

HARMONIC

Human-AI Robotic team Member Operating with Natural Intelligence and Communication

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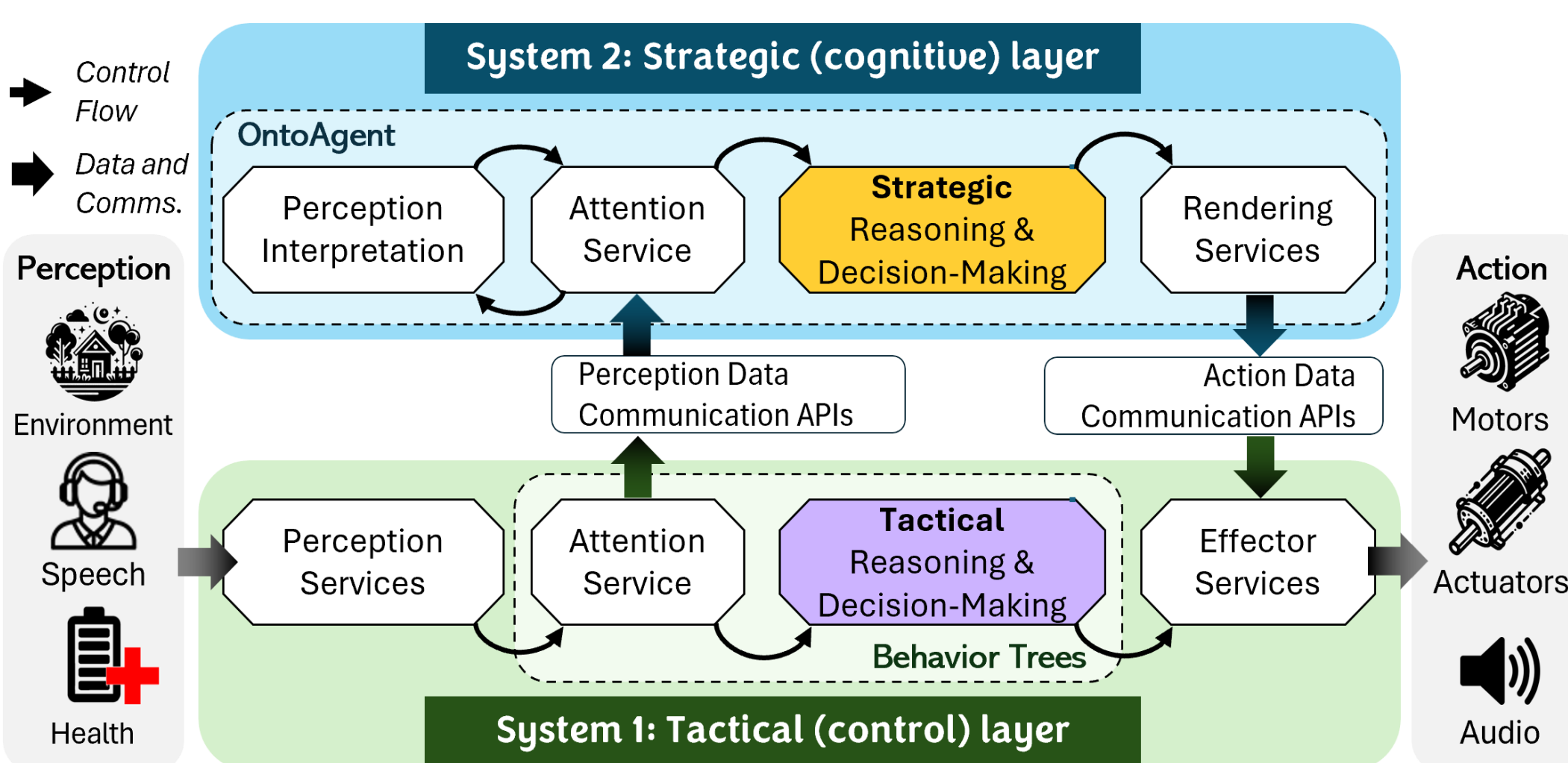
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Overview

A framework for implementing cognitive robots that transforms general-purpose robots into trusted teammates capable of

- complex decision-making,
- natural communication, and
- human-level explanation.

