Transforming Agriculture with Intelligent Cyber-Physical Systems

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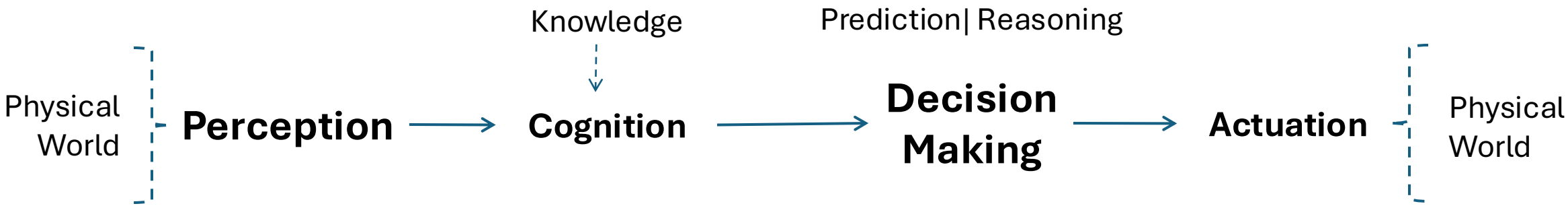
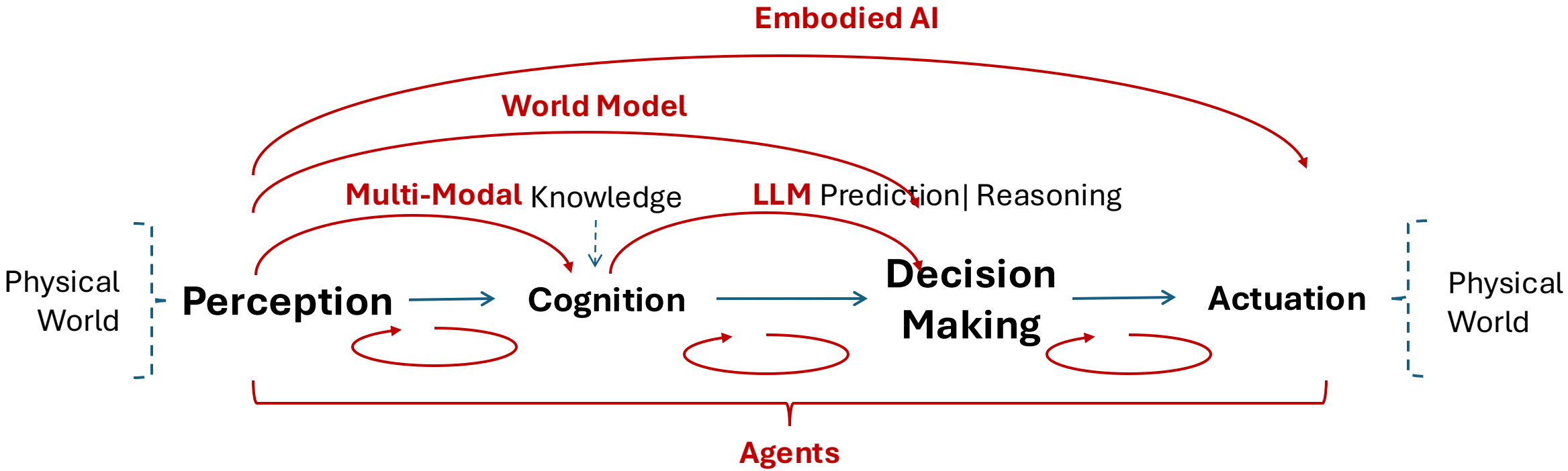
A Typical CPS 1.0



When Turing Meets Wiener



Wants for 20 years from now

- **AI4CPS:**
  - Physical, generalizable AI help handle unexpected environments and disturbance
  - Quantum computing, organoid intelligence(OI), satellites, 6G and beyond further accelerate
  - Exploratory AI and agentic composition will discover patterns and evolve with applications
  - Transform domains that weren't possible/popular before, such as agriculture, scientific discovery, deep space/deep ocean frontiers

- **CPS will be systems of heterogeneous, autonomous, and self-evolving systems**
  - Personalization and customization will be the norm
  - Resilience, not peak performance, will be a key requirement
  - We need an architecture for intelligent CPS
  - Trust will be the bottleneck

- **CPS4AI:**
  - Scenarios, datasets, simulators, tools and testbeds that enable intelligence to be safely developed and tested
  - Are safety, reliability, security, timeliness, etc. data problems?

Transforming Agriculture with Intelligent CPS

Food Security

is National Security

FAO 2025 Report

28% 2.3 Billion people are vulnerable to food security

Morgan Chase Report

5W Challenges:

War, Weather, Water, Warehouse, Waste

Aging Farming Population

Farmers' average ages are **over 50** in most developed countries

Common Practice

Heavily Rely on Experiences

Experiences are localized. Climate change and new seeds make them obsolete.

