Cognitive Architecture for Cognitive Cyber-Physical Systems

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AI for Cognitive Cyber-Physical Systems Interoperbility (AI4C2PS)

AI4C2PS
Human meets CPS

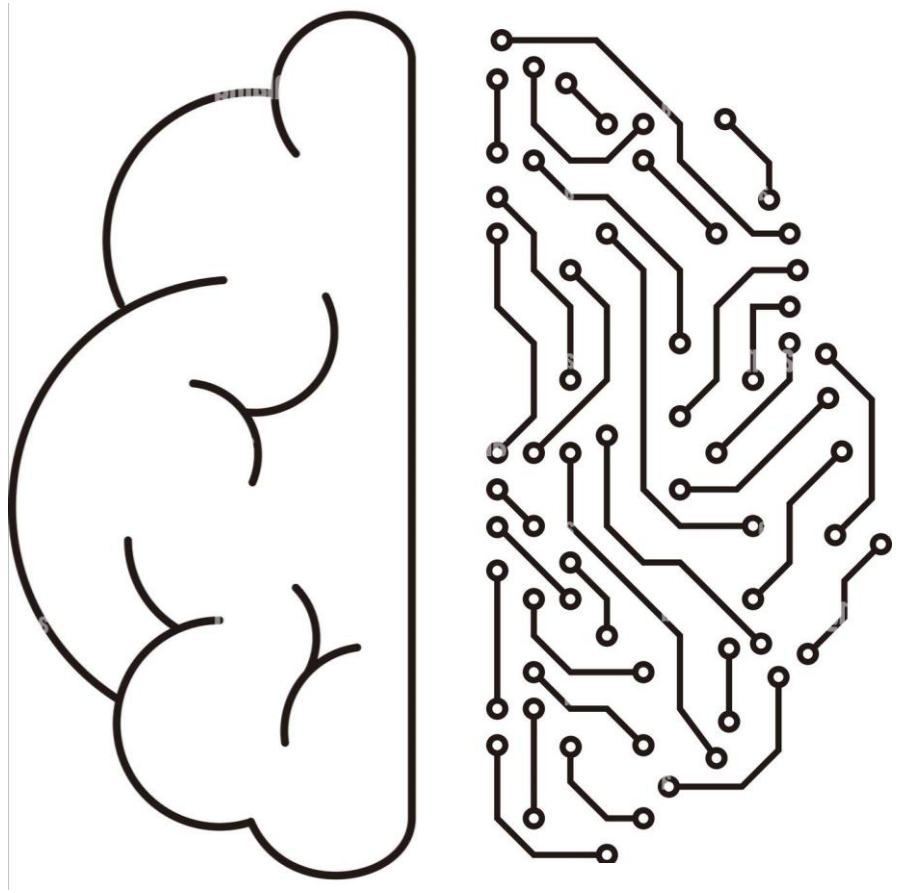
Human System

Brain

- Integration of sensory information
- Decision-Making
- Natural Intelligence
  - Heuristic Analysis
  - Knowledge Representation
- Cognitive Functions

Organs

- Sensory organs
- Effector organs



Artificial System

Cyber System

- Data convergence
- Decision-Making
- Artificial “Intelligence”
  - Statistical Calculus
  - Knowledge Representation

