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Cognition's Interface to the World and to Metacognition in MIDCA

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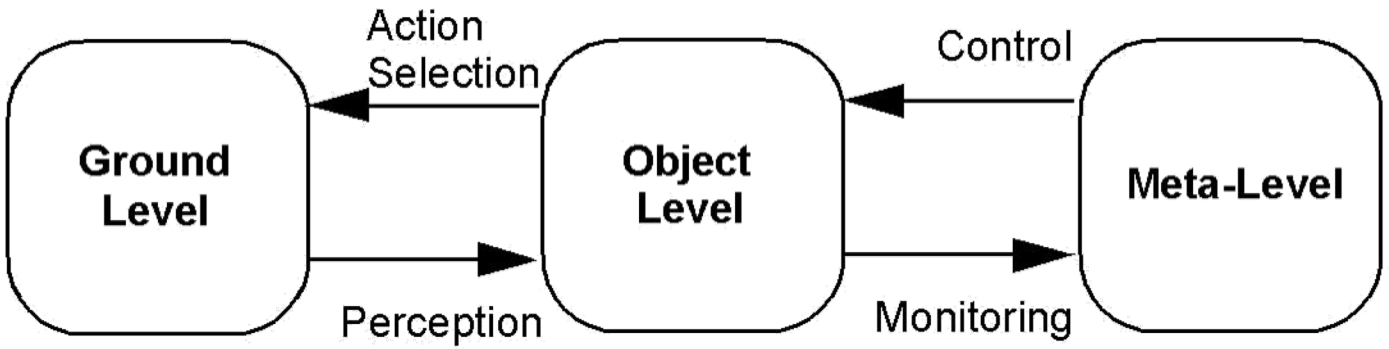
Levels of Cognitive Computation

Ground Level
- Action
- Perception

Object Level
- Problem Solving
- Comprehension

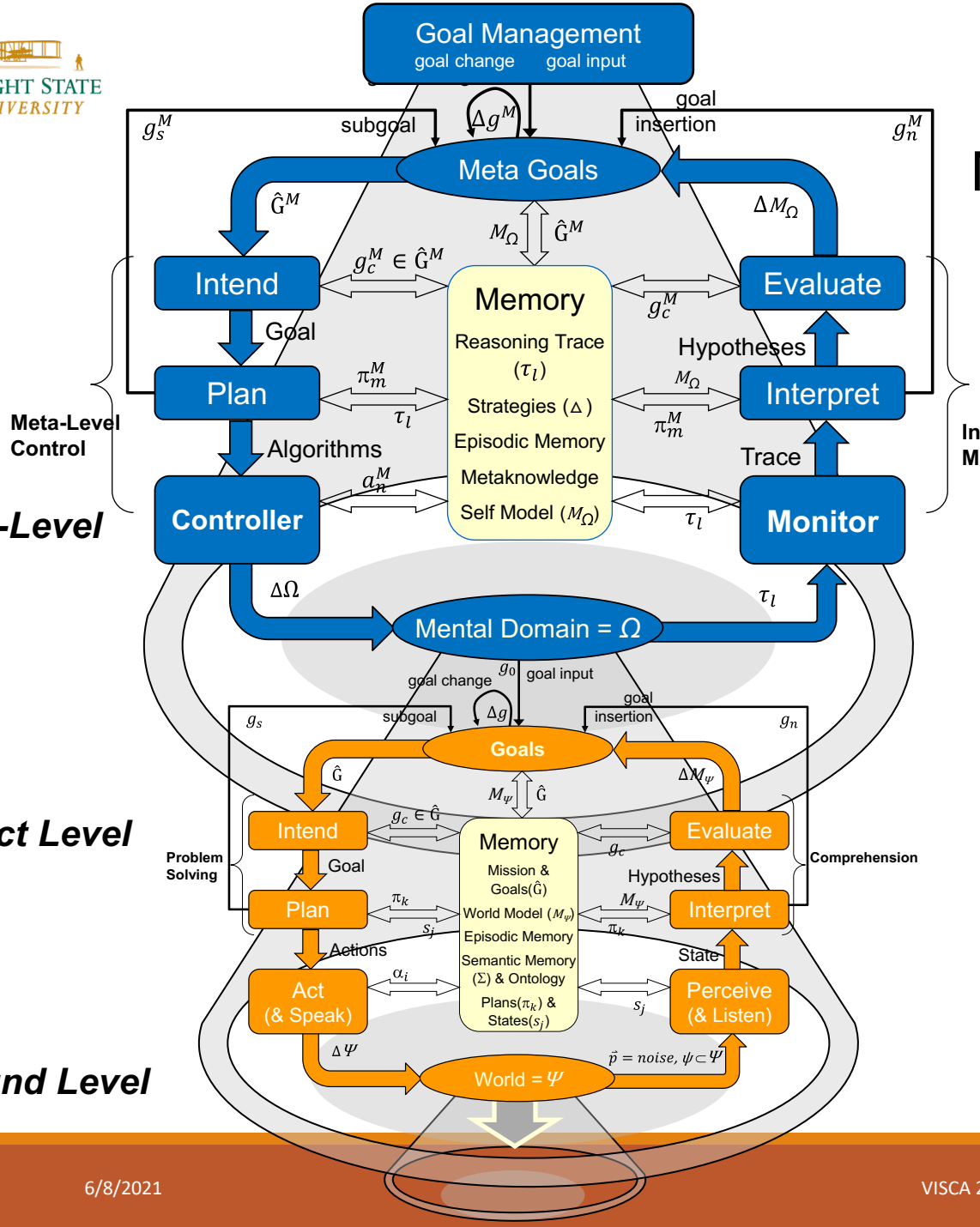
Meta-Level
- Meta-level Control
- Introspective Monitoring



Doing Reasoning Metareasoning

Cox, M. T., & Raja, A. (2011). Metareasoning: An introduction. In M. T. Cox & A. Raja (Eds.) *Metareasoning: Thinking about thinking* (pp. 3-14). Cambridge, MA: MIT Press.

