Abu Dhabi 2023
iCAR
21st International Conference on Advanced Robotics

Abu Dhabi, UAE
6th December 2023

The Situation Model Framework for Cognitive Behavior: Implications for the Design of Robot Cognitive Architectures

David Vernon
Carnegie Mellon University Africa

www.vernon.eu

IEEE Robotics & Automation Society
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It is a special honour to be here today

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Khalifa University

25 Years ago, I joined Etisalat College of Engineering

1998 — 2023

Etisalat College of Engineering

1989
كلية إتصالات الجامعية
Etisalat University College

KHALIFA UNIVERSITY

KHALIFA UNIVERSITY OF SCIENCE, TECHNOLOGY & RESEARCH

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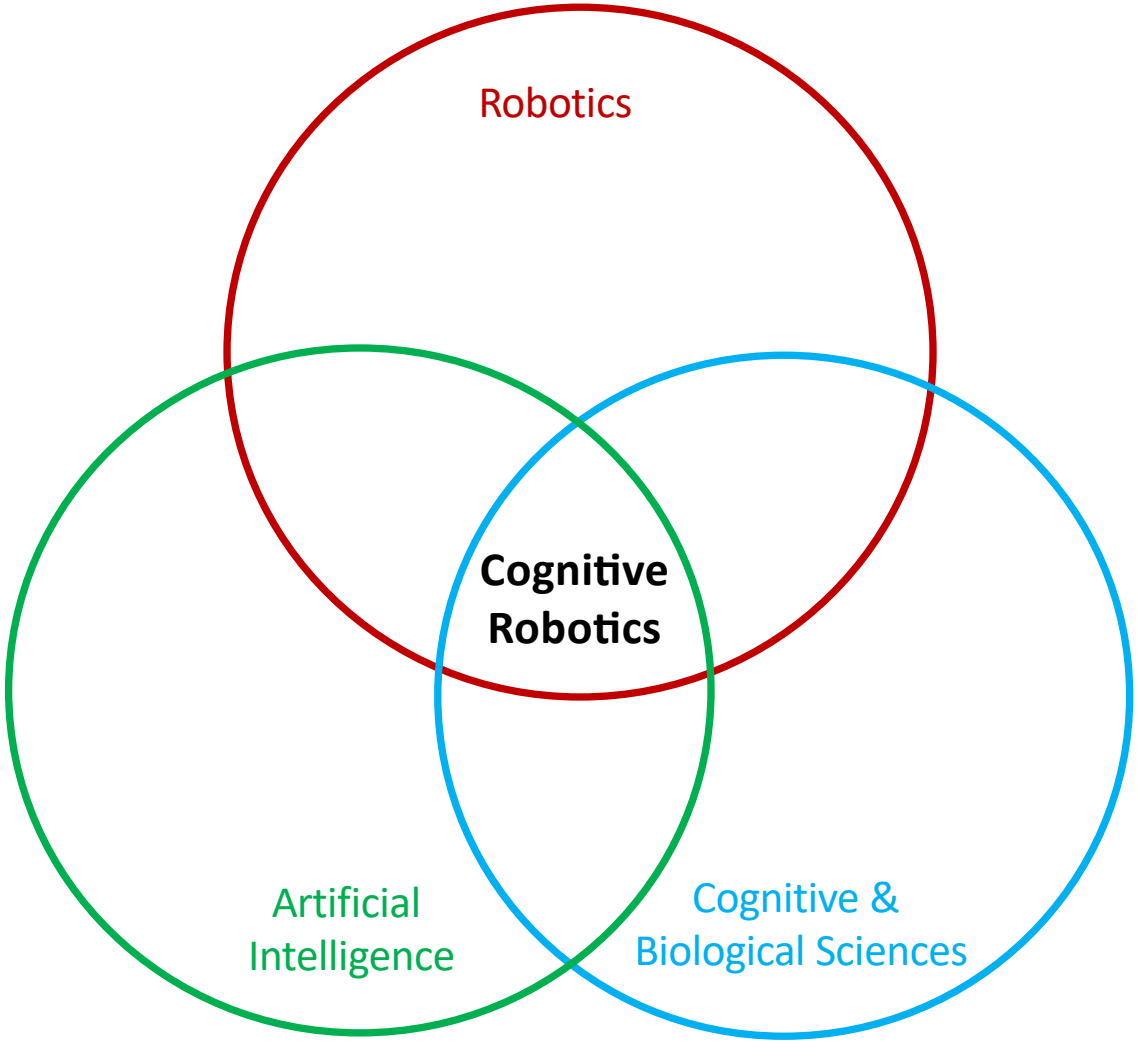
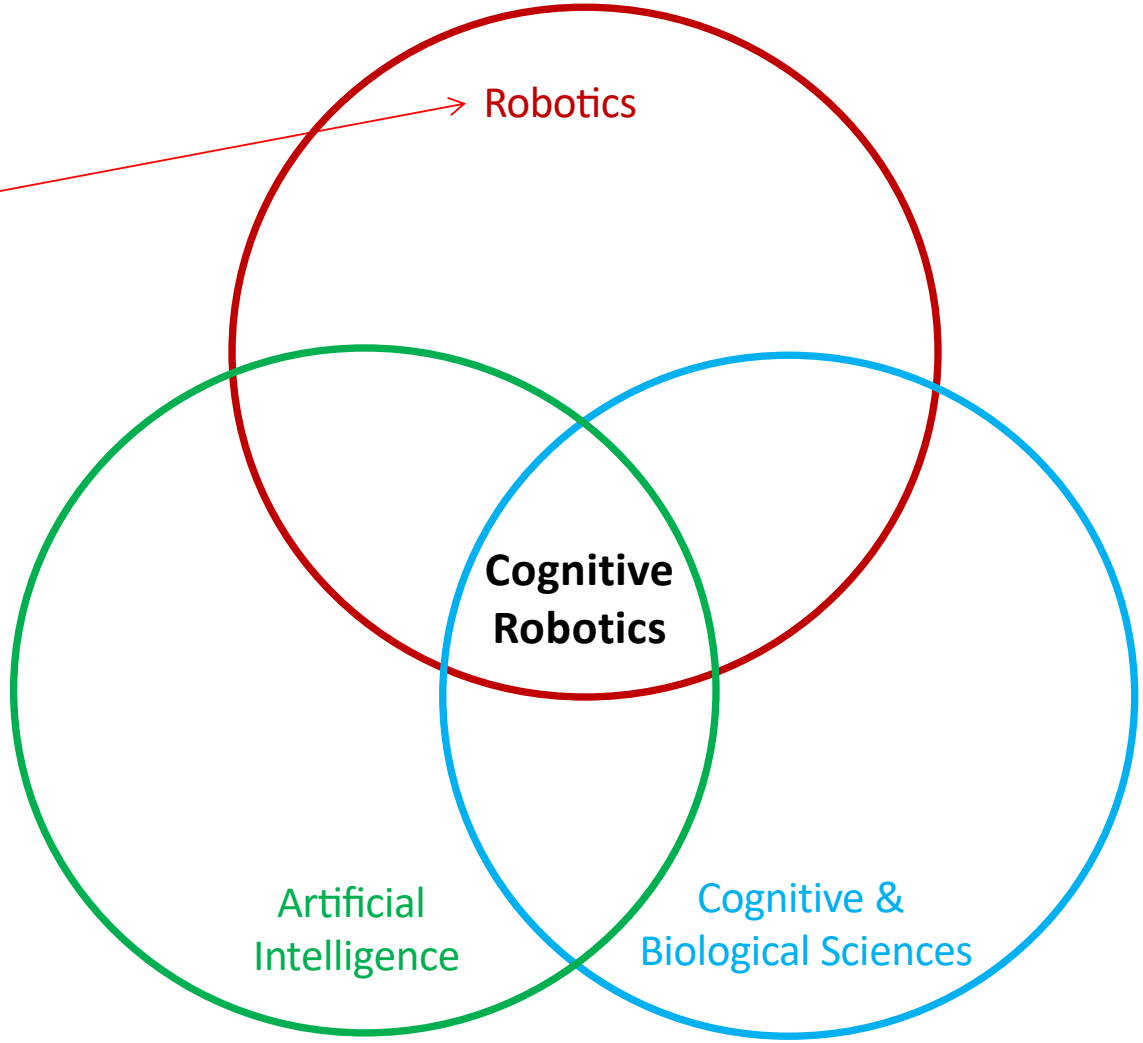
How can robots achieve the versatility and flexibility that is needed to accomplish everyday activities?

Cognition!

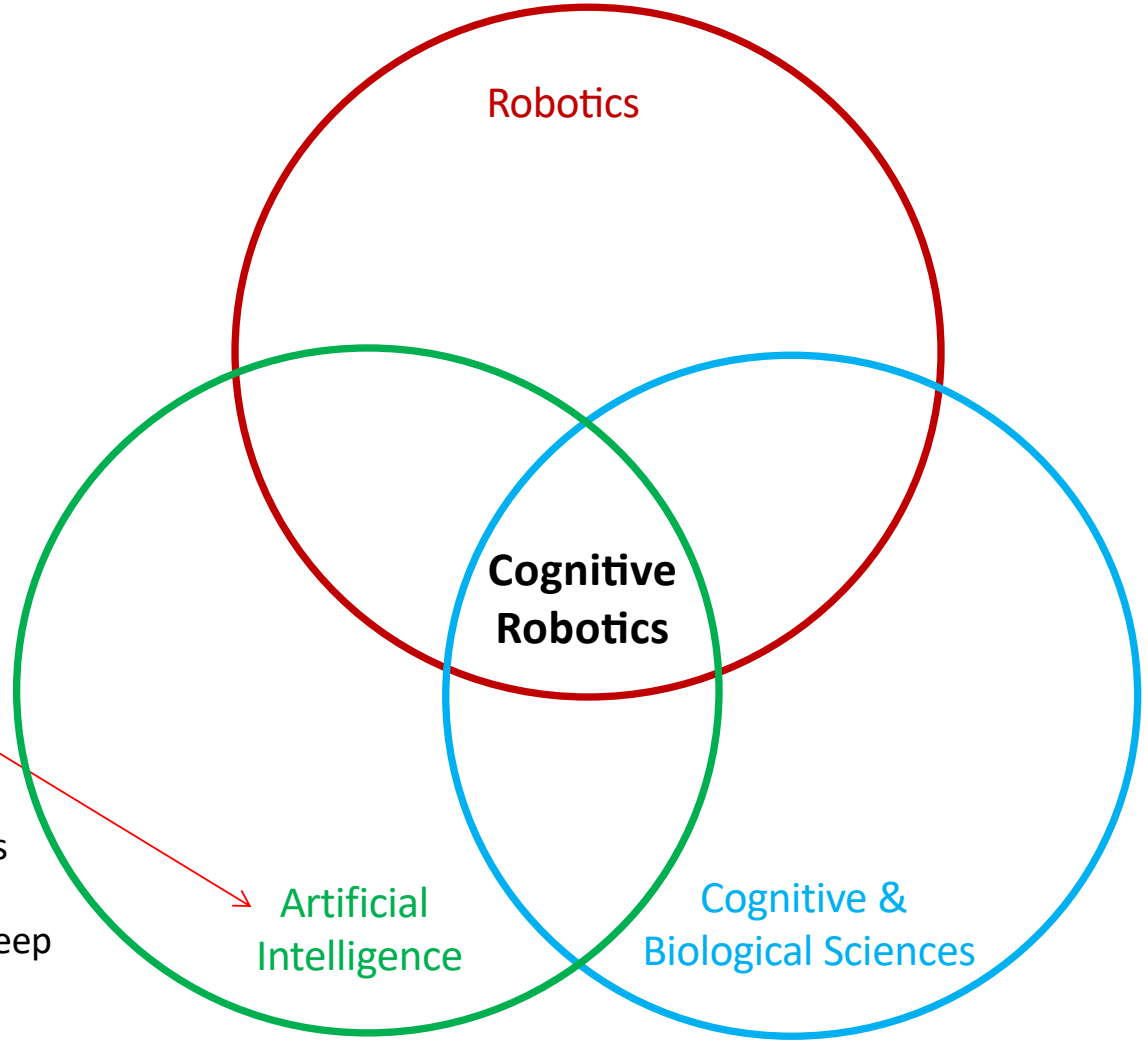
Cognition: breaking free of the present and the limitations of perception

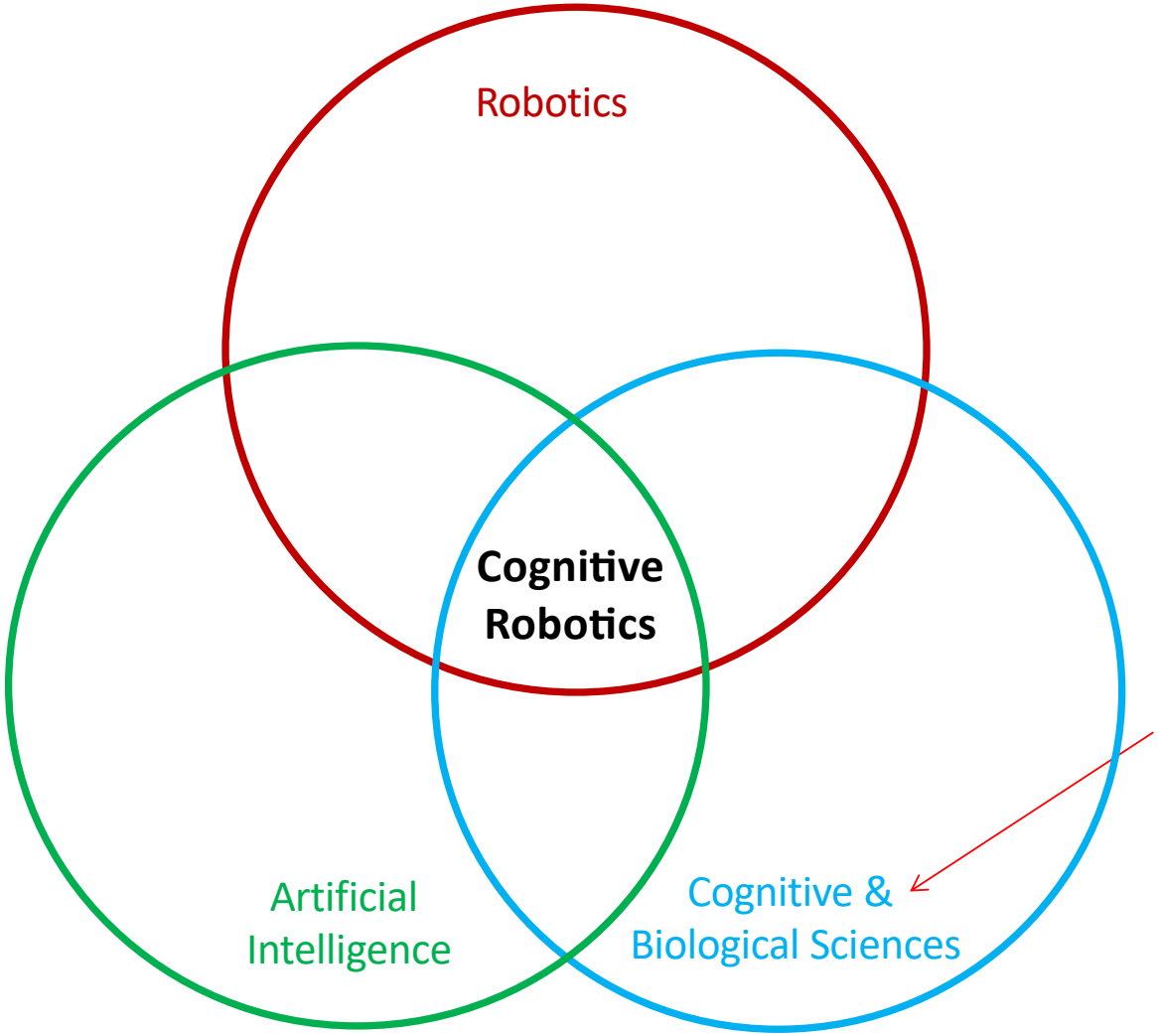

Robotics
Cognitive
Robotics
Artificial
Intelligence
Cognitive &
Biological Sciences

Linear algebra
Calculus
Actuators
Effectors
Sensors
Control
Kinematics
Dynamics
Locomotion
Navigation
SLAM
Vector & quaternion
pose specification
Manipulation
Planning
Social robotics
Human-robot interaction
...



Knowledge representation
Reasoning
Inference
Classical machine learning
Deep machine learning
Reinforcement learning
Supervised learning
Unsupervised learning
Self-supervised learning
Vision-language-action models
Probabilistic graphical models
Computer vision, classical & deep
Natural language processing
Cybernetics (1st & 2nd order)
Unified theories of cognition
Cognitive architectures x n
...





Cognitive science
Neuroscience
Developmental psychology
Social science
Ethnography
...

Unified theories of cognition
Cognitive architectures x n
Semantic memory
Procedural memory
Episodic memory
Working memory
Associative memory
Dual process theory: system 1 & 2
Theory of mind
Joint action
Joint attention
Shared intention
Shared goals
Biological motion
Non-verbal, verbal communication
Autonomy
Self-organization
Emergence
...

Overview

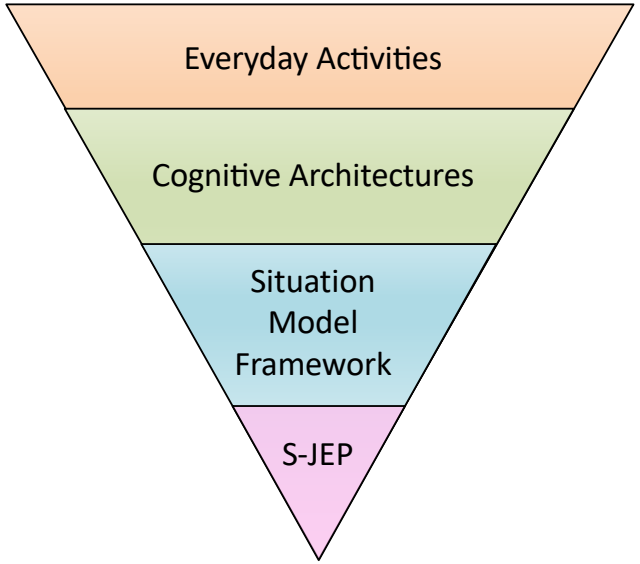
1. Everyday activities: easy & difficult vs. simple vs complex

2. Cognitive Architectures

   - Introduction to cognitive architectures
   - CRAM
   - Extending CRAM

3. The Situation Model Framework (SMF)

   - Behavioral episodes
   - Two-system approach



4. Semantically-Modulated Joint Episodic-Procedural Associative Memory (S-JEP)

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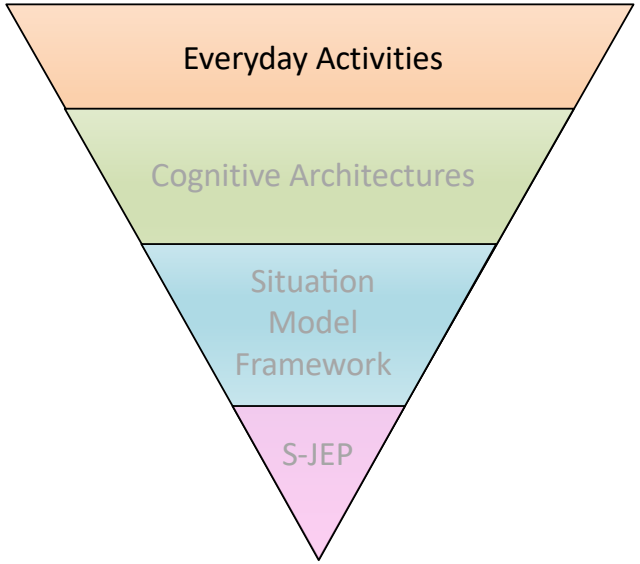

TOPICS
TOPICS IN COGNITIVE SCIENCE

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Action Selection and Execution in Everyday Activities: A Cognitive Robotics and Situation Model Perspective

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[b]*Center for Interdisciplinary Research (ZiF), Bielefeld University*
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Everyday activities: simple, complex, easy, difficult

Everyday activities are carried out routinely by humans

They often seem simple and straightforward
But they can be complex and demanding, at least at first

Everyday activities: simple, complex, easy, difficult

https://www.buzzfeed.com/taylor_steele/unique-dinnerware-sets

Task Transparency	Simple	Complex
Easy	**Easy**: Solution strategy clearly evident. **Simple**: Strong constraints on combination of steps, few degrees of freedom in each step.	**Easy**: Solution strategy clearly evident. **Complex**: Weak constraints on combination of steps, several degrees of freedom in each step.
Difficult	**Difficult**: Solution strategy not clearly evident. **Simple**: Strong constraints on combination of steps, few degrees of freedom in each step.	**Difficult**: Solution strategy not clearly evident. **Complex**: Weak constraints on combination of steps, several degrees of freedom in each step.

