COGNITIVE ARCHITECTURES

ARTIFICIAL INTELLIGENCE | COMP 131

TODAY ON AI

- Cognitive architectures
- Cognitivist cognitive architectures
- Emergent cognitive architectures
- Choices of cognitive architectures
- The SOAR cognitive architecture
- Questions?

The ultimate goal of AI is to construct **generally intelligent systems** with intellectual capacities similar to humans.

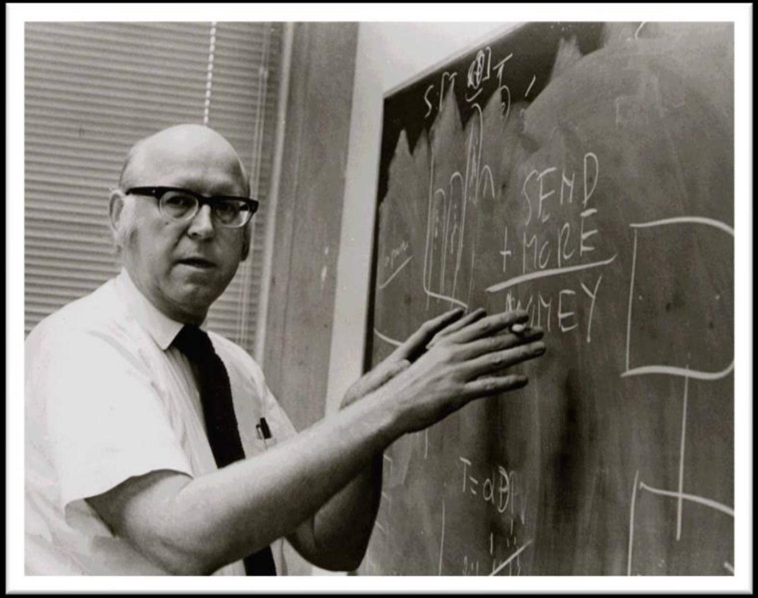
- AI is highly **fractured** in specific fields: **Computer Vision**, **Natural Language Processing**, **Planning**
- We tend to design algorithms for a **single domain**, and evaluated their effectiveness in that domain
- Good performance in these isolated systems **does not guarantee** generally intelligent systems

Cognition is the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses

- **Allen Newell** (1973) critiqued cognitive psychologists who studied components of cognition (e.g., language, memory, attention) in isolation without considering their interaction

- His thesis was that Psychology is ready for a **unified theories of cognition**.

- In 1982, Newell was the first one to use the term **Cognitive Architecture**.