Physical System

- Sensors
- Actuators

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- **Cognitive Functions**

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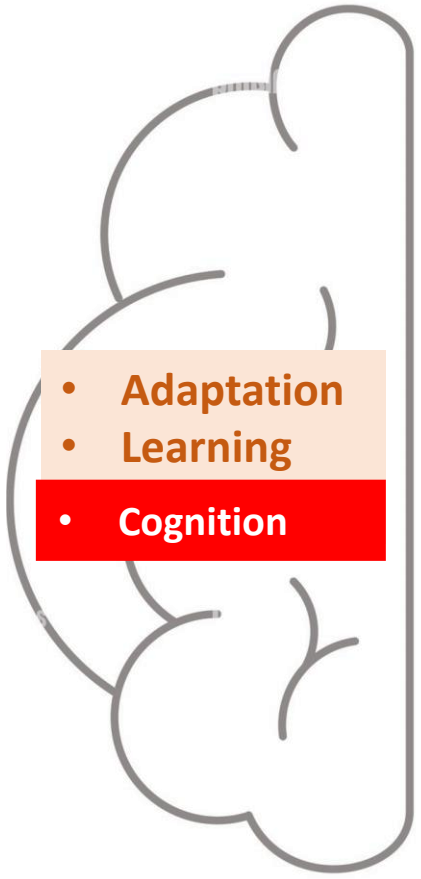
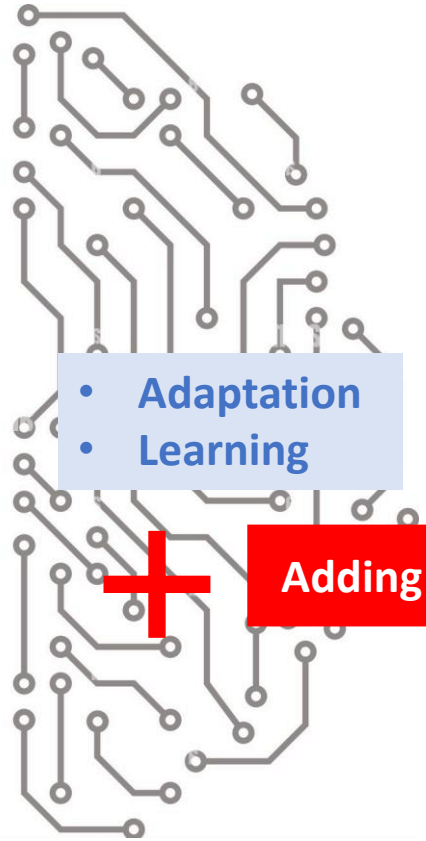


- **Adaptation**
- **Learning**
- **Cognition**

Artificial System



- **Adaptation**
- **Learning**

Cyber System

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  - Statistical Calculus
  - Knowledge Representation

Adding Cognition → **Cognitive Architecture**

Physical System

- Sensors
- Actuators

Outlines

1. **Introduction**
2. **Cognitive Functions**
3. **Cognitive Architecture**
4. **Comparison between Cognitive Architectures**
5. **Application of Cognitive Architectures**
6. **Conclusion and Perspectives**

Introduction

Cognitive system (CS) [1]:

- ✓ Emulates Specific Cognitive Functions.
- ✓ Learns and Reasons.
- ✓ Decision-Making.
- ✓ Continuous Improvement.
- ✓ Complex Problem Solving.

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Cognitive cyber-physical system (CCPS) [1]:

- ✓ Emulates Specific Cognitive Functions.
- ✓ Learning and Understanding.
- ✓ Autonomous Interaction and Decisions.
- ✓ Dynamic Adaptation.

[1] Al Haj Ali, J., Gaffinet, B., Panetto, H., & Naudet, Y. (2024). Cognitive systems and interoperability in the enterprise: A systematic literature review. Annual Reviews in Control, 57, 100954.