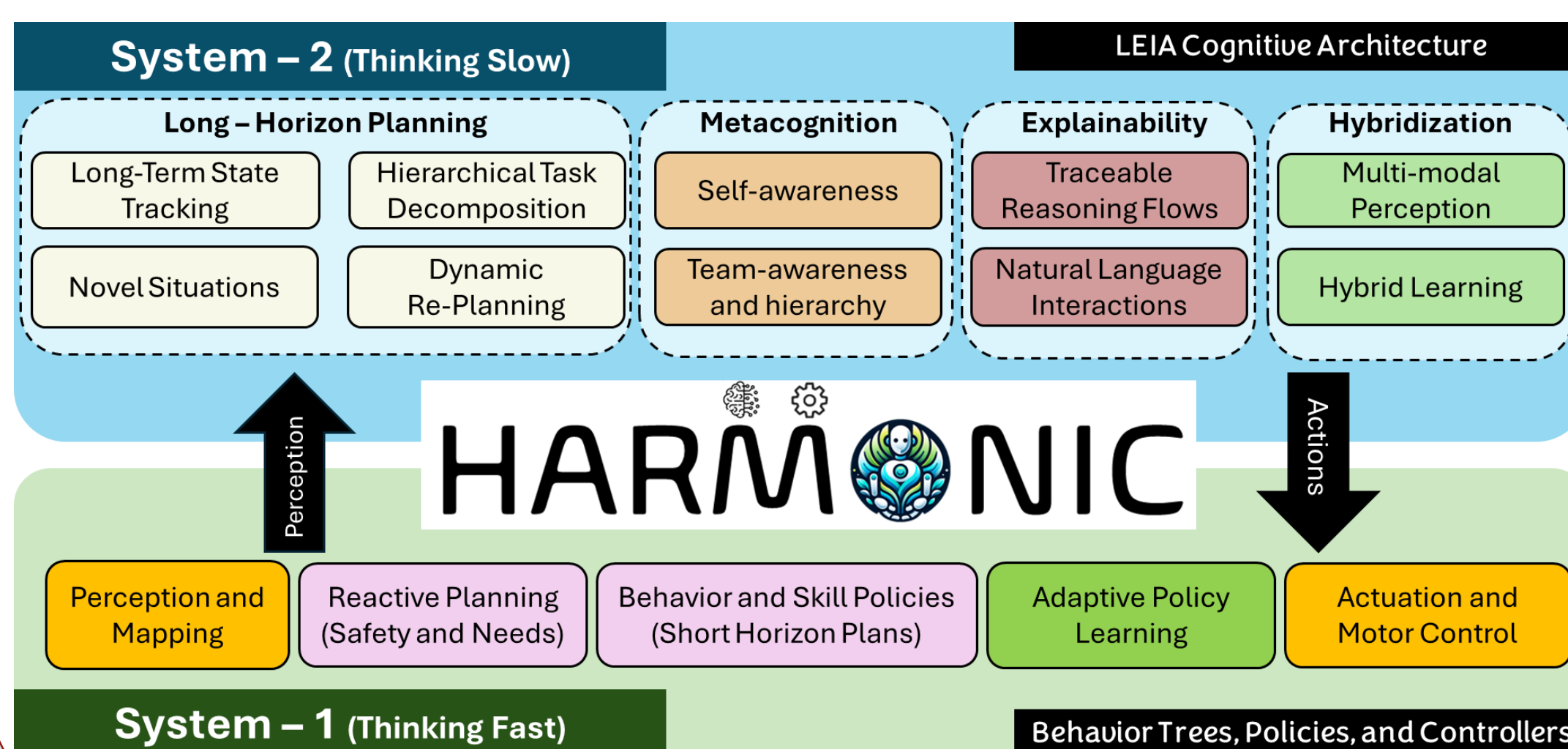


Capabilities

Inspired by the two-system architecture