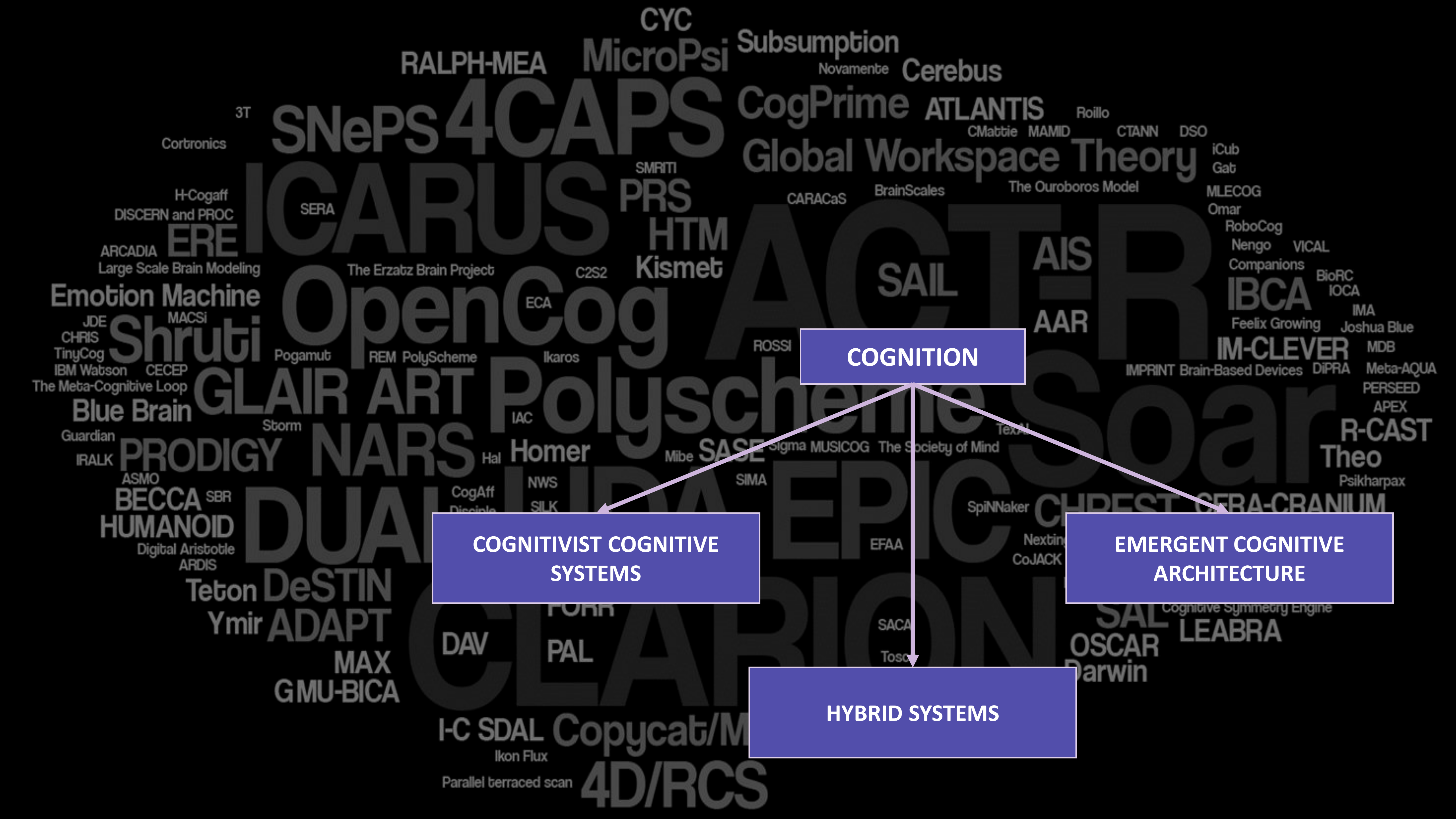
SECTION 01

Cognitive architectures

- Cognitive architectures go beyond the traditional agent architectures by making **architectural commitments** based on cognitive theories.

- A cognitive architecture is an **embodiment of a scientific hypothesis** about those aspects of human cognition that are:
  - **Constant over time**
  - **Independent of task**

- Overall structure and organization of a cognitive system has:
  - **Essential modules** that implement basic functionalities
  - **Essential relations** between these modules
  - **Essential algorithmic** and **representational details** in each module


