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AI-Enabled Digital Agriculture - Overview of the Activities at the NSF-AI Institute ICICLE

Talk at Multicore World (Feb '24)

by

http://icicle.ai

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Credits to all ICICLE Team Members!!

[ICICLE Members Attending All-Hands-Meeting In-Person (Nov ‘23)]

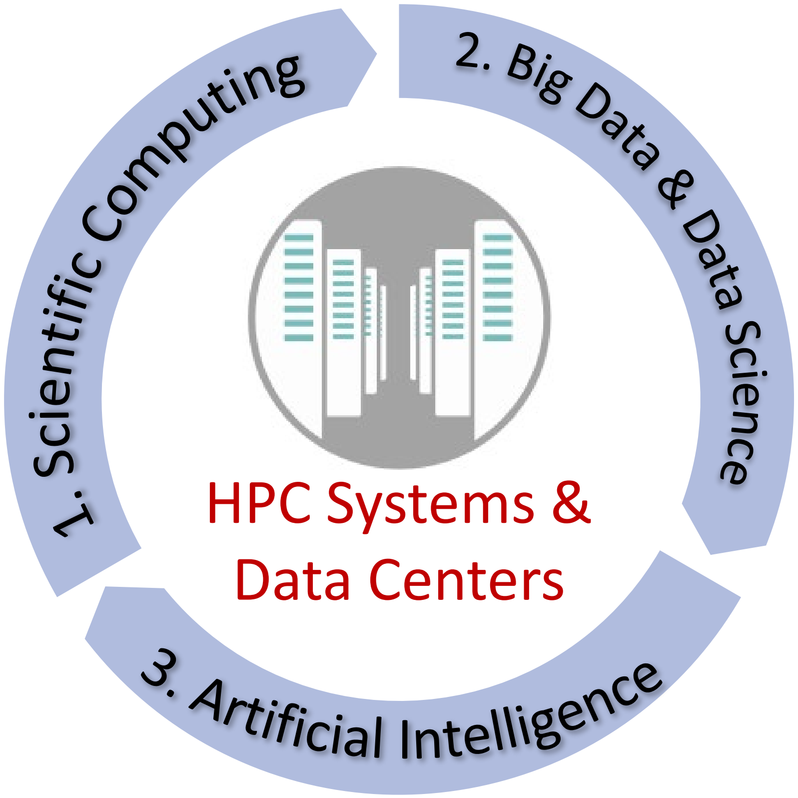
Outline

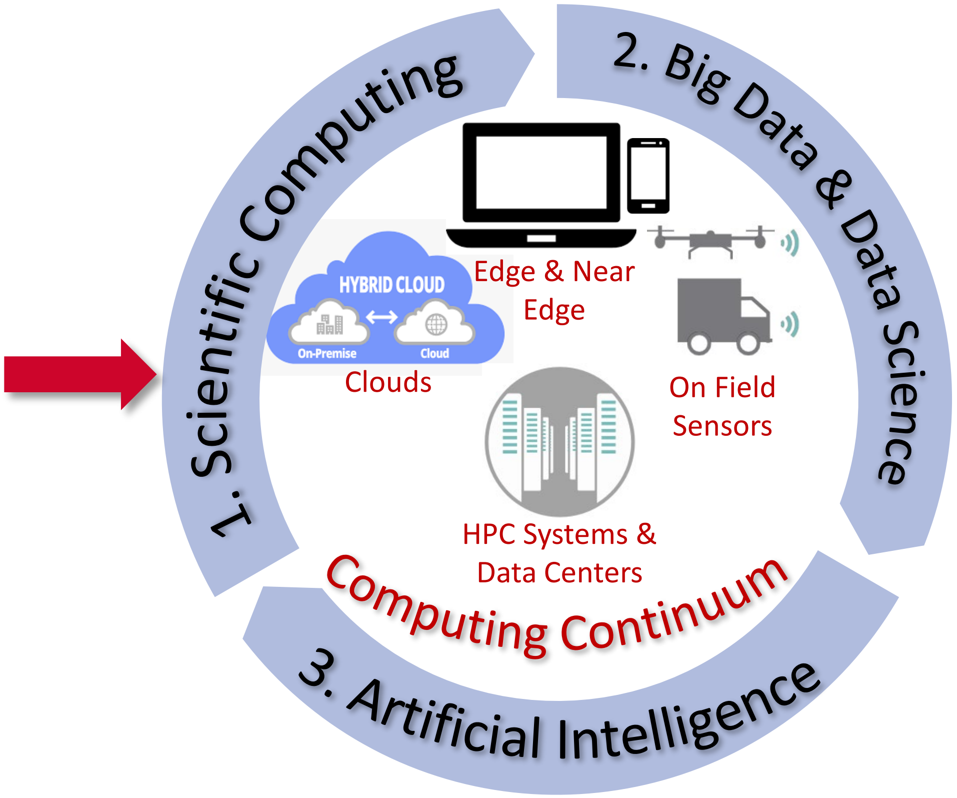
- ICICLE Vision and Goals
- Research Challenges Addressed
- Highlights of Digital Agriculture Activities
- CI/Software Released
- How to Get Engaged?
- Conclusions

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

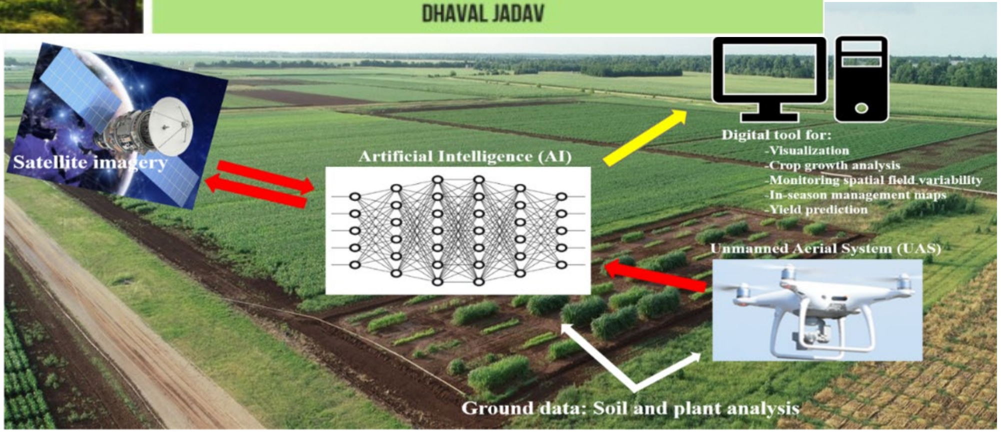
- Phase 1 (1975-): Scientific Computing/HPC
- Phase 2 (2000-): HPC + Big Data Analytics
- Phase 3: (2010-): HPC + AI (Machine Learning/Deep Learning)