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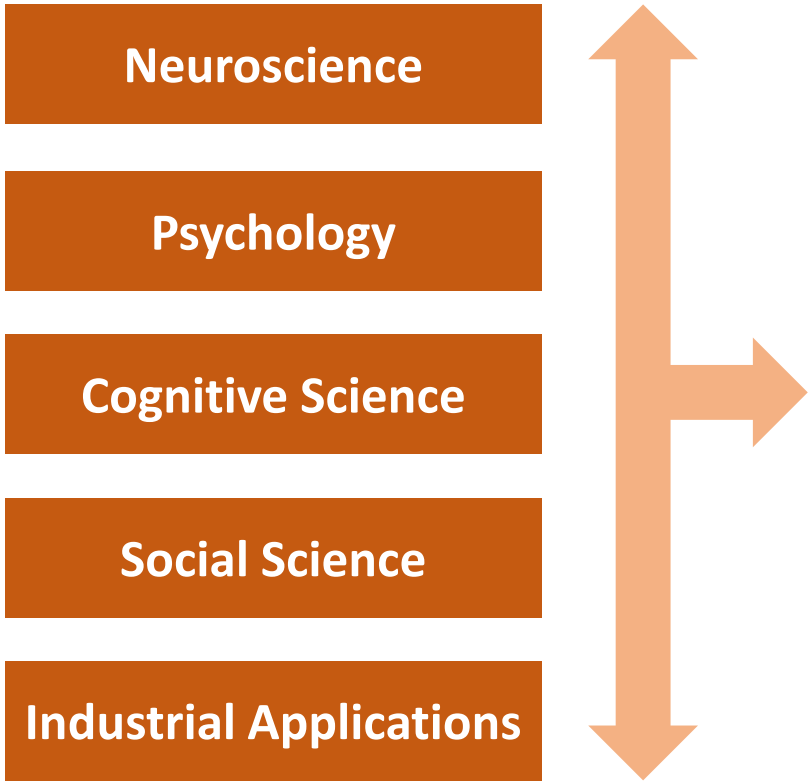
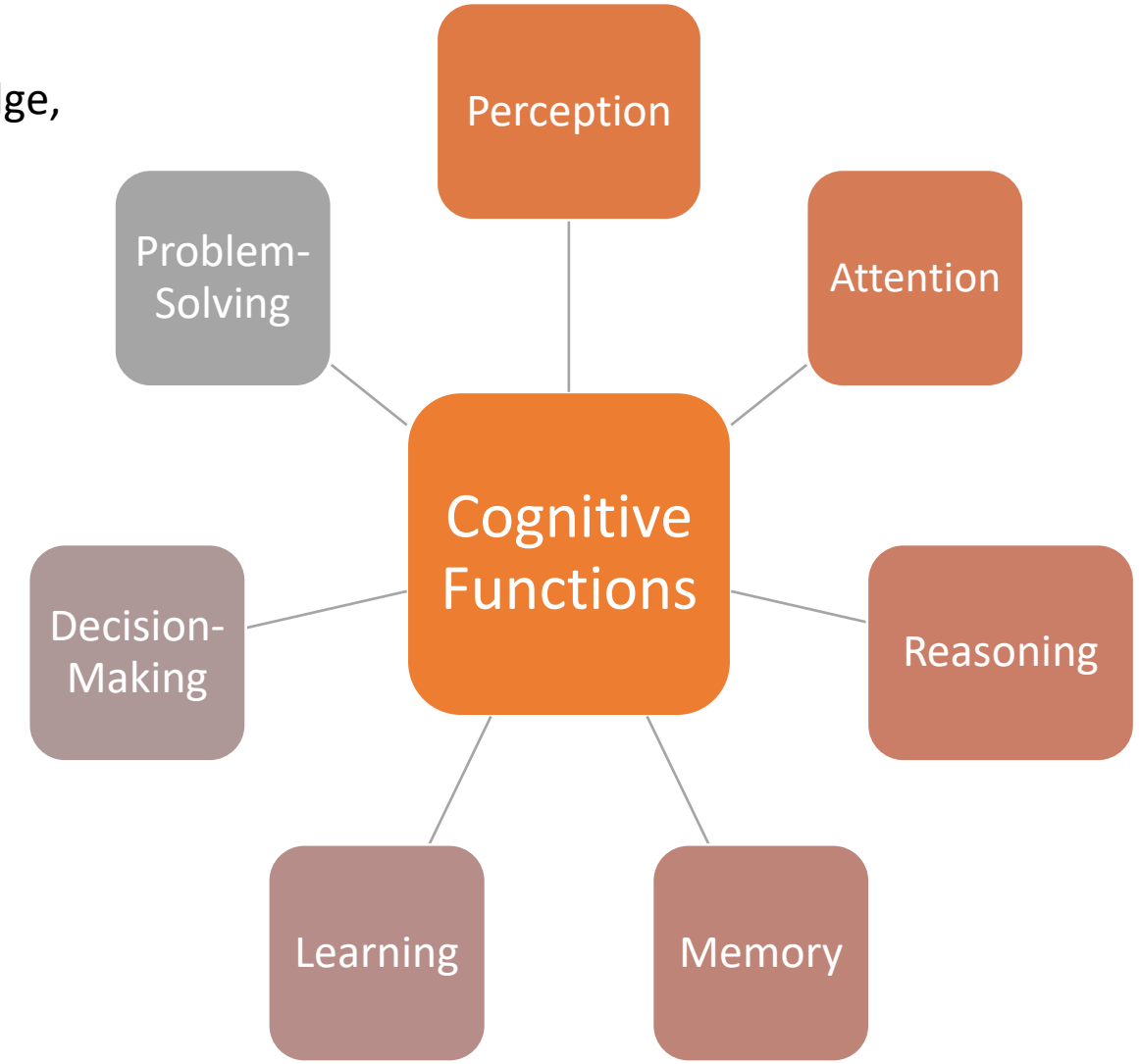
Cognitive Functions

Mental processes involved in the acquisition of knowledge, manipulation of information, and reasoning [2].





[2] K. M. Kiely, “Cognitive Function,” in Encyclopedia of Quality of Life and Well-Being Research, A. C. Michalos, Ed., Dordrecht: Springer Netherlands, 2014, pp. 974–978.

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Cognitive Architectures vs Cognitive Agents

Cognitive Architectures

- Models based on human brain function.
- Theories of the fixed mechanism and structures that underlie human cognition.
- Created to model human performance in multimodal multiple task situations.