The Metacognitive Integrated Dual-Cycle Architecture (MIDCA)



Metacognition

Cognition

Cox, M. T., Alavi, Z., Dannenhauer, D., Eyorokon, V., Munoz-Avila, H., & Perlis, D. (2016). MIDCA: A metacognitive, integrated dual-cycle architecture for self-regulated autonomy. *Proceedings of the 30th AAAI Conference on Artificial Intelligence.*

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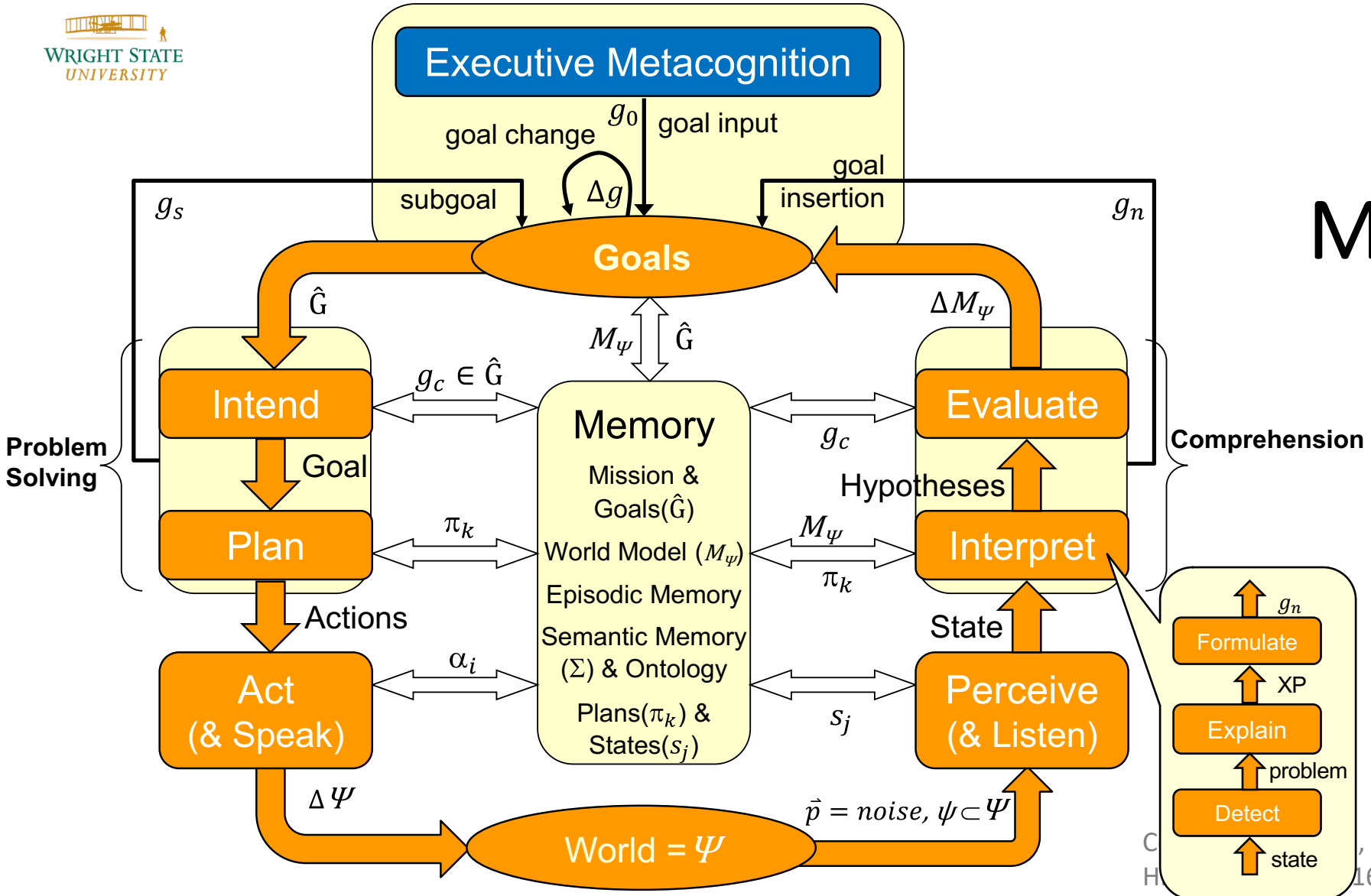

C , Dannenhauer, D., Eyorokon, V., Munoz-Avila, H 16). MIDCA: A metacognitive, integrated dual-cycle architecture for self-regulated autonomy. *Proceedings of the 30th AAAI Conference on Artificial Intelligence.*

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Outline

Introduction

Cognition's Interfaces

Cognition's Interface to the Environment

Cognition's Interface to Metacognition

Conclusion

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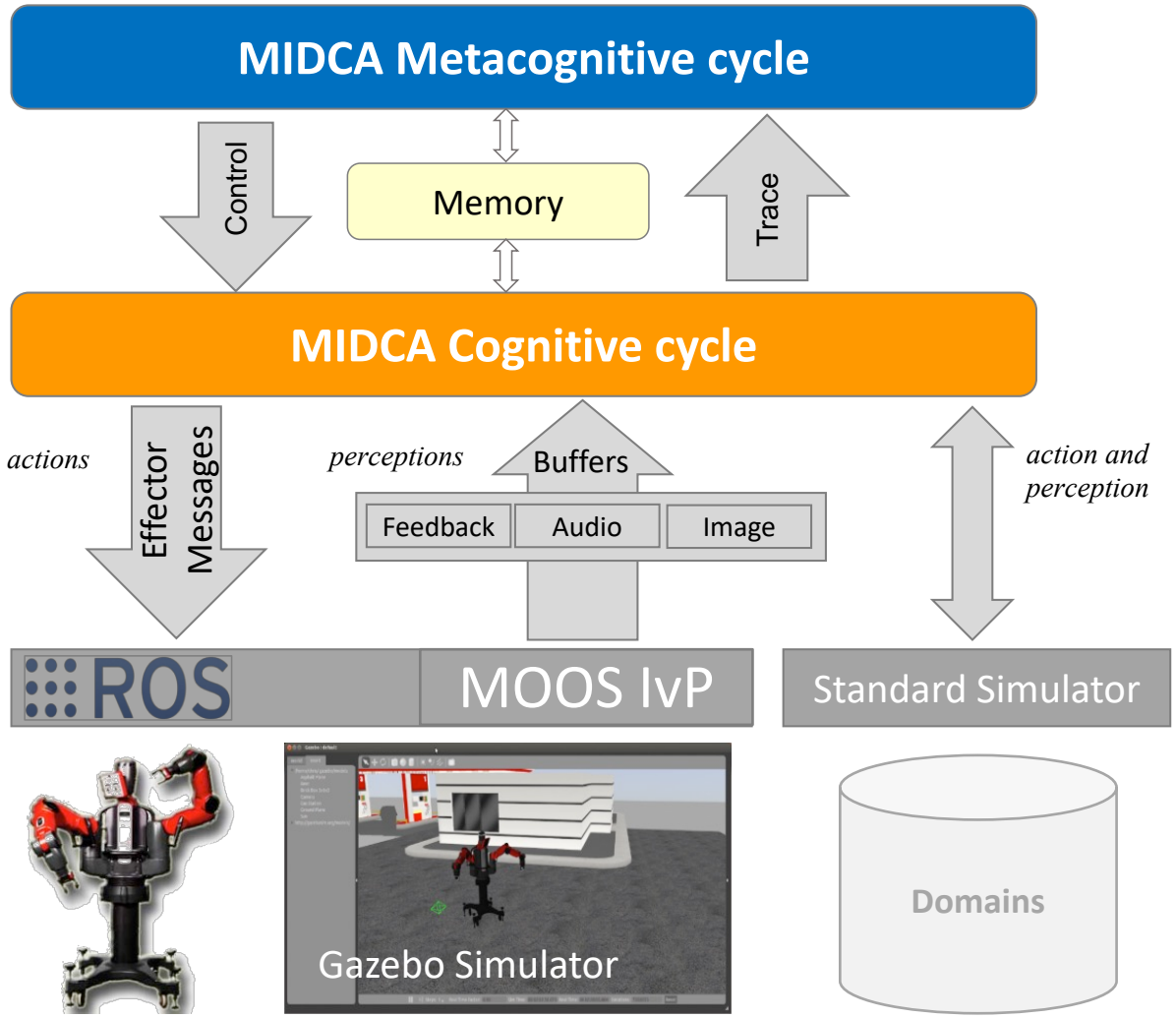
Cognition's Interfaces

