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Creating Intelligent Cyberinfrastructure for Democratizing AI: Overview of the Activities at the NSF-AI Institute ICICLE

http://icicle.ai

Plenary Talk at PEARC '23

by

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Credits to all ICICLE Team Members!!

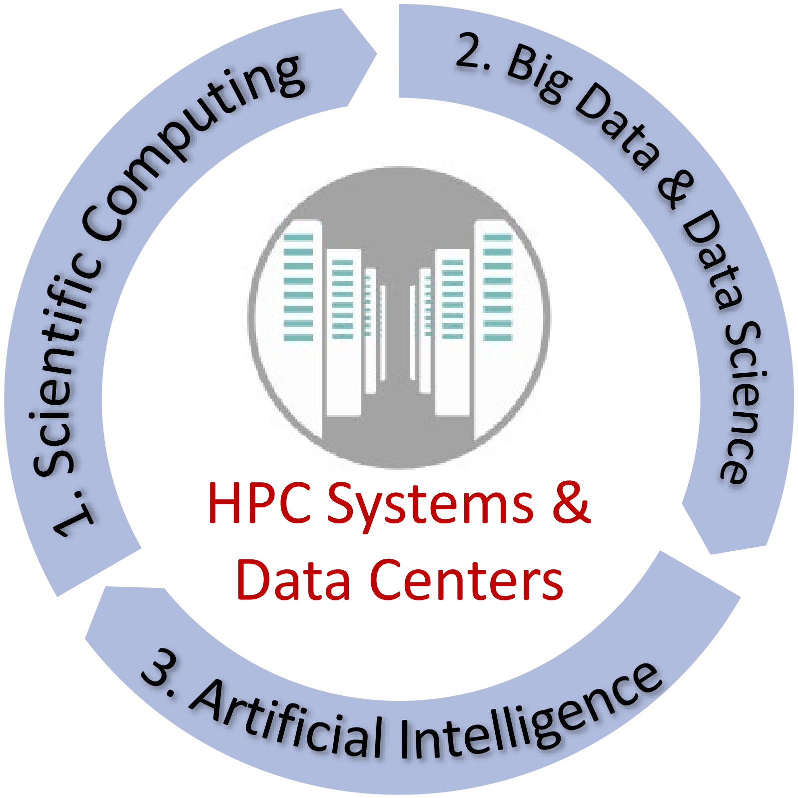
Outline

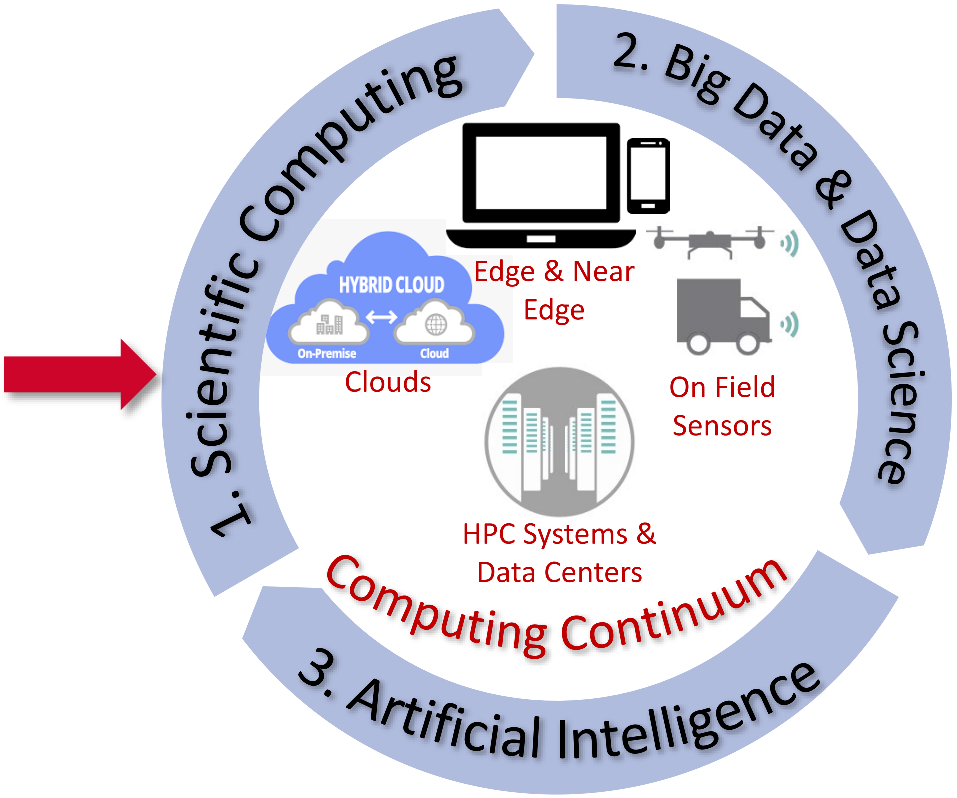
- ICICLE Vision and Goals
- Research Challenges Addressed
- Highlights of Selected Accomplishments
- How to Get Engaged?
- Conclusions

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





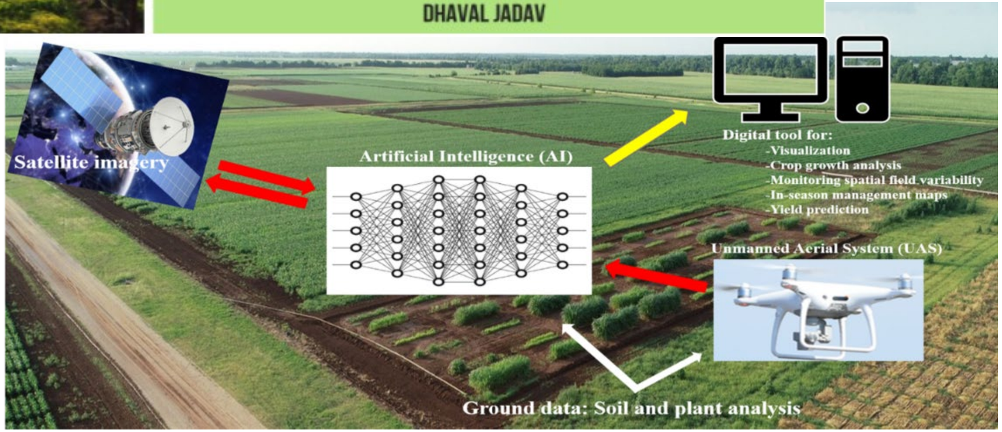
Societal Challenge (Example #1): Agriculture

- **Food security/sustainability in 2050**
  - 9.8B people, climate; 0.5x arable land per cap vs 1985
  - Wide gains in crop management needed (typical yields fall 3X below best practice)

- **Sustainable agricultural workforce**
  - The next generation of agriculture professionals will include engineers, computer scientists, data scientists

- **Democratization of digital agriculture capabilities**
  - Autonomous unmanned aerial vehicles, self-driving tractors and sprayers, fertilizer and seed recommendations
  - Big and small farms, staple and specialty crops, underrepresented communities
  - Privacy and ethical considerations