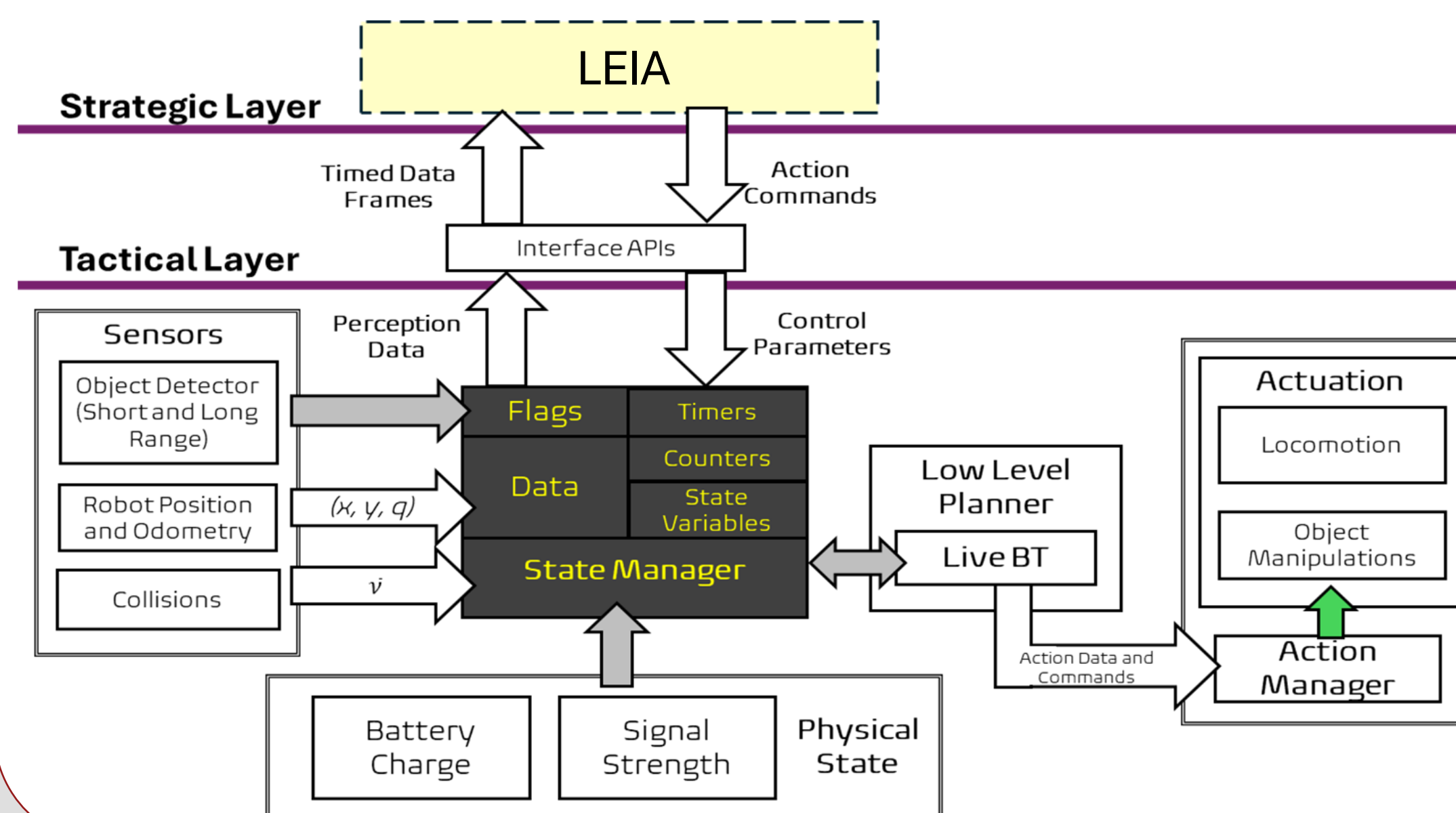
System 1: Thinking Fast or the tactical layer for robotic control.