COGNITION
COGNITIVIST COGNITIVE SYSTEMS
HYBRID SYSTEMS
EMERGENT COGNITIVE ARCHITECTURE
CYC
MicroPsi
Subsumption
RALPH-MEA
Novamente
Cerebus
SNePS
4CAPS
CogPrime
ATLANTIS
Roillo
3T
Cortronics
CMattie
MAMID
CTANN
DSO
Global Workspace Theory
iCub
Gat
SMRITI
ICARUS
PRS
H-Cogaff
SERA
CARACaS
BrainScales
The Ouroboros Model
MLECOG
Omar
DISCERN and PROC
ERE
HTM
ACT-R
RoboCog
ARCADIA
Nengo
VICAL
Large Scale Brain Modeling
The Erzatz Brain Project
C2S2
Kismet
AIS
Companions
SAIL
BioRC
IOCA
Emotion Machine
OpenCog
ECA
IBCA
IMA
JDE
MACSi
AAR
Feelix Growing
Joshua Blue
CHRIS
Shruti
ROSSI
IM-CLEVER
MDB
TinyCog
Pogamut
REM
PolyScheme
Ikaros
IBM Watson
CECEP
IMPRINT
Brain-Based Devices
DiPRA
Meta-AQUA
The Meta-Cognitive Loop
GLAIR
ART
Polyscheme
PERSEED
Soar
APEX
Blue Brain
IAC
Storm
R-CAST
Guardian
Theo
IRALK
PRODIGY
NARS
Hal
Homer
Mibe
SASE
Sigma
MUSICOG
The Society of Mind
ASMO
NWS
SIMA
Psikharpax
BECCA
SBR
CogAff
EPIC
SpiNNaker
HUMANOID
DUAL
SILK
CERA-CRANIUM
Digital Aristotle
EFAA
CoJACK
ARDIS
Teton
DeSTIN
Cognitive Symmetry Engine
Ymir
ADAPT
CLARION
SACA
LEABRA
DAV
OSCAR
MAX
PAL
Darwin
GMU-BICA
I-C SDAL
Ikon Flux
Parallel terraced scan
4D/RCS

SECTION 02

Cognitivist cognitive architectures

- How are the agent’s **beliefs**, **goals**, and **knowledge** stored and accessed in **short-term memory** and **long-term memory**?

- How are such memories **structured**?

- What **process** make use of these structures to make decisions and solve problems?

Cognitivist cognitive architectures try to answer questions like:

- What process adapt these structures to effect **learning**?
- How is **attention** directed, and what is its effect?
- How can we, as humans, go about **encoding knowledge** and **processes** (i.e., program) in a way that supports these commitments?

SECTION 03

Emergent cognitive architectures

Emergent approaches focus on development – from a primitive state – to fully cognitive state, over the system's lifetime.

- The cognitive architecture is the system's **phylogenetic configuration**, or original configuration:
  - **Innate skills**
  - **Core knowledge** (initial skills)
- The phylogenetic configuration represents the basis for **ontogenesis**: growth and development
- Ontogenesis represents a structure in which to embed mechanisms for: **perception, action, adaptation, anticipation, and motivation**
- How does the agent's **physical morphology** affect development?

Children go through **four distinct stages** of cognitive development

Focuses on active **assimilation or accommodation** of new information

JEAN PIAGET

1896 - 1980

LEV VYGOTSKY

1896 - 1934

Cognitive development is **continuous**

Focuses on internalization of **interactions and dialogues**

1. **Sensorimotor stage** (0 – 2 years): the infants constructs an understanding of the world by coordinating sensory experiences with physical actions

2. **Preoperational stage** (2 – 7 years): the child beings to represent the world with words and images. These words and images reflect increased symbolic thinking and go beyond the connection of sensory information and physical action

3. **Concrete operational stage** (7 – 11 years): The child can now reason logically about concrete events and classify objects into different sets

4. **Formal operational stage** (11 – adulthood): The adolescent reasons in more abstract, idealistic, and logical ways