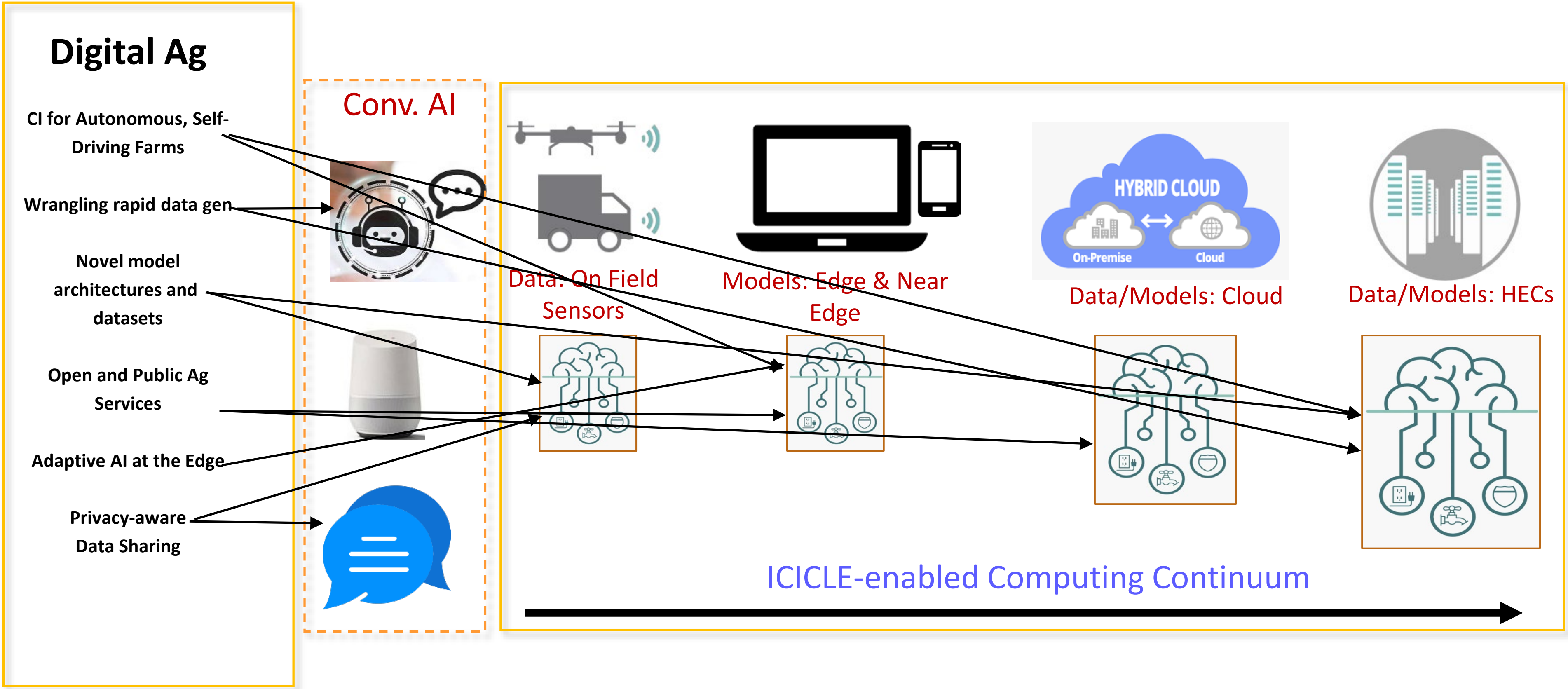
AI-Driven Digital Agriculture



https://ccag.tamu.edu/research-project/digital-agriculture/

https://medium.datadriveninvestor.com/artificial-intelligence-in-agriculture-62f71f8f6ae6

Challenges in Designing AI-Driven CI for Digital Agriculture in Computing Continuum



Societal Challenge (Example #2): Animal Ecology

- **Basic science:** The focus of Animal Ecology is understanding the functioning and behavior of animals individually and in groups *in the context of environment* and evolution.

- **Science + translational:**
  - Monitoring, understanding, and protecting biodiversity of the planet
  - Monitoring and understanding the impact of changing habitats on animals that live in them

- **Translational:** biodiversity conservation and mitigating the impact of climate change

Societal Challenge (Example #3): Smart Foodsheds

- **Food Supply Chain Vulnerabilities**
  - Concentration contributes to bottlenecks, lack of resilience to disruptions
- **High Food Insecurity**
  - Supply chain decisions fail to account for impacts on food access, cost, availability
- **Food Waste**
  - Inefficiencies in food supply chains and food systems lead to 30-40% waste
- **Negative Environmental Footprint**
  - Farming and food system has major impacts on environment
- **Holistic Food Systems Planning is Difficult**
  - Data is difficult to access, not coordinated across sectors or food supply chain actors

How AI can Help the Users of these Science Cases?

For the three use-inspired science cases:

- Massive and ever-growing gap between AI and its accessibility to the users
- Existing AI applications are developed largely ad-hoc and lack coherent, standardized, modular, and reusable infrastructure
- Successful AI solution(s) for one use case rarely generalize to other use cases, or even the same use case even with slightly different context.

<u>CI's complexity to deploy AI impedes research discoveries and innovations!</u>

Many more examples

- Smart Cities
- Smart Manufacturing
- Smart Transportation
- Real-time Surveillance
- Computational Medicine (Pathology, Radiology, ..)

Broad Challenge

Designing the next-generation intelligent cyberinfrastructure for a computing continuum with heterogenous resources that is usable in a plug-and-play manner by stakeholders to solve societal challenges?

Click here to watch
Introduction to the ICICLE
Project

The Vision

A **national infrastructure** that will:

- Catalyze **foundational AI/CI** and transform application domains
- **Democratize AI** through **integrated plug-and-play AI**
- **Transparent and trustworthy** infrastructure for AI-enabled future
- Address **societal problems** (agriculture, conservation, food insecurity) **globally**
- Grow **new generations of workforce** and incubate **sustainable and inclusive** communities

Objectives: Intelligent CyberInfrastructure for Computing Continuum

Use Inspired Science Domains

Digital Agriculture

Smart Foodsheds

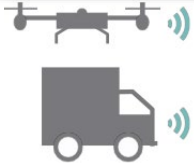
Animal Ecology

ICICLE: Intelligent CyberInfrastructure with Computational Learning in the Environment