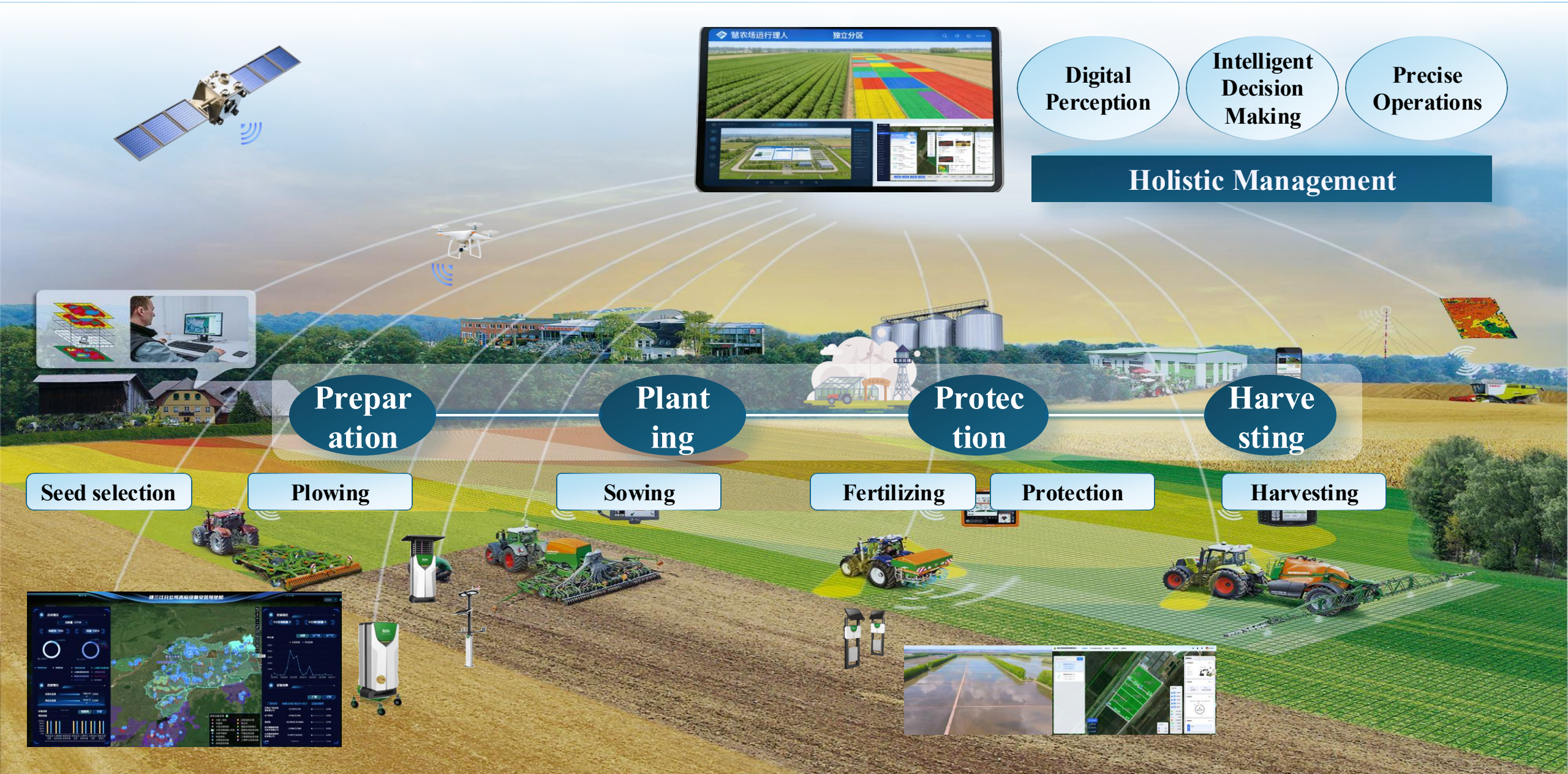
Hard to Close the Loop

Technologies and capabilities are scattered. Most data are collected for human perception.

Equipment is Not Smart Enough

They lack the level of autonomy to adapt to complex enviroments. Most decisions depend on human operators.

What Are Smart Farms

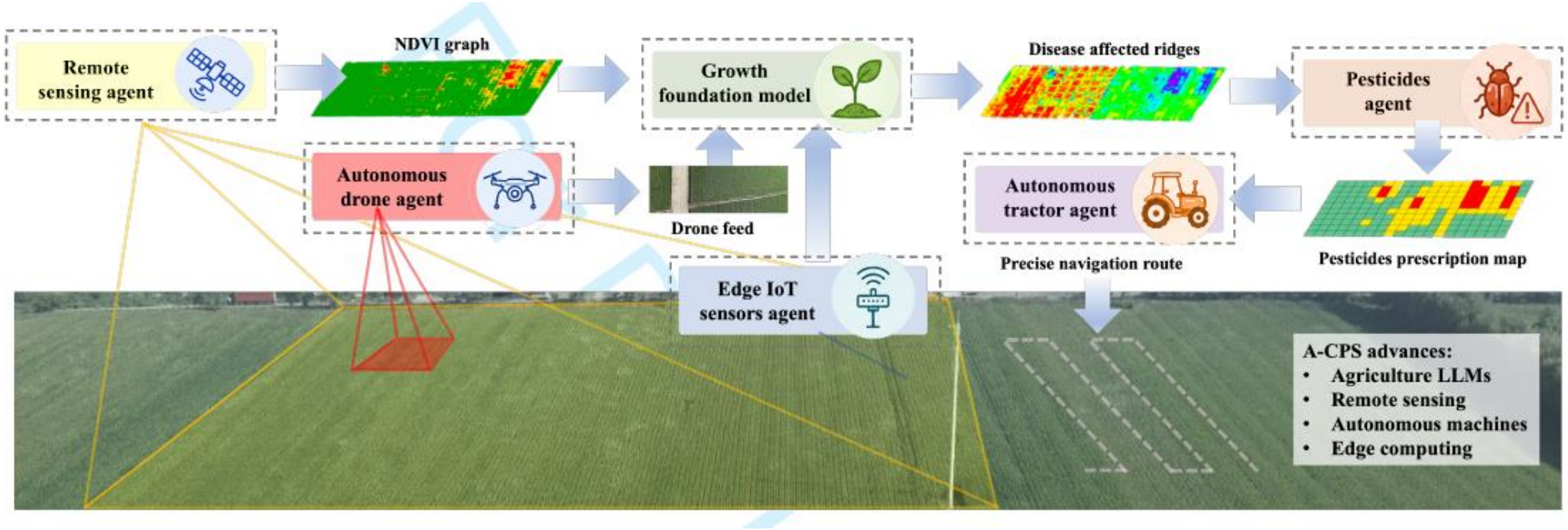


Core Challenges

Challenge	What makes it hard
Biological–physical–cyber complexity	Living crops, soil and weather are coupled to sensors, models and machines — no clean layer boundaries
Uncontrollable environments	Rain, pests, terrain and markets cannot be scheduled, isolated or re-run
Vast areas to cover	Traditional communication infrastructure cannot provide range and bandwidth together
Multi-scale dynamics	Milliseconds (control loops) to seasons (growth); a single plant to an entire region
Low cost	The margin of agriculture is typically low to afford expensive infrastructure

Agriculture stresses every assumption CPS design usually makes.