API TO THE ENVIRONMENT

API TO METACOGNITION

Cognition's Interfaces in MIDCA



Dannenhauer, Z. A., & Cox, M. T. (2018). Rationale-based perceptual monitors. *AI Communications, 31*(2), 197-212.

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Cognition's Interface to the Environment

ACTION-PERCEPTION API

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Domain Structure Definition

Object Detection

- Type hierarchy
- Object attributes and values
- Relationships between objects

Action Execution

- Operators mapped to low-level communication channels

Configuration File parsed for new domain

- Generates object detection stubs
- Creates handlers for MIDCA Act and Perceive phases

Blocksworld configuration file

```
1   middleware,ROS
2   type,block,entity
3   attribute,block,color
4   attribute,block,x
5   attribute,block,y
6   attribute,block,z
7   attributeValue,color,red,green,blue
8   attributeValue,x,INT
9   attributeValue,y,INT
10  attributeValue,z,INT
11  relation,on,block,block
12  relation,clear,block
13  action,pickup,loc,grab,raise
14  action,putdown,loc,release
15  action,stack,loc,release
16  action,unstack,loc,grab,raise
```

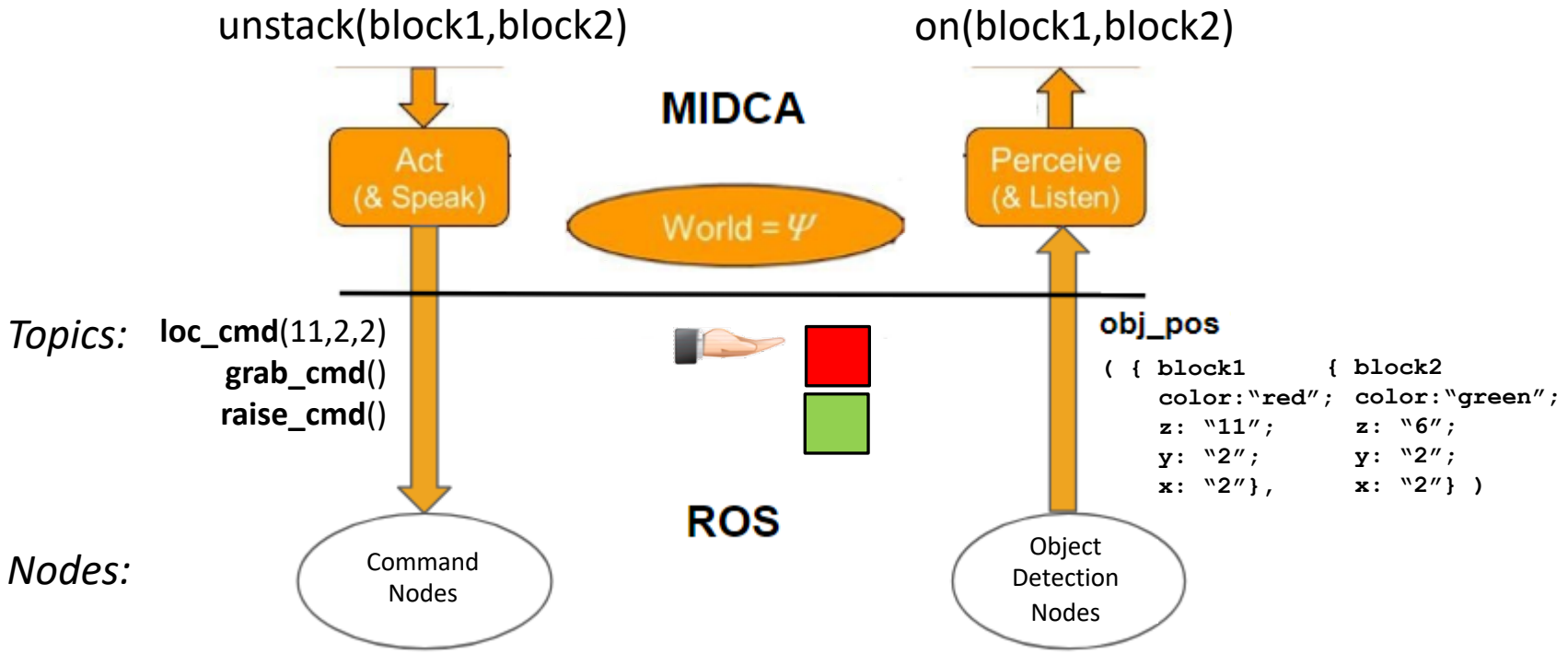
MIDCA / ROS API

MIDCA's Knowledge of states and actions is in terms of

- Logical predicates
- PDDL operators

Mapped to and from

- ROS nodes through
- ROS topics



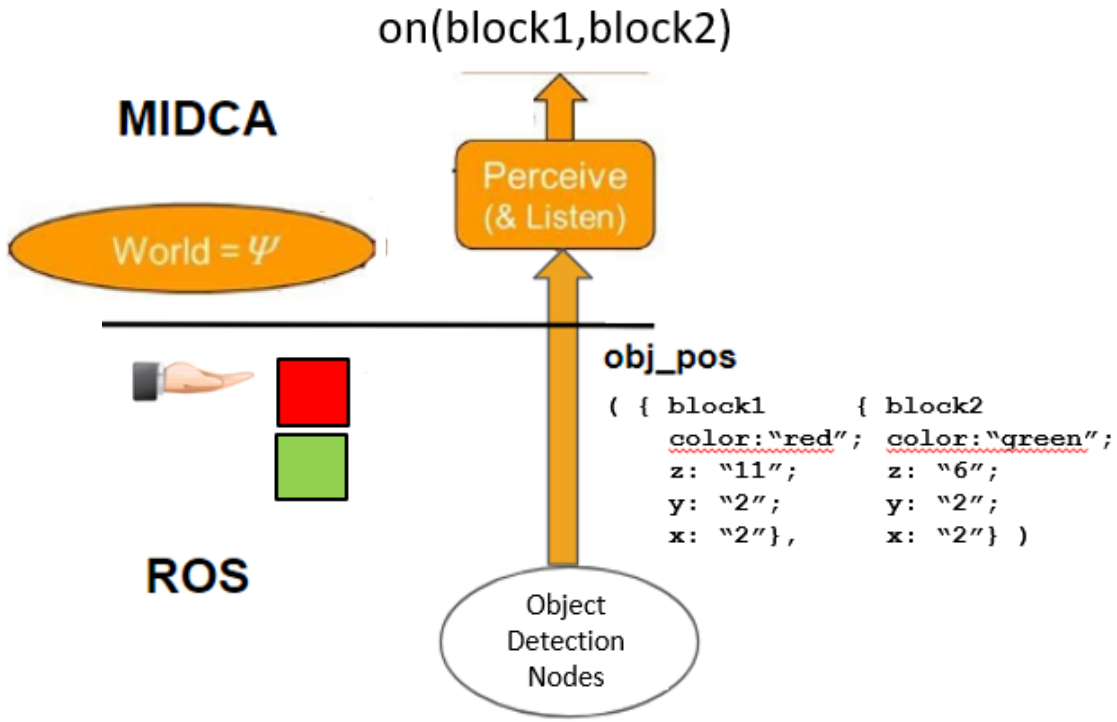
Perception

Sensor Handler

- Detects objects in environment
- Places their IDs and attributes in perceptual buffer

Perceive Phase

- Infers predicate representations of objects and their relationships
- Puts current state information in MIDCA's memory



Action

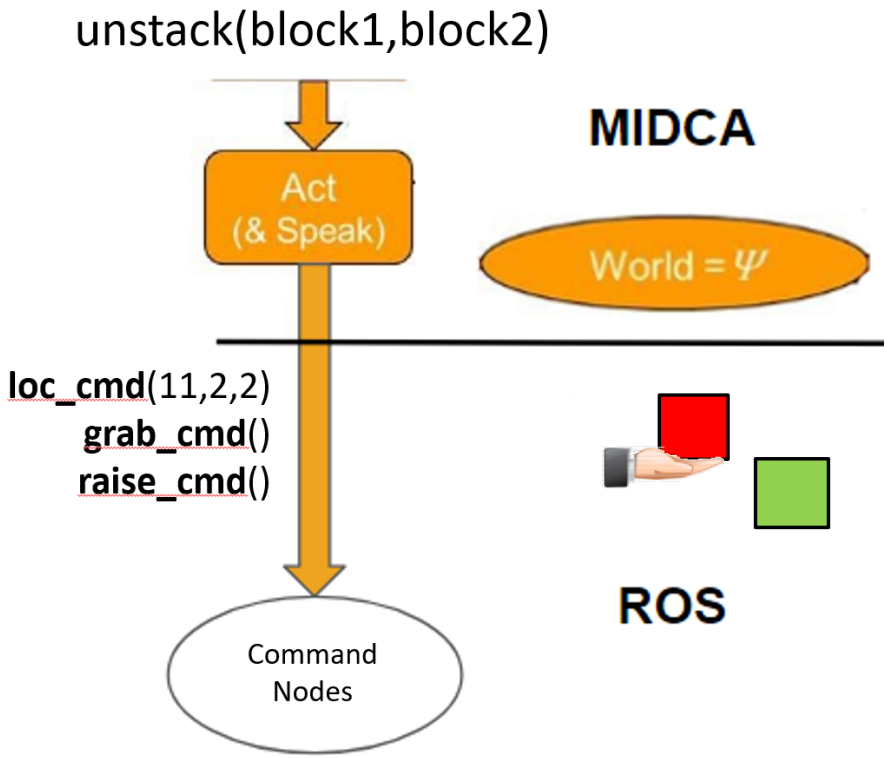
Execution Handler

- Packages command arguments into strings
- Sends message to command nodes through associated topics to control effectors