Systems AI Foundational Research for CI

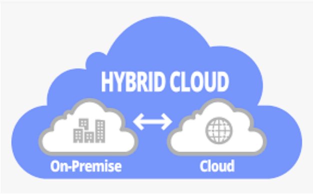
Intelligent Cyber Infrastructure

CI for AI | **AI for "CI for AI"**



On Field Sensors

Edge & Near Edge

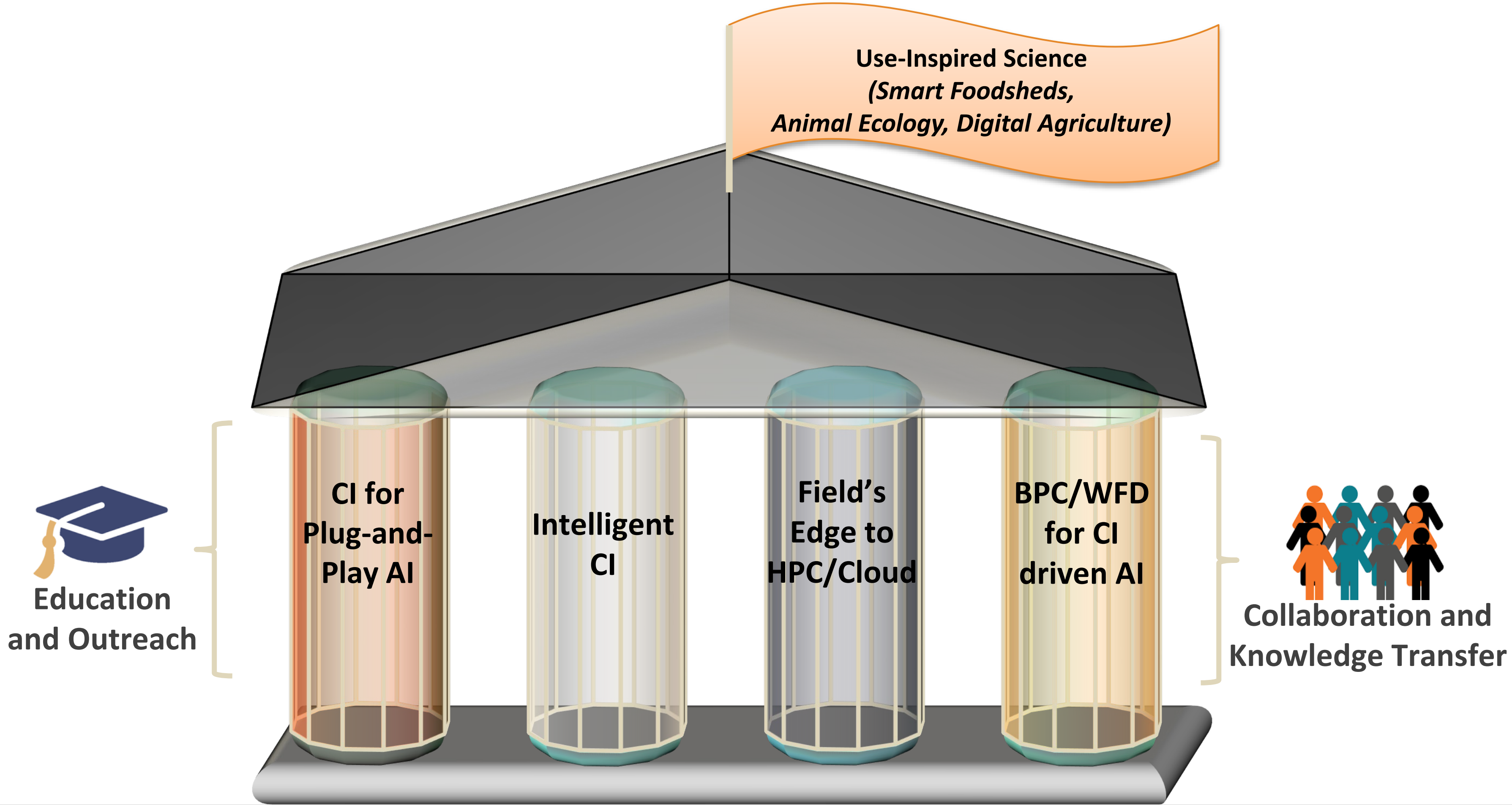


Clouds

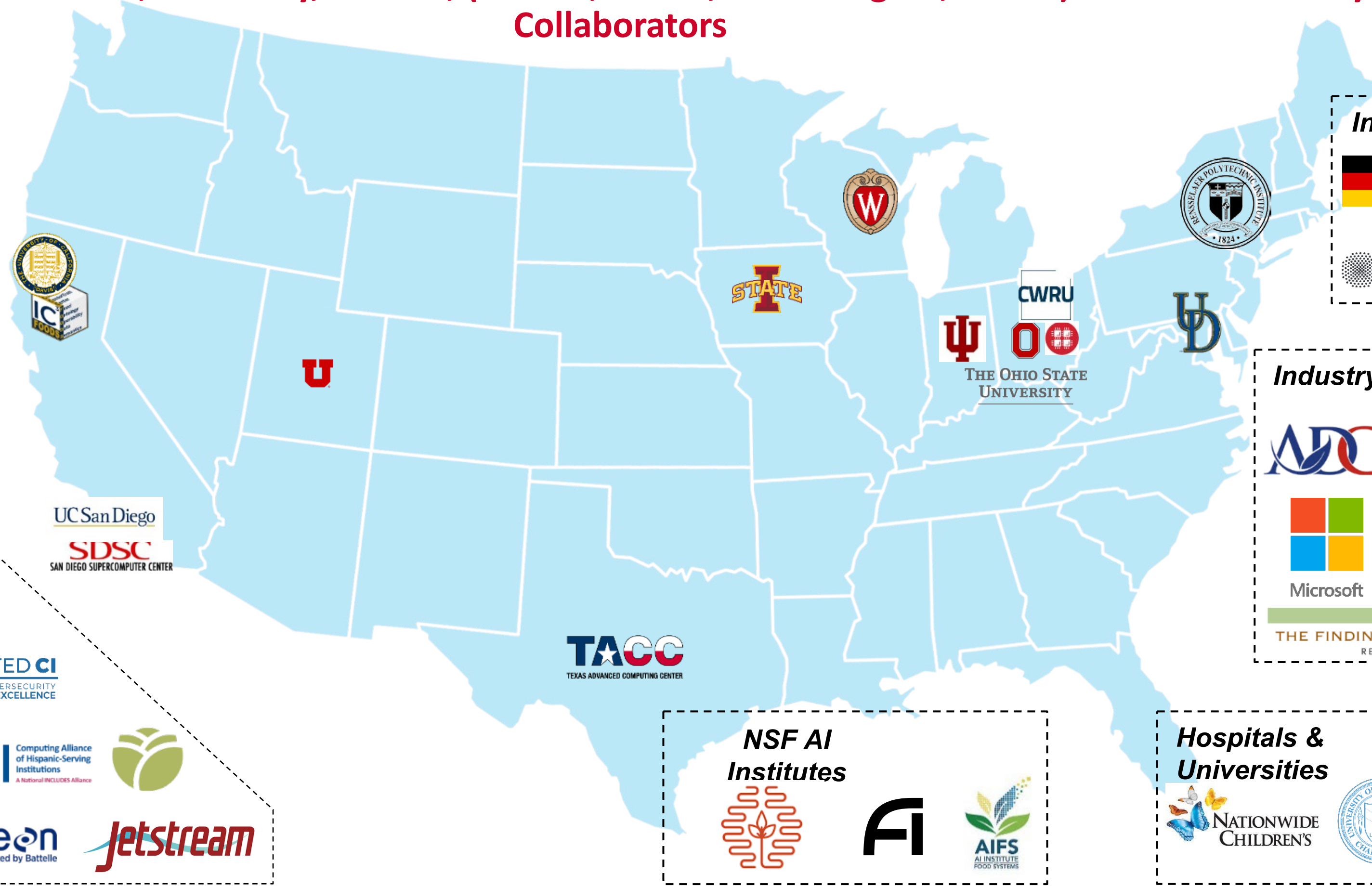
HPC Systems & Data Centers

Emerging Computing Continuum

ICICLE As A Whole



Participation:
14 Organizations, 33 faculty, 41 staff, (58 PhD, 16 MS, 16 undergrad, 6 K-12) students & many Collaborators



Govt. Agencies & National Labs

Lawrence Livermore National Laboratory

U.S. Fish & Wildlife Service

Brookhaven National Laboratory

Fermilab

Research Institutes

national center for women & information technology

MOLSSI

SGCI Science Gateways Community Institute

TRUSTED CI THE NSF CYBERSECURITY CENTER OF EXCELLENCE

ECEP

CAHSI Computing Alliance of Hispanic-Serving Institutions

SCEC AN NSF+USGS CENTER

NSF

neon Operated by Battelle

Jetstream

International

Max-Planck-Gesellschaft

University of Stuttgart Germany

Industry

CNH INDUSTRIAL

ADC

WILDME

Microsoft

FARM 2 FACTS

THE FINDINGS GROUP, LLC RESEARCH & EVALUATION

NSF AI Institutes

AIFS AI INSTITUTE FOOD SYSTEMS

Hospitals & Universities

Nationwide Children's

University of North Carolina Chapel Hill

Collaboration: ICICLE and the Technology Innovation Hub (TIH) at the Indian Institute of Technology Bombay (IIT-B), India

Digital Agriculture

This research collaboration will contribute novel design paradigms for context-adaptive CI and aims to develop next-generation CI for *Digital Agriculture* including AI and machine learning methods targeting 3 core areas.

Crop Health Modeling

- Sense crop health and level context to predict crop yield
- Detect stressors and diseases for geographically diverse crops
- Apply remedies with little human intervention via Internet of Things (IoT) and sensor systems

Aerial Crop Scouting

- CI for fully autonomous aerial systems
- Simplify deployment of UAV in real fields to capture common crop health conditions
- Provide accurate maps that yield valuable insights for crop management

Privacy-Preserving Data Exchange

Create secure, trustworthy, and privacy-preserving platforms that connect farmers and allow them to share information and resources safely.