Task Complexity

Stacking plates:
pick them, put down somewhere else

Complexity is an attribute of the activity / task

https://www.mirror.co.uk/news/weird-news/mum-shares-game-changing-dishwasher-22648263

Filling a dishwasher: placement matters
for effective washing &
for efficient washing (full load)

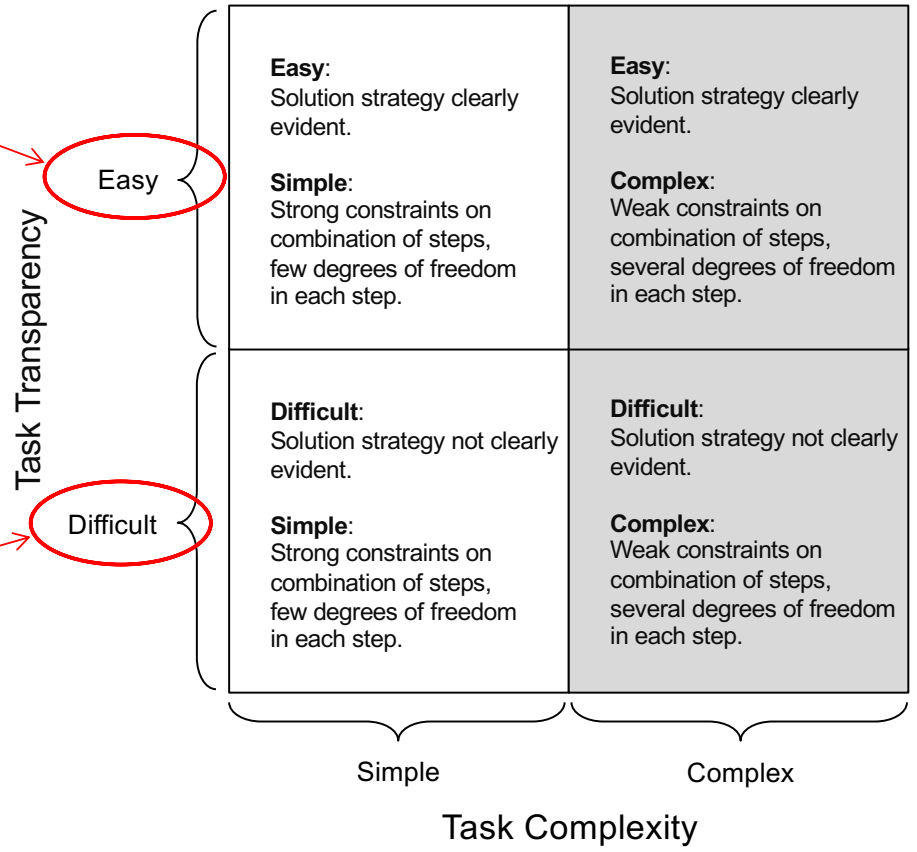
Everyday activities: simple, complex, easy, difficult

Any activity with which an agent is familiar

Task transparency depends on the agent

Any activity with which an agent struggles

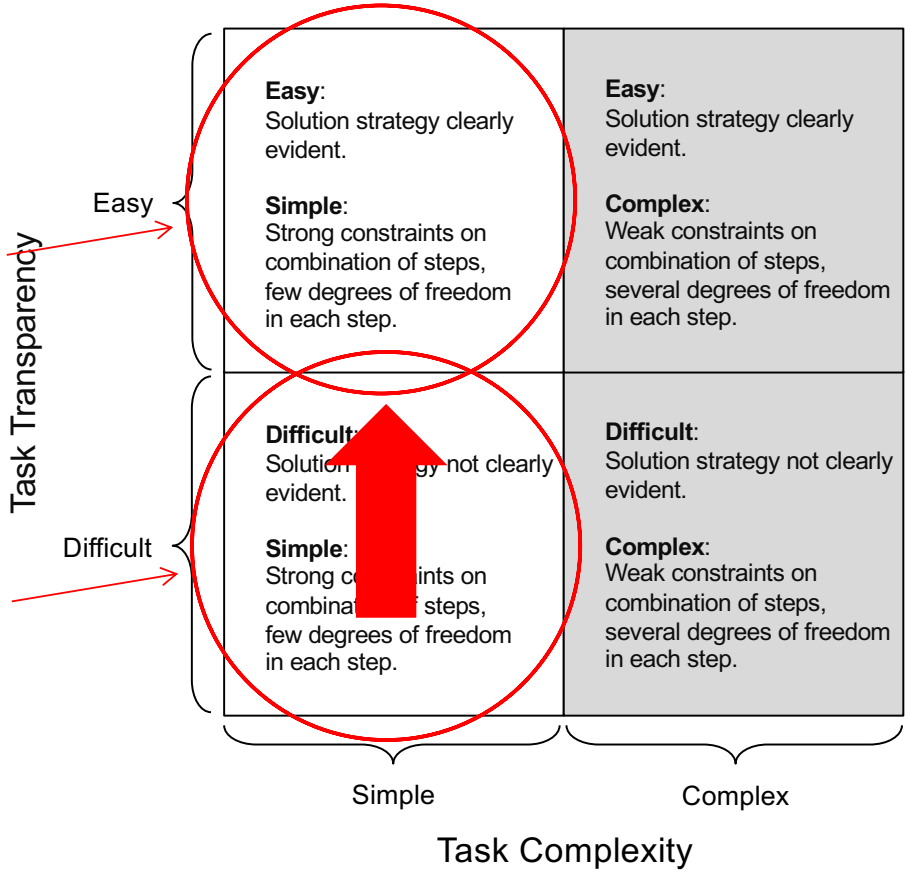
(with unnecessary effort
beyond the intrinsic complexity of the activity)



Everyday activities: simple, complex, easy, difficult

But it may become easy
with repeated routine execution

An agent may need to deliberate for a simple task

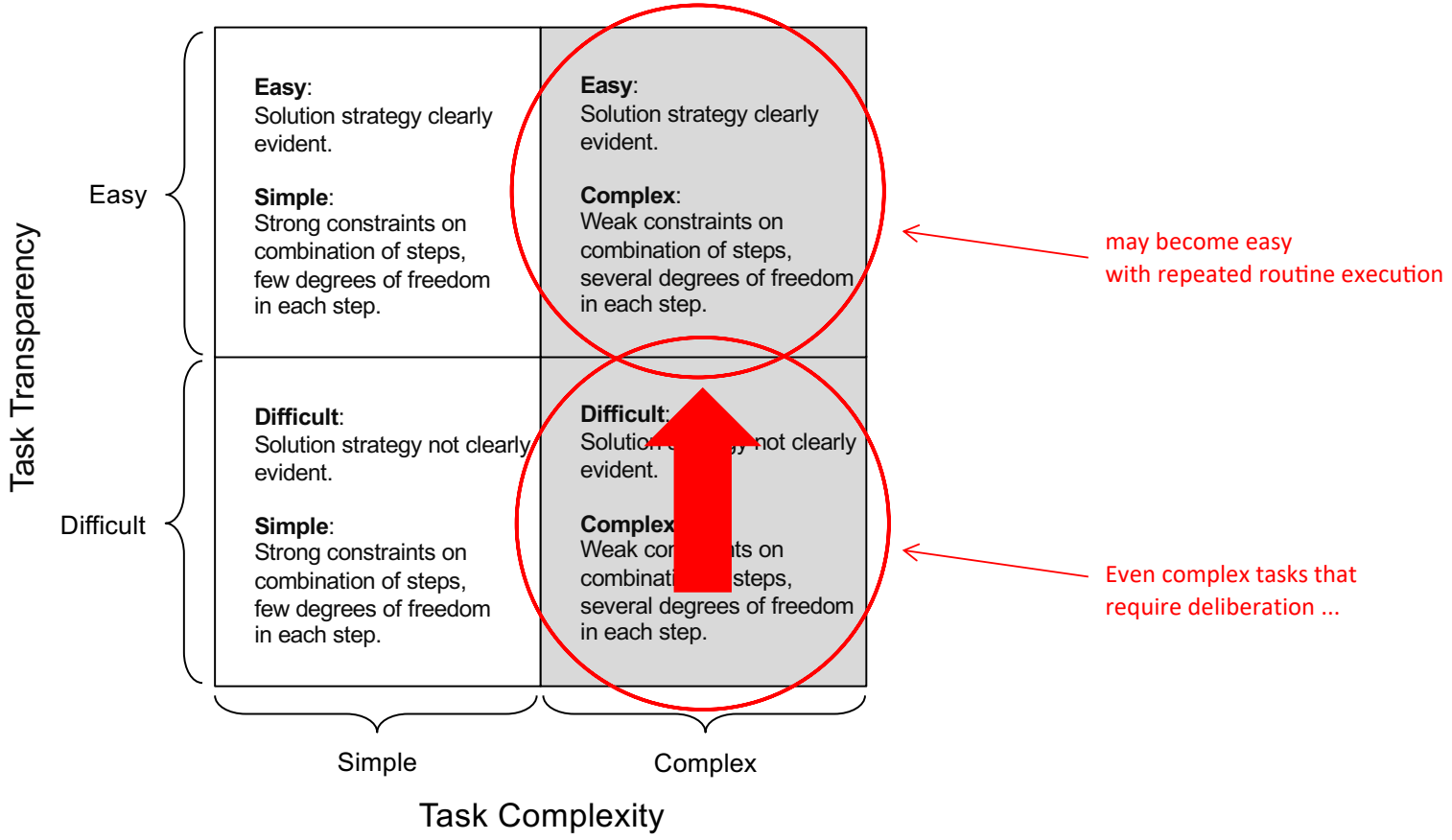


Each quadrant may need an agent **cognitive architecture** to recruit **different mechanisms**

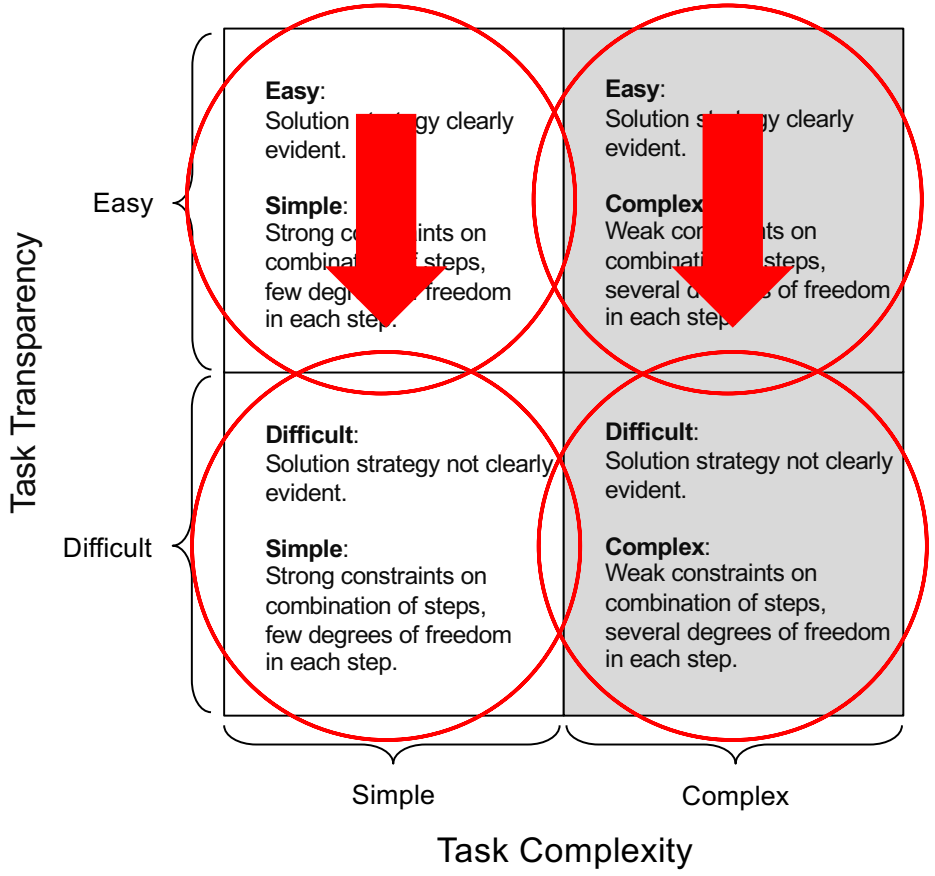
Some tasks being accomplished in a **habitual** manner

Other tasks requiring more **deliberation**

Everyday activities: simple, complex, easy, difficult



Everyday activities: simple, complex, easy, difficult



And easy activities ...

may require **deliberation**,
e.g. when something unexpected happens

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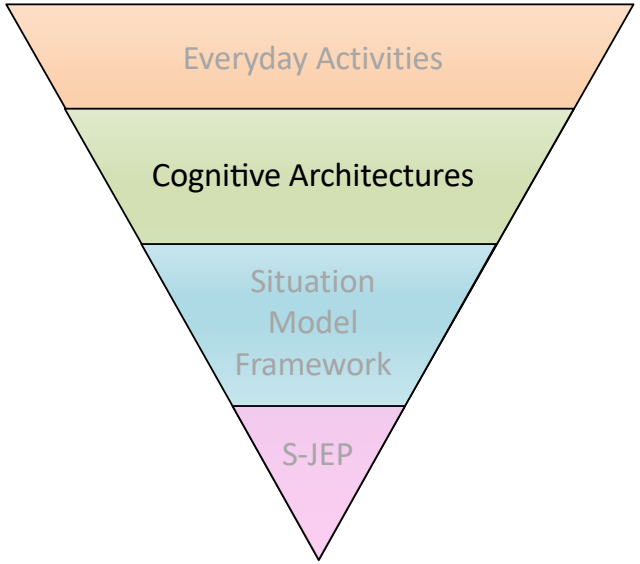


Cognition

"Cognition is the process by which an autonomous system

perceives its environment,

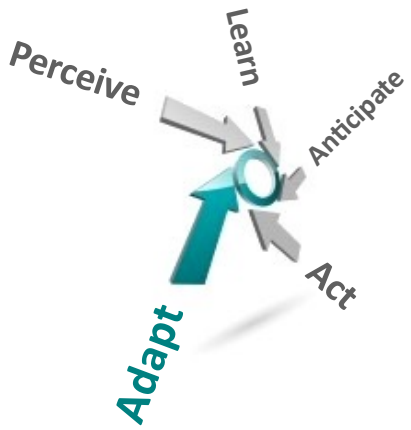
learns from experience,

anticipates the outcome of events,

acts to pursue goals, and

adapts to changing circumstances."

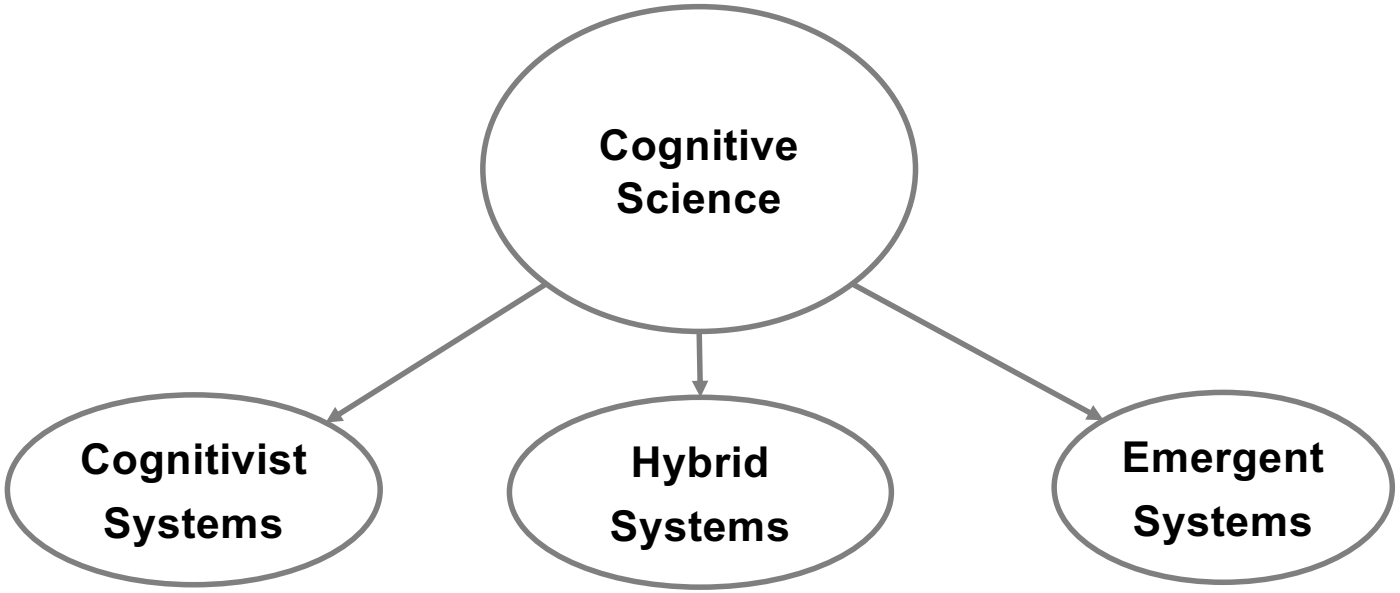
D. Vernon, Artificial Cognitive Systems – A Primer, MIT Press, 2014



Doing this requires a **cognitive architecture** to orchestrate the core cognitive abilities:

Perception
Attention
Action selection
Memory
Learning
Reasoning
Meta-reasoning
Prospection