Emergence of the Computing Continuum





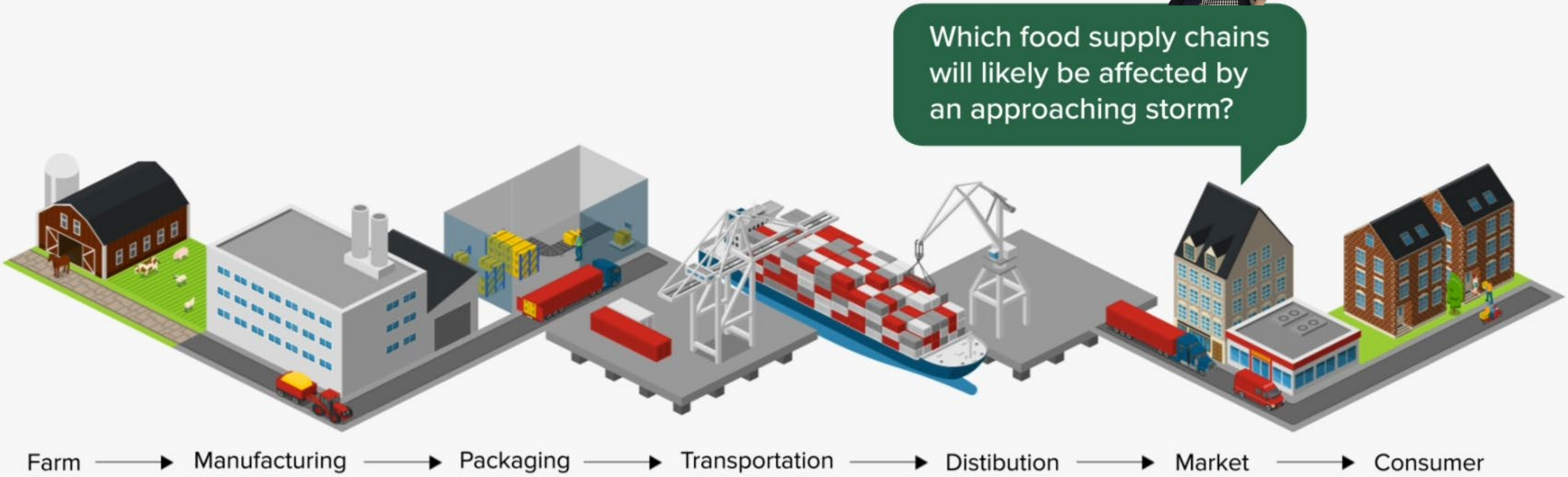
AI-Driven Digital Agriculture



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

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

AI-Driven Foodshed Supply Chain Management?



Many more examples

- Animal Ecology
- 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?

The ICICLE Overview Video

The Video is available from

https://youtu.be/gNFk5tDTtoU

Objectives: Intelligent CyberInfrastructure for Computing Continuum

Use Inspired Science Domains

Digital
Agriculture

Smart
Foodsheds

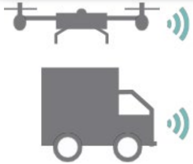
Animal
Ecology

ICICLE: Intelligent CyberInfrastructure with Computational Learning in the Environment