Cognitive Agent (BDI)

- Functional simplification of cognitive processes, often detached from human complexity.
- Model intelligent behavior based on beliefs, desires and intentions.

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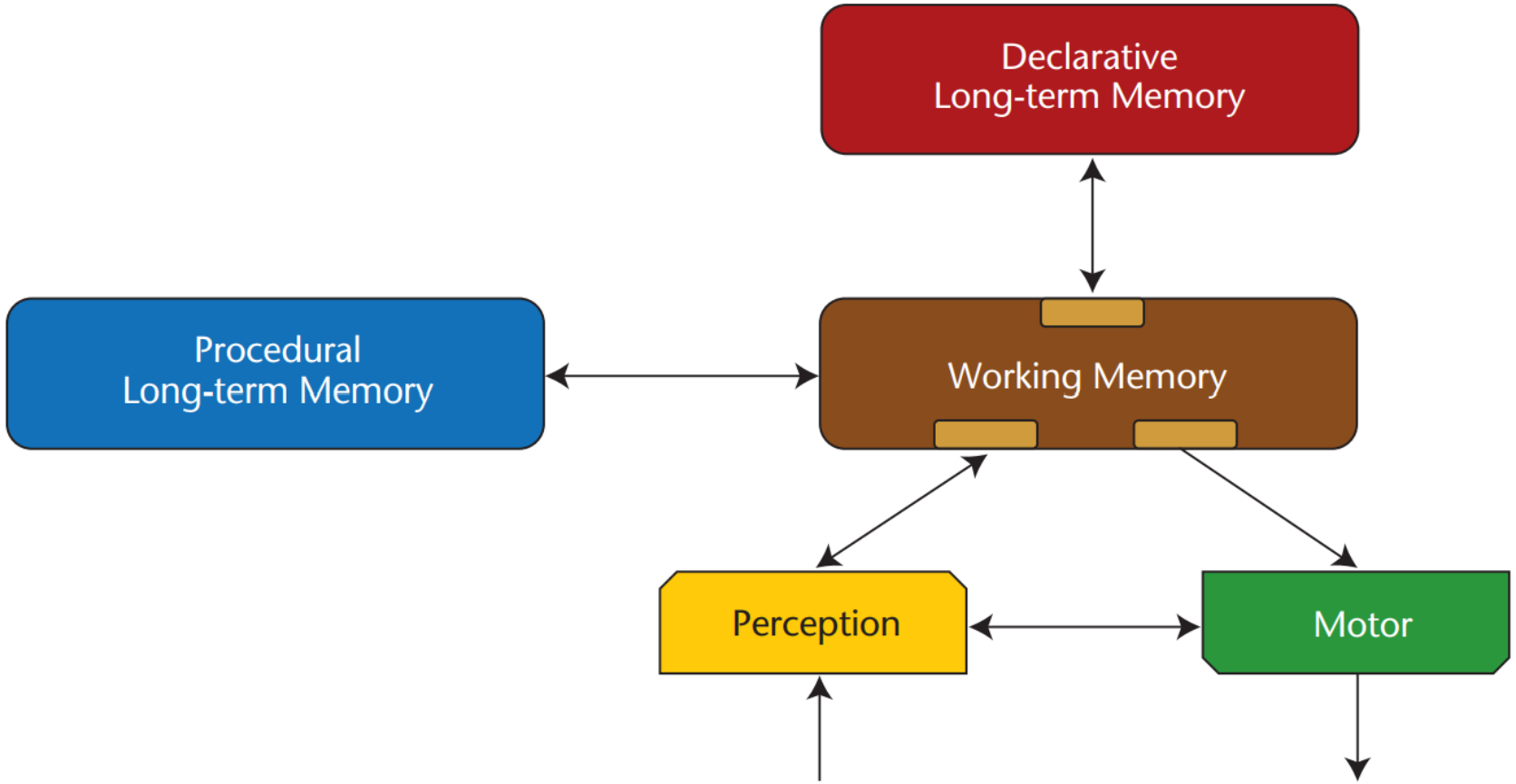
Cognitive architectures

Standard Model of human cognition :