Four Advances Essential for the A-CPS



remote sensing · edge computing & networks · LLMs & agents · autonomous driving

Each advance covers one arc of the loop — together they make it runnable.

What Has Been Done on that so far

- Perception
  - Integrated Air-Gound Perception: Satellites-Drones-Vehicles-IoT Sensors
  - Low-Earth Orbit Satellite Communication
  - Foundation models for remote sensing
  - Data alignment across temporal-spatial-semantic dimensions
- Cognition
  - Domain-specific LLM fine tuning
- Decision Making
  - Foundation Model for Plan Growth
  - Causality reasoning
- Actuation
  - Autonomous farm vehicles
- Integration
  - Demonstrates intelligent A-CPS over 1000ha

Sensing and Perception



Satellite:
Sentinel-2 MSI
Planet Scope SD
etc.



UAV:
DJI Mavic 3
Multispectral

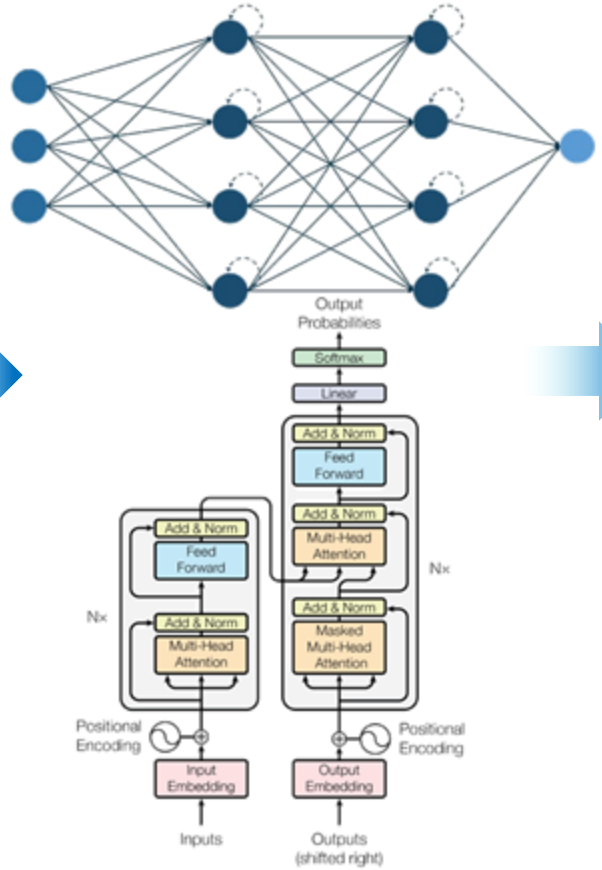


IoT:
stationary
on vehicle
handheld

Data Collection

Calibration
Outlier Removal
Completion
Alignment
Feature Engineering

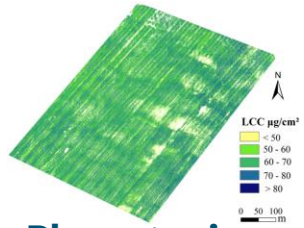
Data Management



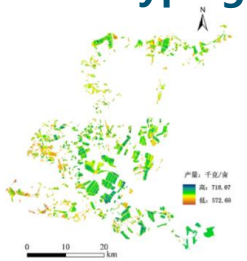