Act Phase

- Watches for feedback from ROS

Problem: Too much unnecessary computation



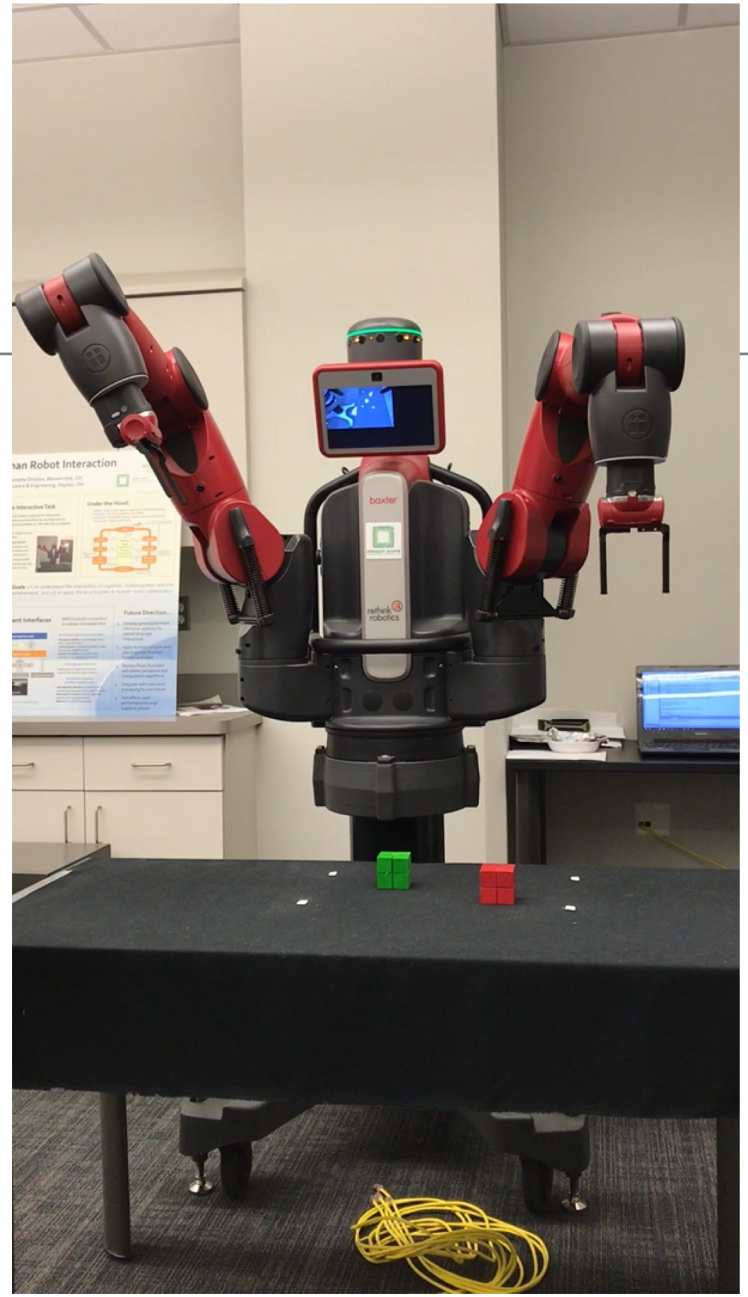
Plan Monitoring Demo

Neo

- The Baxter humanoid robot

Plan and Goal Monitors

- Manage perception
- React to changes in the world



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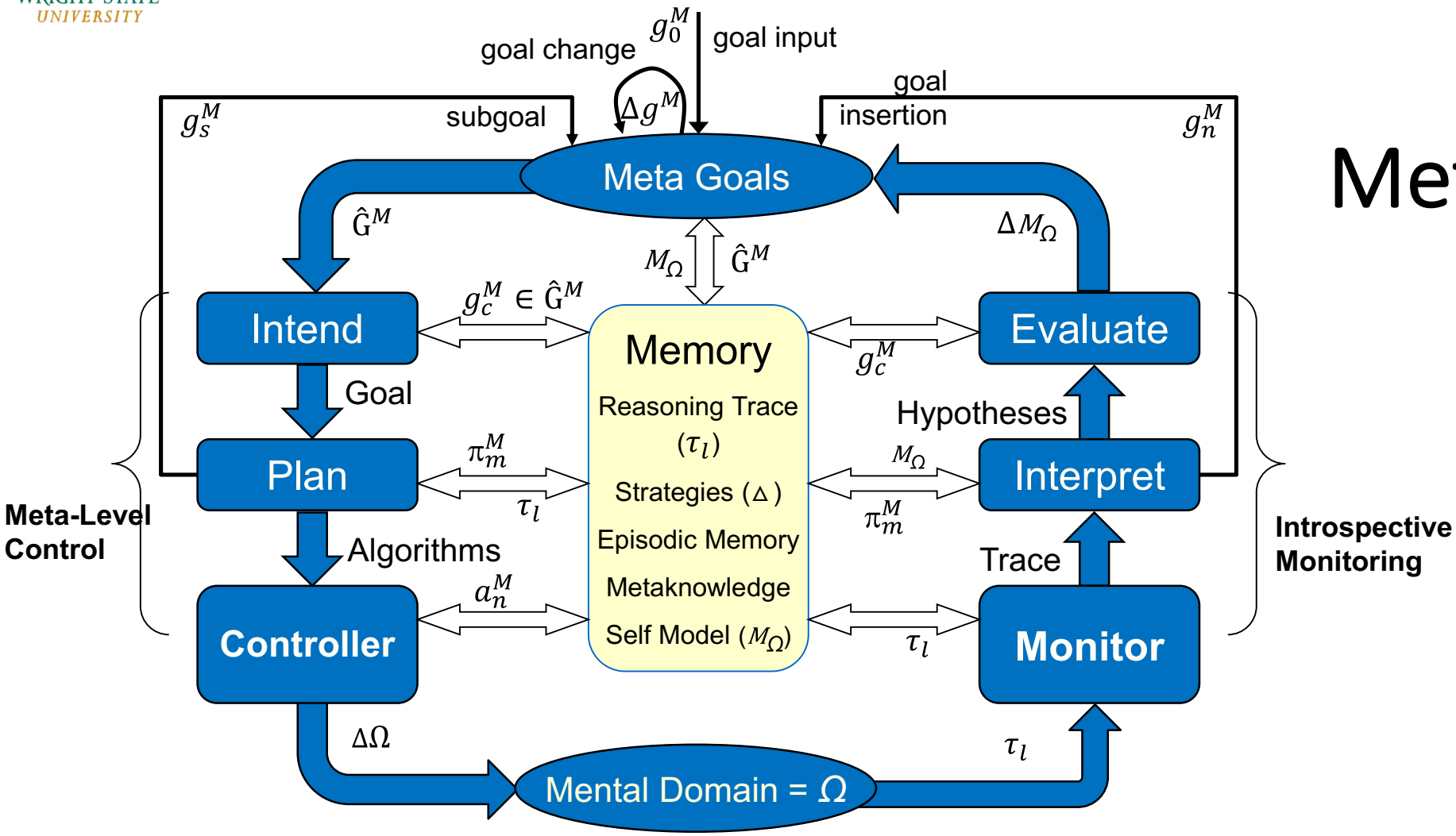
Cognition's Interface to Metacognition