SECTION 04

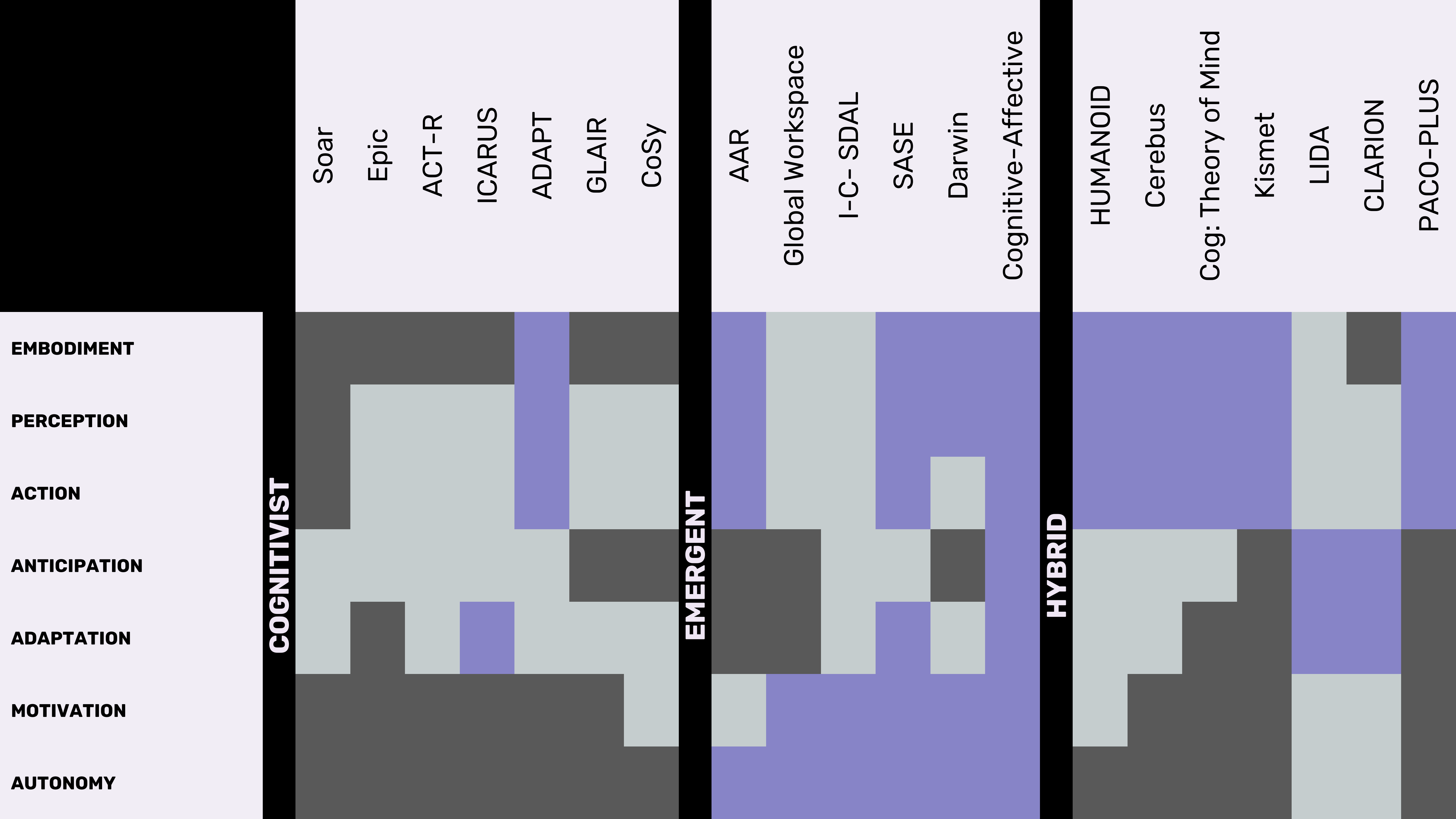
Choices of cognitive architectures

- Is the architecture **ecologically realistic**?
  - Can it perform everyday activities?
  - Can it deal with simultaneous, conflicting goals?
  - Does it take embodiment into account?
- Is the architecture **evolutionarily realistic**?
  - Can it be reduced to a plausible model of animal cognition?
- Is the architecture **cognitively realistic**?
  - Does it capture the essential characteristics of behavior and cognition, based on our knowledge of psychology, philosophy, and neuroscience?
- Is it **methodologically general**?
  - A cognitive architecture shouldn't commit to specific methodologies unless there's a good reason for it, or future research could be overly constrained.