Systems AI Foundational Research for CI

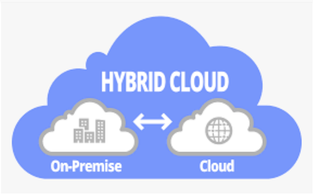
Intelligent Cyber Infrastructure

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



On Field
Sensors

Edge & Near Edge

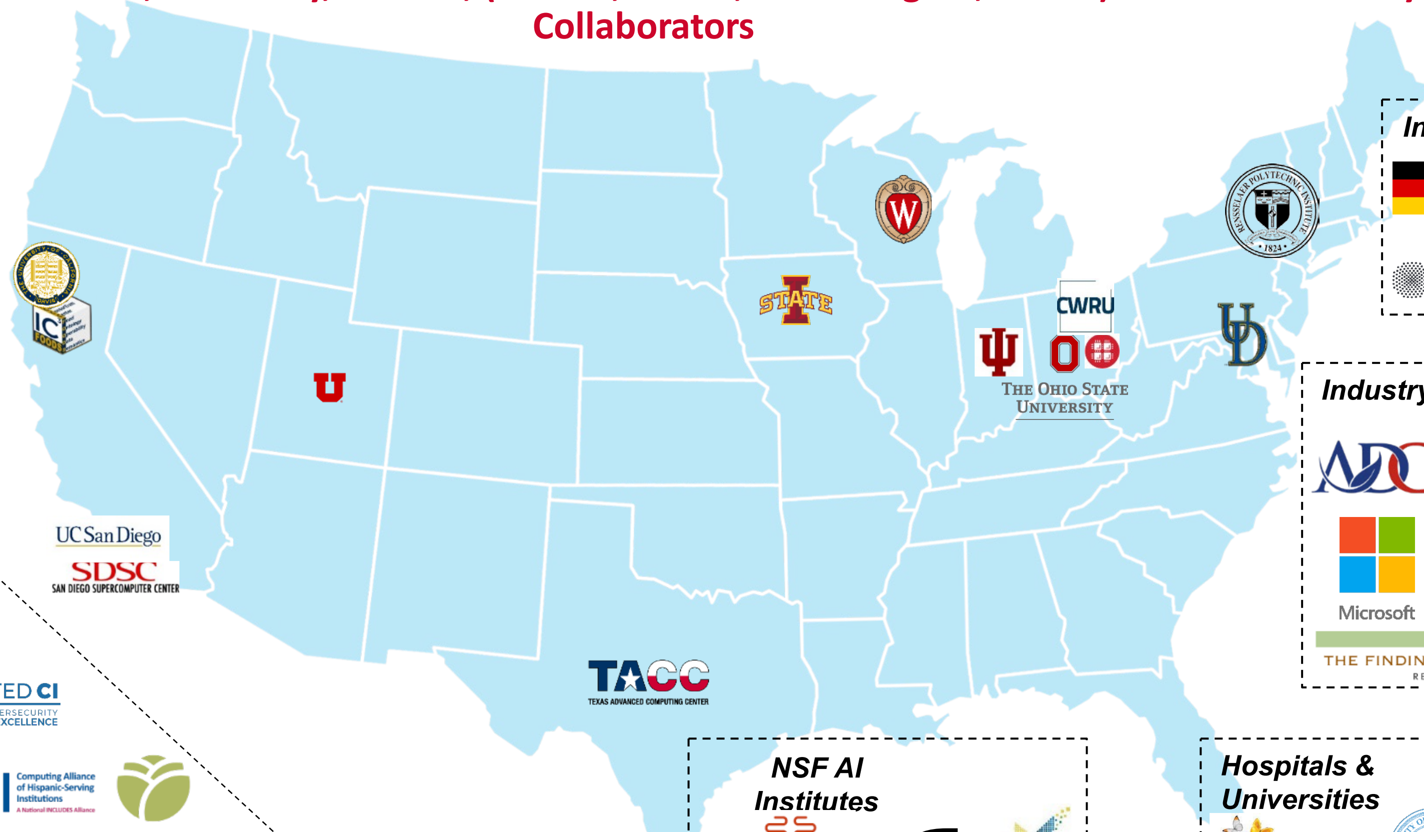


Clouds

HPC Systems & Data
Centers

Emerging Computing Continuum

Participation:
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 A National INCLUDES Alliance

SCEC An NSF+USGS Center

NSF

neon Operated by Battelle

Jetstream

UC San Diego

SDSC San Diego Supercomputer Center

TACC Texas Advanced Computing Center

CWRU

The Ohio State University

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

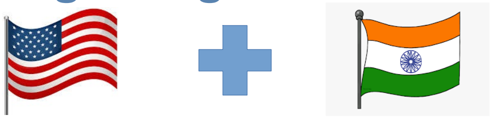
AIFS AI Institute Food Systems

Hospitals & Universities

Nationwide Children's

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)

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Use-Inspired Science, Industry

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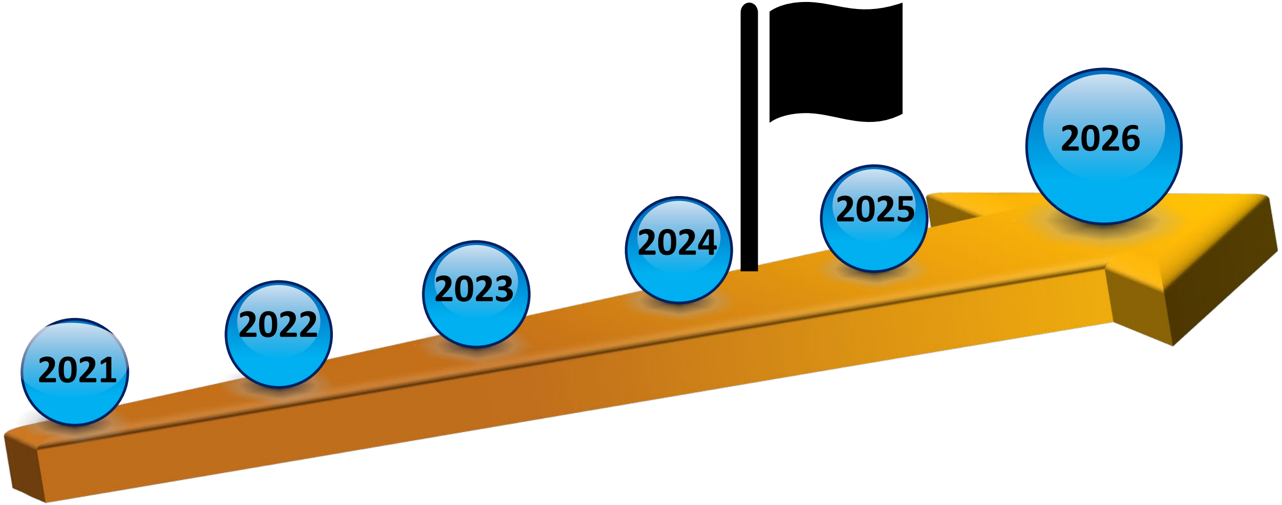
Luke Zettlemoyer
Meta and Univ. of Washington
Artificial Intelligence, Industry

Timeline

- Started on Nov 1, 2021
- Finishing 27 months of the project



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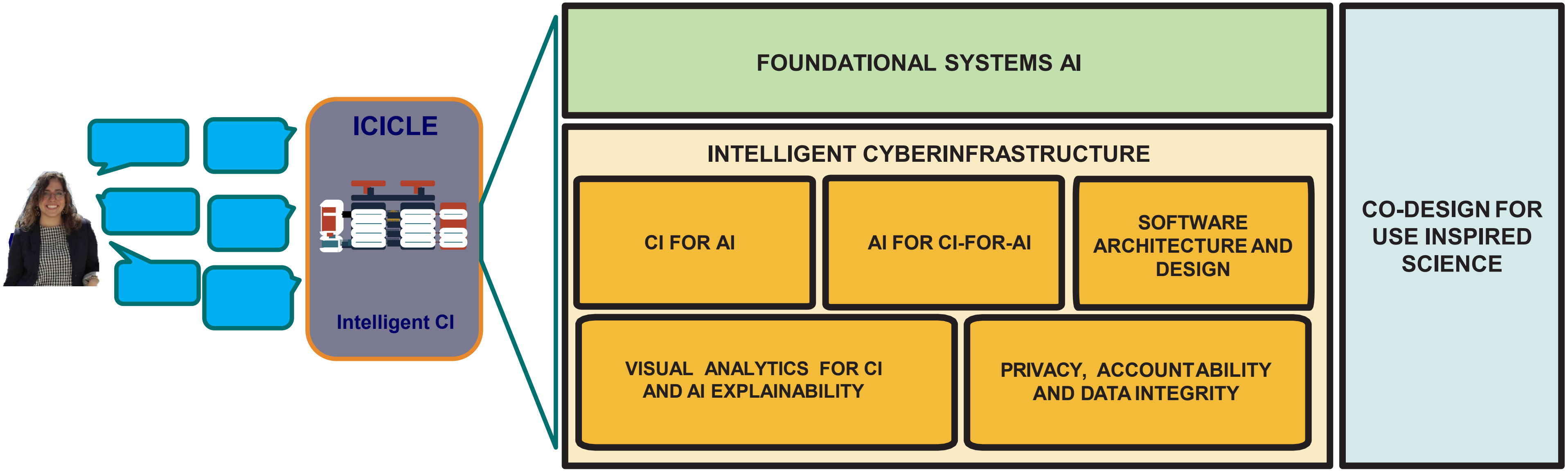
Research Plan: Overall Vision