CONTROL-MONITORING API

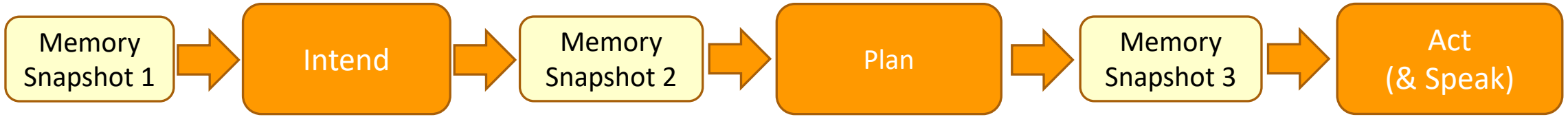
The Metacognitive Cycle of MIDCA



Introspective Monitoring

Cognitive Phases as mental actions

Memory as mental states



Notional Execution Trace of Cognitive Level

Metacognitive Expectations

A Mental State is a vector of variables $\vec{v} = (v_1, \ldots, vn)$

$s^M = (g_c, \hat{G}, \pi, M_\Psi, D, \chi, \alpha_c)$

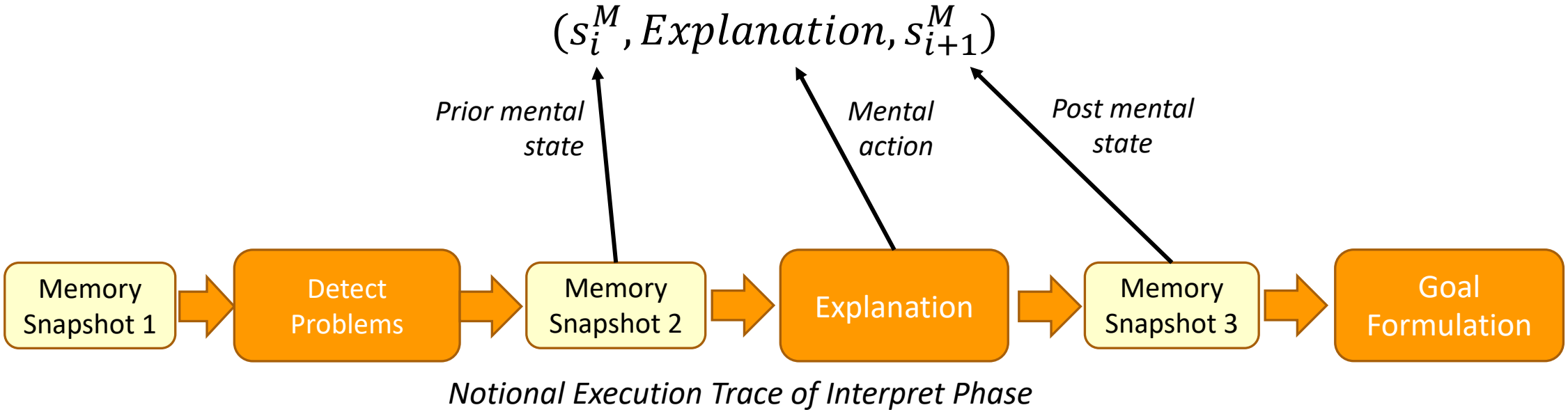
- Current goal set
- Goal agenda
- Current plan
- World state
- Discrepancies
- Explanation
- Current Action

Metacognitive Expectation as Boolean function over segment of mental trace

$$EX^M\left(s_i^M, \alpha_i^M, s_{i+1}^M\right) \rightarrow \{\top, \bot\}$$

Dannenhauer, D., Cox, M. T., & Munoz-Avila, H. (2018). Declarative metacognitive expectations for high-level cognition. *Advances in Cognitive Systems 6*, 231-250.

Metacognitive Expectation for Interpret



Notional Execution Trace of Interpret Phase

Meta-Level Control

Goal Change

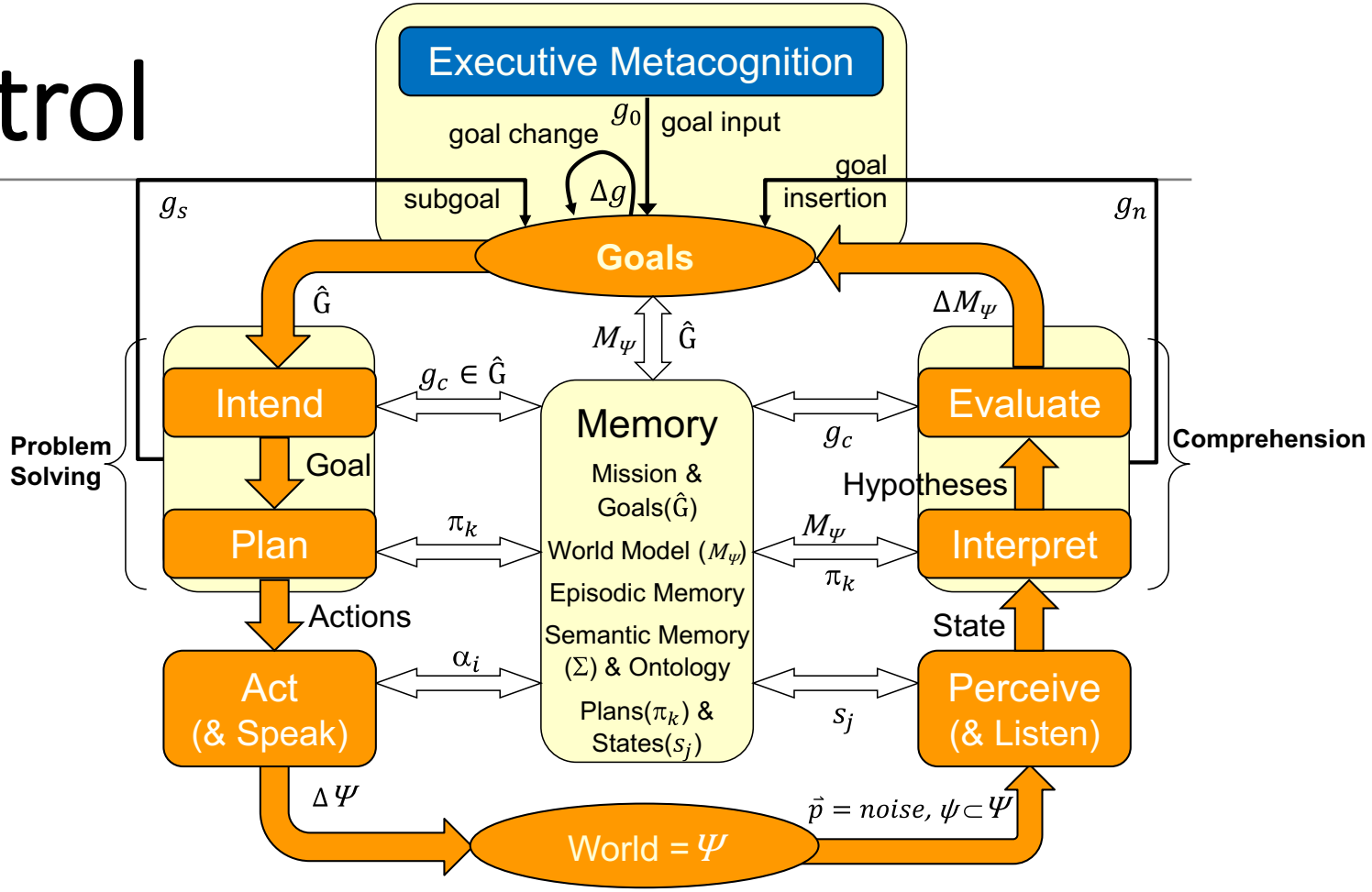
- Goal transformation
- Goal priorities

Execution Control

- Over cognitive phases

Learning

- Action models
- Other?