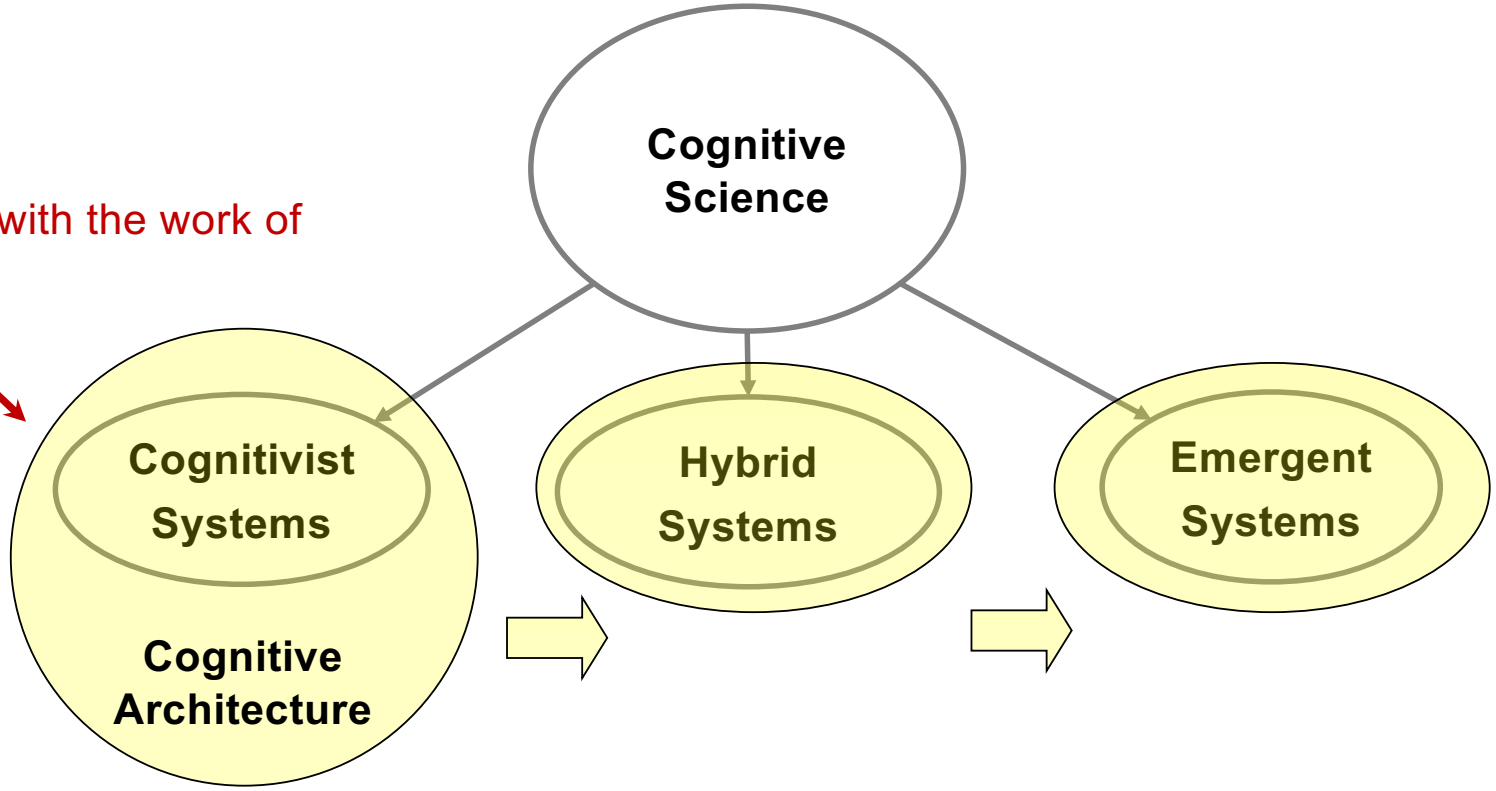
Cognitive Architectures

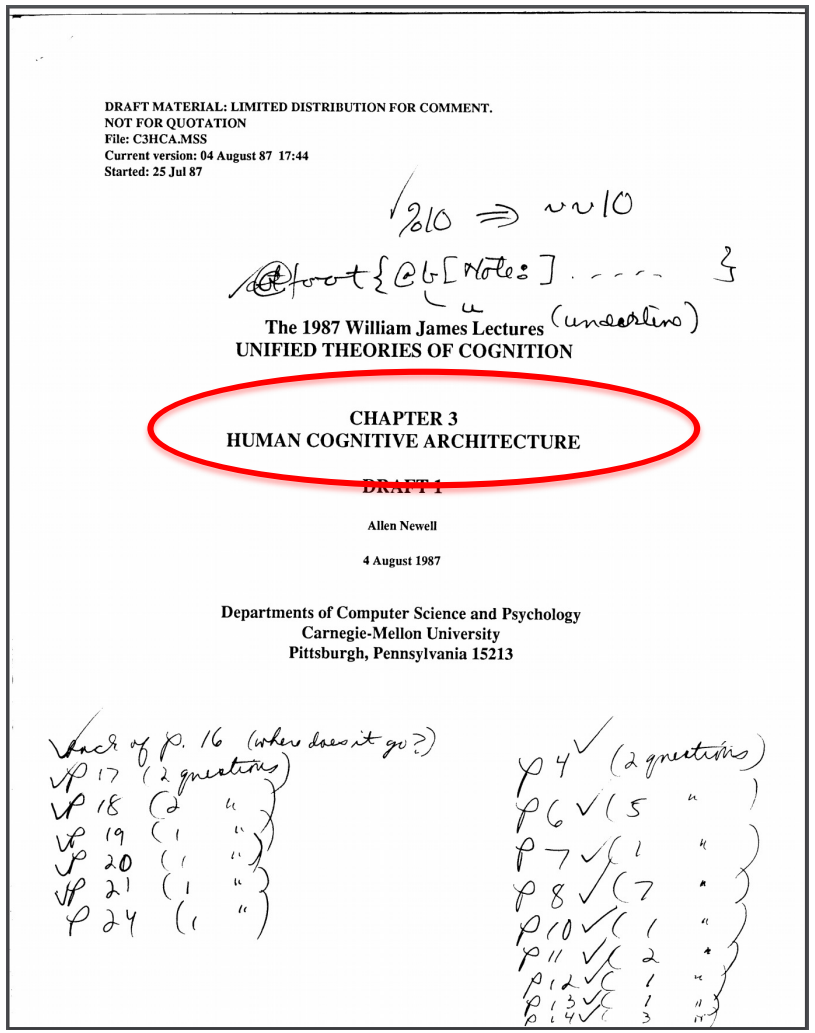


There are three paradigms of cognitive science

Cognitive Architectures

The term originated with the work of Allen Newell (1990)





DRAFT MATERIAL: LIMITED DISTRIBUTION FOR COMMENT.
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File: C3HCA.MSS
Current version: 04 August 87 17:44
Started: 25 Jul 87

The 1987 William James Lectures (underline)
UNIFIED THEORIES OF COGNITION

CHAPTER 3
HUMAN COGNITIVE ARCHITECTURE

DRAFT 1

Allen Newell

4 August 1987

Departments of Computer Science and Psychology
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=352120

Example Cognitive Architectures

Surveys:

Biologically Inspired Cognitive Architectures Society, Comparative Repository of Cognitive Architectures, http://bicasociety.org/cogarch/architectures.htm [25 cognitive architectures]

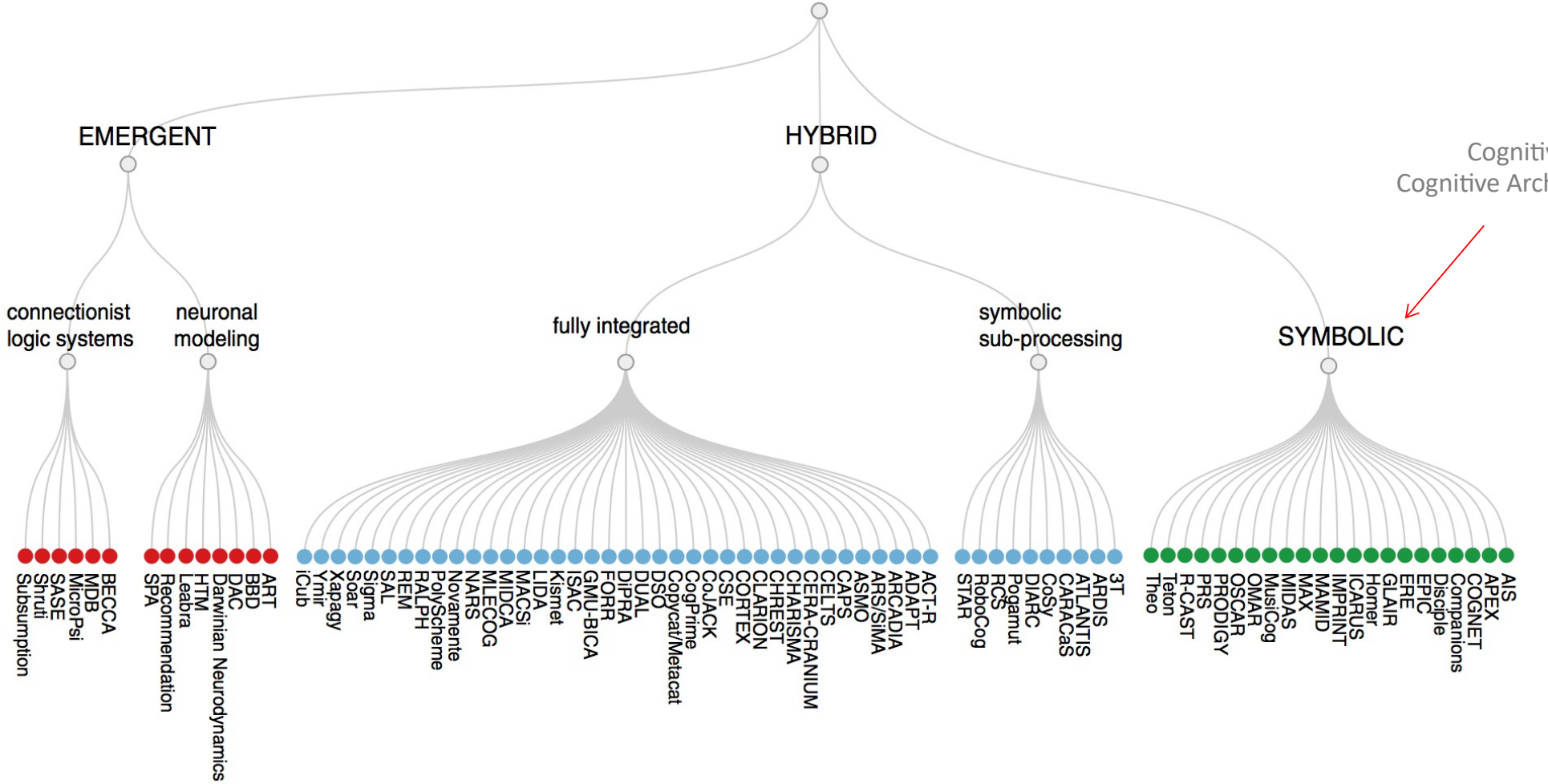
A Survey of Cognitive and Agent Architectures, University of Michigan, http://ai.eecs.umich.edu/cogarch0/ [12 cognitive architectures]

W. Duch, R. J. Oentaryo, and M. Pasquier. “Cognitive Architectures: Where do we go from here?”, Proc. Conf. Artificial General Intelligence, 122-136, 2008. [17 cognitive architectures]

D. Vernon, G. Metta, and G. Sandini, "A Survey of Artificial Cognitive Systems: Implications for the Autonomous Development of Mental Capabilities in Computational Agents", IEEE Transactions on Evolutionary Computation, Vol. 11, No. 2, pp. 151-180, 2007. [14 cognitive architectures]

D. Vernon, C. von Hofsten, and L. Fadiga. "A Roadmap for Cognitive Development in Humanoid Robots", Cognitive Systems Monographs (COSMOS), Vol. 11, Springer, 2011. Chapter 5 and Appendix I [20 cognitive architectures]

I. Kotseruba and J. Tsotsos. 40 years of cognitive architectures: core cognitive abilities and practical applications. Artificial Intelligence Review, Vol. 53, No. 1, pp. 17-94, 2020. [84 cognitive architectures]



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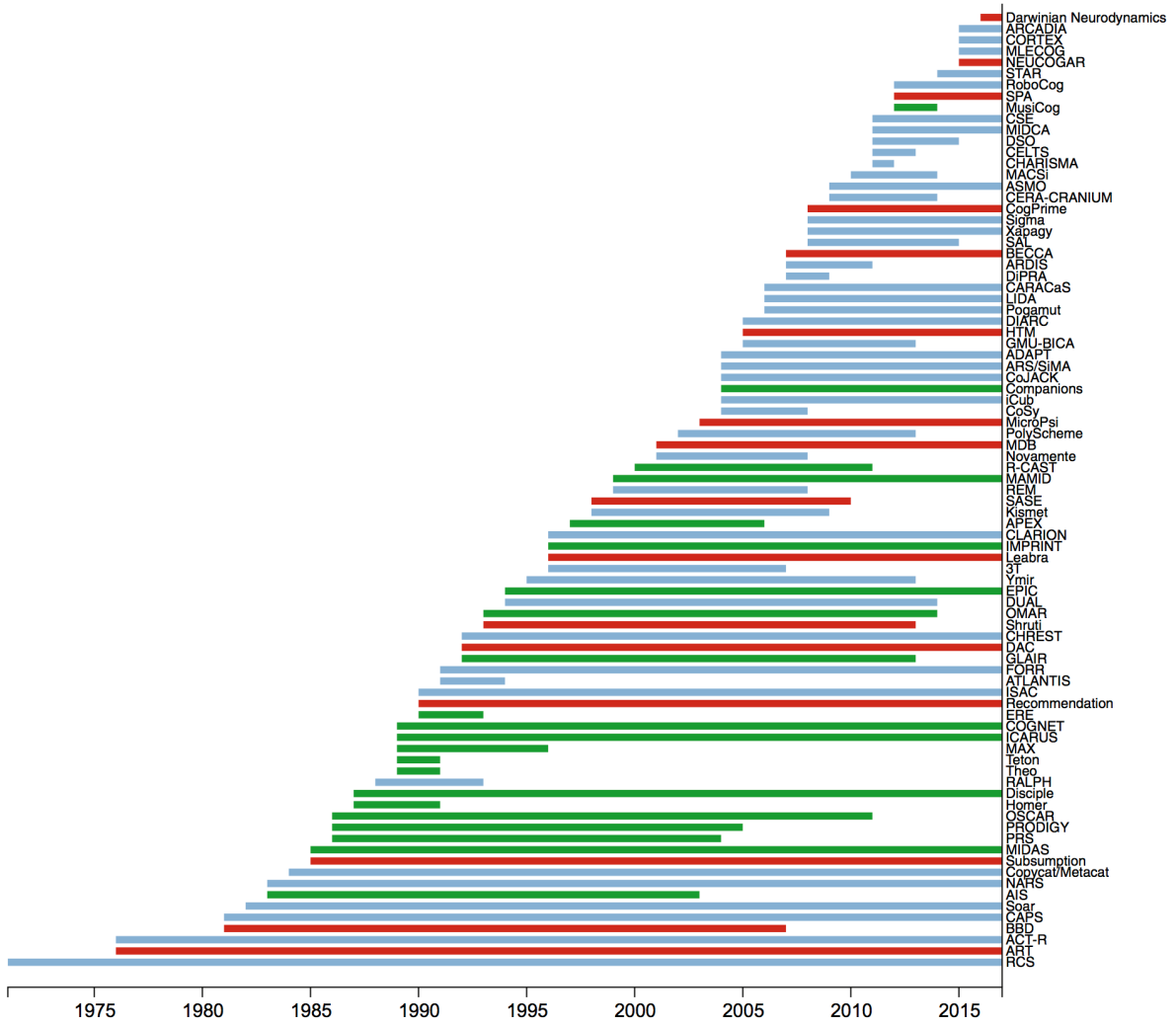

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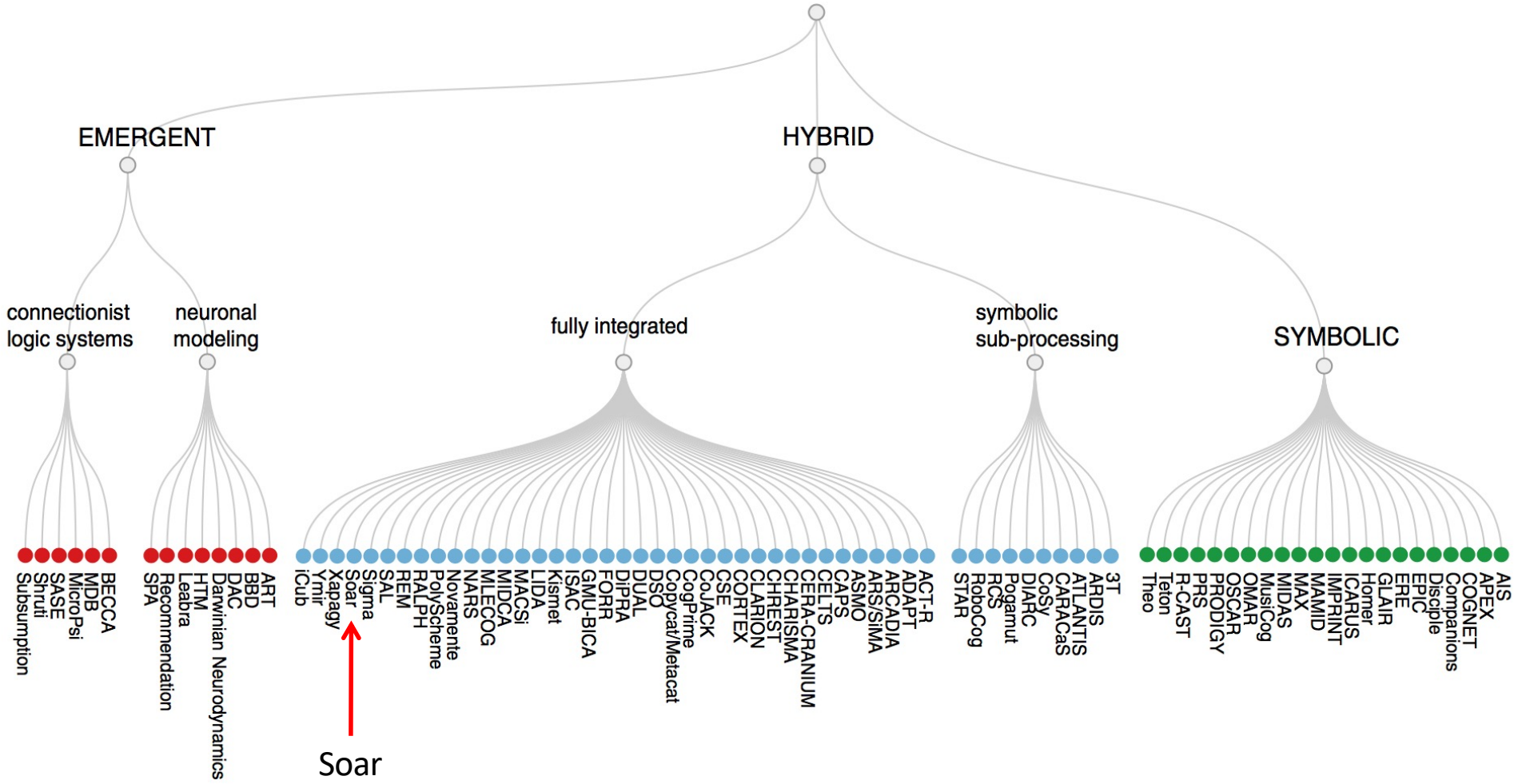
EMERGENT
HYBRID
connectionist logic systems
neuronal modeling
fully integrated
symbolic sub-processing
SYMBOLIC
BECCA
MDB
MicroPsi
SASE
Shruti
Subsumption
ART
BBD
DAC
Darwinian Neurodynamics
HTM
Leabra
Recommendation
SPA
ACT-R
ADAPT
ARCADIA
ARS/SiMA
ASMO
CAPS
CELTS
CERA-CRANIUM
CHARISMA
CHREST
CLARION
CORTEX
CSE
CoJACK
CogPrime
Copycat/Metacat
DSO
DUAL
DiPRA
FORR
GMU-BICA
ISAC
Kismet
LIDA
MACSi
MIDCA
MLECOG
NARS
Novamente
PolyScheme
RALPH
REM
SAL
Sigma
Soar
Xapagy
Ymir
iCub
3T
ARDIS
ATLANTIS
CARACaS
CoSy
DIARC
Pogamut
RCS
RoboCog
STAR
AIS
APEX
COGNET
Companions
Disciple
EPIC
ERE
GLAIR
Homer
ICARUS
IMPRINT
MAMID
MAX
MIDAS
MusiCog
OMAR
OSCAR
PRODIGY
PRS
R-CAST
Teton
Theo
Soar

JOHN E. LAIRD is John L. Tishman Professor of Engineering in the Computer Science Division at the University of Michigan.