COGNITIVIST COGNITIVE ARCHITECTURES	EMERGENT COGNITIVE ARCHITECTURES
EMBODIMENT	
Cognition is independent of the physical platform in which it is implemented	Intrinsically embodied, the physical instantiation plays a direct constitutive role in the cognitive process
PERCEPTION	
Perception provides an interface between the external world and the symbolic representation of that world	Perception is a change in system state in response to environmental perturbations in order to maintain stability
ACTION	
Actions are causal consequences of symbolic processing of internal representations	Actions are perturbations of the environment by the system
ANTICIPATION	
Anticipation typically takes the form of planning using some form of procedural or probabilistic search	Anticipation requires the system to visit several states in its self-constructed perception-action state space without committing to the associated actions

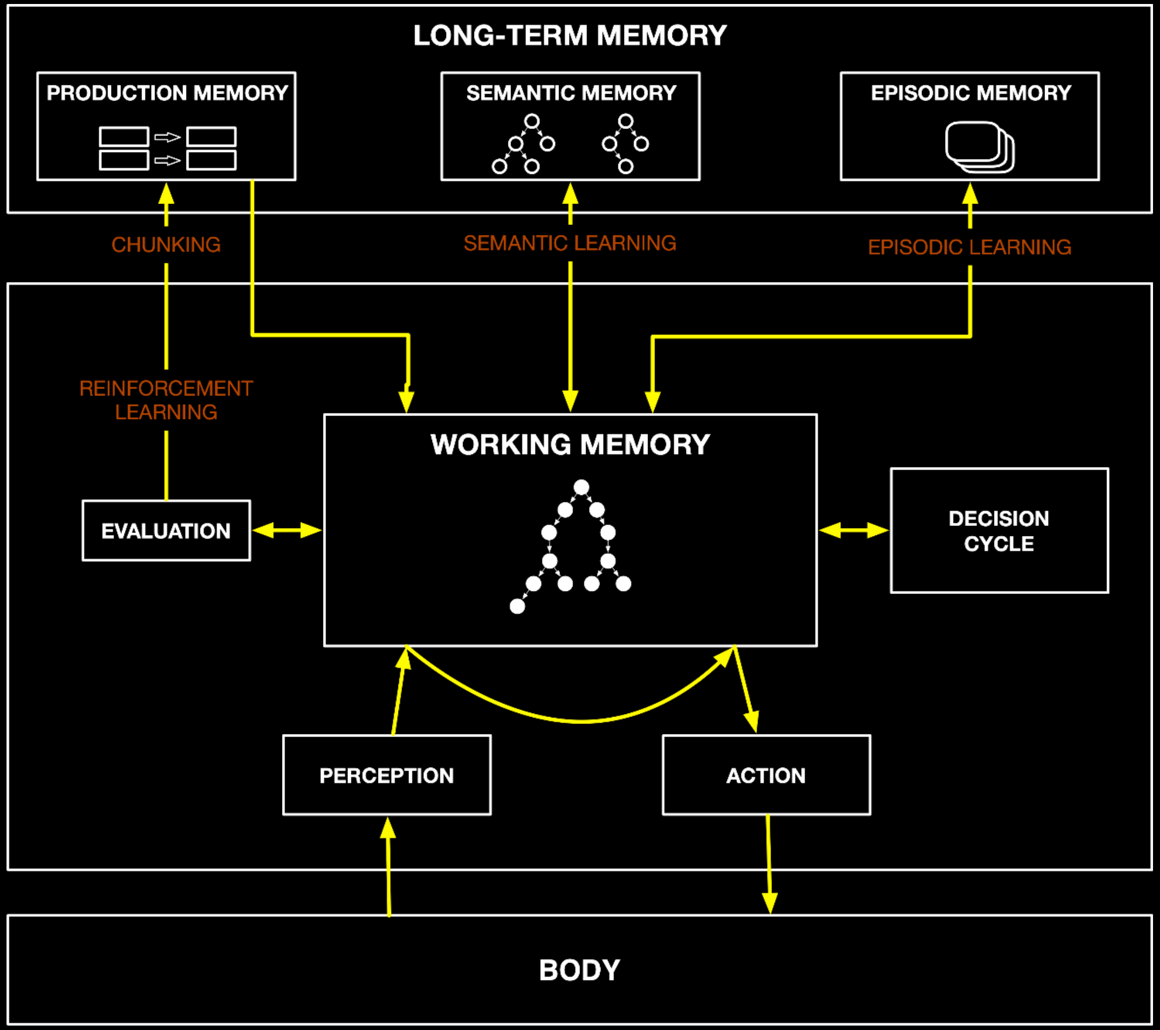
COGNITIVIST COGNITIVE ARCHITECTURES	EMERGENT COGNITIVE ARCHITECTURES
ADAPTATION	
Adaptation usually implies the acquisition of new knowledge	Entails a structural alteration or reorganization to effect a new set of dynamics
MOTIVATION	
Impinge on perception, action and adaption to resolve an impasse	Enlarge the space of interaction
AUTONOMY	
Is not necessarily implied	Autonomy is crucial since cognition is the process whereby an autonomous system becomes viable and effective