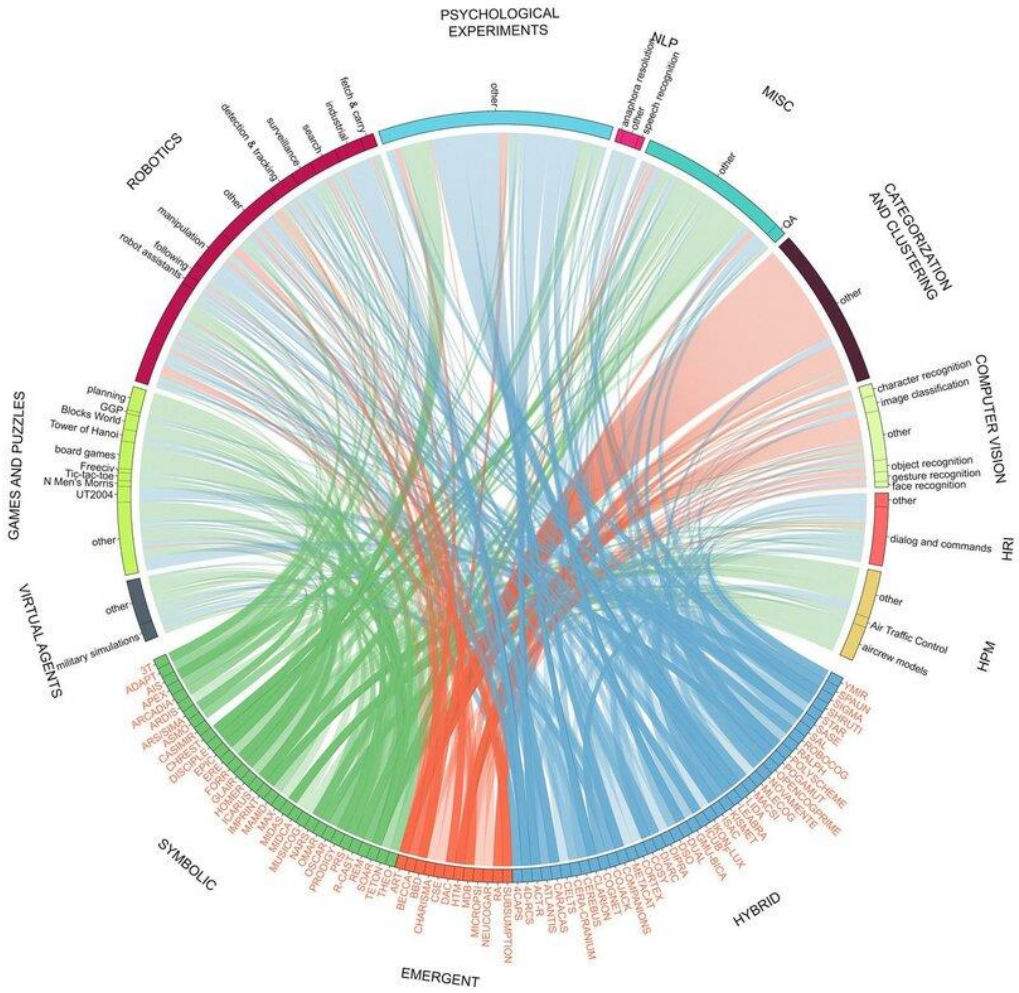
Laird Human model [3]

Laird, J. E., Lebiere, C., & Rosenbloom, P. S. (2017). A standard model of the mind: Toward a common computational framework across artificial intelligence, cognitive science, neuroscience, and robotics. Ai Magazine, 38(4), 13-26.

Advantages of cognitive Architectures

Adaptability

Multi-functionality



Practical Applications of cognitive architectures [4]