System 2: Thinking Slow or the strategic layer for conscious cognition.



Architecture

- Plans at the tactical layer are encoded in Behavior Trees grounded in the LEIA's knowledge.
- Interface APIs manage perception and action channels through a central blackboard.

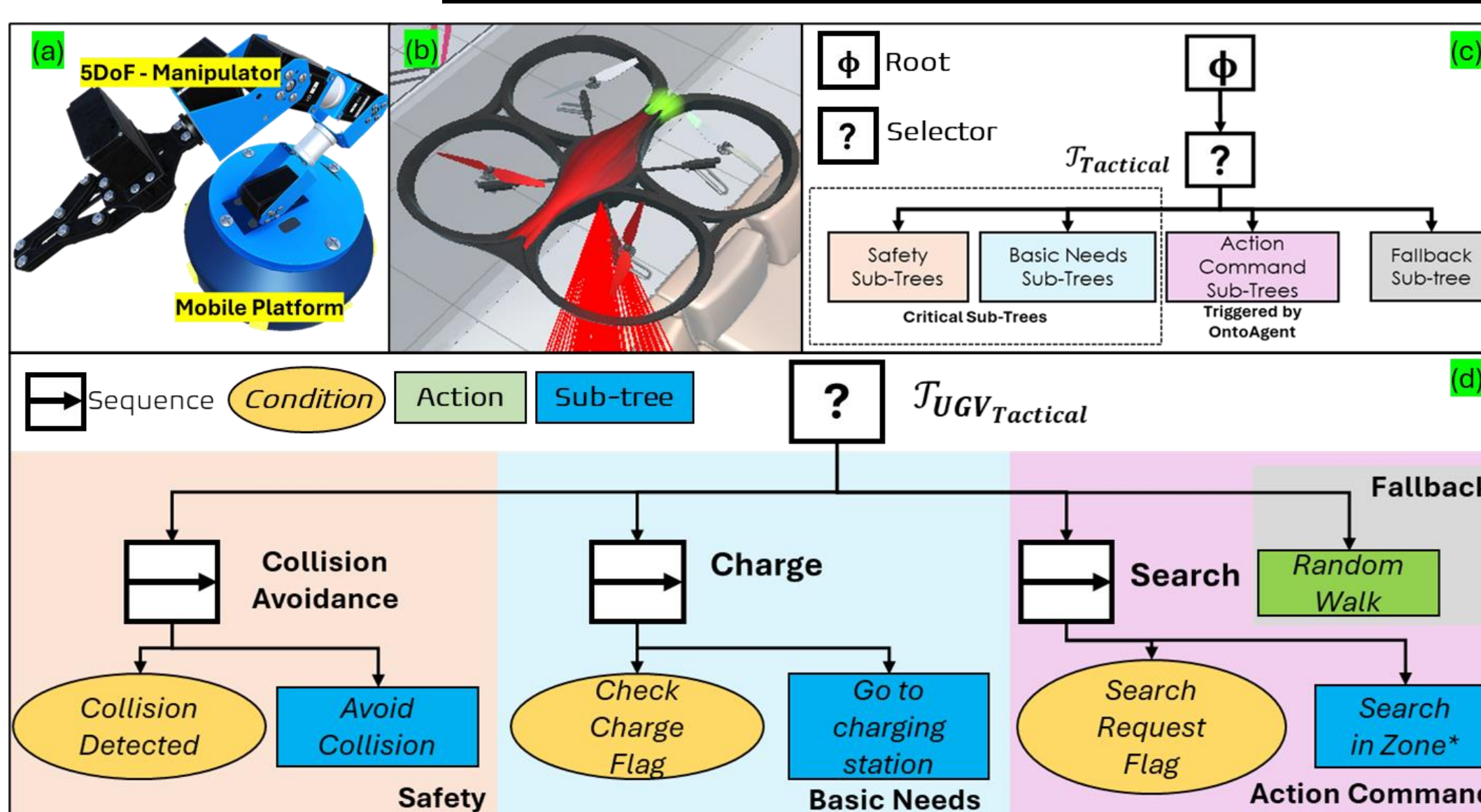


Realization

LEIA Cognitive Architecture

- An ontology of ~9,000 concepts with an average of 16 semantic properties each.
- A lexicon linking ~25,000 English word and phrase senses to their ontological meaning.
- Episodic memory of object and event instances including profiles of known agents detailing beliefs about their team roles, skills, beliefs, biases and physical and mental states.
- OntoSem language analyzer using the above to extract ontologically grounded meanings of texts and dialog turns.
- OntoGen semantically-based language generator
- Hybrid realization with LLMs carrying out all non-semantic processing.

Behavior Trees, Policies, and Controllers



Results

Teamwide Verbal Communication

DANNY to everyone
I think I left my keys at home. Can you look around for them?

UGV-U to DANNY
What do they look like?

DANNY to everyone
They are on a red keychain with a small flashlight.