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

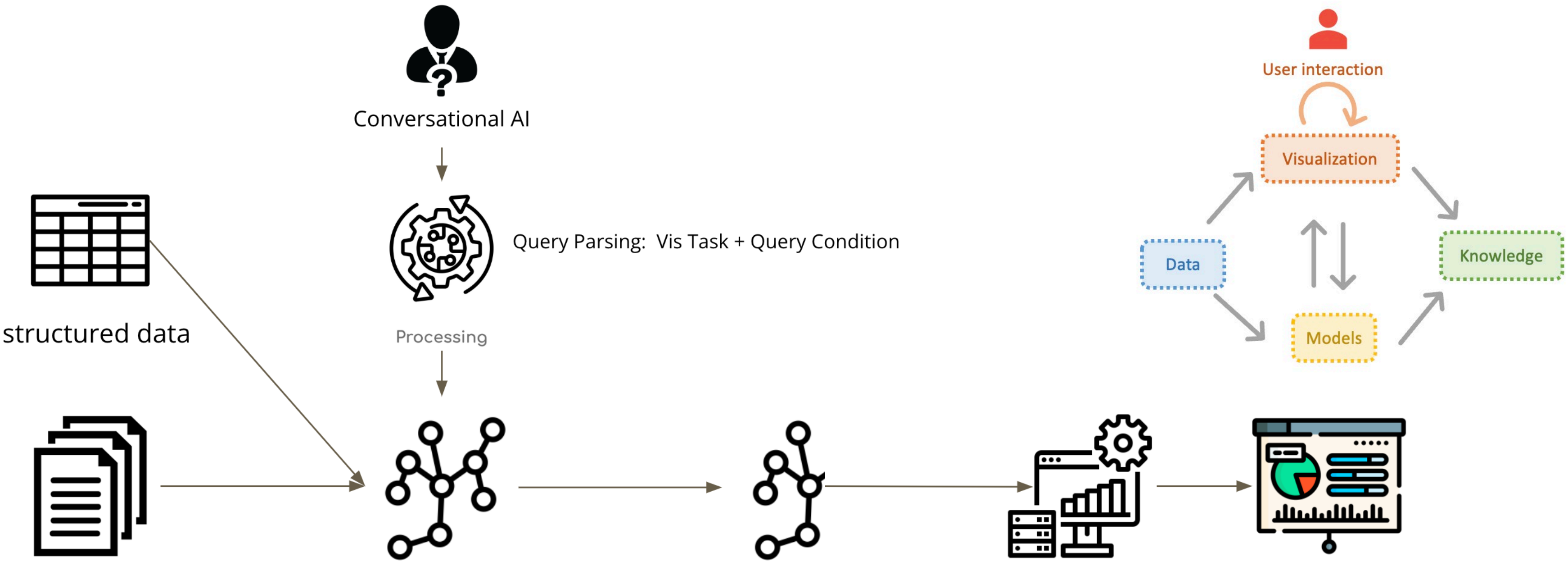
Systems

- 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

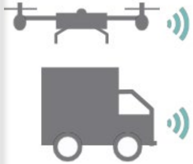


Knowledge Graph
- Meta-info entities
- Content-info entities

- Sub-Graph
- Post-analysis
- Visualization Recommendation

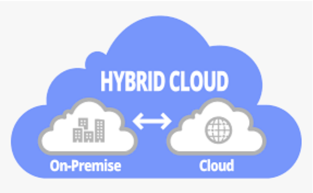
Co-Designing with use-inspired domains

Conv. AI

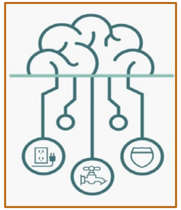


Data: On Field Sensors

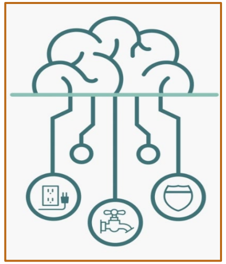
Models: Edge & Near Edge



Data/Models: Cloud

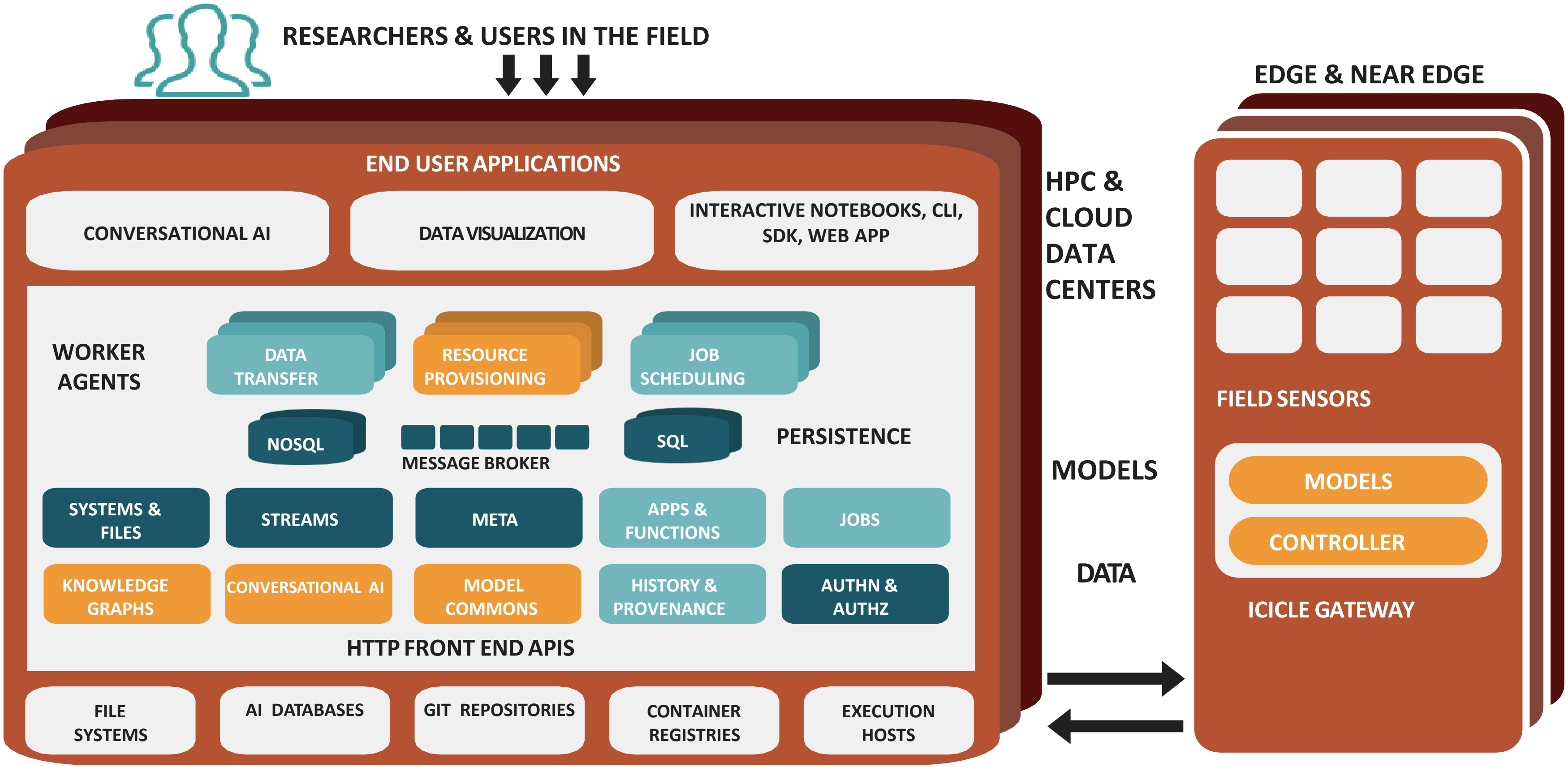


Data/Models: HECs



ICICLE-enabled Computing Continuum

The Deliverable: The ICICLE Software Stack

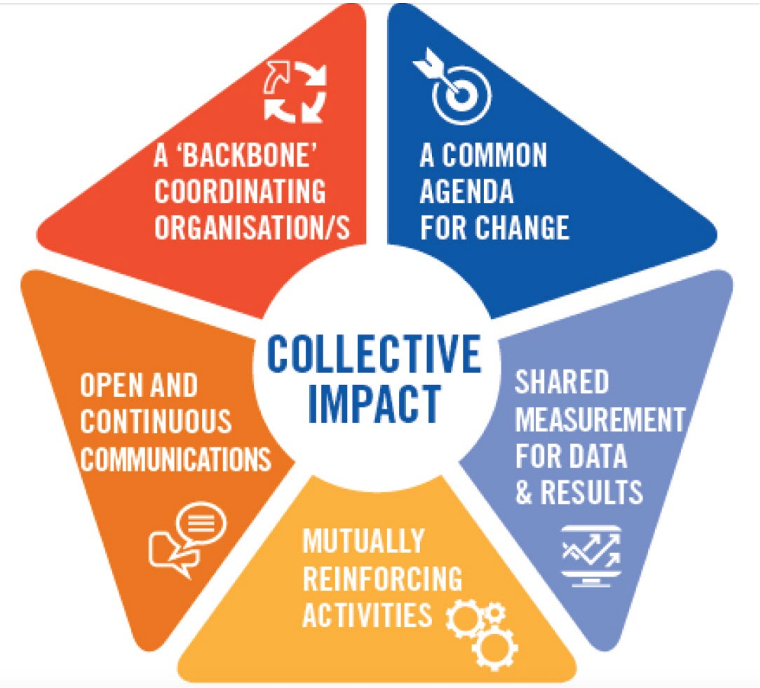


Broader Impacts Backbone Network (BIBN)

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)



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ICICLE Use-Inspired Science: Digital Agriculture






Scott Shearer
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Computer Science & Eng

Co-Leads

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Jenna Kline

John C. Chumley

Kevyn Angueira Irrizary

Ohio State University

Digital Agriculture Hub and Use-Inspired Technologies







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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

Digital Agriculture

What does CI for digital agriculture look like?

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

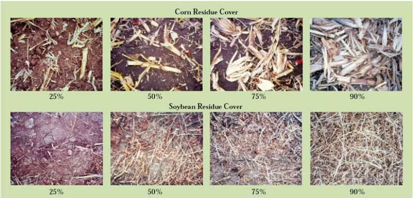
Why use-inspired CI will be transformative?

Multiple Challenges

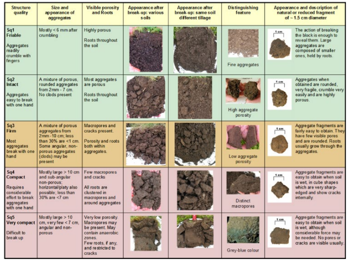
- **Application Domain**
- **Data Labeling**
- **Distributed Training with Semi-Supervised Learning**
- Quantization on Edge Devices
- Aerial Crop Scouting
- End-to-end CI