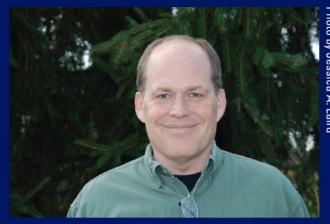

Photo by Jessica A. Laird

artificial intelligence/cognitive science

"John Laird's book gives a complete account of the momentous developments that have occurred in the Soar Cognitive Architecture. This book is a must-read for researchers and students who are interested in the grand goals of Cognitive Science and AI."—JOHN R. ANDERSON, Carnegie Mellon University

"John Laird has been at the forefront of research on cognitive architectures since the early 1980s and this book is a culmination of nearly 30 years of work. The book is a substantial achievement and a fine synthesis of the author's work. It provides both a study of how integrated computational mechanisms can generate intelligent behavior and a renewed opportunity for cognitive science to pursue integrated theories. It is essential reading."—ANDREW HOWES, School of Computer Science, University of Birmingham

"A clear and comprehensive account of decades of effort aimed at understanding intelligence and building intelligent systems. The detailed discussion of cognitive architectures, the enumeration of criteria for judging cognitive architectures, and the description of Soar make this a book that belongs in the library of everyone seriously interested in AI and its applications."—PATRICK HENRY WINSTON, Ford Professor of Artificial Intelligence and Computer Science, Massachusetts Institute of Technology

"The Soar enterprise is one of the most interesting big bets in Artificial Intelligence and Cognitive Science. John Laird's impressive book provides an excellent synopsis of the important ideas, results, and new directions in Soar research. Anyone interested in the computational modeling of minds should read this book."—KEN FORBUS, Northwestern University

Jacket art: Block diagram of Soar 9, redrafted by Carl O. Hueter

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THE SOAR COGNITIVE ARCHITECTURE LAIRD

THE SOAR COGNITIVE ARCHITECTURE

JOHN E. LAIRD

JOHN E. LAIRD

THE SOAR COGNITIVE ARCHITECTURE

JOHN E. LAIRD

In development for 30 years, Soar is a general cognitive architecture that integrates knowledge-intensive reasoning, reactive execution, hierarchical reasoning, planning, and learning from experience, with the goal of creating a general computational system that has the same cognitive abilities as humans. In contrast, most AI systems are designed to solve only one type of problem, such as playing chess, searching the Internet, or scheduling aircraft departures. Soar is both a software system for agent development and a theory of what computational structures are necessary to support human-level agents. Over the years, both software system and theory have evolved. This book offers the definitive presentation of Soar from theoretical and practical perspectives, providing comprehensive descriptions of fundamental aspects and new components.

The current version of Soar features major extensions, adding reinforcement learning, semantic memory, episodic memory, mental imagery, and an appraisal-based model of emotion. This book describes details of Soar's component memories and processes and offers demonstrations of individual components, components working in combination, and real-world applications. Beyond these functional considerations, the book proposes requirements for general cognitive architectures and explicitly evaluates how well Soar meets those requirements.

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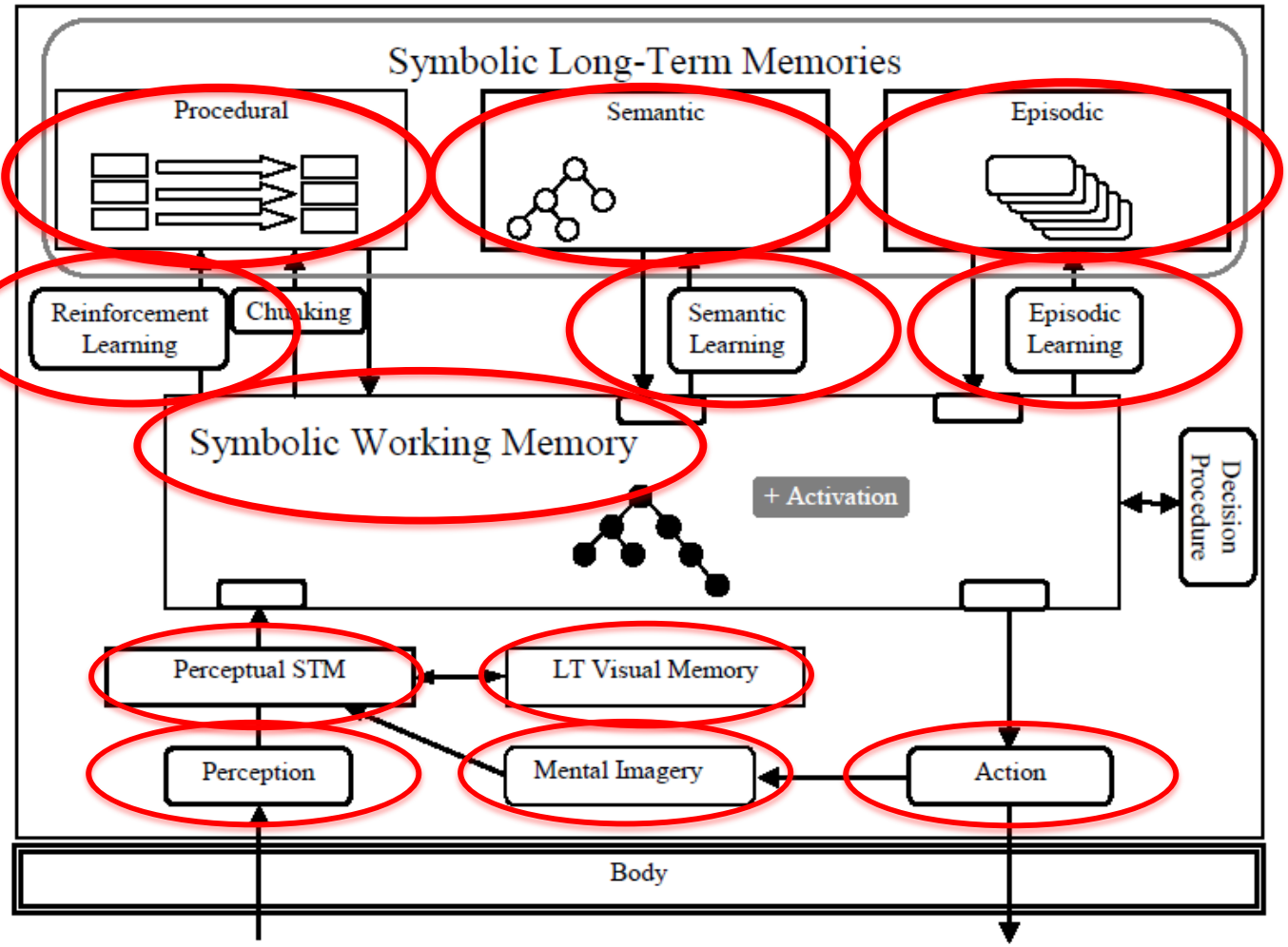

Symbolic Long-Term Memories
Procedural
Semantic
Episodic
Reinforcement Learning
Chunking
Semantic Learning
Episodic Learning
Symbolic Working Memory
+ Activation
Decision Procedure
Perceptual STM
LT Visual Memory
Perception
Mental Imagery
Action
Body

AAAI 2018 Fall Symposium on
A Common Model of Cognition
October 18-20, Westin Arlington Gateway
Arlington, Virginia

Home

Organizing Committee

Call for Participation

Registration

Schedule

2017 AAAI Fall Symposium on a 'Standard Model of the Mind'

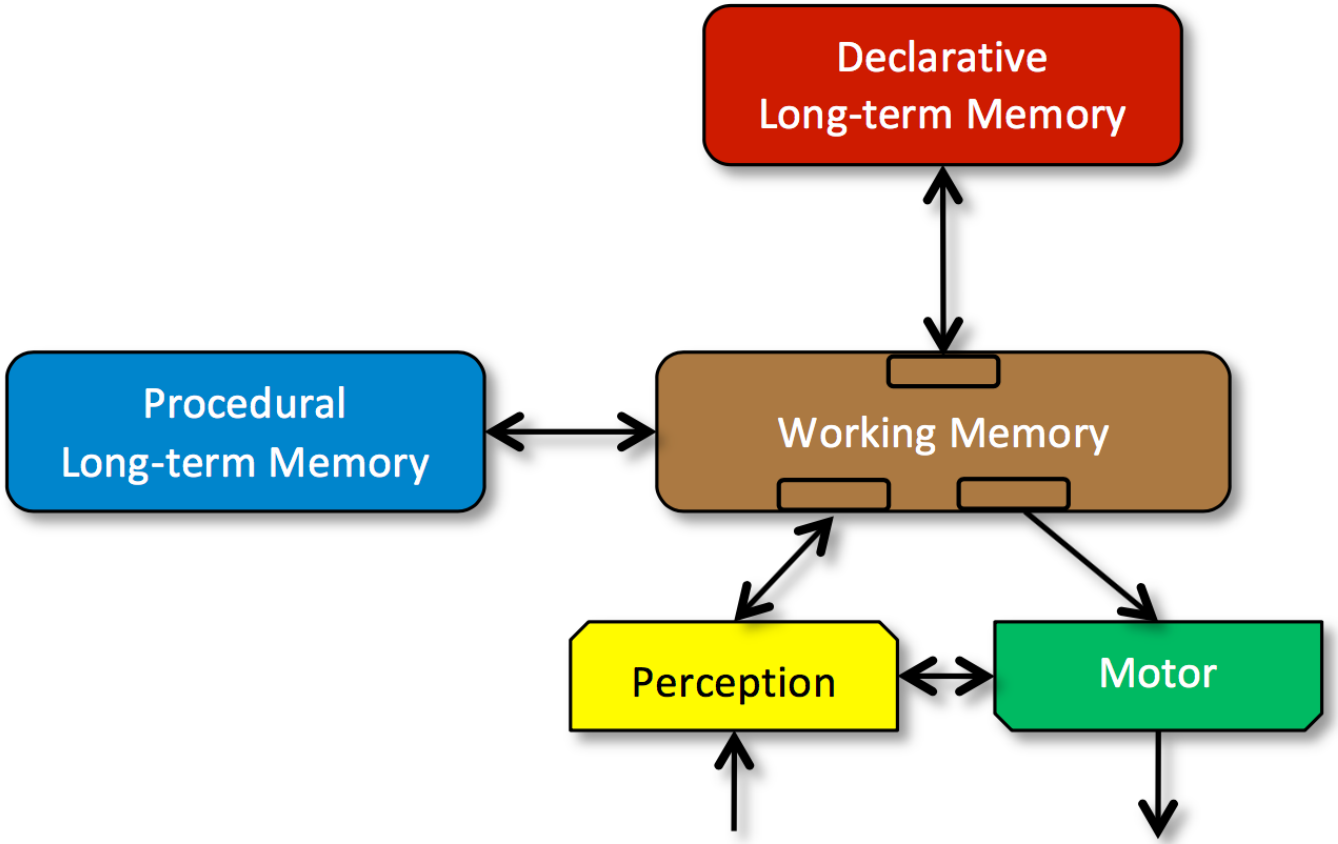
2017 Schedule and Slides

2018 AAAI Fall Symposium on 'A Common Model of the Cognition'

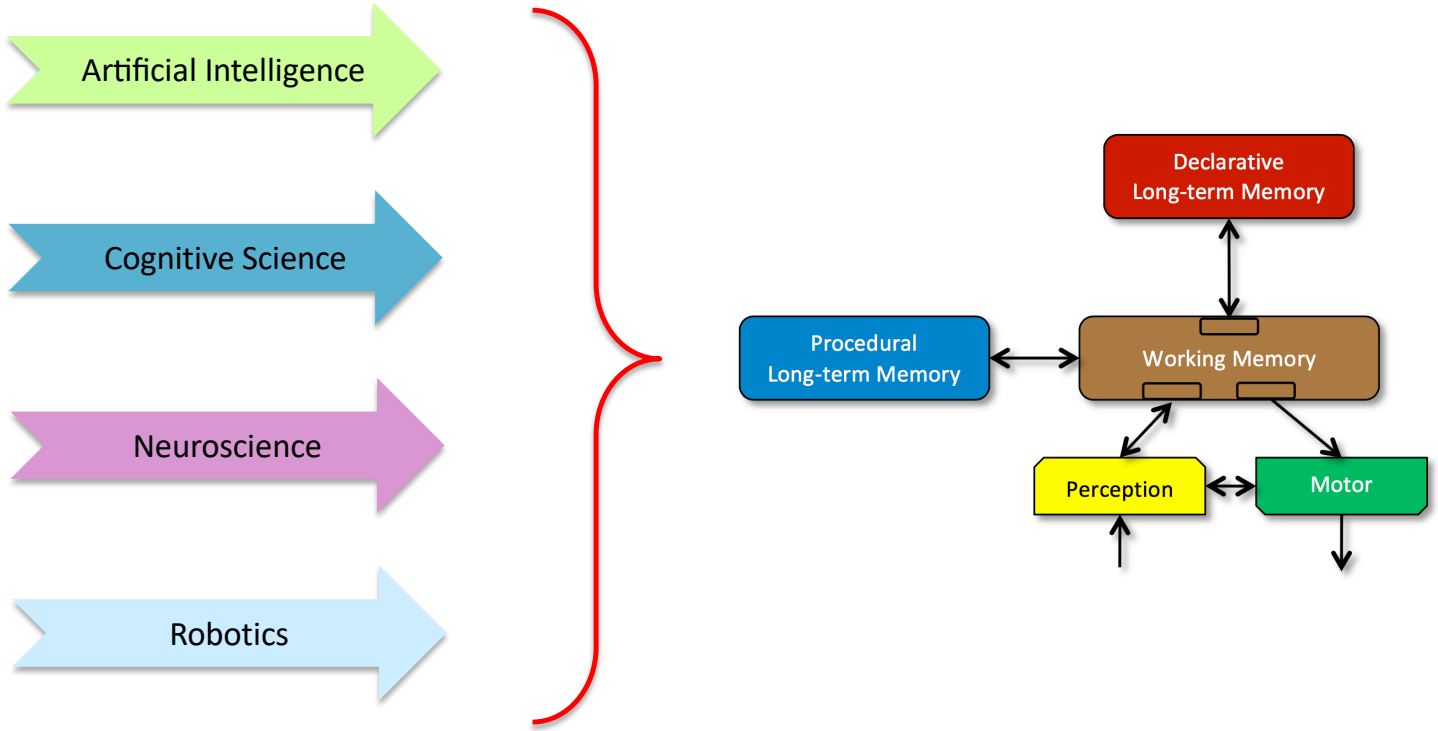
A mind is a functional entity that can think, and thus support intelligent behavior. Artificial intelligence, cognitive science, neuroscience, and robotics all contribute to our understanding of minds, although each draws from a different perspective. Artificial intelligence concerns building artificial minds, and thus cares most about how systems can be built that exhibit intelligent behavior. Cognitive science concerns modeling natural minds, and thus cares most about understanding cognitive processes that yield human thought. Neuroscience concerns the structure and function of brains, and thus cares most about how brains induce minds. Robotics concerns building and directing artificial bodies, and thus cares most about how minds control such bodies.

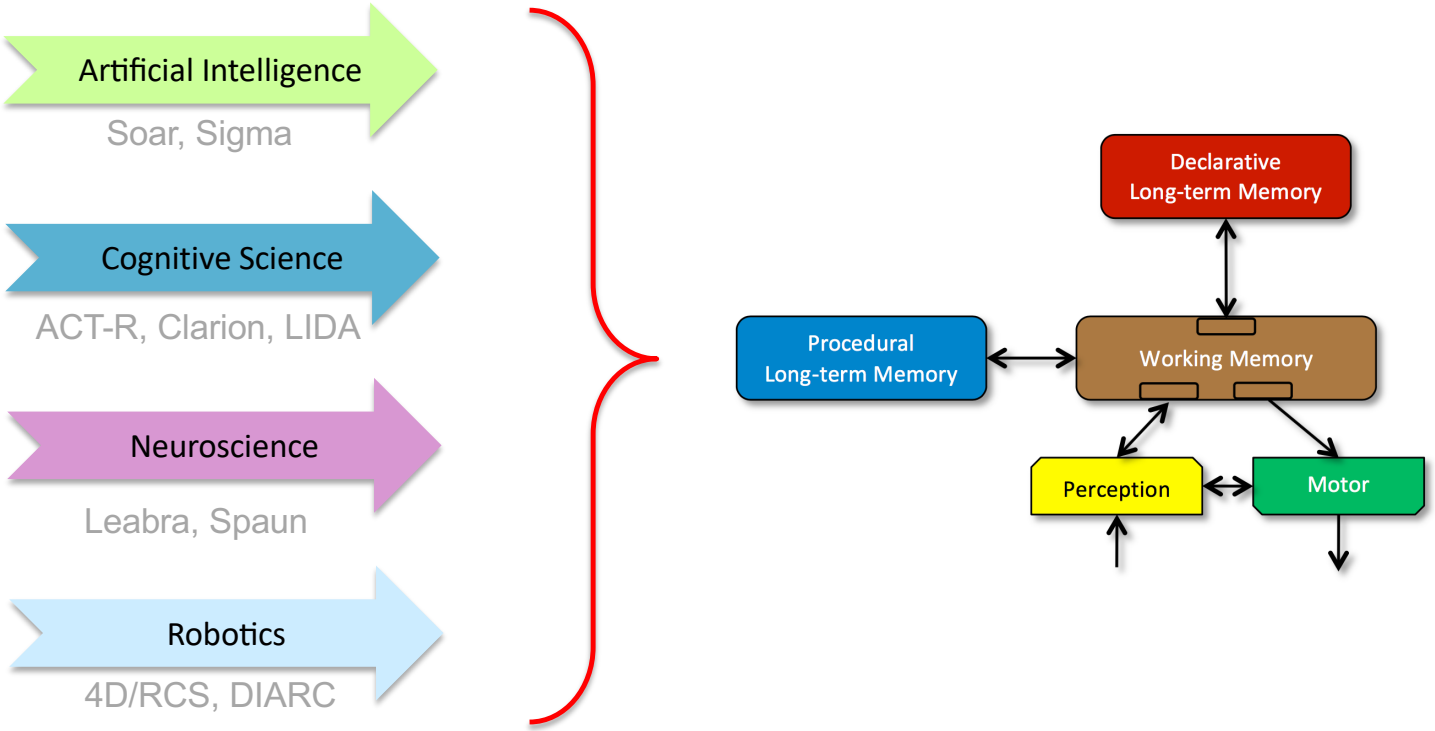
Will research across these disciplines ultimately converge on a single understanding of mind? This is a deep scientific question to which there is as yet no answer. However, there must at least be a single answer for cognitive science and neuroscience, as they both investigate the same mind, or narrow class of minds, albeit at different levels of abstraction. Research that is inspired by natural systems also may fit within this class of minds, particularly if it is slightly abstracted; but so too may research that has no such aspiration yet still finds itself in the same neighborhood for functional reasons. This broader class comprises what can be called human-like minds.