UGV-U to DANNY
Do you recall where you last had them?

DANNY to everyone
I used them last night to open the front door, but they could be anywhere.

UGV-U to DRONE-D
Let's search the apartment.

DRONE-D to UGV-U
Ok.

UGV-U to DRONE-D
They aren't in the doorway.

UGV-U to DRONE-D
I found them north of the couch.

UGV-U to DANNY
I found them behind the couch.

Under the hood operations

UGV-U [LEADER]	UGV-U [LEADER]	UGV-U [LEADER]
KEY.1 CARDINALITY COREFER TMR.3/KEY.1, #KEY.1	COUCH.1 COLOR SHAPE PATTERN MATERIAL SPATIAL-ORIENTATION LOCATION-ABSOLUTE ROTATION-ABSOLUTE COREFER	FLASHLIGHT.1 SIZE COREFER
LEIA.1 COREFER #LEIA.1	FLASHLIGHT.1 SIZE COREFER	KEY.1 SUB-CLASS COLOR PATTERN MATERIAL
REQUEST-ACTION.1 BENEFICIARY THEME AGENT	FLASHLIGHT.1 SIZE COREFER	KEY.1 SUB-CLASS COLOR PATTERN MATERIAL
SEARCH-FOR-LOST-OBJECT.1 AGENT THEME TIME	FLASHLIGHT.1 SIZE COREFER	KEY.1 SUB-CLASS COLOR PATTERN MATERIAL
UGV-U [LEADER] @COLLABORATIVE-ACTIVITY [SELECT-PLAN] [PRECONDITIONS] @REQUEST-OBJECT-TYPE @REQUEST-OBJECT-FEATURES @REQUEST-LAST-SEEN-AT @REQUEST-LOCATION-CONSTRAINED @PROPOSE-PLAN [RUN-PLAN] @SEARCH-FOR-LOST-OBJECT	FLASHLIGHT.1 SIZE COREFER	KEY.1 SUB-CLASS COLOR PATTERN MATERIAL