The Application Domain Challenge (Digital Agriculture)

Computer Vision (CV) based classification scenarios are ubiquitous in use-inspired science domains such as Digital Agriculture

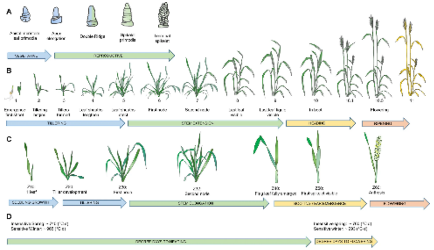


Residue Cover on Soil Surface



Structure quality	Size and appearance of aggregates	Visible porosity and Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature	Appearance and description of natural or reduced fragment of ~ 1.5 cm diameter
Sq1 Friable Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous Roots throughout the soil			Fine aggregates	1 cm The action of breaking the block is enough to reveal them. Large aggregates are composed of smaller ones, held by roots.
Sq2 Intact Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous Roots throughout the soil			High aggregate porosity	1 cm Aggregates when obtained are rounded, very fragile, crumble very easily and are highly porous.
Sq3 Firm Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Porosity and roots both within aggregates.			Low aggregate porosity	1 cm Aggregate fragments are fairly easy to obtain. They have few visible pores and are rounded. Roots usually grow through the aggregates.
Sq4 Compact Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks All roots are clustered in macropores and around aggregates			Distinct macropores	1 cm Aggregate fragments are easy to obtain when soil is wet, in cube shapes which are very sharp-edged and show cracks internally.
Sq5 Very compact Difficult to break up	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low porosity. Macropores may be present. May contain anaerobic zones. Few roots, if any, and restricted to cracks			Grey-blue colour	1 cm Aggregate fragments are easy to obtain when soil is wet, although considerable force may be needed. No pores or cracks are visible usually.