Our goal with this symposium is to engage the international research community in developing *A Common Model of Cognition;* that is, a community consensus concerning the mental structures and process implicated in human-like minds to the extent that such a consensus exists. The intent, at least for the foreseeable future, is not to develop a single implementation or model of cognition by which everyone concerned with human-like cognition would abide, or even a theory in which all of the details are agreed to as correct. What is sought though is a statement of the best consensus given the community's current understanding of cognition, plus a sound basis for further refinement as more is

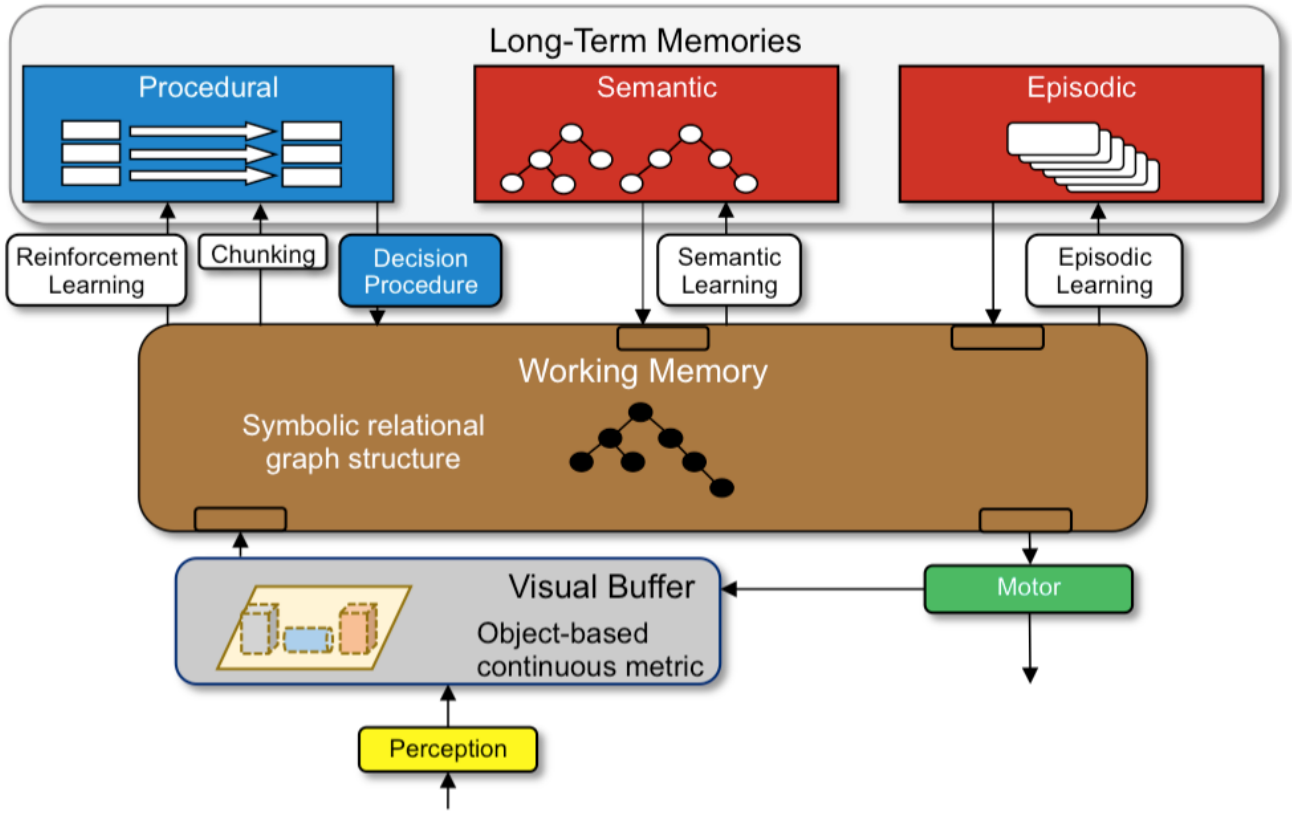


Laird, J. E., Lebiere, C., & Rosenbloom, P. S. "A standard model of the mind: Toward a common computational framework across artificial intelligence, cognitive science, neuroscience, and robotics", *AI Magazine*, *38*(4), 13-26 , 2017.


Artificial Intelligence
Cognitive Science
Neuroscience
Robotics
Declarative
Long-term Memory
Procedural
Long-term Memory
Working Memory
Perception
Motor


Artificial Intelligence
Soar, Sigma
Cognitive Science
ACT-R, Clarion, LIDA
Neuroscience
Leabra, Spaun
Robotics
4D/RCS, DIARC
Declarative Long-term Memory
Procedural Long-term Memory
Working Memory
Perception
Motor

Soar


Long-Term Memories
Procedural
Semantic
Episodic
Reinforcement Learning
Chunking
Decision Procedure
Semantic Learning
Episodic Learning
Working Memory
Symbolic relational graph structure
Visual Buffer
Object-based continuous metric
Motor
Perception

A short video by John Laird on Soar can be found at the
2021 TransAIR Workshop on Cognitive Architectures for Robot Agents

https://transair-bridge.org/workshop-2021/

Yiannis Aloimonos, University of Maryland: **Minimalist Cognitive Architectures** (Video)

Minoru Asada, Osaka University: **Affective Architecture: Pain, Empathy, and Ethics** (Video)

Tamim Asfour, Karlsruhe Institute of Technology: **ArmarX – A Robot Cognitive Architecture** (Video)

Angelo Cangelosi, University of Manchester: **Developmental Robotics – Language Learning, Trust and Theory of Mind** (Video)

Yiannis Demiris, Imperial College London: **Cognitive Architectures for Assistive Robot Agents** (Video)

Kazuhiko Kawamura, Vanderbilt University: **Cognitive Robotics and Control** (Video)

Jeffrey Krichmar, University of California: **Neurorobotics: Connecting the Brain, Body and Environment** (Video)

Sean Kugele, University of Memphis: **The LIDA Cognitive Architecture – An Introduction with Robotics Applications** (Video)

John E. Laird, University of Michigan: **The Soar Cognitive Architecture: Current and Future Capabilities** (Video)

Tomaso Poggio, Massachusetts Institute of Technology: **Circuits for Intelligence** (Video)

Helge Ritter, Bielefeld University: **Collaborating on Architectures: Challenges and Perspectives** (Video)

Matthias Scheutz, Tufts University: **The DIARC Architecture for Autonomous Interactive Robots** (Video)

Alessandra Sciutti, Istituto Italiano di Tecnologia: **A Social Perspective on Cognitive Architectures** (Video)

Ron Sun, Rensselaer Polytechnic Institute: **Clarion: A comprehensive, Integrative Cognitive Architecture** (Video)

Agnieszka Wykowska, Istituto Italiano di Tecnologia: **Mechanisms of Human Cognition in Interaction** (Video)

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The CRAM Cognitive Architecture

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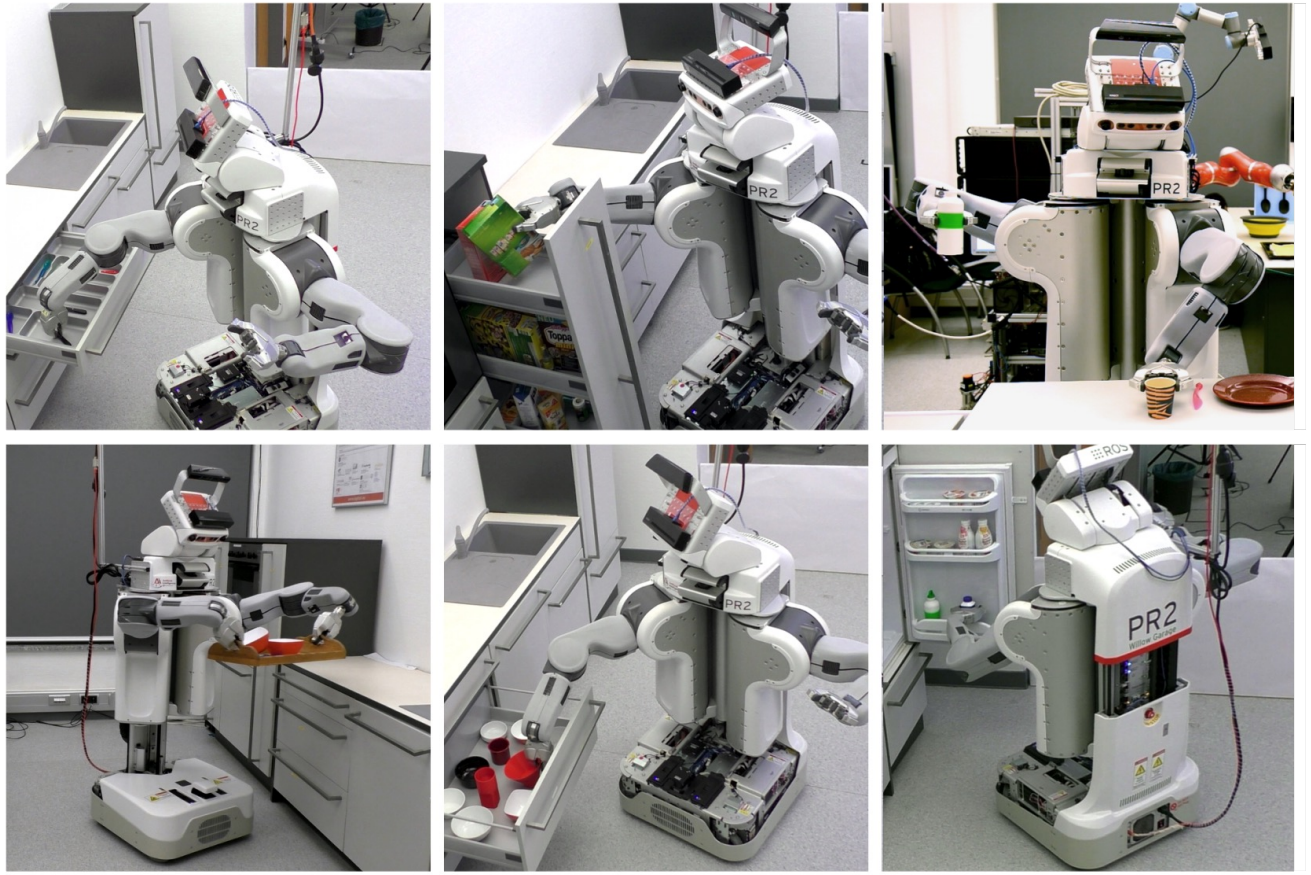
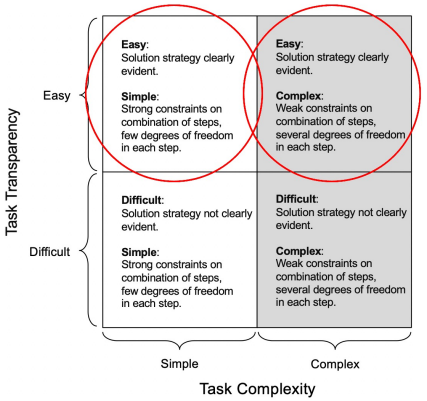
CRAM - Cognitive Robot Abstract Machine

A robot **cognitive architecture** that can carry out **easy** tasks





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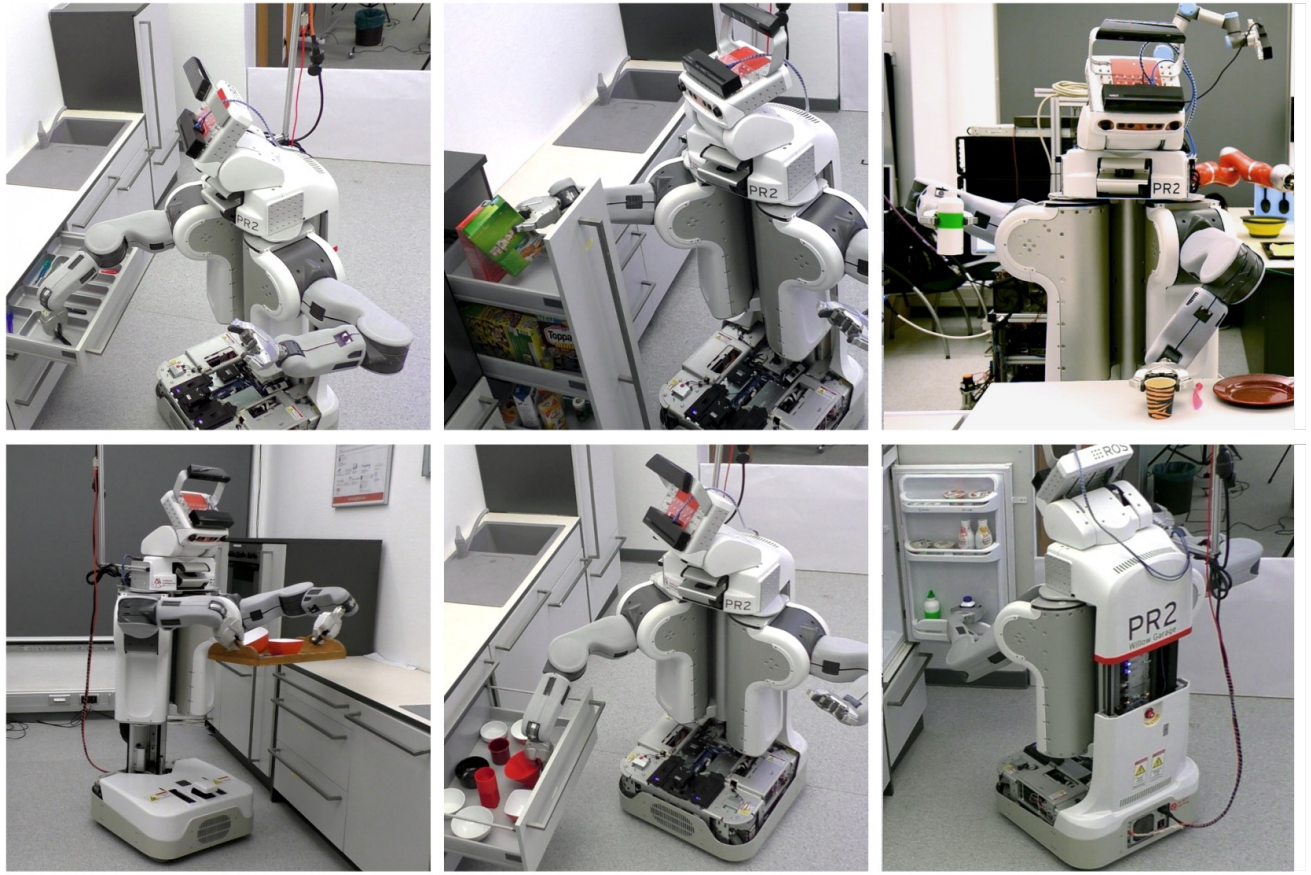
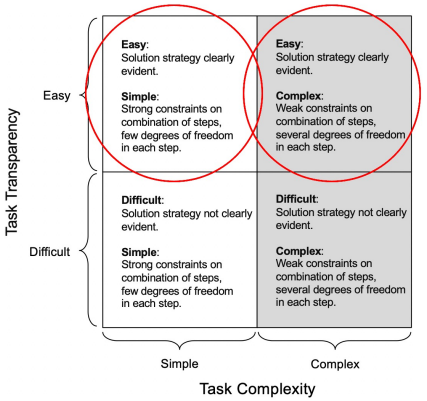
CRAM - Cognitive Robot Abstract Machine

based on high-level
underdetermined action descriptions





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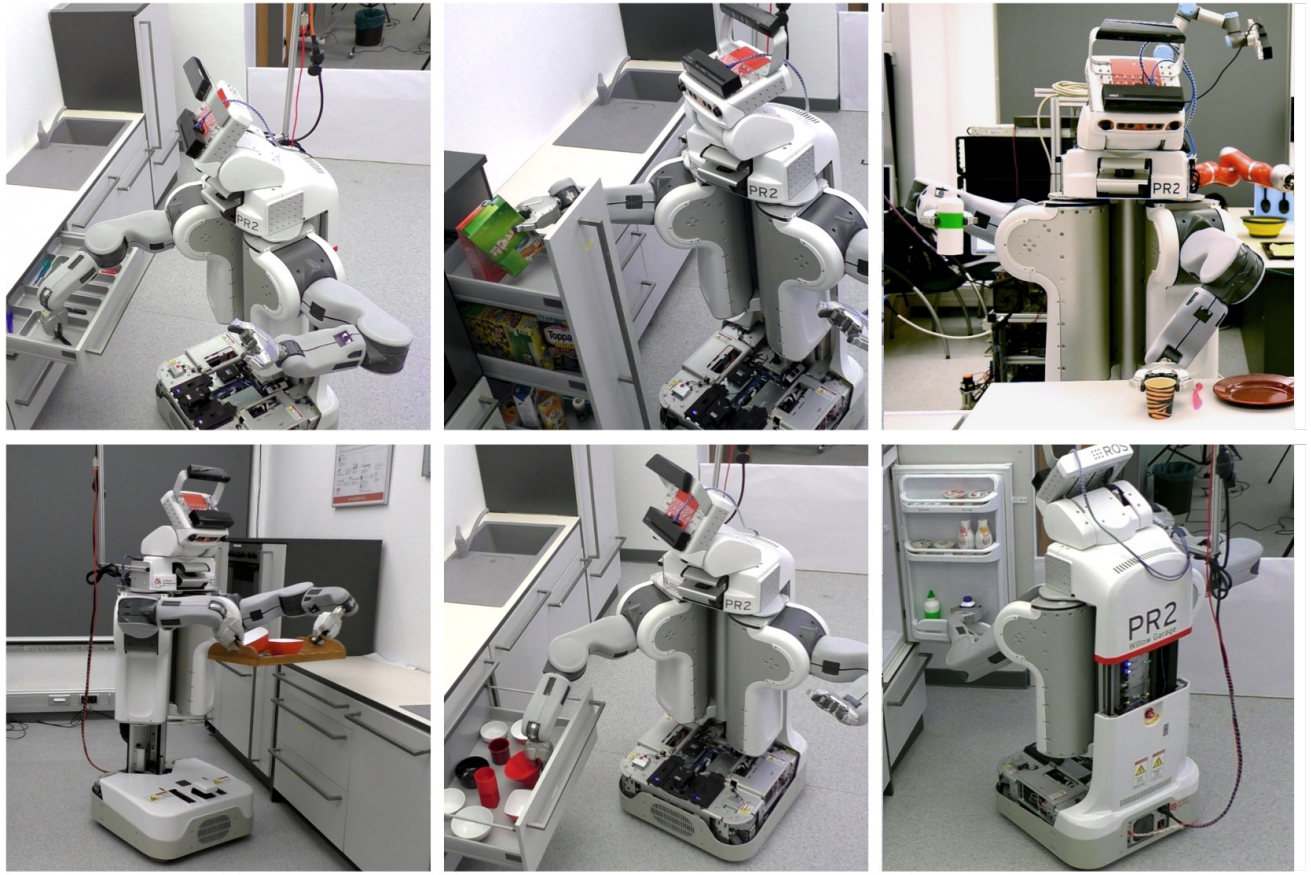
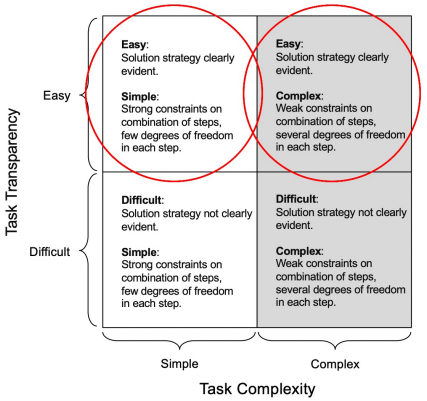
CRAM - Cognitive Robot Abstract Machine

using a **generalized action plan** for fetching and placing objects





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The CRAM Cognitive Architecture

- Hybrid cognitive architecture
- Introduced by Michael Beetz in 2010

  developed significantly since then based on several research projects

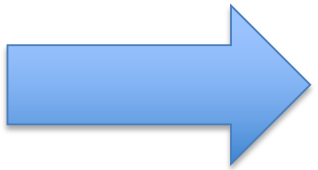
- Designed to address robot manipulation tasks in everyday activities

  tasks that would typically be carried out by people in household settings, e.g. in a kitchen.