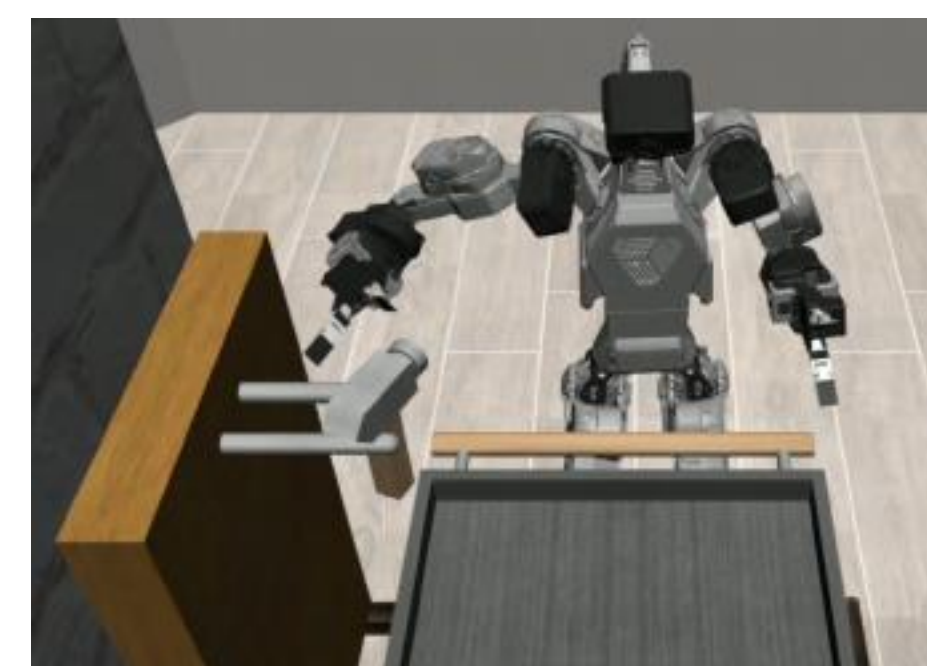
Simulated Operational Environment



Learn more about HARMONIC at
sanjayovs.github.io/HARMONIC2025ICRA

Current and Future work

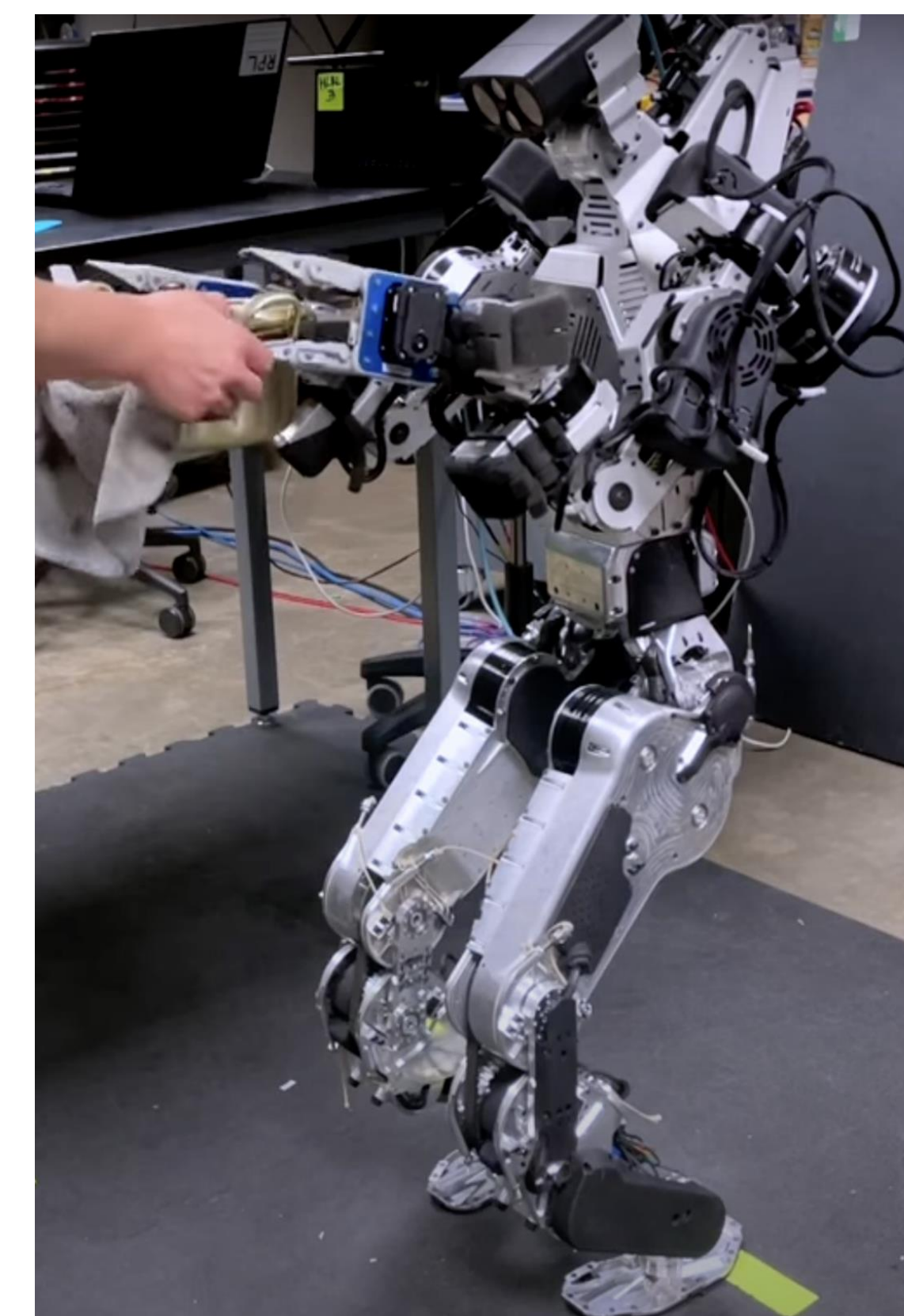
- Ship maintenance assistance for human operators with the DRACO3 humanoid.
 - Integration of HARMONIC system with DRACO3.
 - Domain-specific knowledge engineering for maintenance tasks.
 - Development of tactical procedures and policies.
 - Work on long-horizon maintenance tasks in simulated and real environments.
- Multi-modal perception data fusion and interpretation.
- Combining multi-modal instruction: speech, haptic, and gesture information.
- Using LLMs to foster LEIAs' learning
- Application to heterogeneous multi-robot teams.