Edge/Cloud AI



Planting Structure



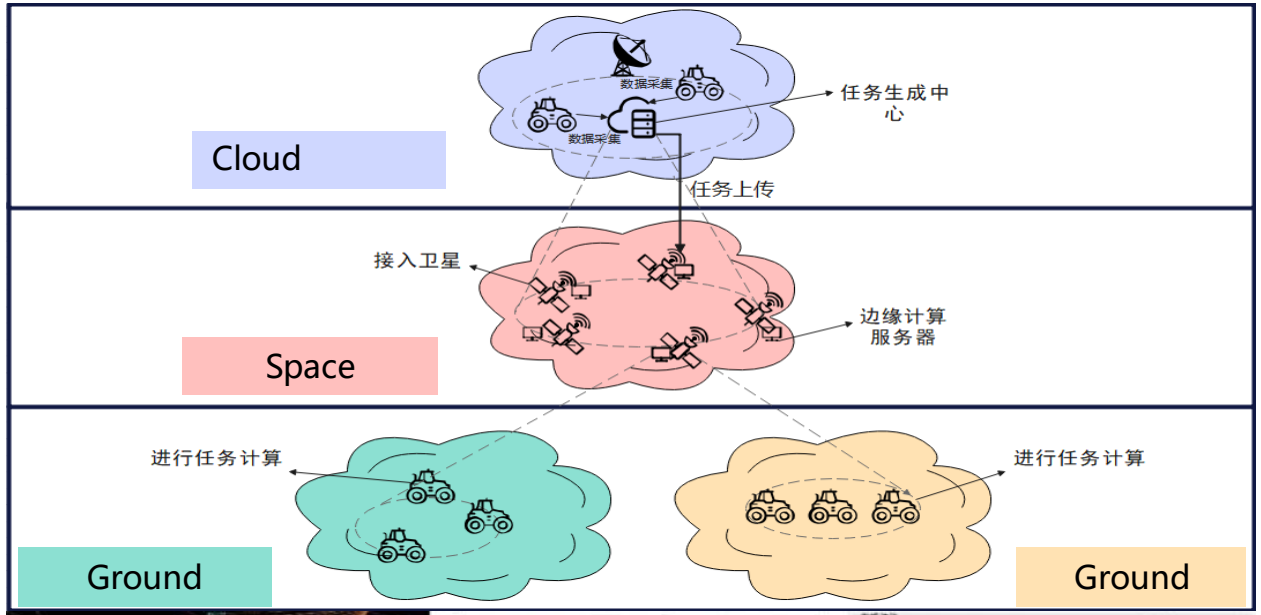
Phenotyping

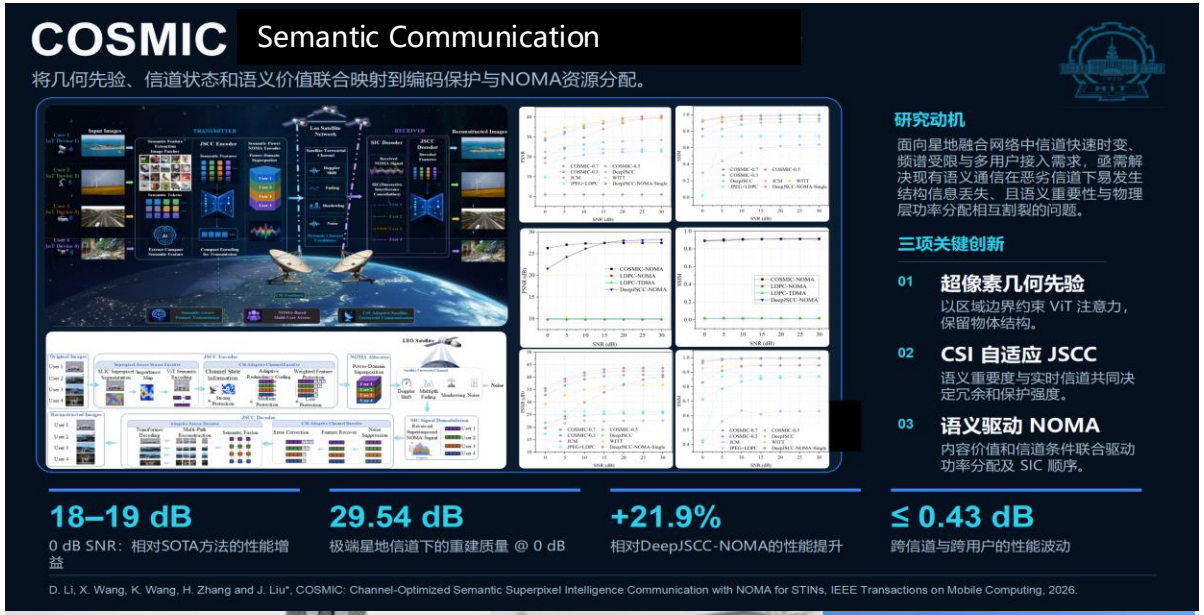


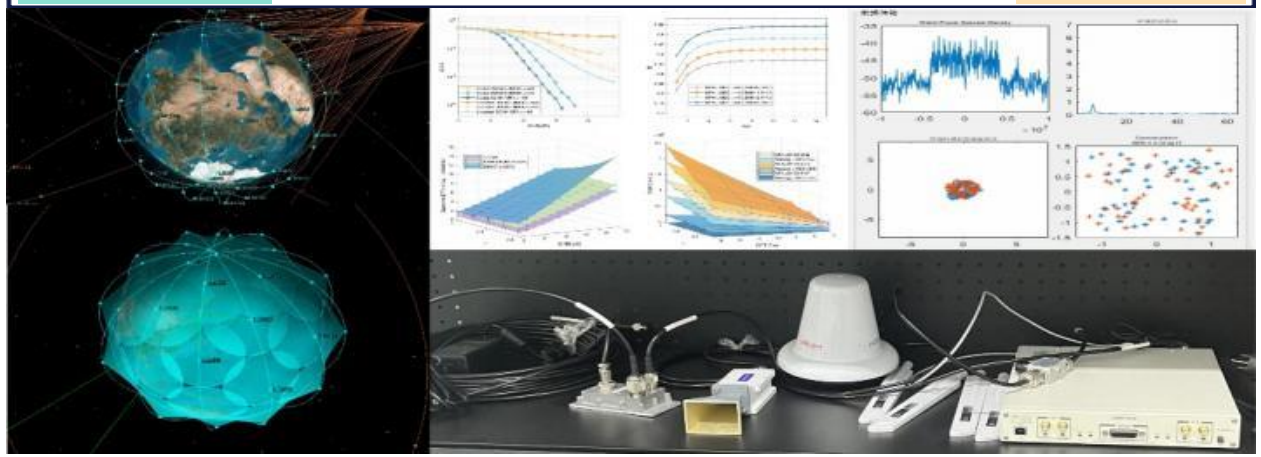
Stress

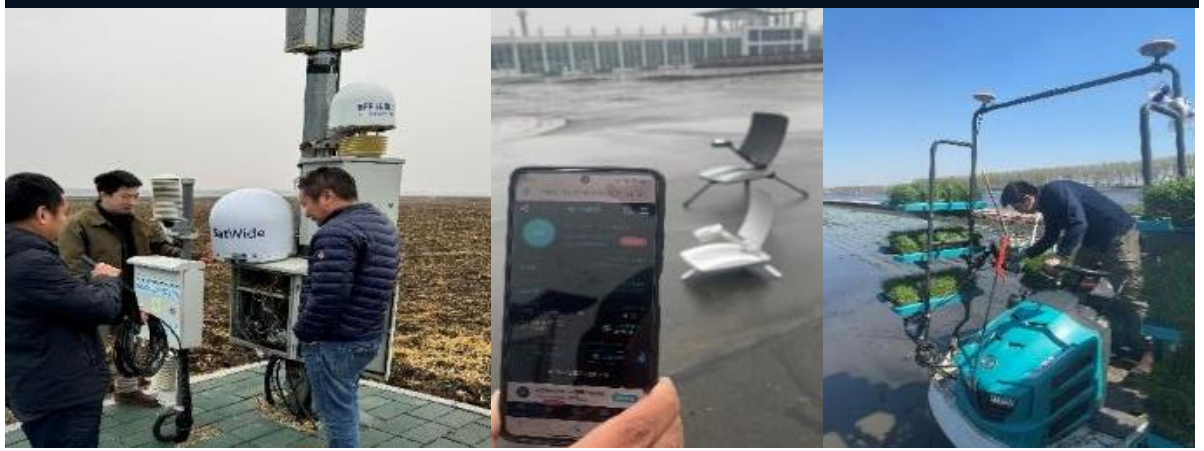
Perception

Satellite Communication and Edge Computing



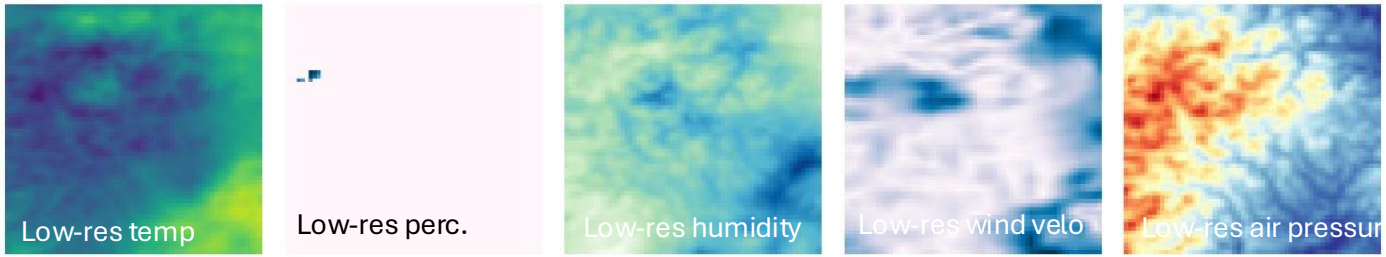


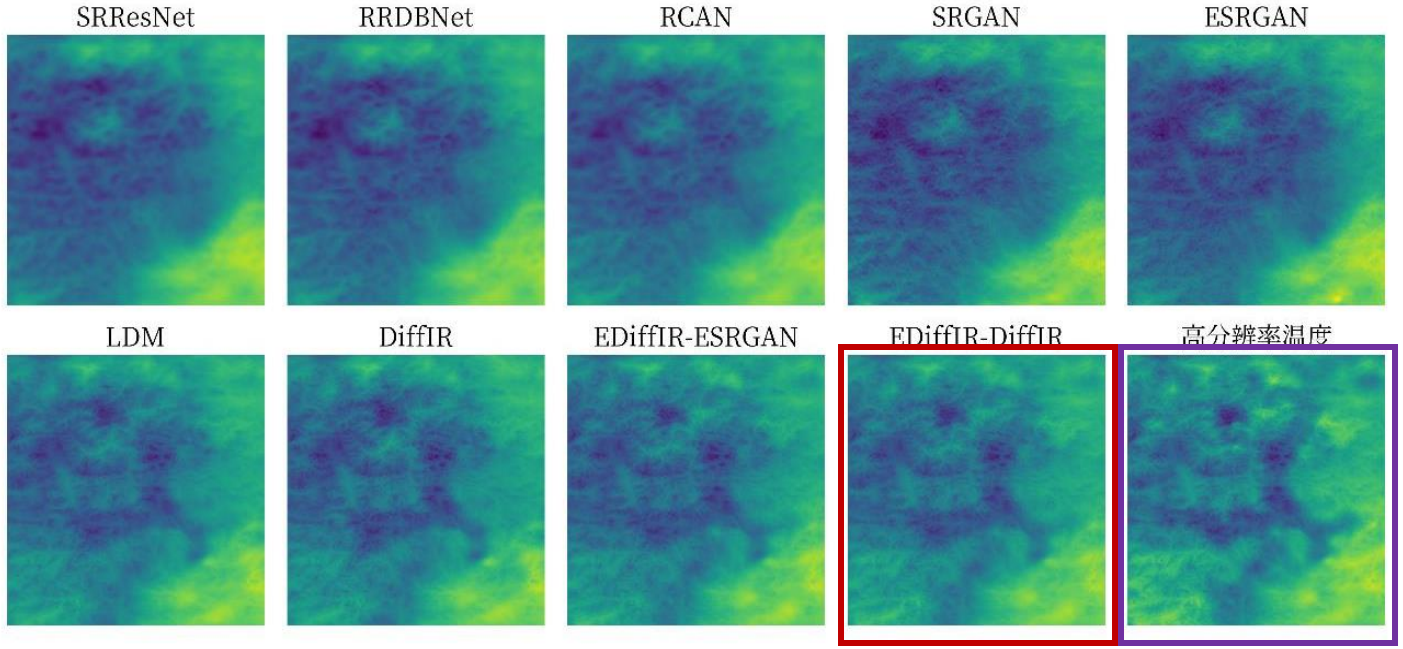


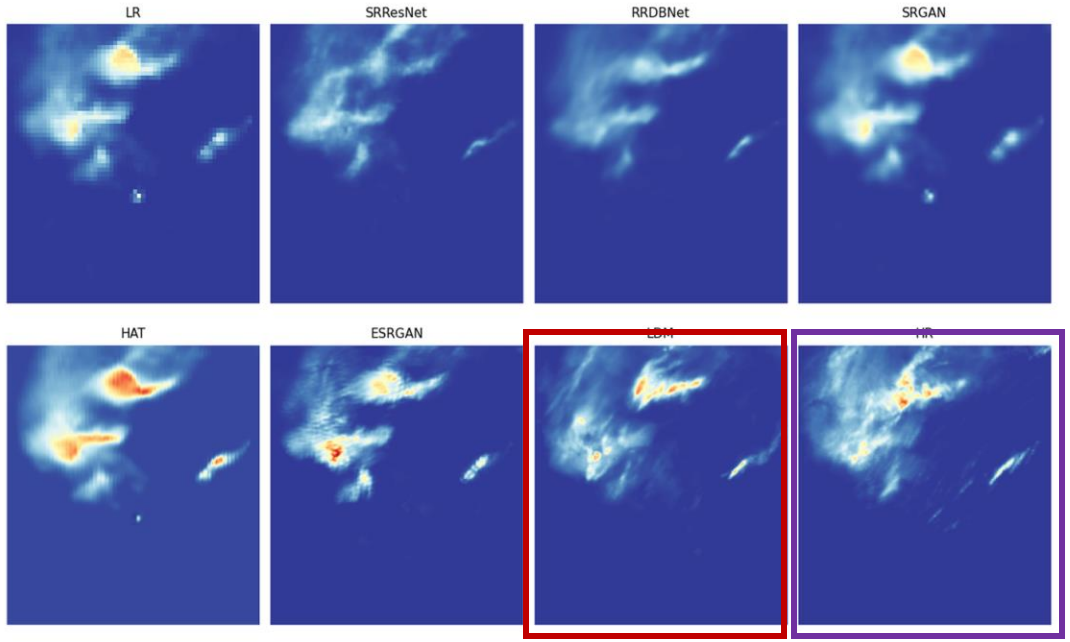


Short Term Weather Forecasting

Multi-modal and diffusion technologies for high-res temperature and rain forecast