Building upon the existing ICICLE infrastructure, CI and AI capabilities, researchers will leverage contextual conditions in India for *Digital Agriculture* that differ from the United States to (1) expose brittle CI components, (2) make AI4CI more robust and expansive in the long-term, (3) devise principles that yield context-aware CI

External Advisory Board (EAB)

Ewa Deelman
Univ. of Southern California
Cyberinfrastructure, Academia

Vipin Kumar
University of Minnesota
Cyberinfrastructure, Academia

Ted Schmitt
Allen Institute for AI
Applications, Non-profit

Sergio Soares
CNH Industrial
Use-Inspired Science, Industry

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Valerie Taylor
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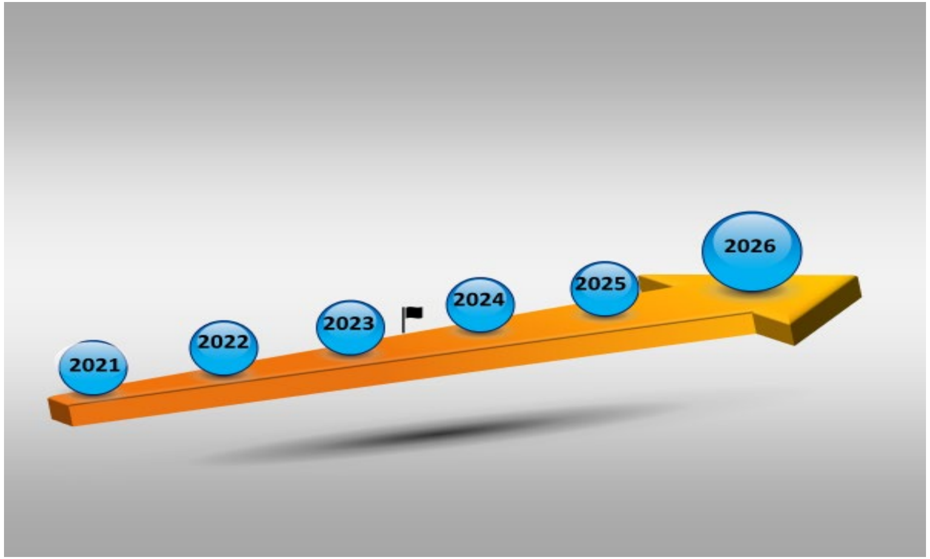
Tiffani Williams
Univ. of Illinois, Urbana-Champaign
WFD/BPC, Academia

Luke Zettlemoyer
Meta and Univ. of Washington
Artificial Intelligence, Industry

Timeline

- Started on Nov 1, 2021
- Finished 20 months of the project



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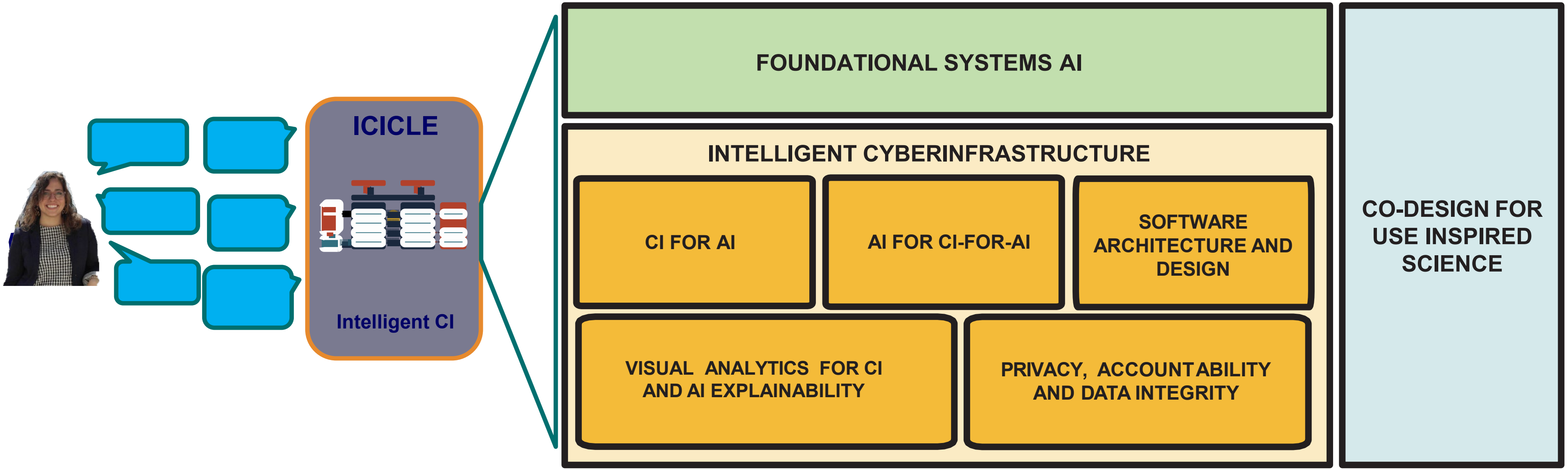
- Conclusions

Research Plan: Overall Vision



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

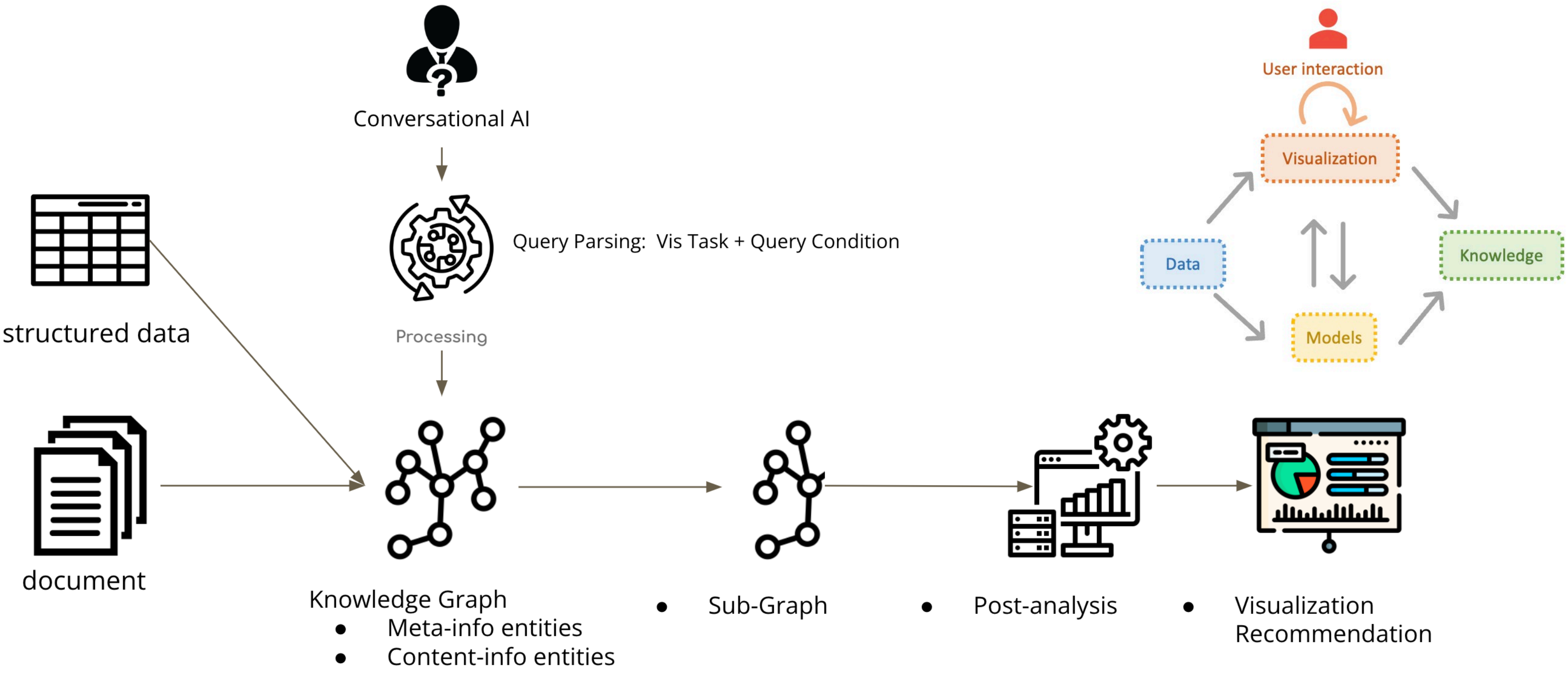
Systems

- 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)