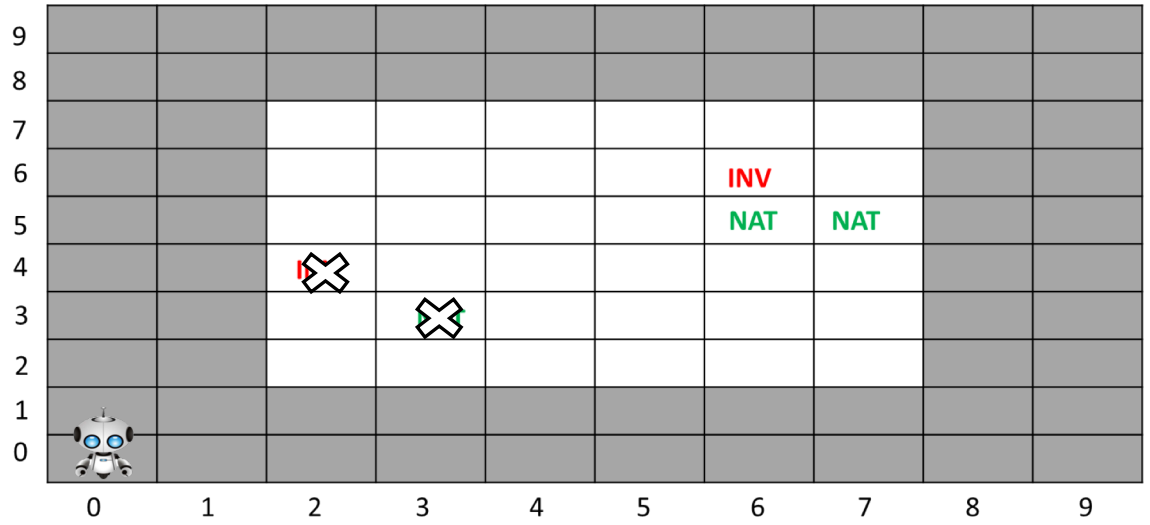


Metacognition Example

Plant Protection Domain with faulty spray op
- Goals: all invasive plants; all native plants alive
- Spray herbicide in one cell but kills native plant in adjacent cell

Goal Expectation Failure detected by Interpret at object level
- Goal to preserve native plant but now dead
- MIDCA cannot explain the failure

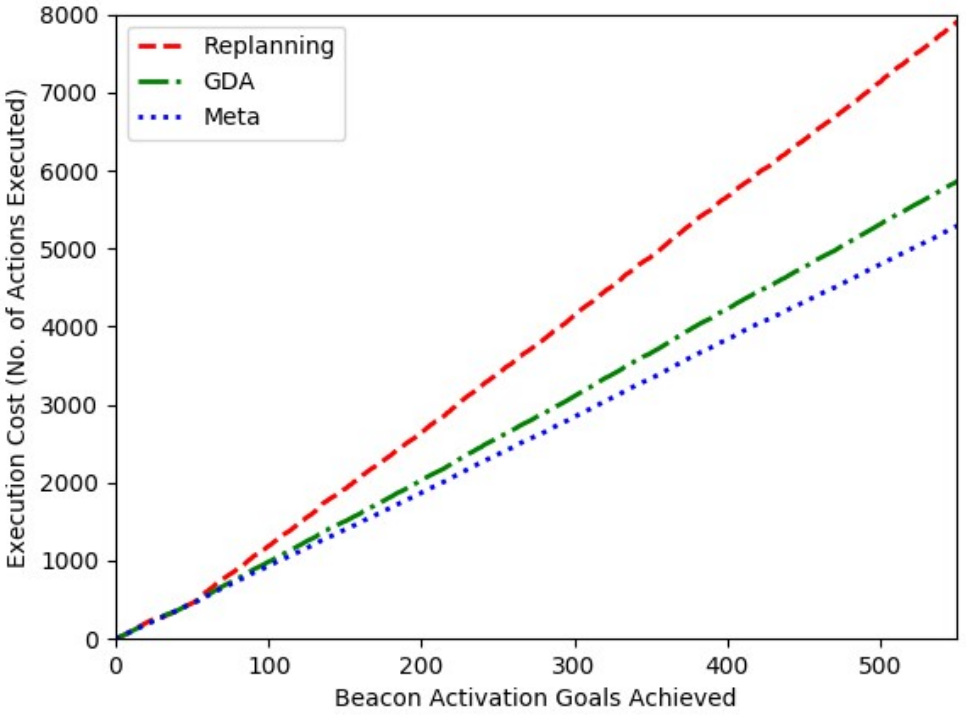
Metacognitive Expectation Failure detected by meta-level Interpret at meta-level
- Generates goal to learn spray operator
- Plans to use relational learning
- Control phase calls FOIL



Mohammad, Z., Cox, M. T., & Molineaux, M. (2020). Rebel agents that adapt to goal expectation failures. In *Proceedings of the Integrated Execution / Goal Reasoning Workshop* (held at ICAPS-20), Nancy, France.

Experimental Results in Two Domains

Average performance cost as a function of goals achieved in the NBeacons domain.



