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

1. Scientific Computing
2. Big Data & Data Science
3. Artificial Intelligence

HPC Systems & Data Centers

Clouds

HPC Systems & Data Centers

On Field Sensors

Edge & Near Edge

Hybrid Cloud

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/

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

Digital Ag

- CI for Autonomous, Self-Driving Farms
- Wrangling rapid data gen.
- Novel model architectures and datasets
- Open and Public Ag Services
- Adaptive AI at the Edge
- Privacy-aware Data Sharing

Conv. AI

- Data: On Field Sensors
- Models: Edge & Near Edge
- Data/Models: Cloud
- Data/Models: HECs

ICICLE-enabled Computing Continuum

ICICLE - PEARC ‘23
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.

**CI's complexity to deploy AI impedes research discoveries and innovations!**
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

Cl for AI

AI for “Cl for AI”

Emerging Computing Continuum

On Field Sensors

Edge & Near Edge

Clouds

HPC Systems & Data Centers
ICICLE As A Whole

Use-Inspired Science
(Smart Foodsheds, Animal Ecology, Digital Agriculture)

Education and Outreach

CI for Plug-and-Play AI
Intelligent CI
Field’s Edge to HPC/Cloud
BPC/WFD for CI driven AI

Collaboration and Knowledge Transfer

Use-Inspired Science
(Smart Foodsheds, Animal Ecology, Digital Agriculture)
Participation:
14 Organizations, 33 faculty, 41 staff, (58 PhD, 16 MS, 16 undergrad, 6 K-12) students & many Collaborators
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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Artificial Intelligence, Industry
Timeline

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

• ICICLE Vision and Goals

• Research Challenges being Addressed
  • Selected Accomplishment Highlights
  • How to Get Engaged?
  • Conclusions
Research Plan: Overall Vision

ICICLE

Intelligent CI

FOUNDATIONAL SYSTEMS AI

INTELLIGENT CYBERINFRASTRUCTURE

CI FOR AI

AI FOR CI-FOR-AI

SOFTWARE ARCHITECTURE AND DESIGN

VISUAL ANALYTICS FOR CI AND AI EXPLAINABILITY

PRIVACY, ACCOUNTABILITY AND DATA INTEGRITY

CO-DESIGN FOR USE INSPIRED SCIENCE
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: CI4AI**

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

Structured data

Document

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

Query Parsing: Vis Task + Query Condition

Processing

Conversational AI

User interaction

Data

Visualization

Models

Knowledge

Sub-Graph

Post-analysis

Visualization Recommendation
Co-Designing with use-inspired domains

ICICLE-enabled Computing Continuum

Conv. AI

Data: On Field Sensors

Models: Edge & Near Edge

Data/Models: Cloud

Data/Models: HECs
The Deliverable: The ICICLE Software Stack

RESEARCHERS & USERS IN THE FIELD

END USER APPLICATIONS
- CONVERSATIONAL AI
- DATA VISUALIZATION
- INTERACTIVE NOTEBOOKS, CLI, SDK, WEB APP

WORKER AGENTS
- DATA TRANSFER
- RESOURCE PROVISIONING
- JOB SCHEDULING
- MESSAGE BROKER
- SQL
- PERSISTENCE
- NOSQL
- SYSTEMS & FILES
- STREAMS
- META
- APPS & FUNCTIONS
- JOBS
- KNOWLEDGE GRAPHS
- CONVERSATIONAL AI
- MODEL COMMONS
- HISTORY & PROVENANCE
- AUTHN & AUTHZ

HTTP FRONT END APIs
- FILE SYSTEMS
- AI DATABASES
- GIT REPOSITORIES
- CONTAINER REGISTRIES
- EXECUTION HOSTS

ICICLE GATEWAY
- MODELS
- CONTROLLER

HPC & CLOUD DATA CENTERS
- FIELD SENSORS
- EDGE & NEAR EDGE
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

**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

[https://icicle.osu.edu/cyberinfrastructure/software](https://icicle.osu.edu/cyberinfrastructure/software)
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.

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Computer Science & Eng

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Co-Leads

Digital Agriculture Hub and Use-Inspired Technologies

Artificial Intelligence for Cyberinfrastructure

Cyberinfrastructure for AI-Driven Digital Agriculture

Privacy-aware, Explainable AI, & Democratization

Stakeholder Engagement
Demo: Digital Agriculture

**Digital Agriculture Hub:** We have developed a cloud-to-edge middleware for data-driven agriculture-related services. In which, all stakeholders can integrate projects as microservices (using Python + Apache Web server + JetStream 2).

- [https://go.osu.edu/icicle-ag](https://go.osu.edu/icicle-ag)
- [https://icicle.osu.edu/cyberinfrastructure/software](https://icicle.osu.edu/cyberinfrastructure/software)
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  Xiaqi Wang  Rui Qiu  Han-Wei Shen
The Ohio State University

Patrick R Huber  Allan D Hollander
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Matthew Lange  Michelle Miller  Jinmeng Rao  Song Gao  Alfonso Morales
International Center for Food Ontology Operability Data and Semantics (IC-FOODS)
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)
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
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.
Broader Impact Backbone Network (BIBN)

- **Beth Plale**
  - Indiana University

- **Maureen Biggers**

- **Sadia Khan**

- **Julie Wernert**

- **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
Outline

• ICICLE Vision and Goals
• Research Challenges being Addressed
• Selected Accomplishment Highlights
• 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

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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 Cyber Infrastructure with Computational Learning in the Environment
 Systems AI Foundational Research for CI

Intelligent Cyber Infrastructure

CI for AI
AI for “CI for AI”

Emerging Computing Continuum

On Field Sensors
Edge & Near Edge
Clouds
HPC Systems & Data Centers
ICICLE Enabling Global Leadership in `Computing + AI’

- 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

Join Us!
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- M. Kuhn, UW Madison
- Y. Hu, UCSD
- K. Sung, UW Madison

## Educational Fellows (2023)
- B. Alston, OSU
- TE. Feiten, UC
- A. Hingle, GMU
- C. Lucken, UC
- C. Okolo, CU

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Thank You!