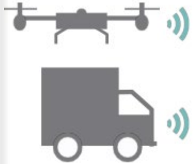
- PADI contributes to
  - ICICLE vision as *transparent and trustworthy* infrastructure for AI-enabled future
  - An ethically aligned infrastructure and workforce through an *AI ethics framework*
- PADI advances both technical and non-technical innovations and best practices that collectively contribute 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)

Thrust: Visual Analytics



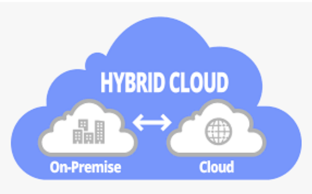
Co-Designing with use-inspired domains

Conv. AI

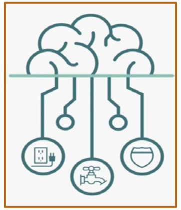


Data: On Field Sensors

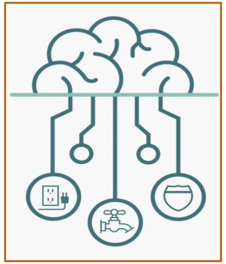
Models: Edge & Near Edge



Data/Models: Cloud

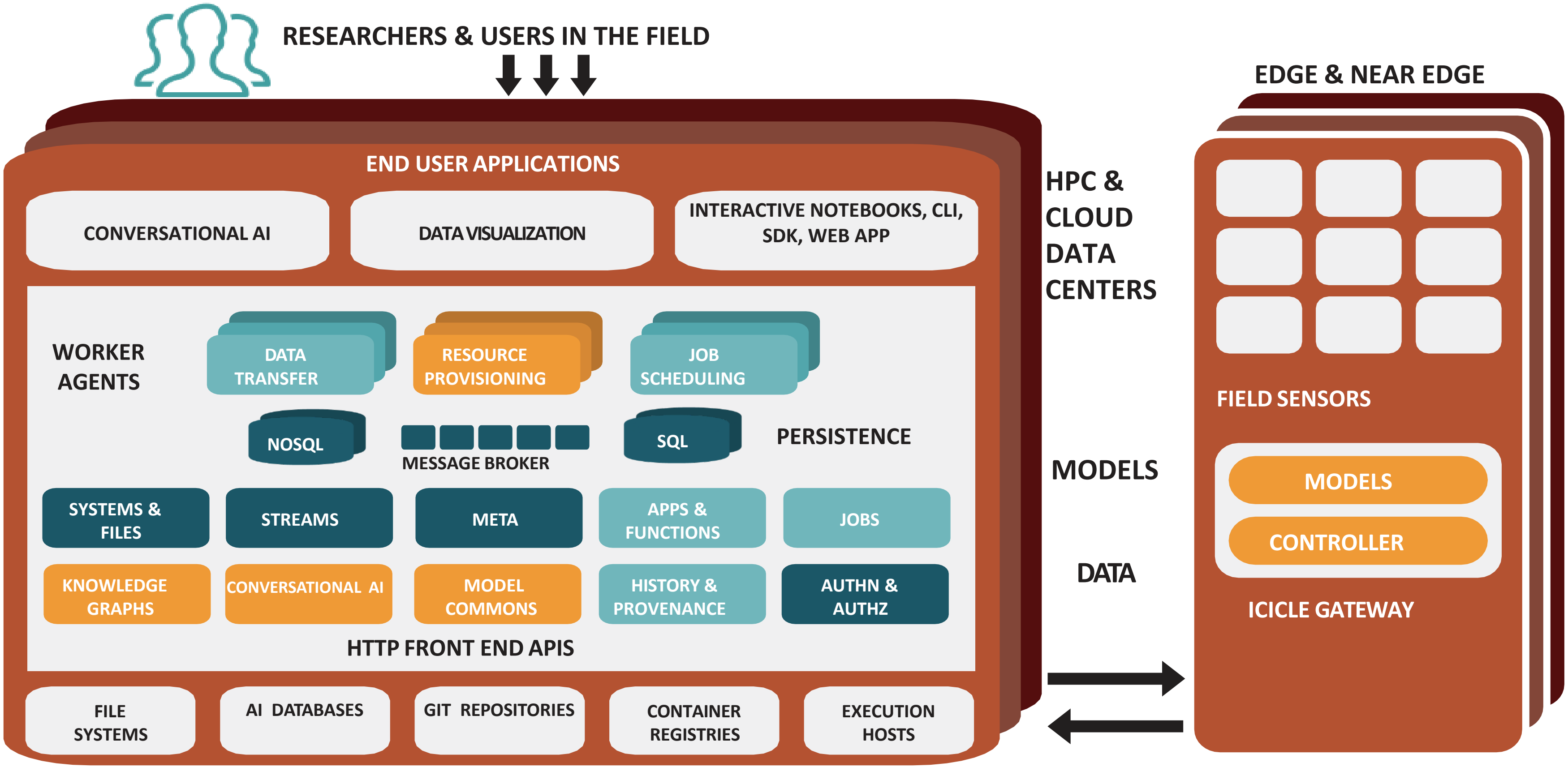


Data/Models: HECs



ICICLE-enabled Computing Continuum

The Deliverable: The ICICLE Software Stack

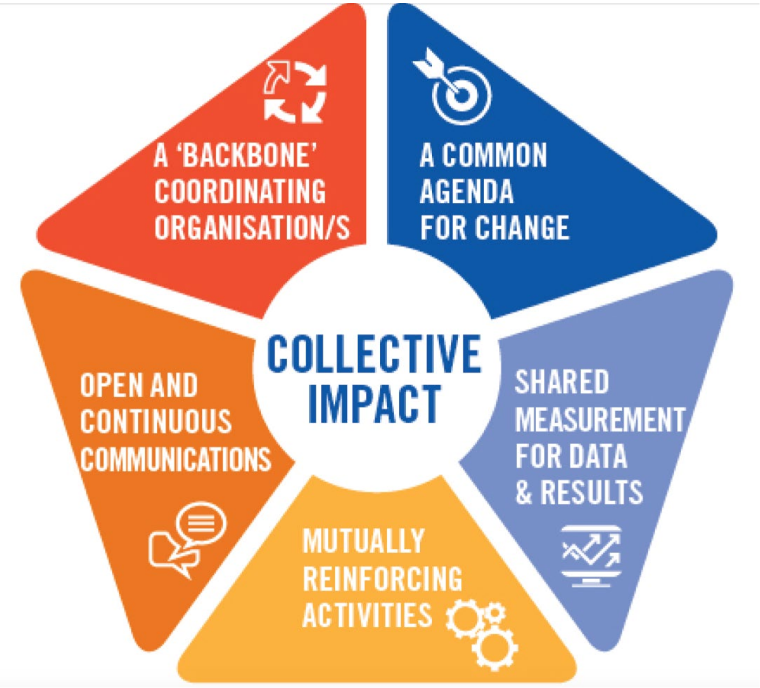


Broader Impacts Backbone Network (BIBN)

BIBN is a consortium with the goal of democratizing AI!