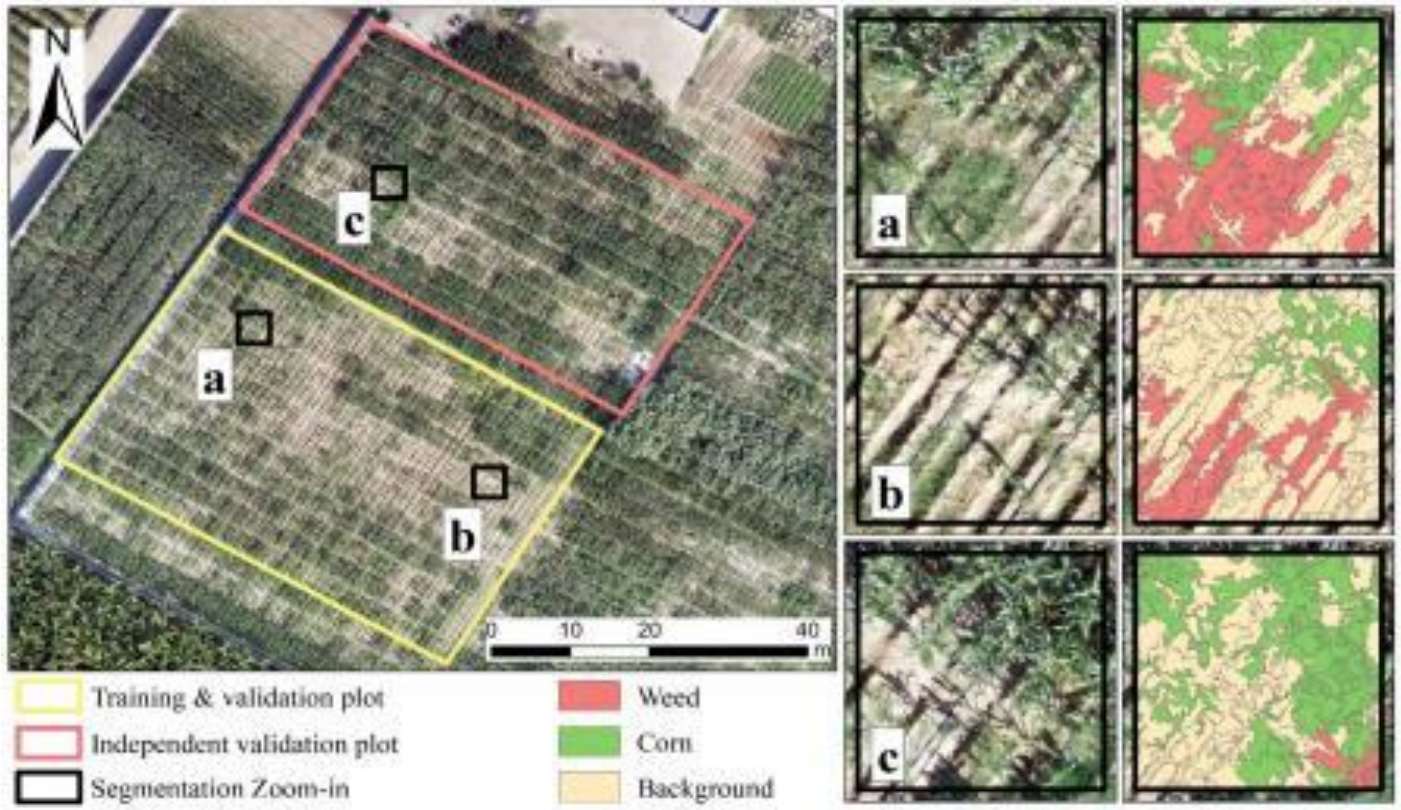




Remote Sensing Foundation Model

- A single model supports various downstream tasks, including plant water content, plant height, leaf area index (LAI), chlorophyll content, above-ground biomass, and yield prediction.