Snapshot of Draco 3
executing PICKUP action
in MuJoCo

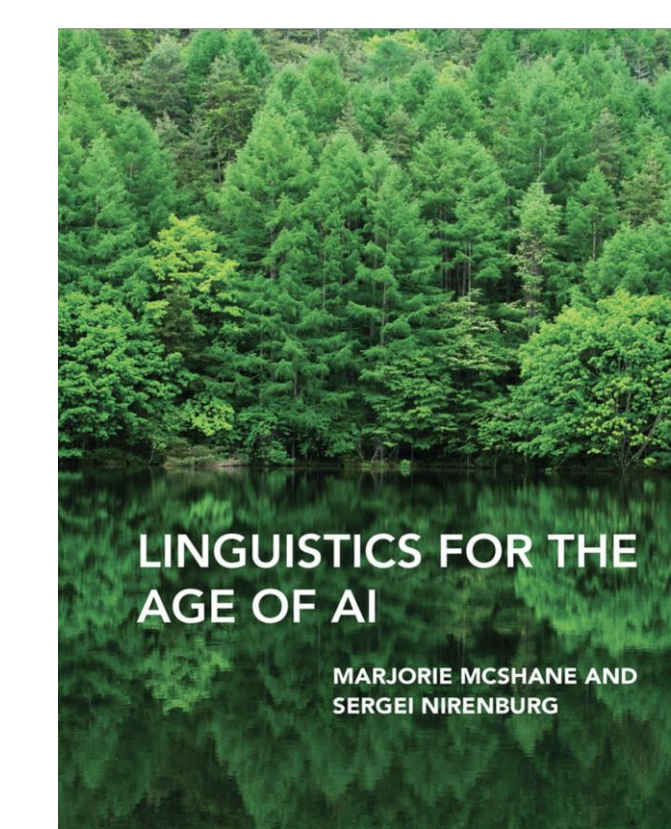


Snapshot Draco 3
executing WAYPOINT
action in MuJoCo



Draco 3 at HCRL, UT Austin

References



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MIT, 2021



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S. Oruganti, S. Nirenburg, M. McShane, J. English, M. K. Roberts, C. Arndt, and S. Kamireddy, "HARMONIC: Cognitive and Control Collaboration in Human-Robotic Teams," arXiv preprint arXiv:2409.18047, 2025.

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