Oversees activities towards broader impacts and engagement:

- Diversity Equity and Inclusion (DEI)
- Broaden Participation in Computing (BPC)
- Workforce Development (WFD)
- Collaboration and Knowledge Transfer (CKT)



Outline

- ICICLE Vision and Goals
- Research Challenges being Addressed
- **Selected Accomplishment Highlights**
  - **CI/Software Released**
  - **Digital Agriculture (demo)**
  - **Smart Foodsheds (demo)**
  - **Grocery Store Closure (demo)**
  - **AI4CI**
  - **BIBN**
- How to Get Engaged?
- Conclusions

CI/Software Components Released (so far)

2023.04 Release (04/30/23)

- **AI4CI**
  - HPC Application Runtime Predictor (HARP) v1.0
  - Intelligent Sparse Library (iSpLib) v1.0
- **Software and Reference Architecture**
  - Base ICICLE Tapis Software v1.3.0
  - Event Engine v0.2.0
  - Hello ICICLE Authentication Clients v0.0.1
  - Tapis Pods Service v1.3.0
  - CI Components Catalog v0.1.0
- **Animal Ecology**
  - Camera-Traps Edge Simulator v0.3.0
- **Digital Agriculture**
  - SoftwarePilot v1.2.5
- **Smart Foodsheds**
  - Persons-Projects-Organizations-Datasets (PPOD) Schema v0.9.1
  - Smart Foodsheds Visual Analytics (VA) Dashboard v0.1

https://icicle.osu.edu/cyberinfrastructure/software

2023.06 Release (06/30/23)

- **AI Foundations**
  - ICICLE Foodshed Parser v0.1
  - Species Classification using Multimodal Heterogeneous Context v0.1.0
  - Region2vec v1.0
- **Software and Reference Architecture**
  - Tapis Federated Authentication Service v1.3.4
  - ICICONSOLE v0.0.10
  - TapisCL-ICICLE v0.1.4
  - Tapis Pods Service v1.3.2
- **Animal Ecology**
  - Camera-Traps Edge Simulator v0.3.1
- **Digital Agriculture**
  - ICICLE Digital Agriculture Hub v1.0
  - Far-Edge Edge Simulator v1.0
  - In-Field Helper for Crop Scouts v1.0
- **Smart Foodsheds**
  - Persons-Projects-Organizations-Datasets_California (PPOD_CA) Knowledge Graph v23.06
  - Kroger Store Closure v0.1
  - Smart Foodsheds Visual Analytics (VA) Dashboard v0.2

Digital Agriculture

What does CI for digital agriculture look like?

How to build CI that connects a wide range of digital agriculture stakeholders?

Why use-inspired CI will be transformative?

ICICLE Use-Inspired Science: Digital Agriculture






Scott Shearer
Food, Agriculture and Biological Eng.

Christopher Stewart
Computer Science & Eng

Co-Leads

Zichen Zhang

Jenna Kline

John C. Chumley

Kevyn Angueira Irrizary

Ohio State University

Digital Agriculture Hub and Use-Inspired Technologies


P. Sadayappan
University of Utah

Jinghua Yan
University of Utah

Artificial Intelligence for Cyberinfrastructure


Hari Subramoni

Nawras Alnaasan

Cyberinfrastructure for AI-Driven Digital Agriculture


Erman Ayday
Case Western

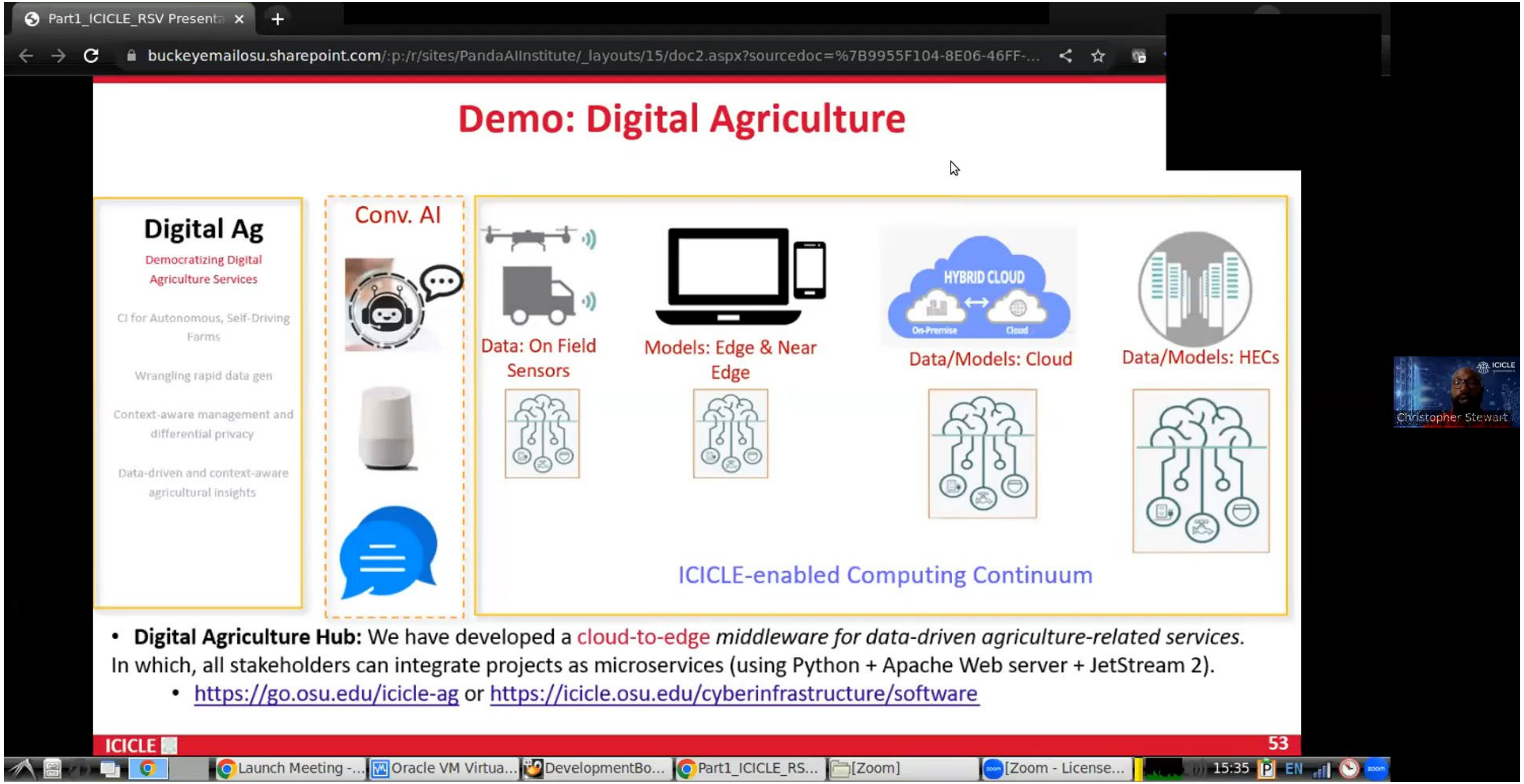
Beth Plale
Indiana University

Privacy-aware, Explainable AI, & Democratization

Alfonso Morales
University of Wisconsin

Stakeholder Engagement

Demo: Digital Agriculture



Smart Foodsheds

The Challenges

- Food system lacks resilience (highlighted by the pandemic)
- Food system actors are diverse, work in silos
- Access to data is difficult as is reconciling across data sources
- Need a common framework to organize, share, visualize, and deploy datasets and workflows

The Strategies

- Develop relationships between ICICLE and private partners to empower stakeholders to access, interpret, and utilize food systems processes, trends, and outcomes
- Use knowledge graphs to link domain knowledge of the environment, agriculture, food, diet, and health
- Develop PPOD, a schema that describes the attributes and relationships between **Persons, Projects, Organizations and Datasets** and instantiate it with real data from California and Ohio as a first use case.