COGNITIVIST COGNITIVE ARCHITECTURES	HYBRID SYSTEMS	EMERGENT COGNITIVE ARCHITECTURES
• **Soar** [Newell et al. 1987] • **EPIC** [Kieras & Meyer 1997] • **ICARUS** [Langley 05, Langley 2006] • **GLAIR** [Shapiro & Bona 2009] • **CoSy** [Hawes & Wyatt 2008]	• **CLARION** [Sun 2007] • **ACT-R** [Anderson et al. 2004] • **ACT-R/E** [Trafton et al. 2013] • **KHR** [Burghart et al. 2005] • **LIDA** [Franklin et al. 2007, Baars & Franklin 2009] • **PACO-PLUS** [Kraft et al. 2008]	• **iCub** [Vernon et al. 2010] • **Global Workspace** [Shanahan 2006] • **SASE** [Weng 2004] • **Darwin** [Krichmar et al. 2005] • **Cognitive Affective** [Morse et al 2008]


COGNITIVIST
Soar
Epic
ACT-R
ICARUS
ADAPT
GLAIR
CoSy
EMERGENT
AAR
Global Workspace
I-C- SDAL
SASE
Darwin
Cognitive-Affective
HYBRID
HUMANOID
Cerebus
Cog: Theory of Mind
Kismet
LIDA
CLARION
PACO-PLUS
EMBODIMENT
PERCEPTION
ACTION
ANTICIPATION
ADAPTATION
MOTIVATION
AUTONOMY