The Kwoo Agricultural LLM

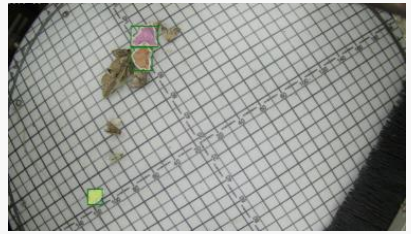
Domain Q&A



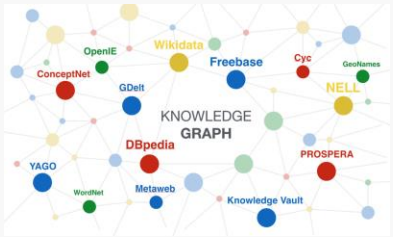
Crop Variety Recommend



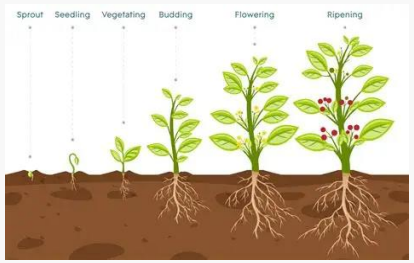
Pest & Weed Identification



Bwd Compatible



Growth Prediction

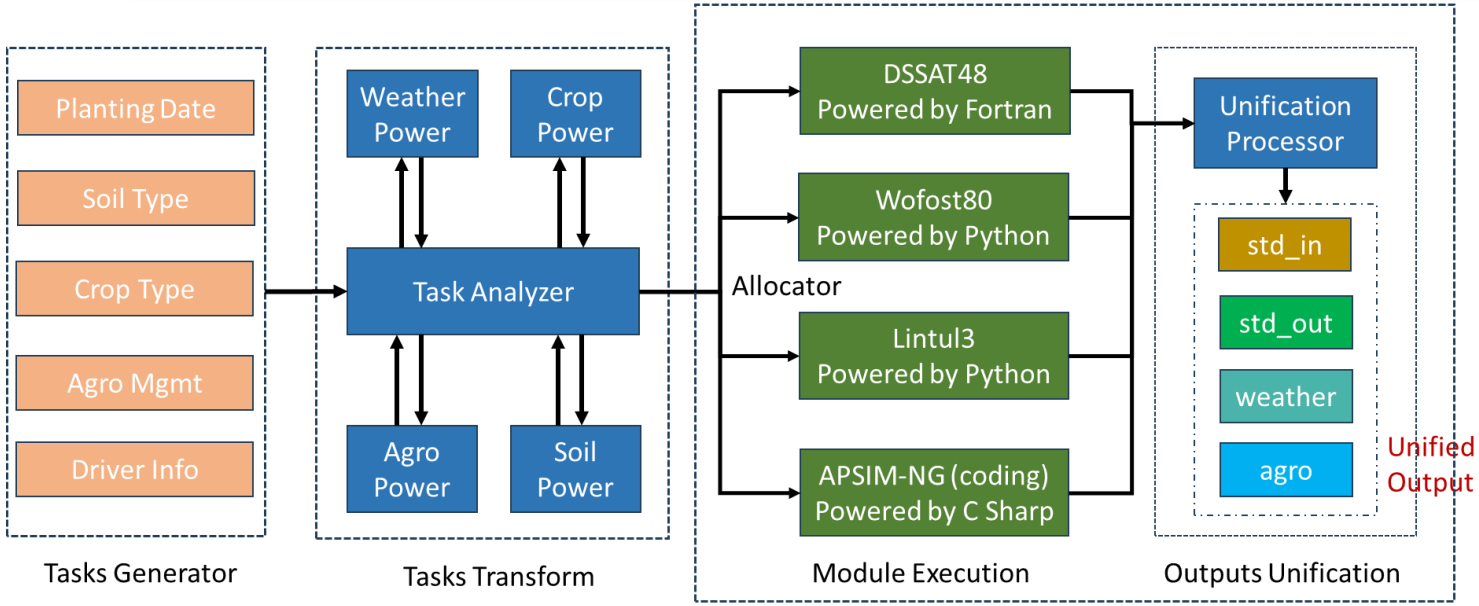


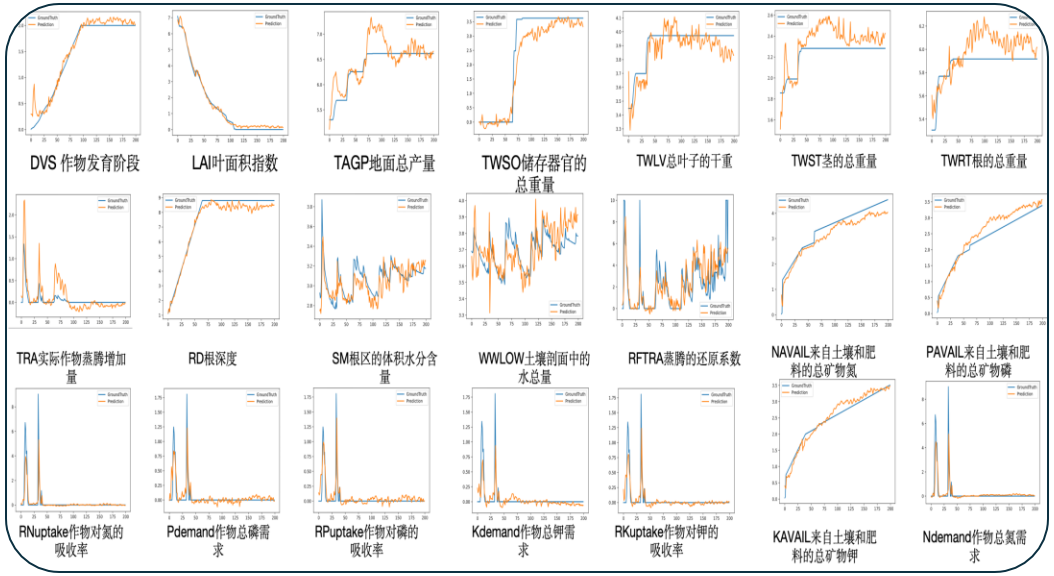
Farming Op. Generation



Kwoo Plant Growth Model: A World Model

- Overcome data sparsity with first-principle simulations
- Train a foundation model that can work for different climate and seed varieties
- Tested on 1400 kinds of soybeans, 11different regions, Critical growth stages prediction correctness above 95%, without individual parameter engineering