Interactive Knowledge Learning & Environment (IKLE) for Smart Foodshed




Yamei Tu | *Xiaoqi Wang* | *Rui Qiu* | *Han-Wei Shen*

The Ohio State University


Patrick R Huber | *Allan D Hollander*

University of California Davis

Matthew Lange

International Center for Food Ontology Operability Data and Semantics (IC-FOODS)



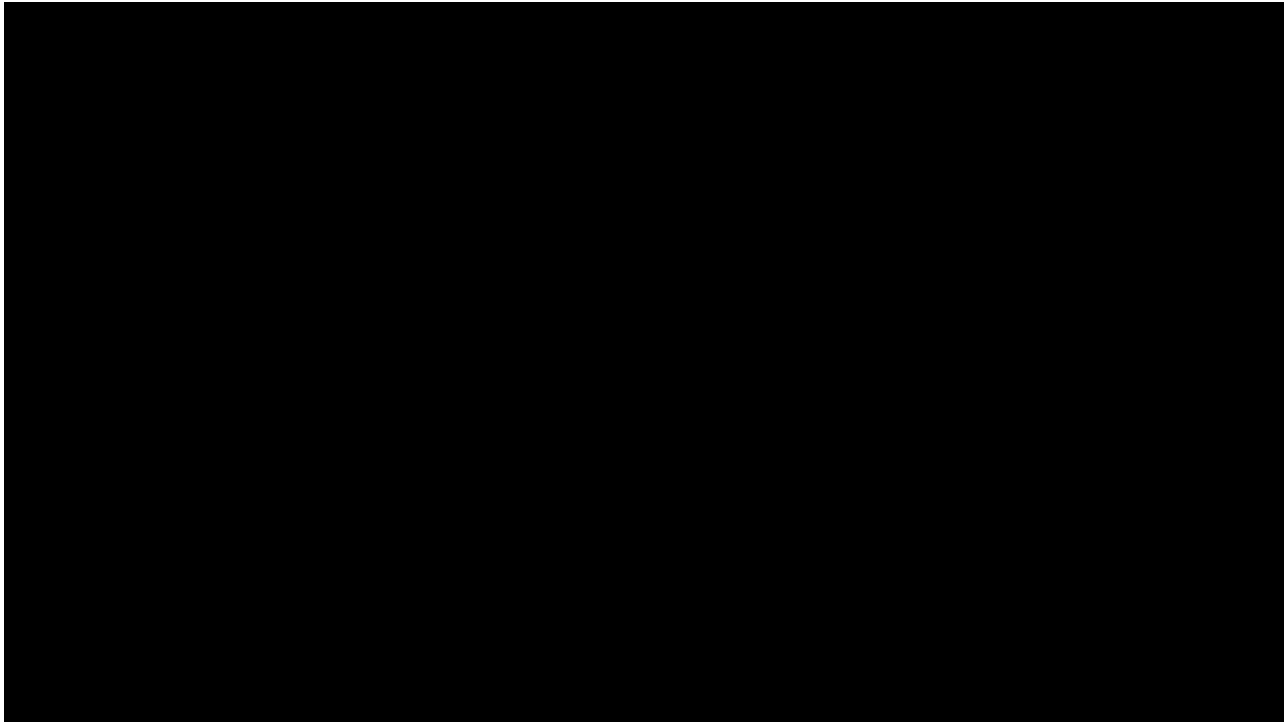

Michelle Miller | *Jinmeng Rao* | *Song Gao* | *Alfonso Morales*

University of Wisconsin-Madison


Christian R Garcia | *Joe Stubbs*

The University of Texas at Austin Texas Advanced Computing Center

Demo : Smart Foodsheds + Visual Analytics (IKLE)



GROCERY STORE CLOSURE & COMMUNITY HEALTH

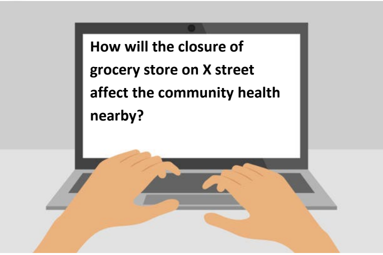
Pain points

- In public health and food systems, computer models are not used or have limited impact because decision-makers are not able to access them in a practical and timely manner.

SCENARIO

A food retail company announces plans to **close a grocery store** in a Columbus, Ohio neighborhood with **very high % of food-insecure households**.

Now the health commissioner wants to know how the grocery store closure will affect community health so they can lobby the food retail company to not close the grocery store or set up emergency food supply to reduce the impact on community health.



Our Solution (and use case in ICICLE)

A conversational AI-enabled web interface that allows decision-makers to run "What if?" scenarios based on an agent-based model for food insecurity.

Use Case

Objective: Help food system leaders quickly evaluate the impact of a food store closure on household food insecurity

Significance: Improving access to community-informed computational models empowers communities to use models to make better decision involving complex systems, such as the local foodshed.

Grocery Store Closure Team







Harsh Panday

Amad Hussain

Erika Goetz

Carlos Guzman

Ayaz Hyder

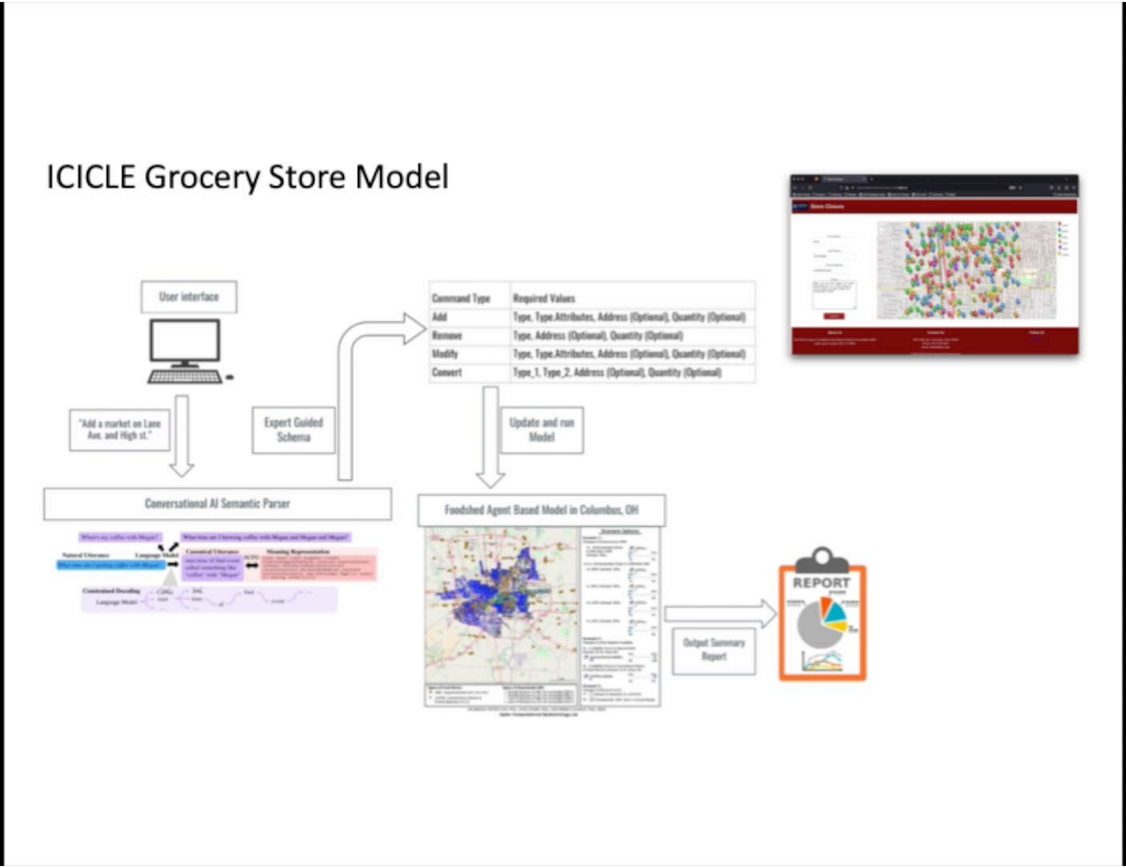
Huan Sun

Eric Fosler-Lussier

The Ohio State University

College of Public Health / Dept. of Computer Science & Engineering

Demo: GROCERY STORE CLOSURE & COMMUNITY HEALTH



AI4CI: HARP – HPC Application Runtime Predictor


Swathi Vallabhajosyula


Rajiv Ramnath


Carlos Guzman


Joe Stubbs

The Ohio State University
Dept. of Computer Science & Engineering

The University of Texas at Austin
Texas Advanced Computing Center

n-tasks-per-node	Walltime (mins)	Cost Per job ($)
10	8.5954	0.01719
14	8.5768	0.01886
20	8.5852	0.02189
28	8.5931	0.02492