SECTION 05

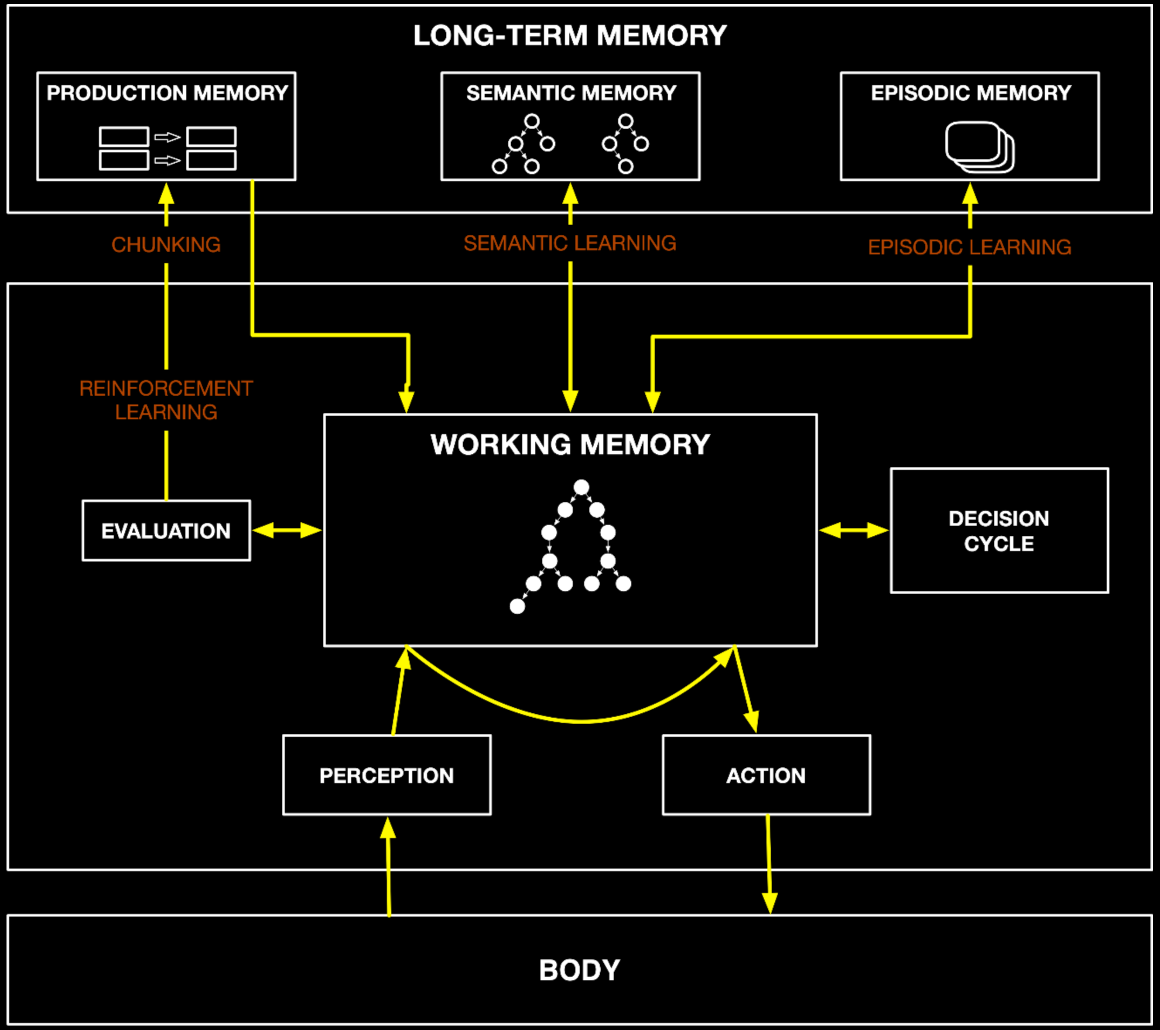
The SOAR cognitive architecture



SOAR

Laird, Newell, Rosenbloom (1987)

The goal of SOAR is to develop the fixed computational building blocks needed by a general intelligent agent.



Production memory: Long-term memory of knowledge about how to apply operations

Semantic memory: Long-term memory of the semantic relationship among operations/facts/things

Episodic memory: Working memory snapshots

Working memory: A representation of the current state of the world

Decision cycle: A repetitive interaction between **production memory** and **working memory** to select and apply operations

Evaluation and learning: Soar uses **Reinforcement Learning** to support the **evaluation** of facts in the **working memory** in order to extract rules (**chunking**) that will eventually be transferred into the production memory.

SOAR architecture

1. **Problem Space Hypothesis**: All goal-oriented behaviors can be seen as a search in the space of all possible states

2. **Only one operator at the time**: Only one operator at the time can be selected

3. **Impasse resolution via sub-state creation**: If the knowledge needed by an operator is incomplete, a new sub-goal is created to search for the missing information (**hierarchical task decomposition**)

4. **Modularity**: Soar's task modules are isolated and independent

5. **Symbolic memory**: Almost all memory elements in Soar are symbolic (except for the visual memory)

There are many aspects and open questions regarding cognition in humans:

Attention
Memory
Problem solving
Decision making
Learning
Concept formation
Embodiment

Reasoning
Prospection
Motivation
Planning
Language
Representation

QUESTIONS ?

ARTIFICIAL INTELLIGENCE

COMP 131

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