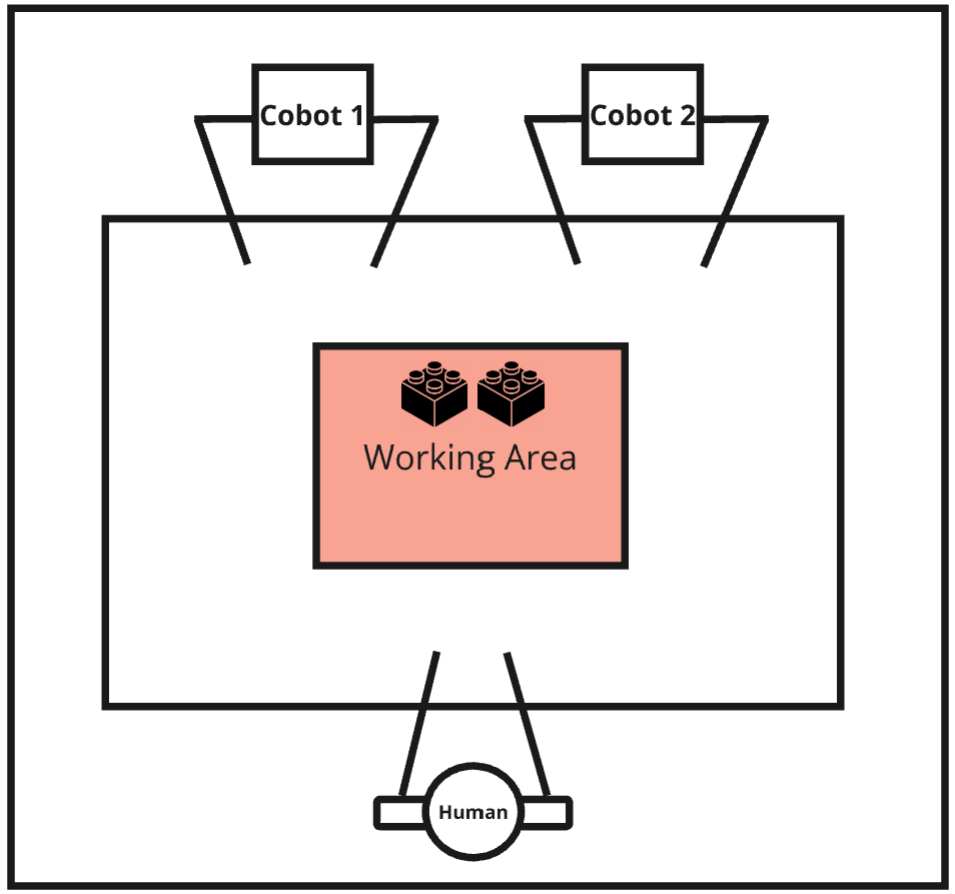
Efficient Processing

Artificial Agent Control

[4] Kotseruba, I., Gonzalez, O. J. A., & Tsotsos, J. K. (2016). A review of 40 years of cognitive architecture research: Focus on perception, attention, learning and applications. *arXiv preprint arXiv:1610.08602*, 1-74.

Requirements

Human Cobot Collaboration scenario :



- R1 — **Perception**
- R2 — **Intent Interpretation**
- R3 — **Decision Making**
- R4 — **Efficiency**
- R5 — **Flexibility**

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Comparison of Cognitive Architectures

Architecture	Type	Strengths	Weakness	CPS Application
ACT-R	Hybrid	Learning, Rule-based Decision-Making	Dynamic environments and Real-time perception	Potential for symbolic tasks
SOAR	Symbolic	Generalist, good at Reasoning	Continuous learning and perceptive skills	Effective at solving complex problems
LIDA	Hybrid	Adapted to Dynamic Environments	Complexity of implementation and calibration	Highly suitable for dynamic interaction with the environment
CLARION	Hybrid	Social Cognition and Motivation	Architecture complexity	Suitable for social interaction

[5] Kotseruba, I., & Tsotsos, J. K. (2020). 40 years of cognitive architectures: core cognitive abilities and practical applications. *Artificial Intelligence Review*, *53*(1), 17-94.

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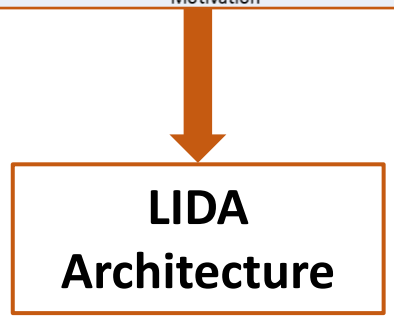
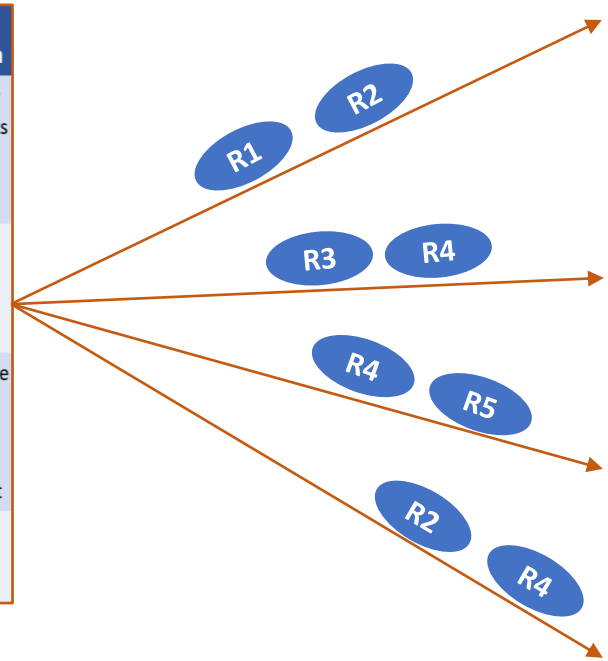




Complete visual processing including simulation and physical sensors.