The CRAM Cognitive Architecture

Implicit-to-explicit manipulation: “fetch the spoon and put it on the table”

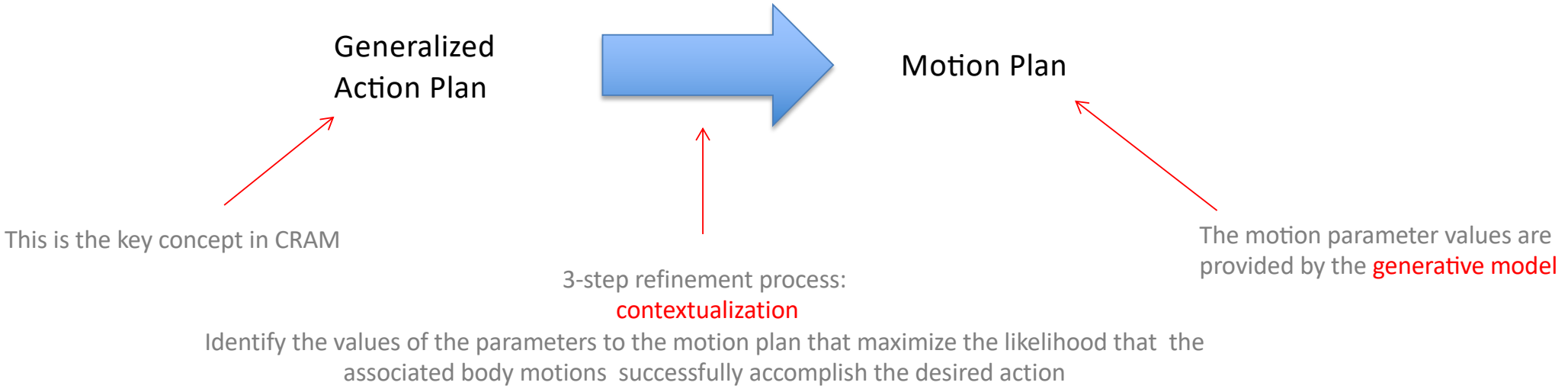
Vaguely-stated high-level goal



Specific low-level motions required to accomplish the goal

The CRAM Cognitive Architecture

The control program is stated as a generalized action plan



The CRAM Cognitive Architecture

Full text provided by www.sciencedirect.com
ScienceDirect

ELSEVIER

Control strategies in object manipulation tasks

J Randall Flanagan[1], Miles C Bowman[1] and Roland S Johansson[2]

The remarkable manipulative skill of the human hand is not the result of rapid sensorimotor processes, nor of fast or powerful effector mechanisms. Rather, the secret lies in the way manual tasks are organized and controlled by the nervous system. At the heart of this organization is prediction. Successful manipulation requires the ability both to predict the motor commands required to grasp, lift, and move objects and to predict the sensory events that arise as a consequence of these commands.

Addresses
[1] Department of Psychology and Centre for Neuroscience Studies, Queen's University, Kingston, ON, K7L 3N6, Canada
[2] Section for Physiology, Department of Integrative Medical Biology, Umeå University, SE-901 87 Umeå, Sweden

Corresponding author: Flanagan, J Randall

and another object or surface. Importantly, these contact events give rise to discrete and distinct sensory events, each characterized by a specific afferent neural signature. Because these sensory events provide information related to the functional goals of successive action phases, they have a crucial role in the sensory control of manipulations. In object manipulation, the brain not only forms action plans in terms of series of desired subgoals but also predicts the sensory events that signify subgoal attainment in conjunction with the generation of the motor commands. By comparing predicted sensory events with the actual sensory events, the motor system can monitor task progression and adjust subsequent motor commands if errors are detected. As discussed further below, such adjustments involve parametric adaptation of fingertip actions to the mechanical properties of objects, triggering

J Randall Flanagan, Miles C Bowman, and Roland S Johansson. Control strategies in object manipulation tasks. *Current opinion in neurobiology*, 16(6):650–659, 2006.

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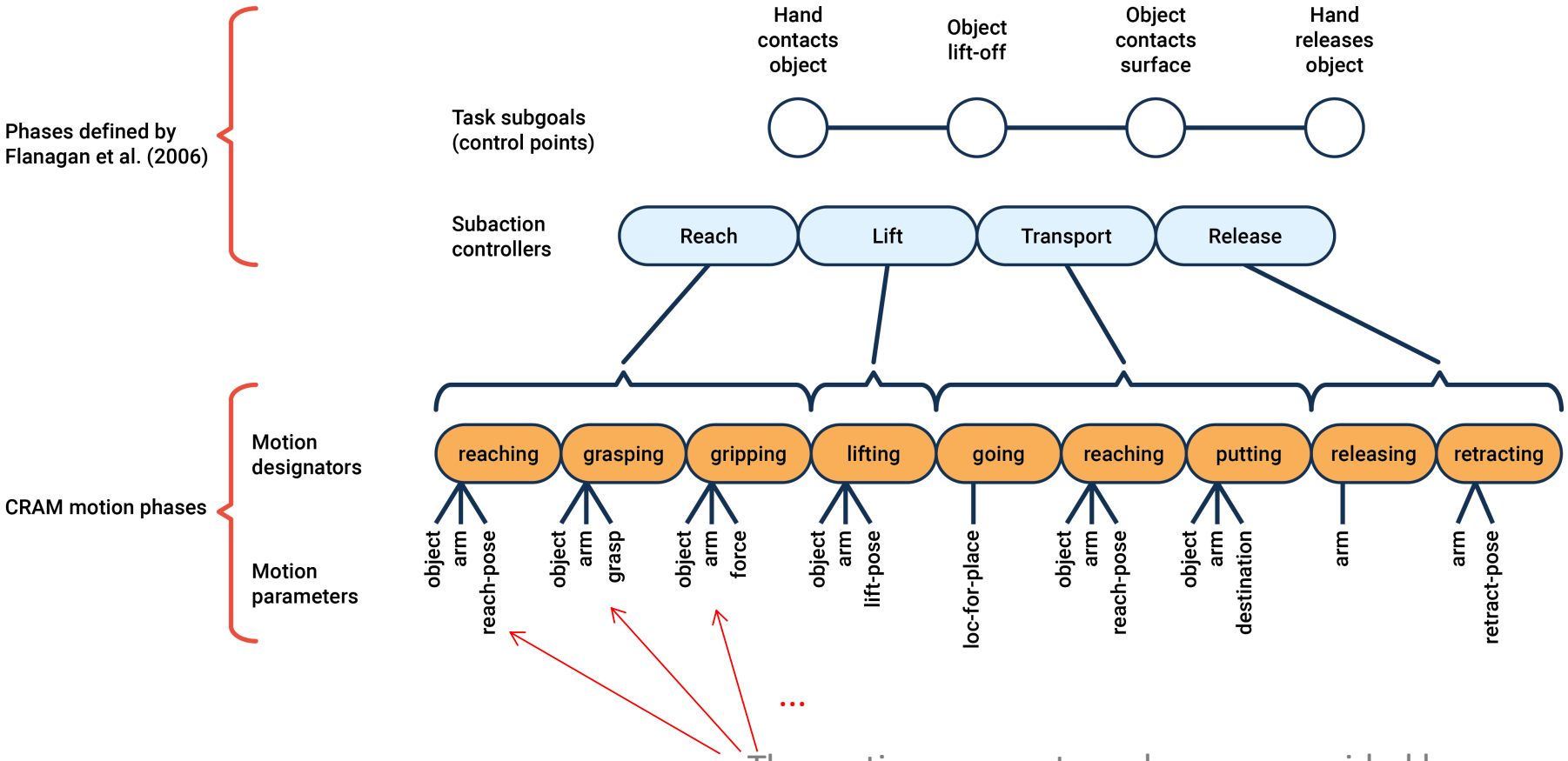
The CRAM Cognitive Architecture

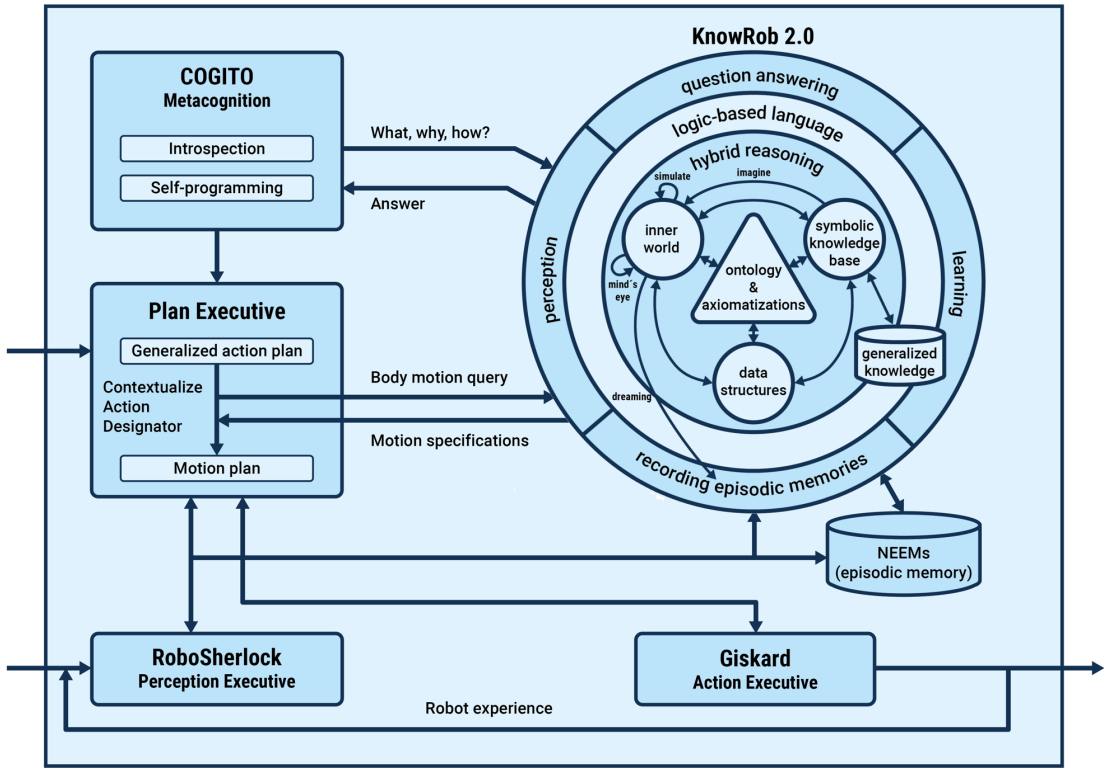


The motion parameter values are provided by a reasoning generative model

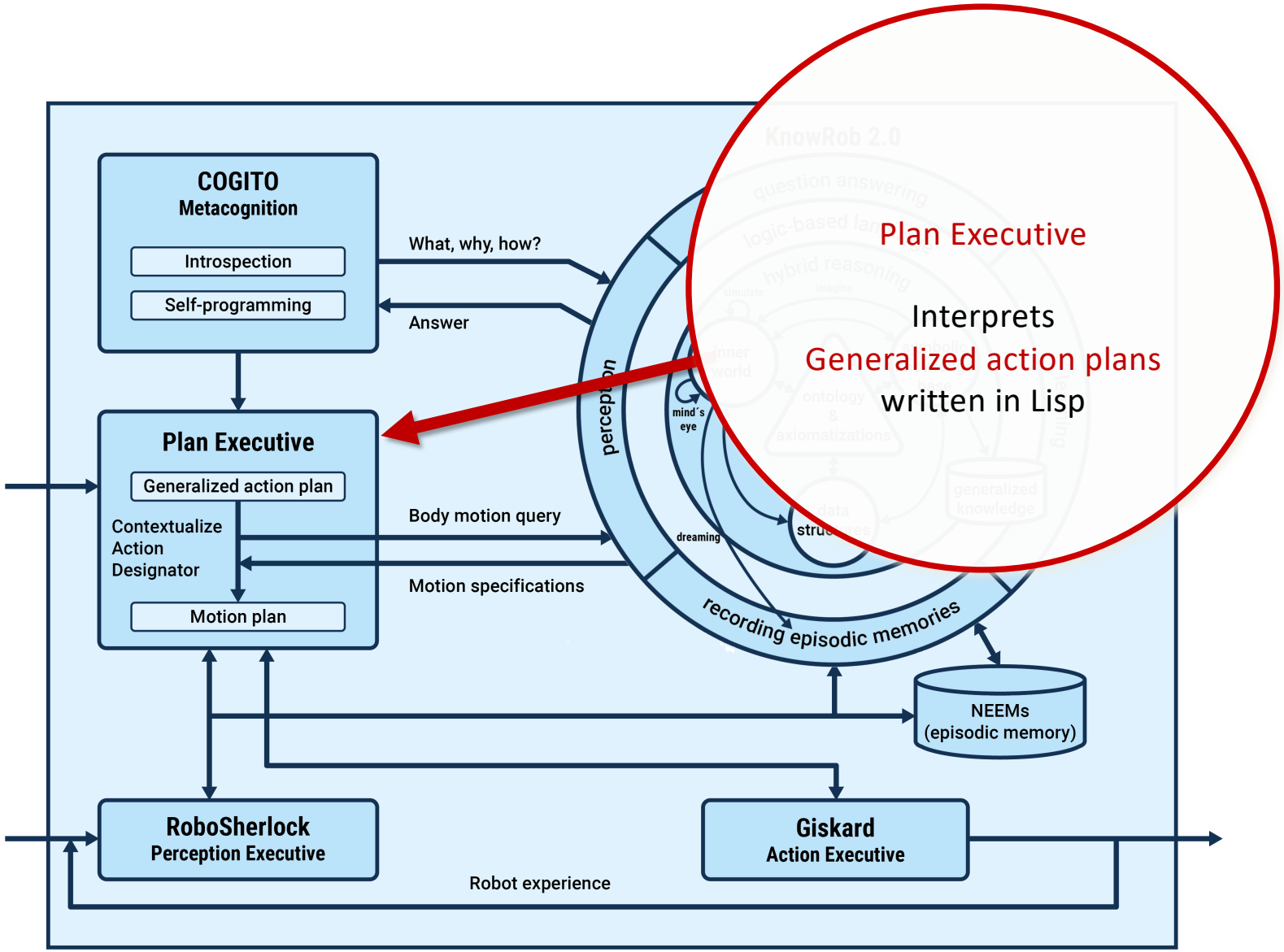
The CRAM Cognitive Architecture

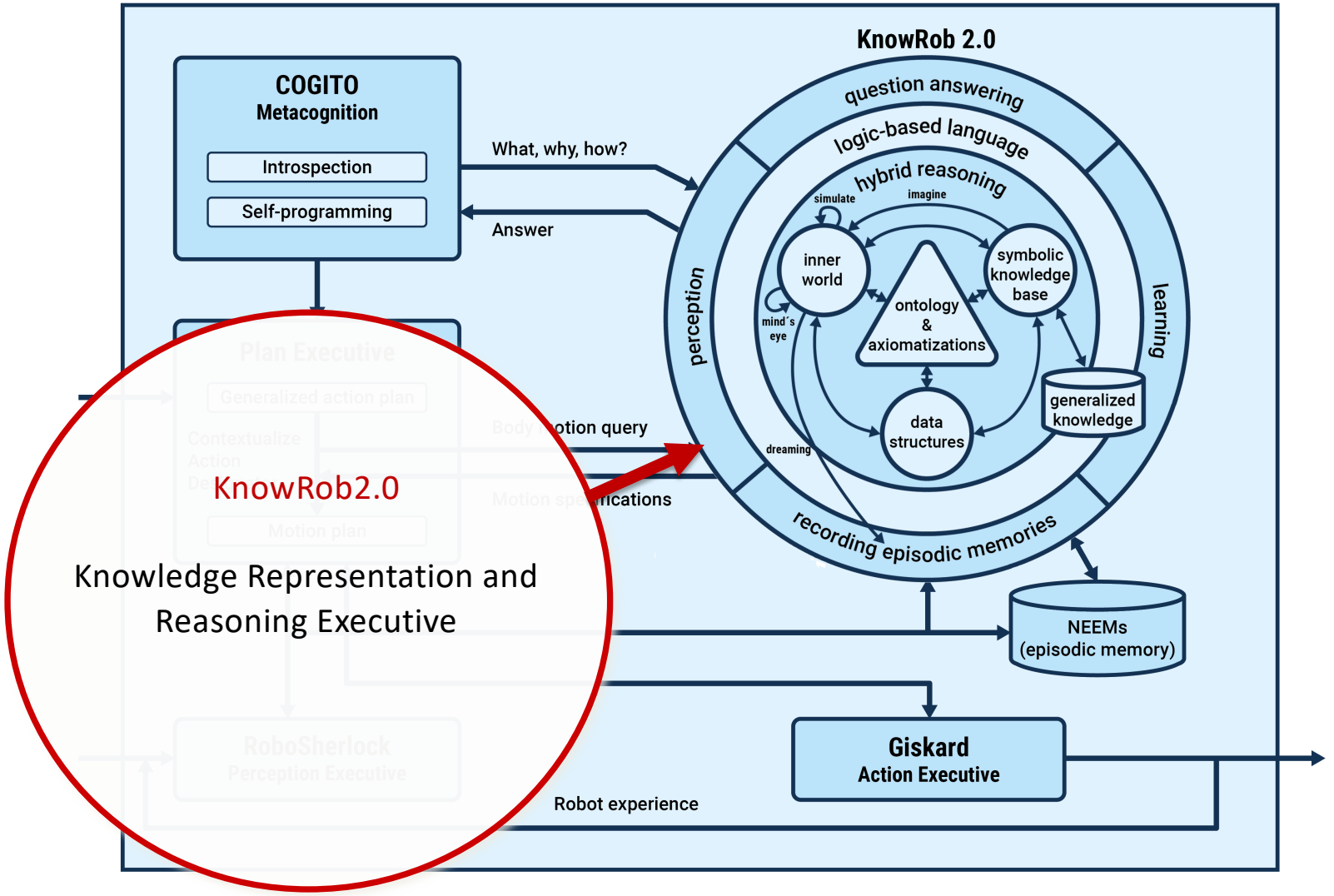
CRAM has five core elements:

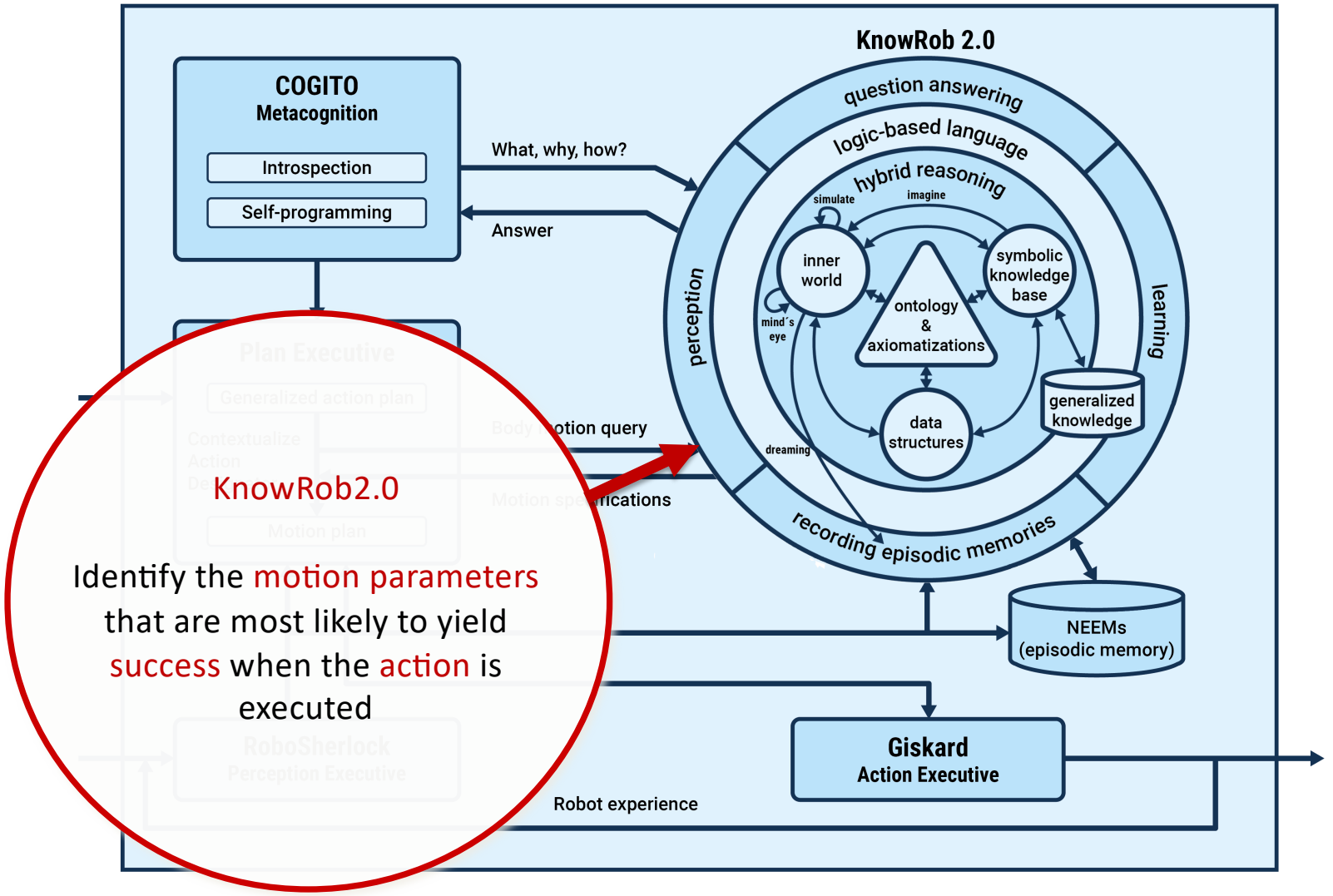
1. CRAM Plan Language (CPL) Executive
2. KnowRob2.0 knowledge representation and reasoning executive
3. RoboSherlock, the perception executive
4. Giskard, the action executive
5. COGITO, a metacognition system



(Beetz et al., 2010) et seq.


COGITO
Metacognition
Introspection
Self-programming
What, why, how?
Answer
Plan Executive
Generalized action plan
Contextualize
Action
Designator
Motion plan
Body motion query
Motion specifications
perception
mind´s eye
dreaming
recording episodic memories
NEEMs
(episodic memory)
RoboSherlock
Perception Executive
Giskard
Action Executive
Robot experience
Plan Executive
Interprets
Generalized action plans
written in Lisp


KnowRob 2.0
COGITO
Metacognition
Introspection
Self-programming
What, why, how?
Answer
question answering
logic-based language
hybrid reasoning
simulate
imagine
inner world
symbolic knowledge base
ontology & axiomatizations
mind´s eye
data structures
generalized knowledge
dreaming
perception
learning
recording episodic memories
NEEMs (episodic memory)
Giskard
Action Executive
Robot experience
KnowRob2.0
Knowledge Representation and Reasoning Executive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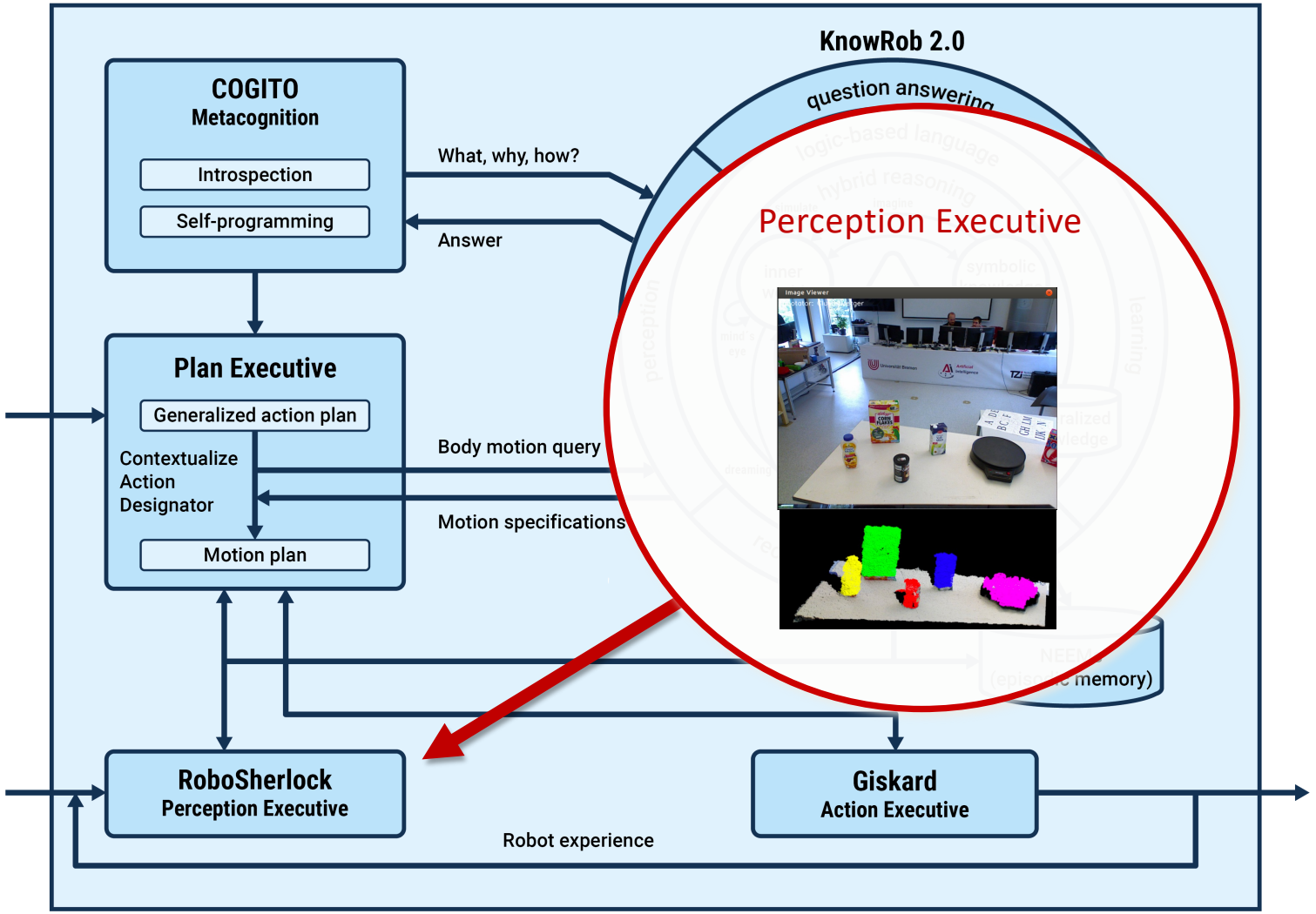
NEEMs (episodic memory)
Giskard
Action Executive
Robot experience
KnowRob2.0
Identify the motion parameters that are most likely to yield success when the action is executed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What, why, how?
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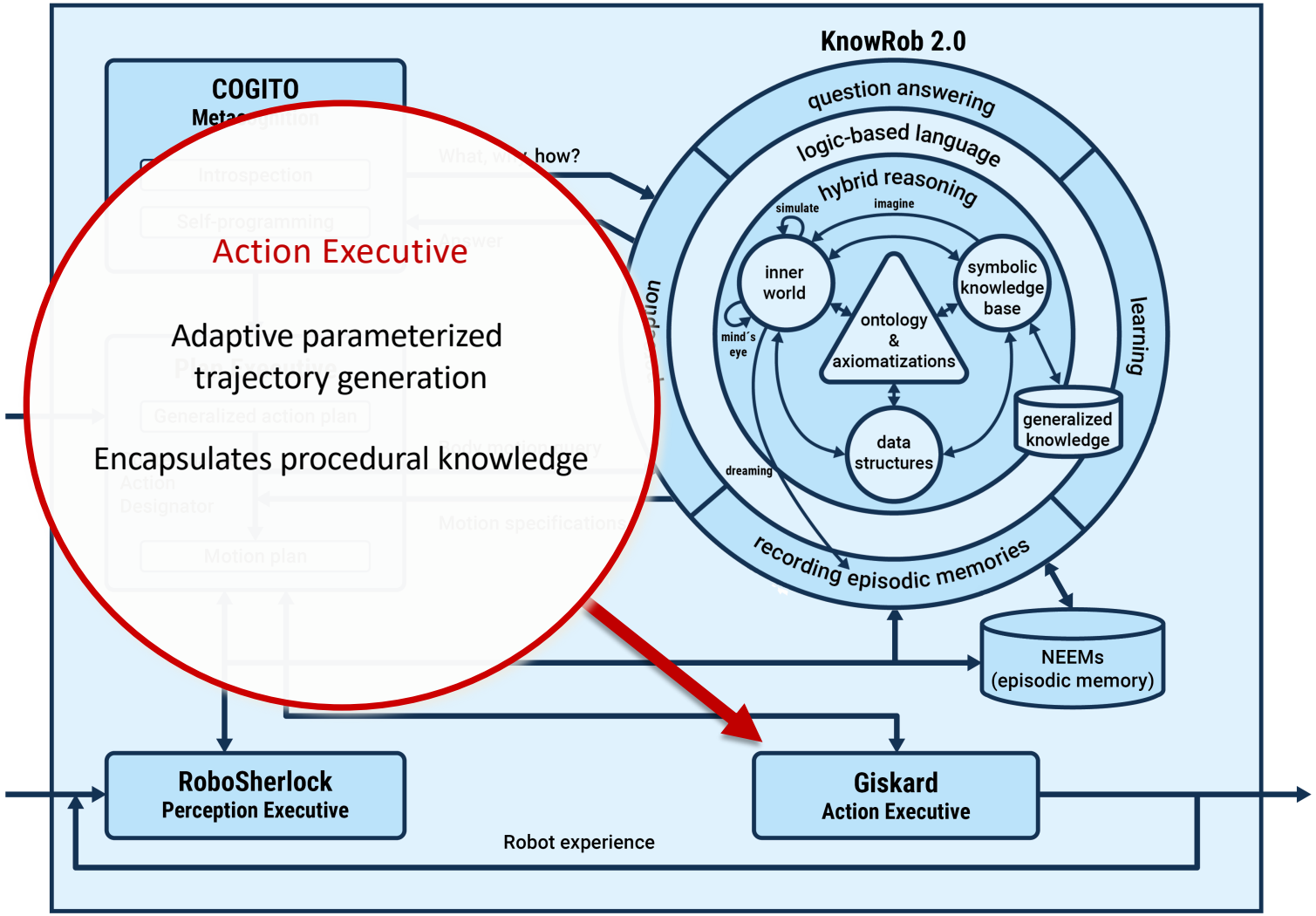
Robot experience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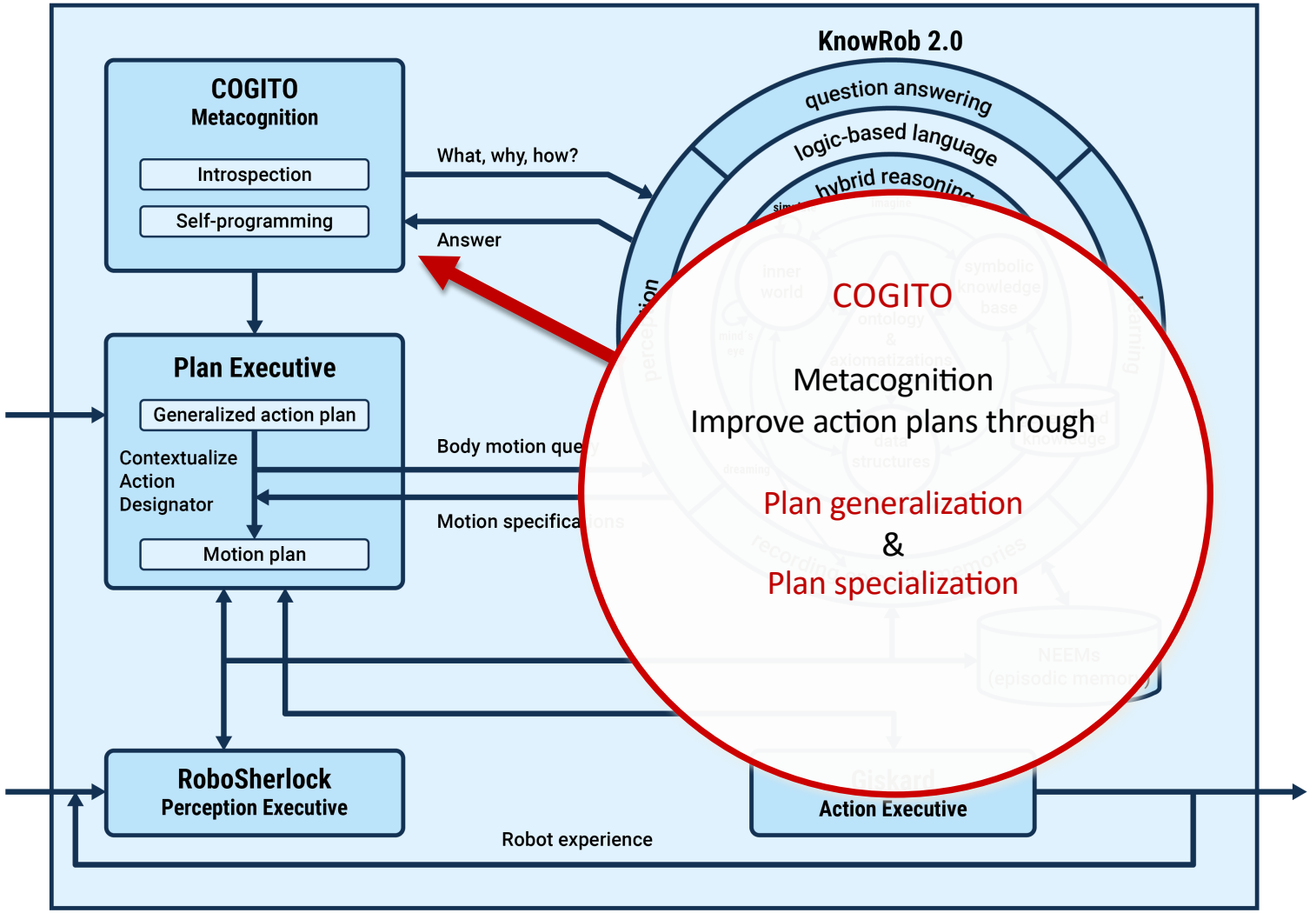
NEEMs (episodic memory)
COGITO
Action Executive
Adaptive parameterized trajectory generation
Encapsulates procedural knowledge
RoboSherlock
Perception Executive
Giskard
Action Executive
Robot experience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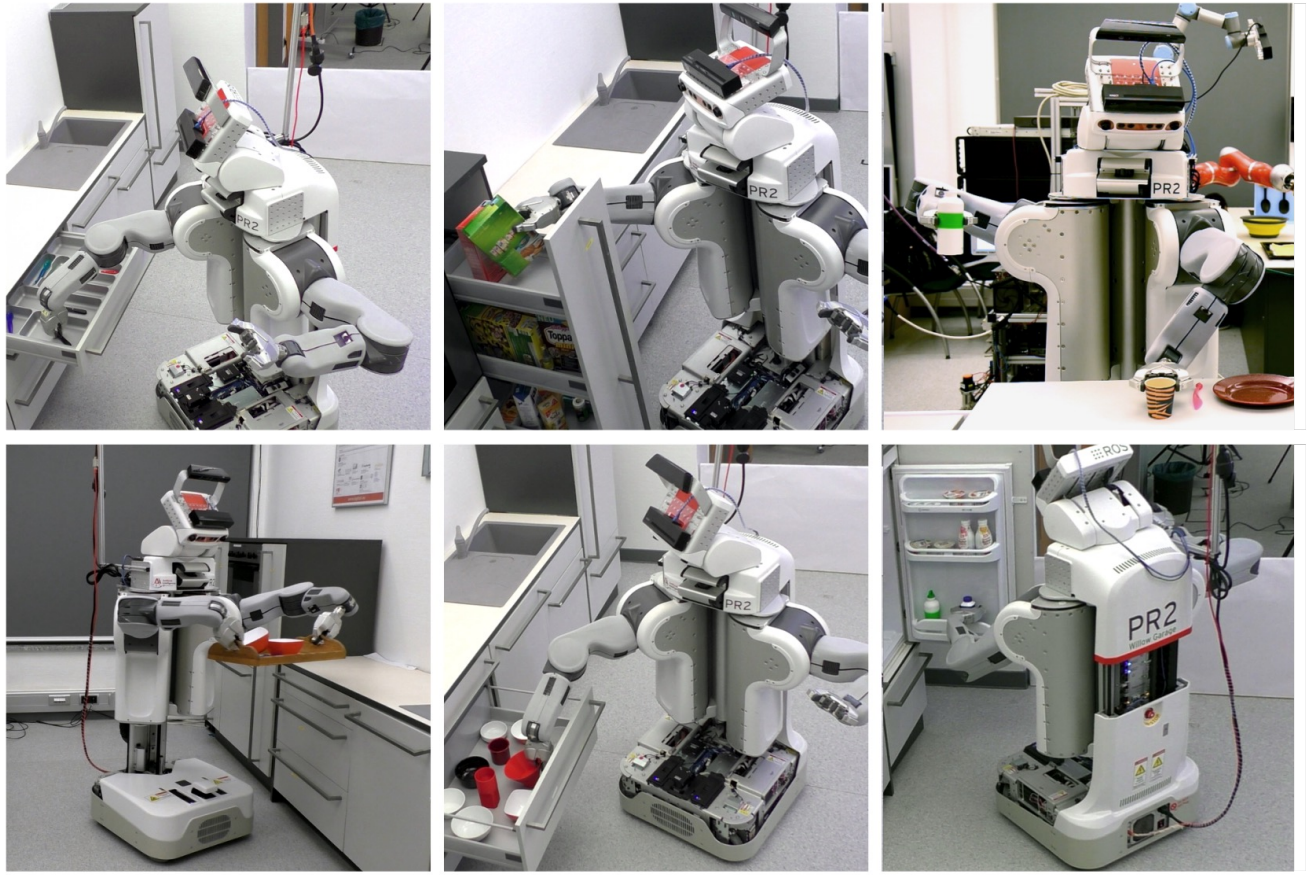
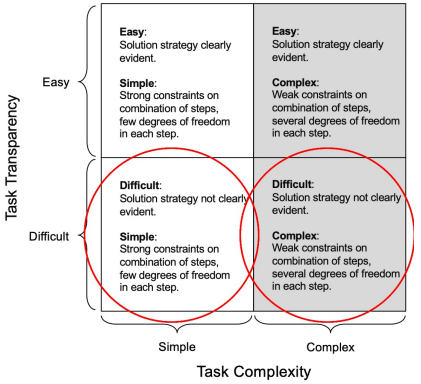
RoboSherlock
Perception Executive
Action Executive
Robot experience
COGITO
Metacognition
Improve action plans through
Plan generalization
&
Plan specialization