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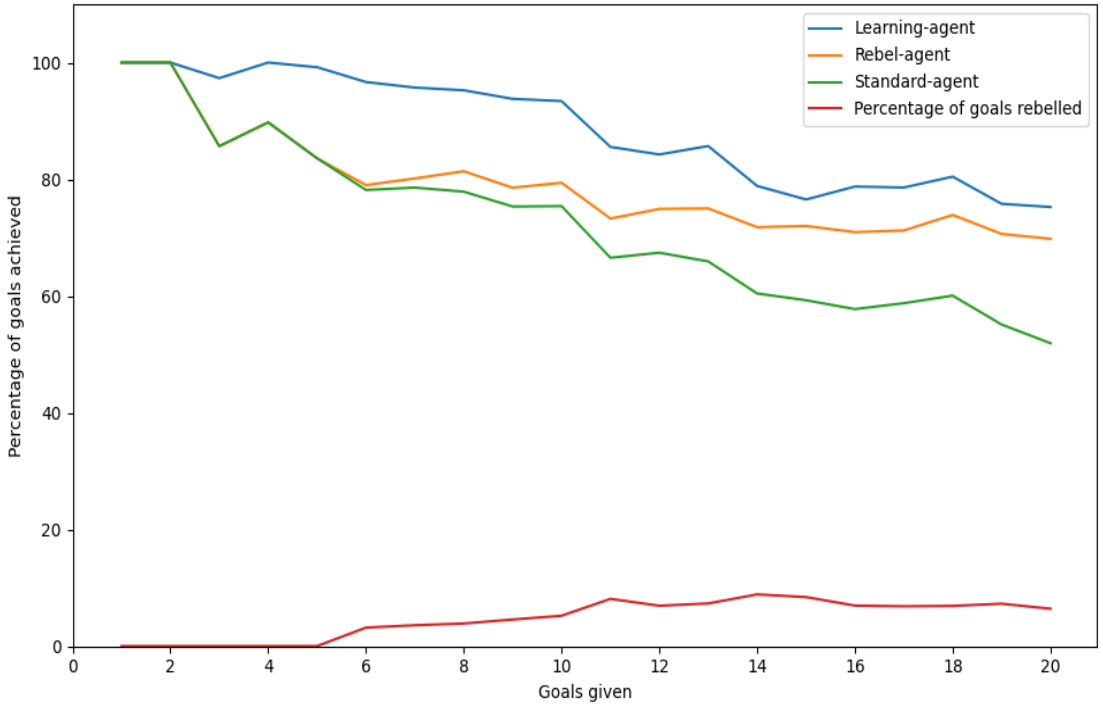
Average performance as a function of problem complexity in the Plant Protection domain.



Mohammad, Z. (2021). *A rebellion framework with learning for goal-driven autonomy*. Masters thesis, Wright State University, Department of Computer Science and Engineering, Dayton, OH.

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Conclusion

Open-source Code available at `https://github.com/COLAB2/midca`

Integrating Behavior, Cognition and Metacognition is hard for any architecture

- MIDCA has explored metacognition from the beginning but only lightly
- MIDCA has ignored grounded cognition for a long time
- But both have started to take off as of late

The Future is interesting

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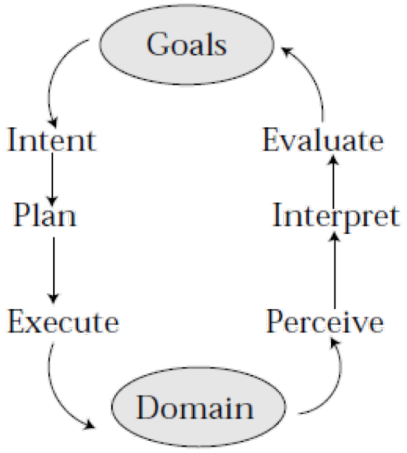
Backup Slides

ORIGINS OF MIDCA: DON NORMAN (1986)

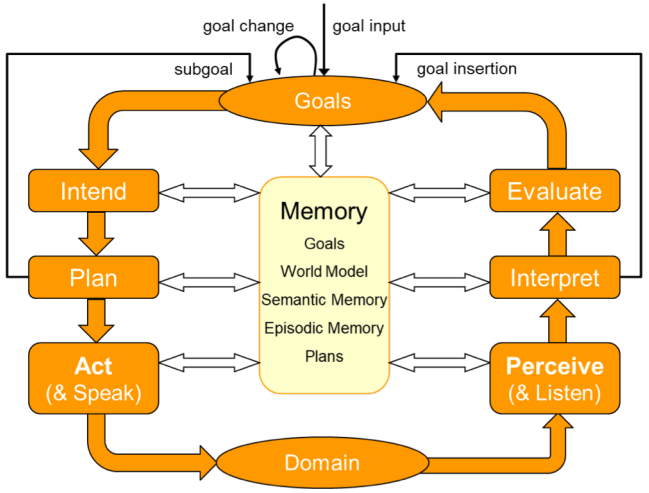
SELF-DESCRIPTION (XKCD)

Origins of MIDCA: Don Norman (1986)

Norman's HCI model



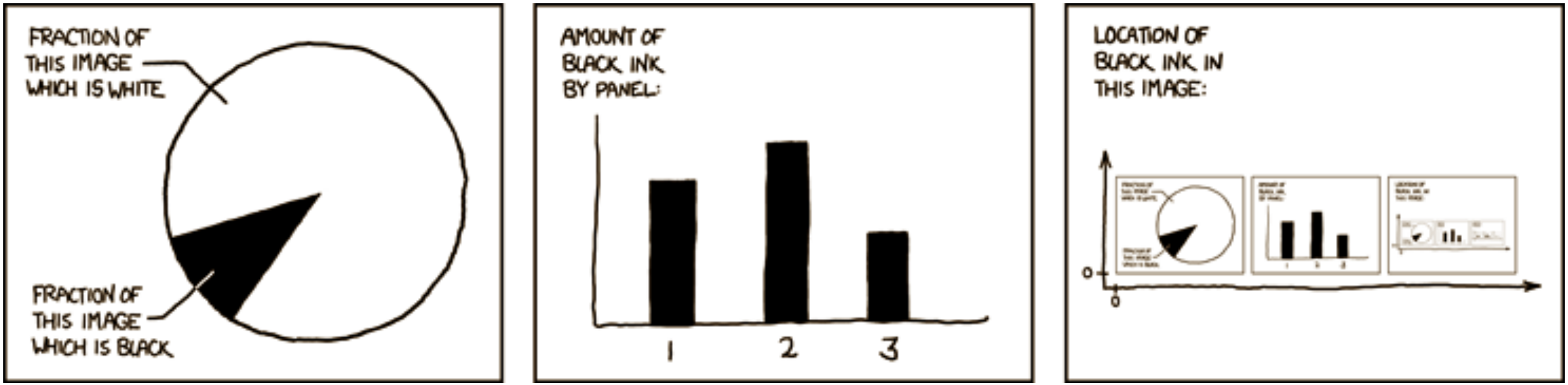
MIDCA's Cognition model



Norman, D. 1986. Cognitive Engineering. In D. Norman and S. Draper eds., *User-centered system design: New perspectives on human-computer interaction. Hillsdale*, NJ: Lawrence Erlbaum.

Lewis, M. 1998. Designing for Human-agent Interaction. *AI Magazine 19*(2): 67-78.

Cox, M. T.; Oates, T.; and Perlis, D. 2011. Toward an integrated metacognitive architecture. In P. Langley ed., *Advances in Cognitive Systems: Papers from the 2011 AAAI Fall Symposium*, 74-81. Tech. Rep. No. FS-11-01. Menlo Park, CA: AAAI Press.



Self-Description

http://imgs.xkcd.com/comics/self_description.png