Cost ↓ ~30%

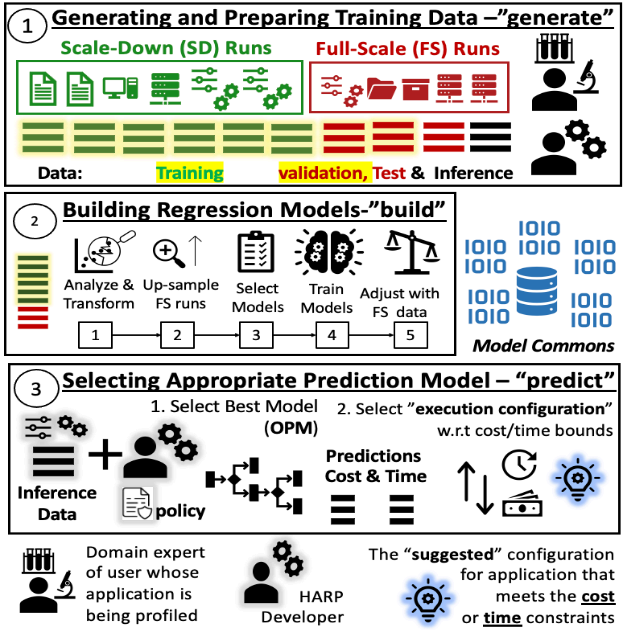
Goal

Estimating the resource requirements to execute an application on shared cyber infrastructures to aid recommendation systems or smart job allocations.

Accomplishments

- **Understanding the allocation behavior of different users against different systems and ways for optimizing the allocations.**
- **Establishing an end-to-end application-independent framework called HARP (HPC Application Runtime Prediction) that can emulate the application executions, profile them, and estimate the resource requirements against targeted environments with cost/time constraints.**
- **Systems Track - HPC Operations (BEST Paper) - Room: D136, Time: Tuesday 07/25, 3-4:30 p.m.**
- **Poster Session - Wednesday 07/26 - Room: Ballrooms 251/252, Time: Wednesday 07/26 5:45-7:45 p.m.**

HARP – HPC Application Resource Predictor = Runtime



Broader Impact Backbone Network (BIBN)




Beth Plale *Maureen Biggers* *Sadia Khan* *Julie Wernert*

Indiana University

Alfonso Morales

University of Wisconsin-Madison

Matthew Lange

International Center for Food Ontology OSemantics (IC-FOODS)

Swathi Vallabhajosyula
ICICLE NextGens Community Leader

Rajiv Ramnath

The Ohio State University

Mary Thomas

San Diego Super Computing Center

Selected Accomplishments from BIBN

- BPC
  - Inclusive environments initiative: **ICICLE NextGens** group, **ICICLE Code of Conduct**
  - Building awareness: bi-weekly **Ally tips (bias);** AI Ethics tips purposed for Indiana Univ **K-12 summer camp**
- WFD
  - **Hello ICICLE:** clients (Notebooks, command line, python, Web client) for testing software
  - Summer 2023 launch of **ICICLE AI Ethics tips** series of 6 videos
  - Consolidation and organization of **ICICLE Publication and Training Resources** (with WFD and HelloICICLE)
- KT
  - ICICLE Seminar Series
  - **Partnership Agreements** for stakeholders to engage with ICICLE. (Students, Academic Scholars, Organizations, Industry Sponsored, and Stakeholder Roundtable)
  - Engaging stakeholders, including through 2023 class of 5 **ICICLE Educational Fellows**

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Multiple Levels of Collaboration and Engagement

- Using the Released Software/CI components
  - Available at https://icicle.osu.edu/cyberinfrastructure/software
  - Get engaged as a member in the Stakeholder Roundtable (more details below)
- Become a part of ICICLE (multiple options)
  - Student Associate
  - Visiting Research Fellow
  - Academic Collaborator
  - Industry Partner
  - Stakeholder Roundtable Member
  - More details at: https://icicle.osu.edu/engagement/join-us
- Join the ICICLE mailing lists (https://icicle.osu.edu/engagement/mailing-lists)
  - icicle-announce
  - icicle-discuss

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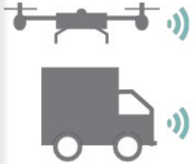
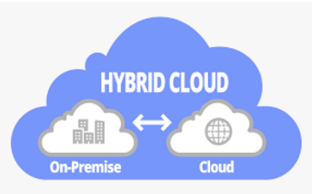
Designing Next-Generation CI through Co-Designing with Use-inspired Domains

Conv. AI

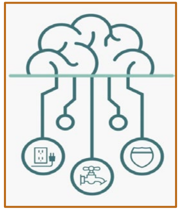


Data: On Field Sensors

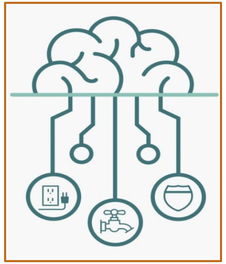
Models: Edge & Near Edge



Data/Models: Cloud



Data/Models: HECs



ICICLE-enabled Computing Continuum

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

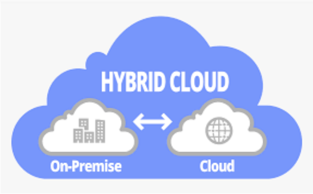
Systems AI Foundational Research for CI

Intelligent Cyber Infrastructure

CI for AI | **AI for "CI for AI"**

On Field Sensors

Edge & Near Edge

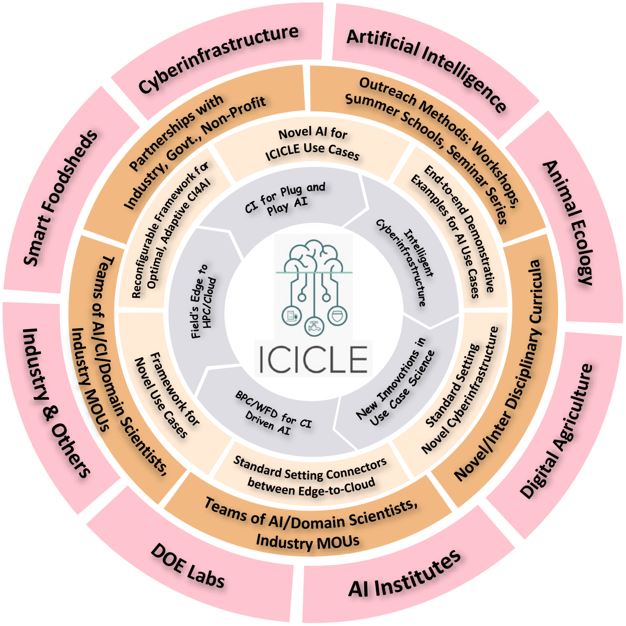


Clouds

HPC Systems & Data Centers

Emerging Computing Continuum

ICICLE Enabling Global Leadership in `Computing + AI'



Join Us!

- **Integrate into the National CI Ecosystem**
- **Integrative and Interoperable**
- **Leverages existing recognized capabilities**
  - **Centers of Excellence, AI Institutes, Large Facilities**
- **Collaborative**
  - **Actively engaging CI experts, domain scientists,**
  - **AI/CI Users and developers**
- **Sustainable and Inclusive**
  - **Workforce Development, Broadening Participation, Collaboration and Knowledge Transfer**
  - **Benefits other institutes, large facilities, and all sciences beyond lifetime of award**

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Thank You!