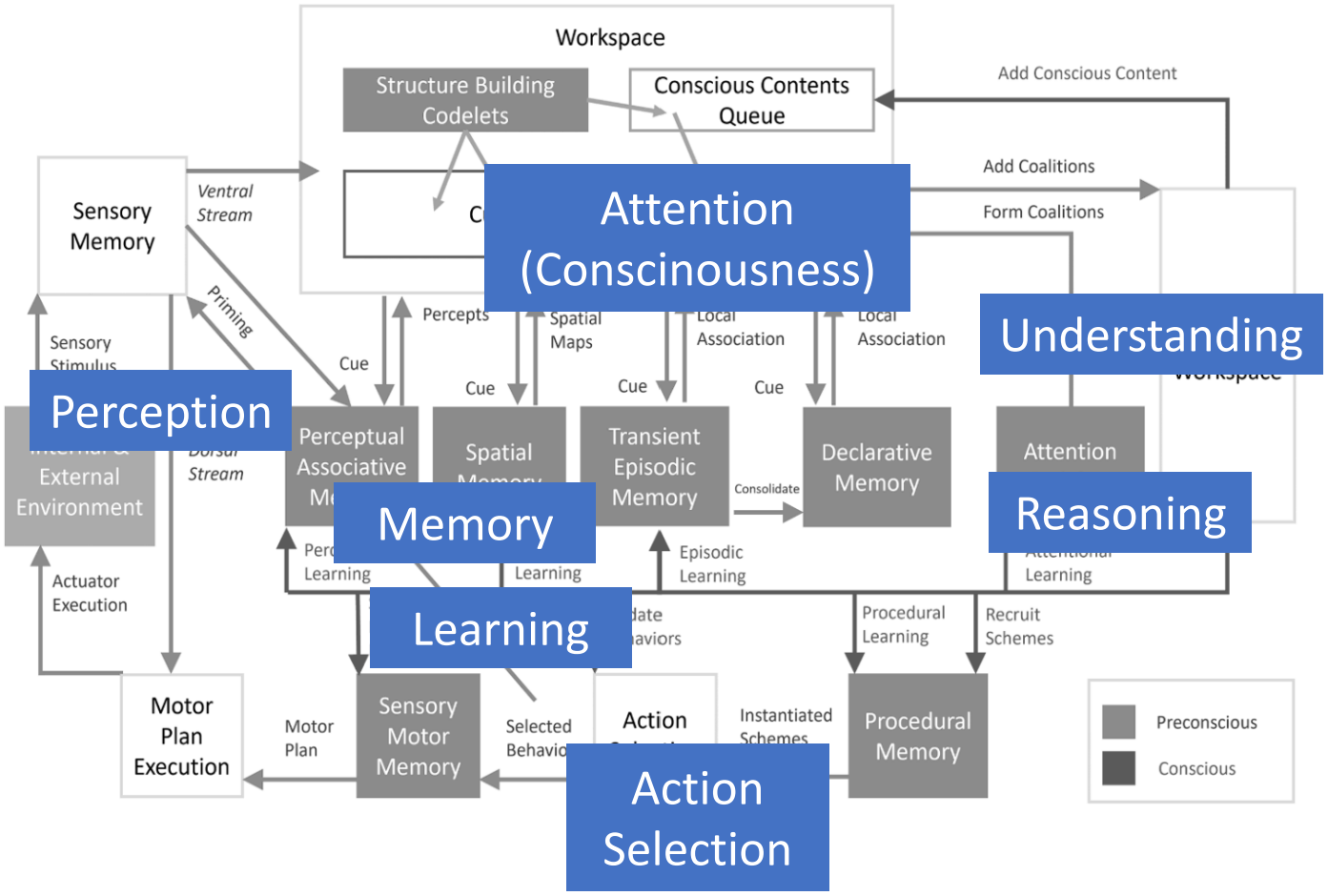
Sensor data merging.

High level of flexibility.

Advanced capabilities in attention.

LIDA Architecture

- Primarily developed by Stan Franklin since 2006.
- A comprehensive cognitive model that simulates a **large spectrum of cognition in biological systems**..
- LIDA can be applied to create **software agents**, **control robots**, and **develop artificial cognitive systems**.



