NSF WORKSHOP ON CYBER-PHYSICAL SYSTEMS · PANEL

Recommended Future Directions for the CPS Program

Perspectives from the CPS founders

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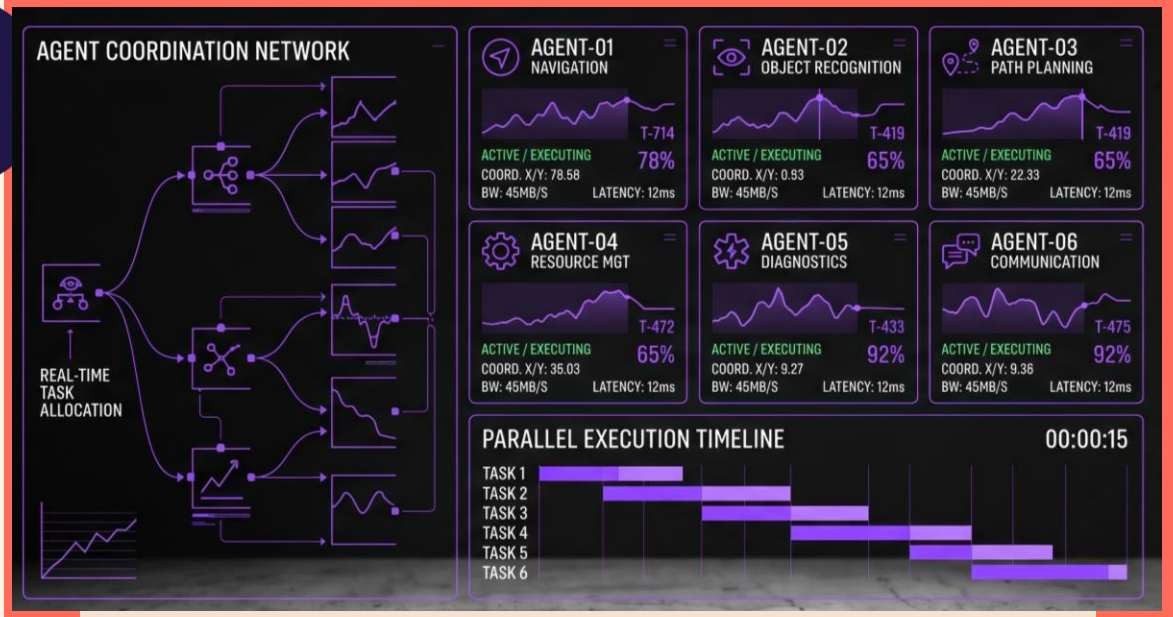
MULTI-AGENT CPS

The future of CPS is multi-agent

Single-system guarantees for safety, reliability and performance are necessary. The frontier is scaling from 10 to 1,000 to 10,000 agents.

- Teams that collaborate and compete under adversity: the environment, shifting dynamics, rival agents in a marketplace
- Safety assurances that hold even as agents show emergent behavior
- Rule-based role assignment does not scale. **MAD Games** (Multi-Agent Dynamic Games) reward teamwork at runtime while honoring individual goals.





EXAMPLE

1,000 delivery drones share a city's airspace and chargers. Instead of a central rulebook, each bids for routes and slots, and the game keeps the fleet cooperative and safe.

PLANT-WIDE OPTIMIZATION

2

Plants that learn to adapt

Today’s plants are many individual PID loops, orchestrated around fixed optimization problems that assume narrow operating ranges.

- Real plants face feedstock variation, component and catalyst degradation, and economic disturbances
- Fast optimizers and controllers that keep adapting after deployment, across the whole plant
- A new science of **Learning to Adapt** for large-scale industrial automation



EXAMPLE

A refinery re-optimizes plant-wide setpoints as crude quality shifts and its catalyst ages, instead of running a fixed recipe until the next manual retune.

AI COACHING

AI that builds human skill

3

With jobs displaced every 1.5 to 2 years, we must raise how fast people build competency in blue-collar and white-collar work.

- AI Coaching for accelerated skill development, with tools for grassroots retraining centers
- Keep the human engaged, challenged and motivated to finish the program
- Not an AI Assistant (does the task) or an AI Co-Pilot (on-the-job help). **Coaching grows the person.**



EXAMPLE

A displaced warehouse worker trains as a robot technician with an AI coach: the same skill in 30% less time, or 30% more competency in the same time.

UNCERTAINTY QUANTIFICATION

4

Digital twins that know their limits

We need a theory of uncertainty quantification for complex systems, built on physics-informed ML (PIML) and neural operators (PINOs).

- **Sample efficiency:** accurate models from far less data
- **Calibrated confidence:** know where the model is more or less reliable on out-of-distribution data
- **Inverse problems:** infer hidden parameters from obser behavior



EXAMPLE

A battery-pack twin flags low confidence when cells age beyond its training data, and infers internal degradation from voltage and temperature alone.

PHYSICAL AI EDUCATION

CPS 2.0 is Physical AI

Start Physical AI training in high school to build a systems mindset. CPS 2.0 is Physical AI, and Physical AI is CPS 2.0.

- **RoboRacer.ai** as a community-driven CPS competition and challenge-problem dojo
- Students loop from concept to code to competition, a fun and efficient path to mastery
- Competitions that push the limits teach us safety cases along the long tail of operating regimes



Physical AI: Autonomous Machines for K-12

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Concept

Code

Competition

EXAMPLE

High-school teams build small-scale autonomous robots, race head to head, and learn overtaking safety from their own near misses.