray, SDSC
– S. Samar, SDSC

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– D. Sykes, UW Madison

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– L. Waltz, OSU
– B. Wang, OSU

– X. Wang, OSU
– J. Yao, OSU
– X. Yue, OSU
– T. Zhang, OSU
– K. Zhang, OSU

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– J. Rao, UW-Madison
– J. Kline, OSU
– G. Ubbiali, IC-Foods

Current Institute Evaluators (WFD)
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– C. Wise, TFG

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– A. Sarin, SDSC

Past UG Students
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– C. Washington, OSU
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– A. O'Quinn, OSU

– C. Wang, OSU
– J. Yang, OSU
– Q. Ding, TACC
– V. deBella, UW Madison
– M. Krempely, UW Madison

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– M. Kuhn, UW Madison
– Y. Qu, UW Madison
– K. Sung, UW Madison

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– TE. Feiten, UC
– A. Hingle, GMU
– C. Lucken, UC
– C. Okolo, CU

Thank You!

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Network-Based Computing Laboratory
http://nowlab.cse.ohio-state.edu/

The High-Performance MPI/PGAS Project
http://mvapich.cse.ohio-state.edu/

The High-Performance Big Data Project
http://hibd.cse.ohio-state.edu/

The High-Performance Deep Learning Project
http://hidl.cse.ohio-state.edu/