Soil Aggregate Size



Wheat Development

Non-Uniform Emergence

Nitrogen Deficiency

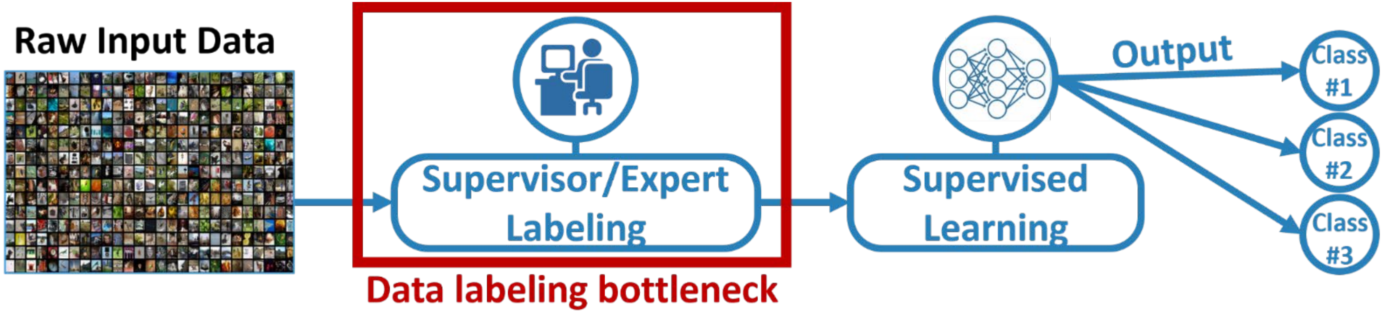
European corn borer

Corn leaf aphid

Mexican bean beetle defoliation

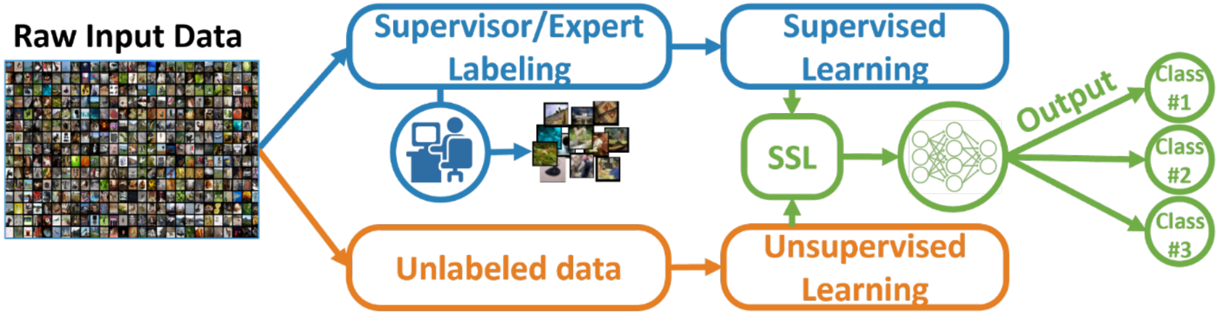
The Data Labeling Challenge

Challenge:



- Data samples need to be fully labeled by an expert for training and evaluation.
- Datasets may be collected frequently and in large volumes (millions of <u>unlabeled</u> images).
- Labeling data by experts is a significant bottleneck.
- Supervised learning can be time-consuming, costly, and infeasible for certain applications

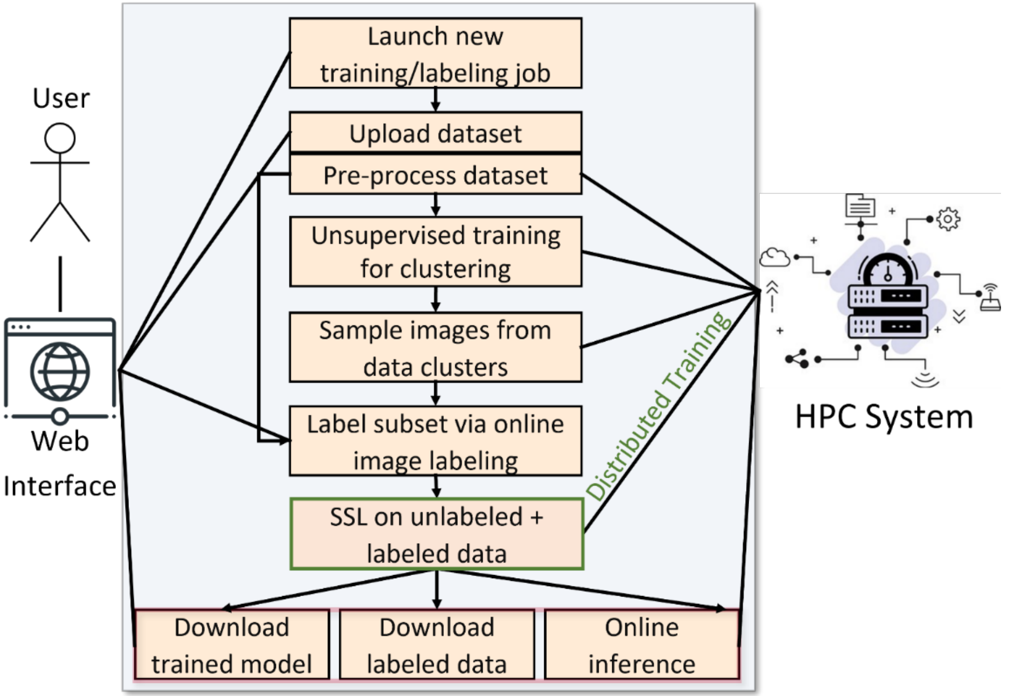
Semi-Supervised Learning (SSL) for Digital Agriculture