LIDA Architecture [6]

[6] Neemeh, Z. A., Kronsted, C., Kugele, S., & Franklin, S. (2021). Body schema in autonomous agents. Journal of Artificial Intelligence and Consciousness, 8(01), 113-145.

Perspectives

- Validate the effectiveness of the LIDA architecture in the industrial use-case in lab, by observing how the cobot adapts and interacts with its environment and with human operators.

- Cognitive architecture could potentially enrich our understanding of "*theory of mind*" by providing a framework through which we can predict human cognitive processes and behaviors, highlighting how we infer the perceptions, thoughts and desires of others.

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Thanks for your attention!

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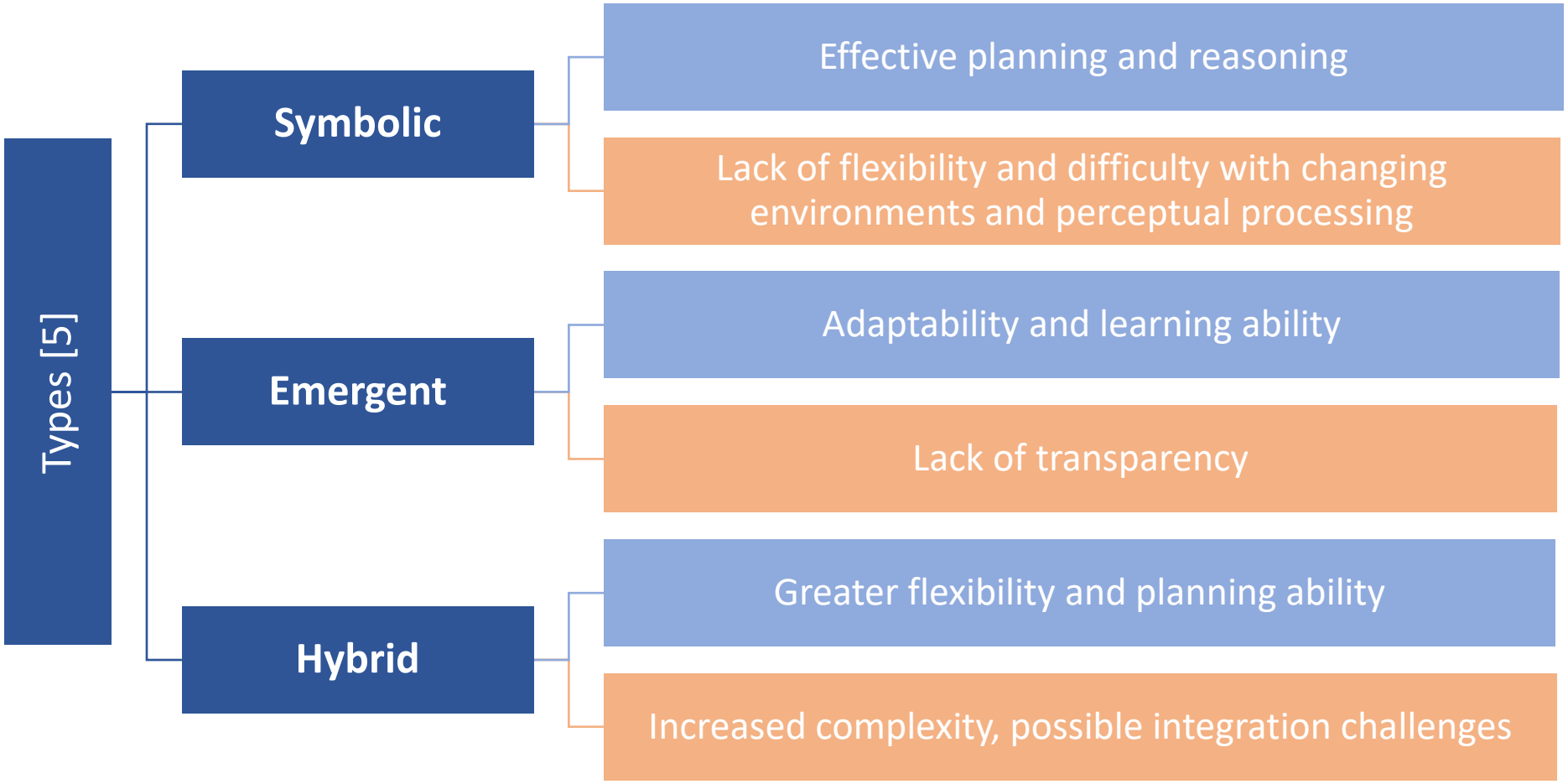
Types of Cognitive Architectures



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