Autonomous Farm Vehicles

Dry Field

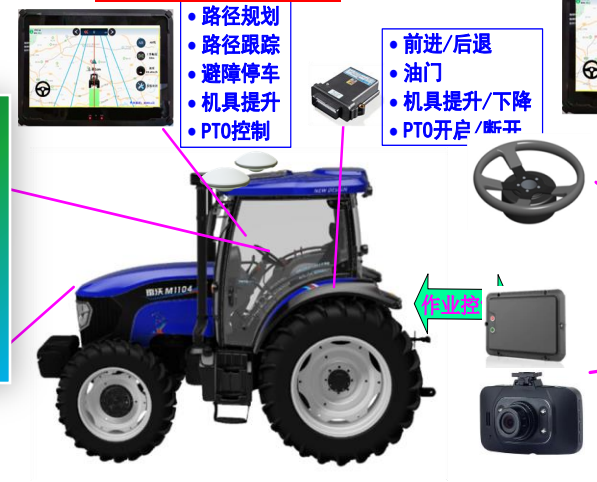




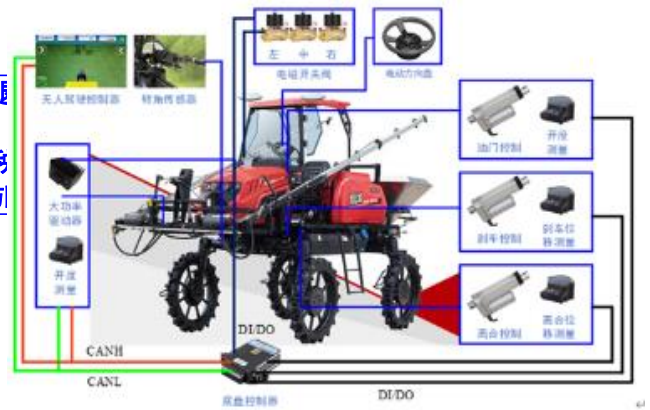


Plow | **Sow** | **Spray** | **Harvest**

Paddy Field



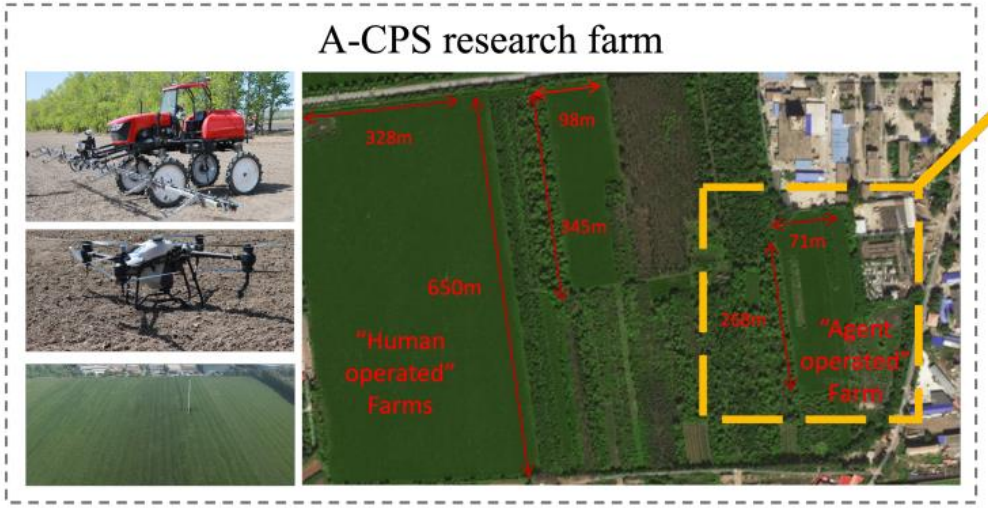


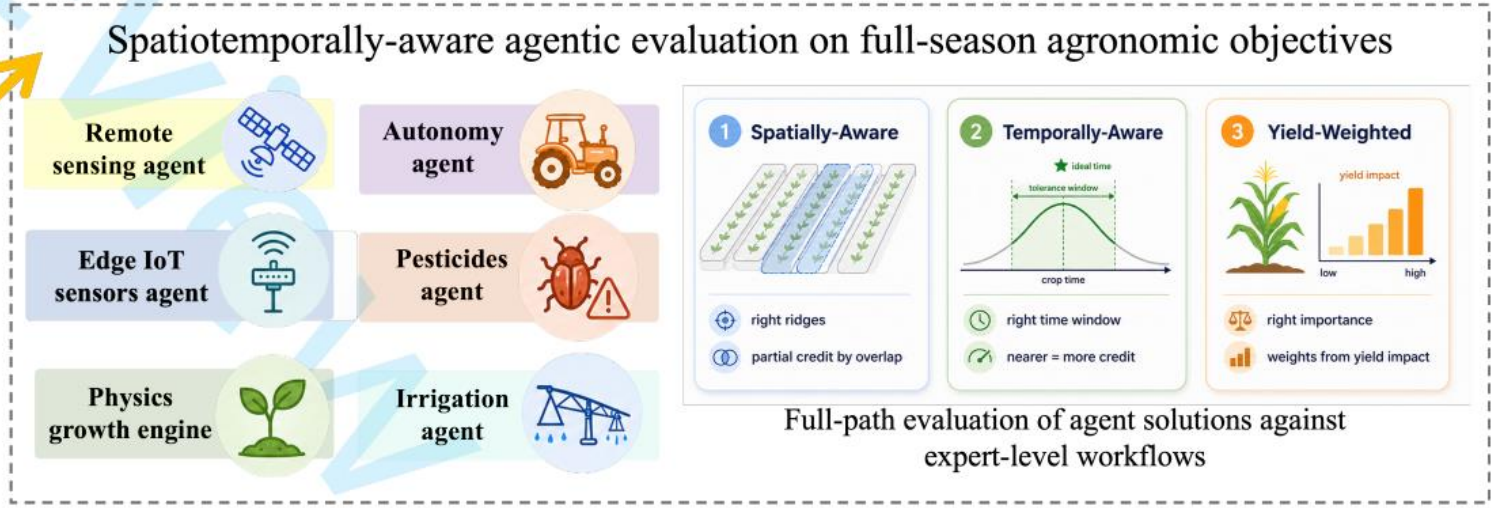




LLMs & Agents: Orchestration & Reasoning

- **Agents for workflows:** farm tasks decomposed into directed graphs of tool-using agents
- **Skill orchestration:** a scheduler hub coordinates perception, decision and actuation agents as skills
- **Reasoning engines:** Symbolic and numerical reasoning with intrinsic uncertainty
- **World models in the loop:** growth models and physical laws used as predictors and harness
- **Human-in-the-loop:** high-stakes actions stay gated by human approval





From Prototype to Production: Deployment Outcomes

>50%
labor savings

>90%
pest & disease recognition accuracy

$R^2 = 96.6\%$
KwooGr growth-stage prediction

2,628
production entities served

35,000
farmers benefited

≈312,600 ha
deployed in production

Cumulative economic benefit: ≈ $17M over three years

The Road Ahead

- Generalize **farm world models** and close the decision loop with more varieties and environments
- Advance **embodied intelligence** in autonomous farms vehicles for precise operations
- **Codesign** hardware, networking, and intelligence for personalized solutions
- Use **uncertainty, safety, trust, and human intervention** as first-class citizens in harnessing multi-agent systems

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- **Commercialization Team:** AIRoHIT
- **Major Collaborators:** Beidahuang Group (largest farming cooperation in China) and its subsidiary farms, China Mobile, Sinichem MAP, Lovol, DEWO, Huida Tech, three National Labs, China Academy of Agriculture, Beijing Academy of Agriculture and Foresty, THU, NEAU, SCAU, Nanjing AU, Huazhong AU, etc.