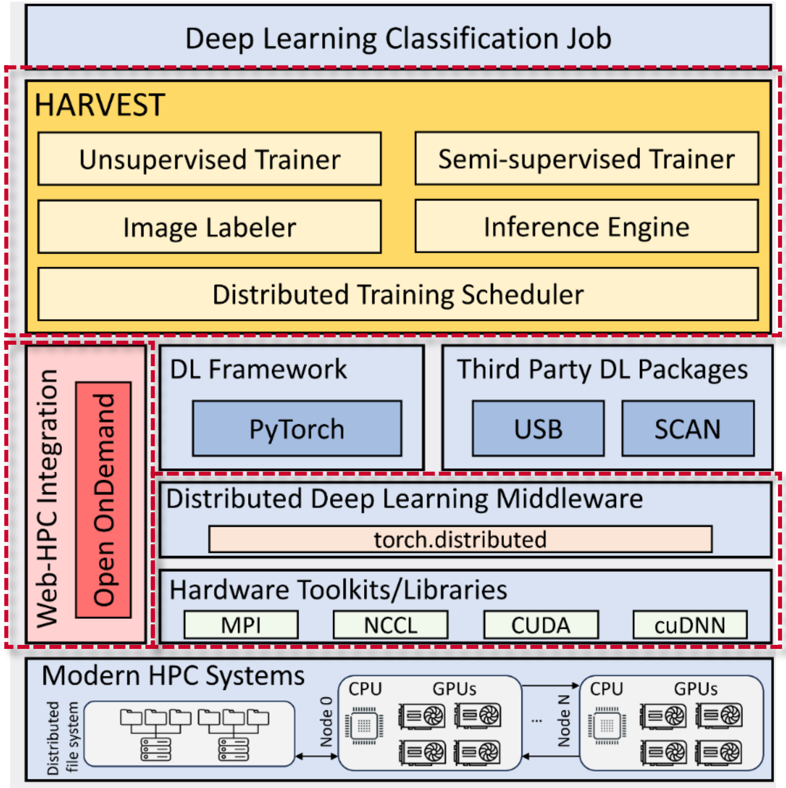
- Only requires a subset of the training dataset to be labeled (less than 1% or few hundreds).
- Achieves high accuracies by training on the rest of the unlabeled data.

HARVEST (High-Performance ARtificial Vision Framework for Expert Labeling using Semi-Supervised Training)

- Design a workflow for domain experts with no prior DL or HPC experience.
- Employ state-of-the-art SSL solutions for computer vision applications.
- Train accurate DL models using only a small fraction of labeled data.
- Accelerate training using distributed training on HPC systems.
- Enable an intuitive and user-friendly interface linked to HPC systems.
- Support any user-defined use case.
- We plan to release HARVEST a service that can be deployed on Cloud/HPC systems.

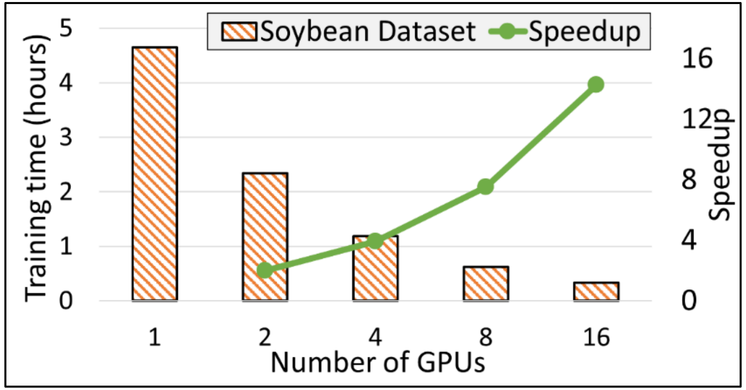


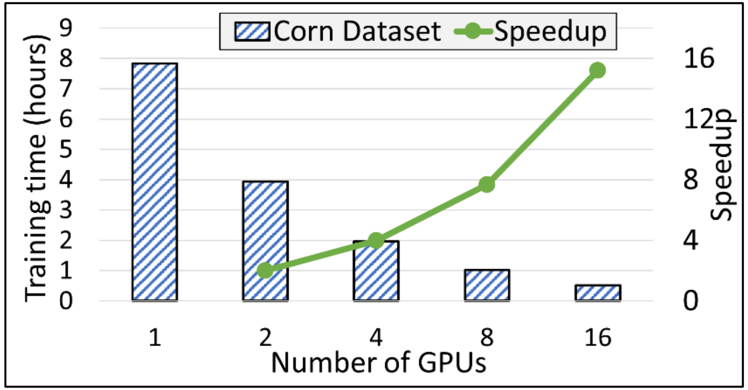
HARVEST Architecture Overview



HARVEST: Evaluation on Digital Agriculture Use Cases

- Use case: Plant stress identification for protecting crops through the growing season.
- Datasets: 1) Corn crops (9558 samples, 12 classes)* 2) Soybean crops (5636 samples, 6 Classes)*
- Achieved 97% and 93% accuracies for the Corn and Soybean datasets using only 80 labeled samples per class.
- Accelerated the training by 15.19x on 16 NVIDIA A100 GPUs reducing the training time from 7.8 hours to 31 minutes.





Dataset	Accuracy	Precision	Recall	F1 Score
Corn Dataset	97.08%	91.77%	95.43%	92.61%
Soybean Dataset	93.07%	88.64%	92.40%	89.61%

N. Alnaasan, M. Lieber, A. Shafi, H. Subramoni, S. Shearer, and DK Panda, "HARVEST: High-Performance Artificial Vision Framework for Expert Labeling using Semi-Supervised Training", 2023 IEEE International Conference on Big Data, December 2023

Multiple Challenges

- Application Domain
- Data Labeling
- Distributed Training with Semi-Supervised Learning
- **Quantization on Edge Devices**
- **Aerial Crop Scouting**
- **End-to-end CI**

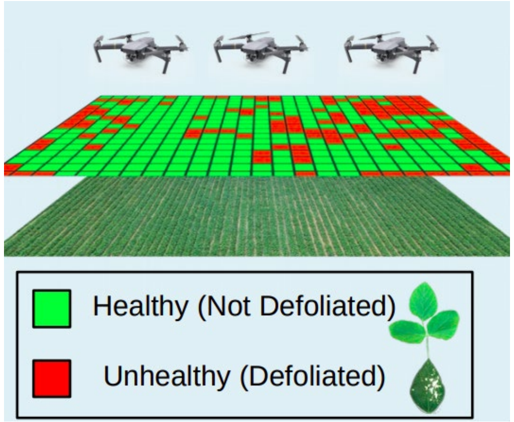
Quantization on Edge Devices

- Edge devices have limited computing power
- Explore the use of various quantization techniques – based on INT8/FP16 and static/dynamic strategies – on a range of DL inference frameworks, including OpenVINO, PyTorch, TFLite, and ONNX.
- The performance evaluation is done on Intel CPUs (Cascade Lake and Skylake) and a Raspberry Pi 4B equipped with an ARM processor.
- The characterization study uses a range of popular DL models – including MobileNetV2, VGG-19, and DenseNet-121. We found that OpenVINO and TFLite are the most optimized frameworks for Intel CPUs and Raspberry Pi 4B device, respectively.
- The performance characterization reveals that the size of original models is reduced by a quarter for INT8-based models without losing accuracy except the slight accuracy reduction of static quantization.

H. Ahn, T. Chen, N. Alnaasan, A. Shafi, M. Abduljabbar, H. Subramoni, and DK Panda,
Performance Characterization of using Quantization for DNN Inference on Edge Devices ,
7th IEEE International Conference on Fog and Edge Computing, May 2023

Digital Agriculture: Aerial Crop Scouting

- **Aerial Crop Scouting:** In this workload, we seek to create *heat maps* that describe crop health for a field
    - *Inform* self-driving tractors and sprayers to reduce the application of pesticide and fertilizer
    - *Predict* crop yields for harvest and market timing
    - *Identify* trends across farms, such as the introduction of resistant weeds
- **Technology:** Unmanned aerial vehicles (UAV) capture high resolution images
    - Flying low (15 ft above ground): 1 pixel -> mm
- **Transformative:** At mm-granularity, stakeholders can detect biological phenomena invisible to satellites
    - Soybean leaf defoliation caused by Japanese beetle
- **Software Pilot** (https://pypi.org/project/SoftwarePilot/)
- **OpenPass** (http://149.165.155.188:2298/)



Courtesy of LaRue Farms Inc.

Goal: Towards Designing End-to-end Digital Agriculture CI Solutions and make these available as Services for various Stakeholders

Use-Inspired Cyberinfrastructure

Crop Health Issues

HPC-Enabled Data Harvesting & Preparation

HPC for Ag AI

From HPC to the field: Computing Continuum

Crop Management Interventions

End-to-end software workflows that democratize access, use, and benefits of AI-driven digital agriculture

Engagement with Other Organizations

- On-going discussions with several other AI Institutes
  - AIFARMS
  - AIIRA
  - AgAID
- Collaboration with TIH-Mumbai (at IIT-Mumbai)
- Interactions with industry
  - CNH Industrial
  - TCS

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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

CI/Software Components Released (so far)

2023.10 Release (10/06/23)

- AI for CI-for-AI
  - High Performance Computing Applications Dataset v1.0
  - HPC Application Runtime Predictor (HARP) v2.0
- Software and Reference Architecture
  - iciflaskn v1.0
  - TapisCL-ICICLE v1.0.11
  - ICICONSOLE v0.8.0
- Animal Ecology
  - Camera-Traps Edge Simulator v0.3.2
- Smart Foodsheds
  - Smart Foodsheds Visual Analytics (VA) Dashboard v0.3

2024.01 Release (01/26/24)

- AI Foundations
  - Iluvatar Functions as a Service (FaaS) Control Plane v1.0.0
- Software Architecture and Design
  - Tapis Federated Authentication Service v1.5.0
  - Tapis Pods Service v1.5.3

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

Outline

- ICICLE Vision and Goals
- Research Challenges Addressed
- Highlights of Digital Agriculture Activities
- CI/Software Released
- **How to Get Engaged?**
- Conclusions

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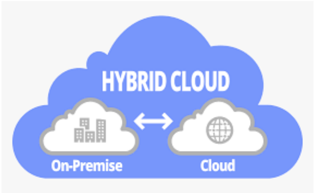
Designing Next-Generation CI through Co-Designing with Use-inspired Domains

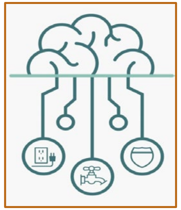
Conv. AI

Data: On Field Sensors

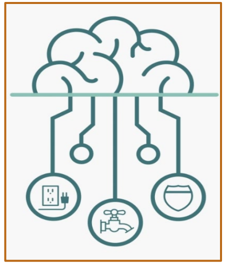
Models: Edge & Near Edge



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

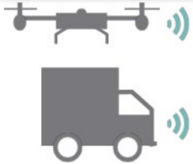
AI for Social Good

ICICLE: Intelligent CyberInfrastructure with Computational Learning in the Environment

Systems AI Foundational Research for CI

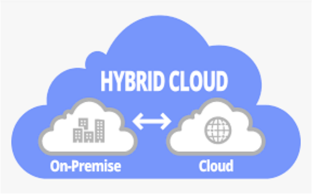
Intelligent Cyber Infrastructure

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



On Field Sensors

Edge & Near Edge

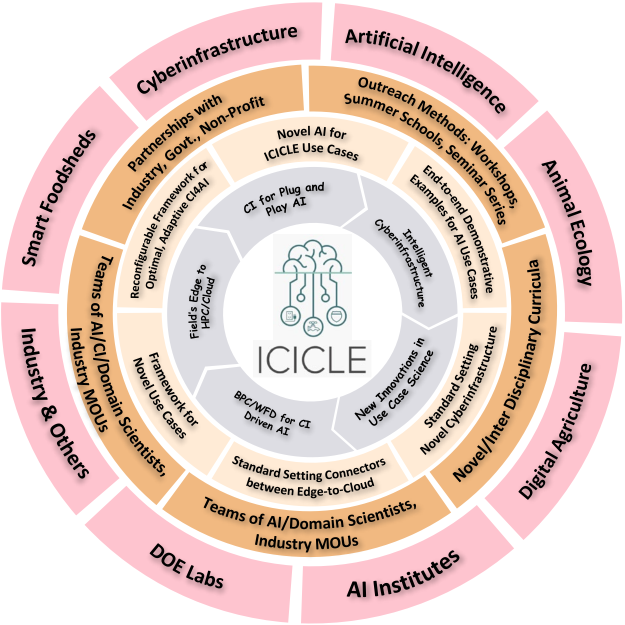


Clouds

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!