The CRAM Cognitive Architecture

Extensions to deal with more difficult activities





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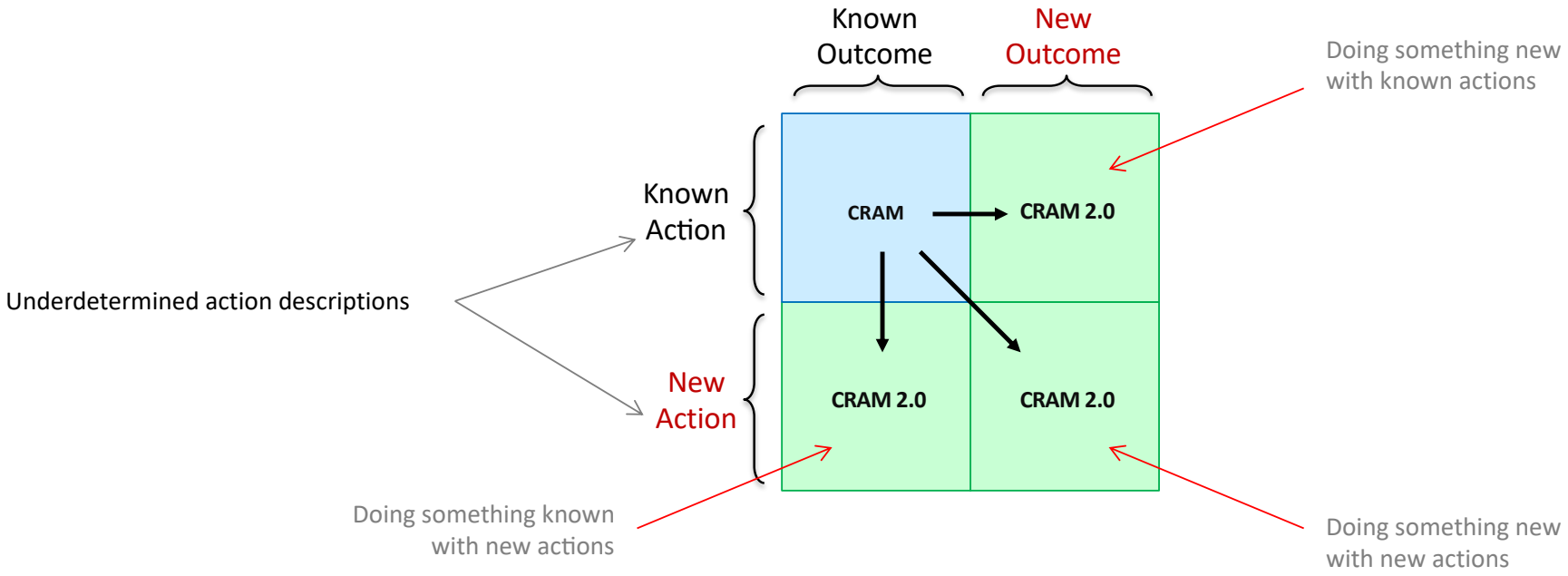
The CRAM Cognitive Architecture

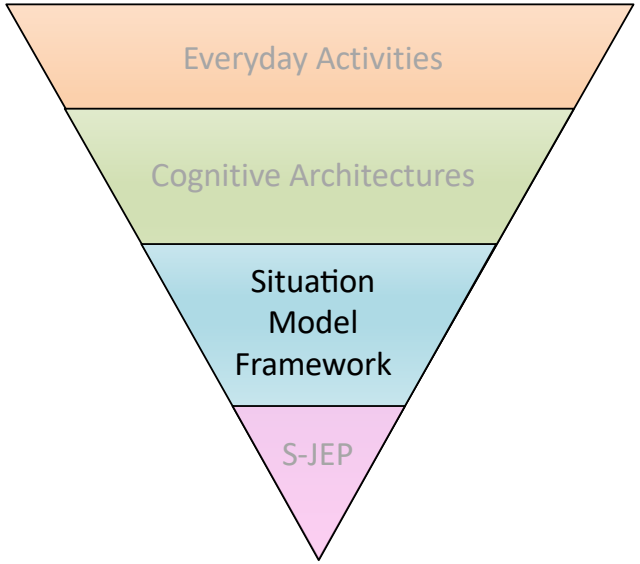
Extensions to deal with more difficult activities:

Flexible, Context-sensitive, Cognitive Behavior



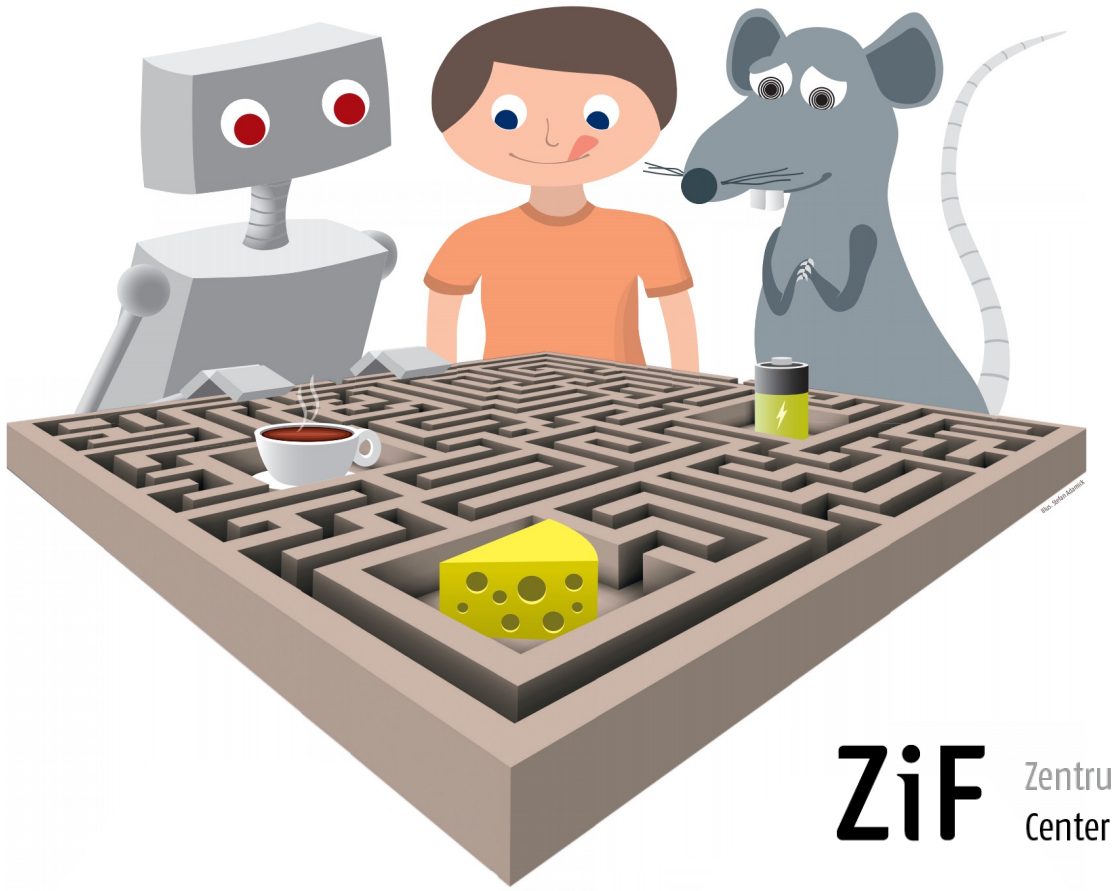
Overview

1. Everyday activities: easy & difficult vs. simple vs complex
2. Cognitive Architectures
   - Introduction to cognitive architectures
   - CRAM
   - Extending CRAM
3. The Situation Model Framework (SMF)
   - Behavioral episodes
   - Two-system approach (dual process theory)
4. Semantically-Modulated Joint Episodic-Procedural Memory (S-JEP)



The ZiF Research Group on

Cognitive behavior of humans, animals, and machines: Situation model perspectives



ZiF
Zentrum für interdisziplinäre Forschung
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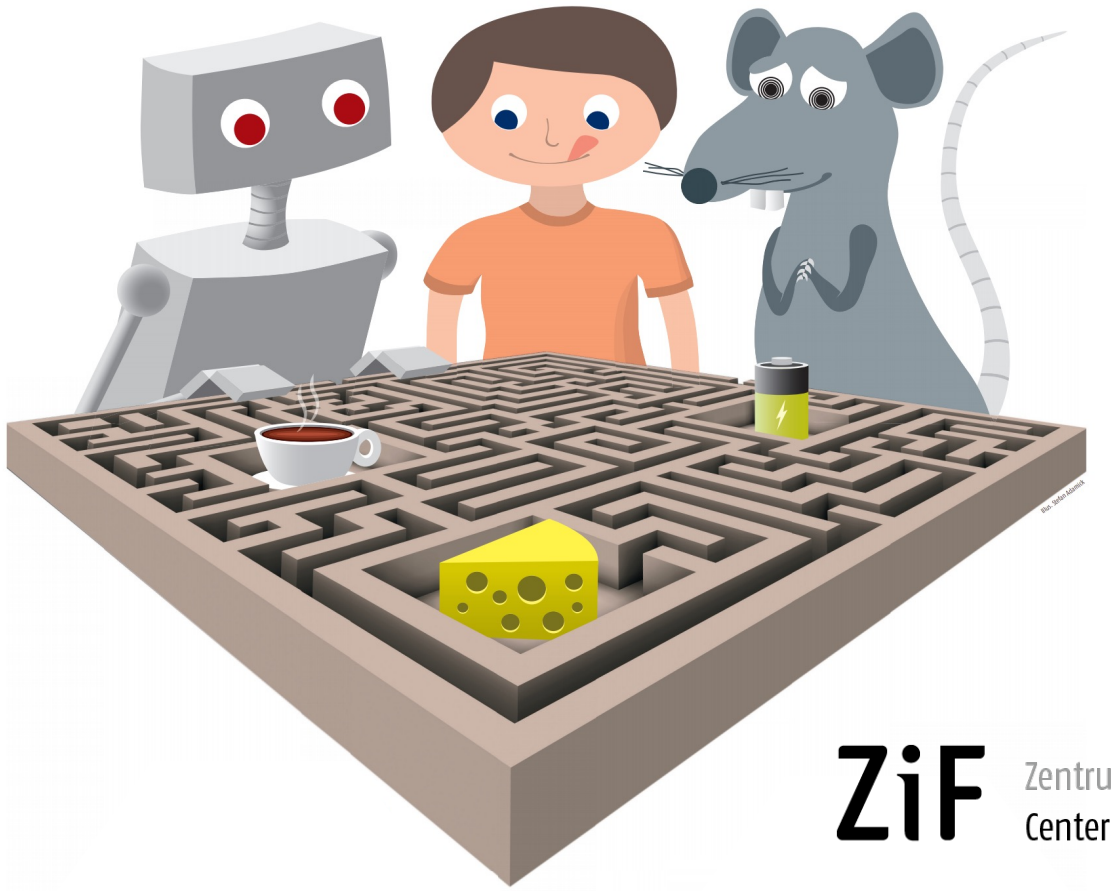

Flexible
Context-sensitive
Behaviour

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The Situation Model Framework

(Schneider et al., 2020)

"Cognition is effective action"
Maturana and Varela, (1989)

Three Foundational Themes:

1. Control of action: integrative role in cognition
2. Complex behaviours emerge by scaffolding simpler behaviours
3. Internal Attention is a prioritizing control mechanism

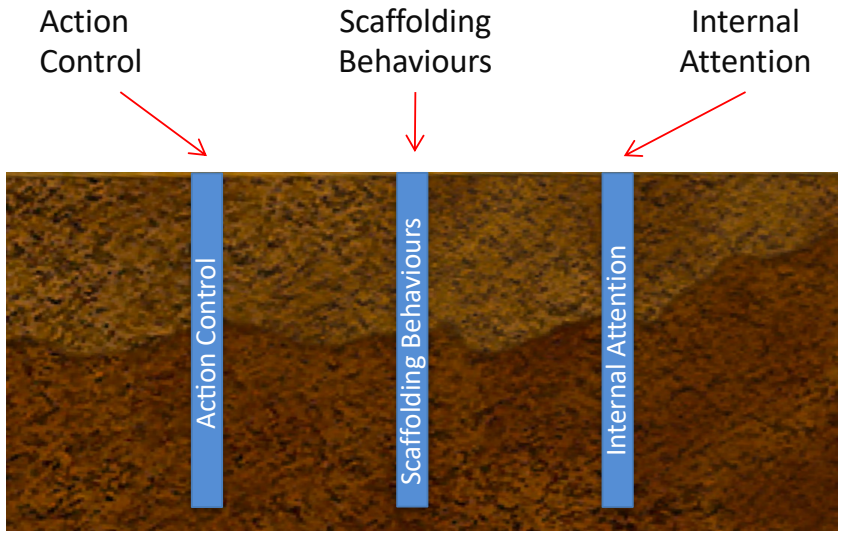
https://www.aboutcivil.org/pile-foundations-design-construction.html

Action Control

Scaffolding Behaviours

Internal Attention

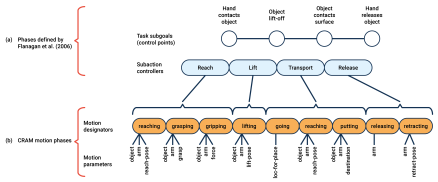
The Situation Model Framework

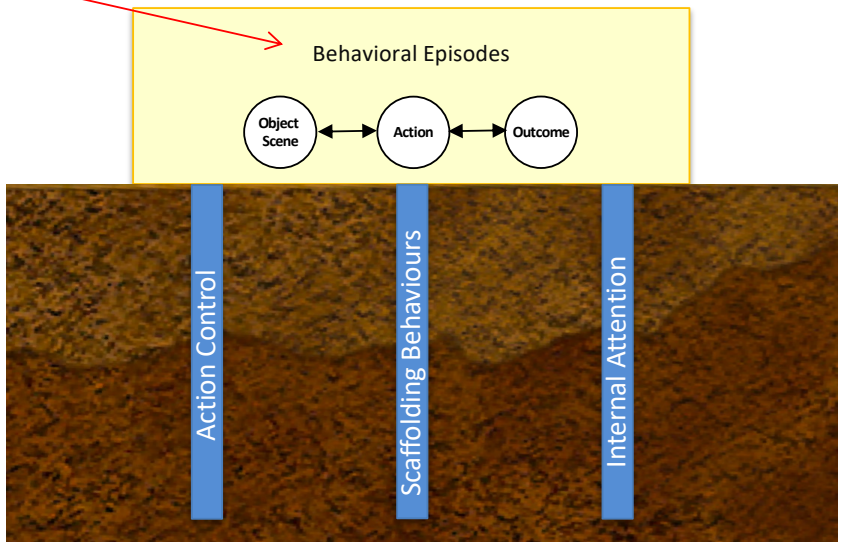


The Situation Model Framework

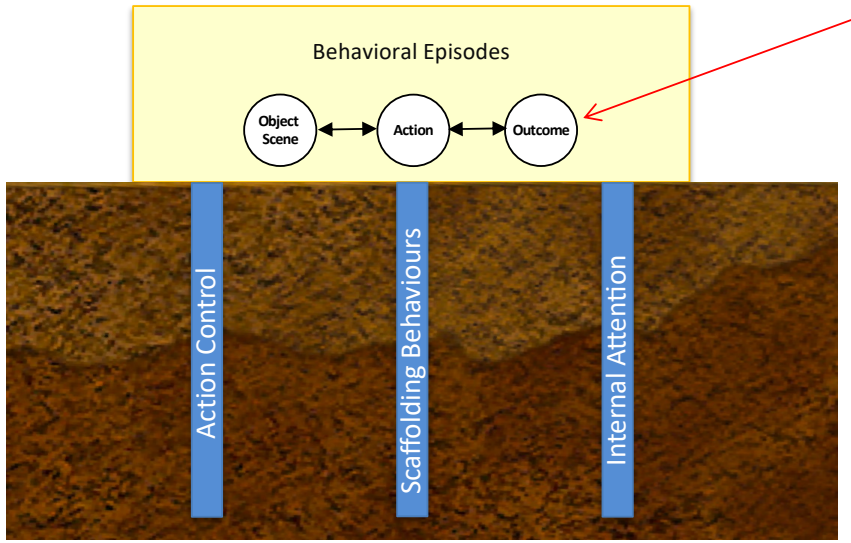
Joint perception-action representation

Abstract representation: unencumbered by low-level sensorimotor information





The Situation Model Framework



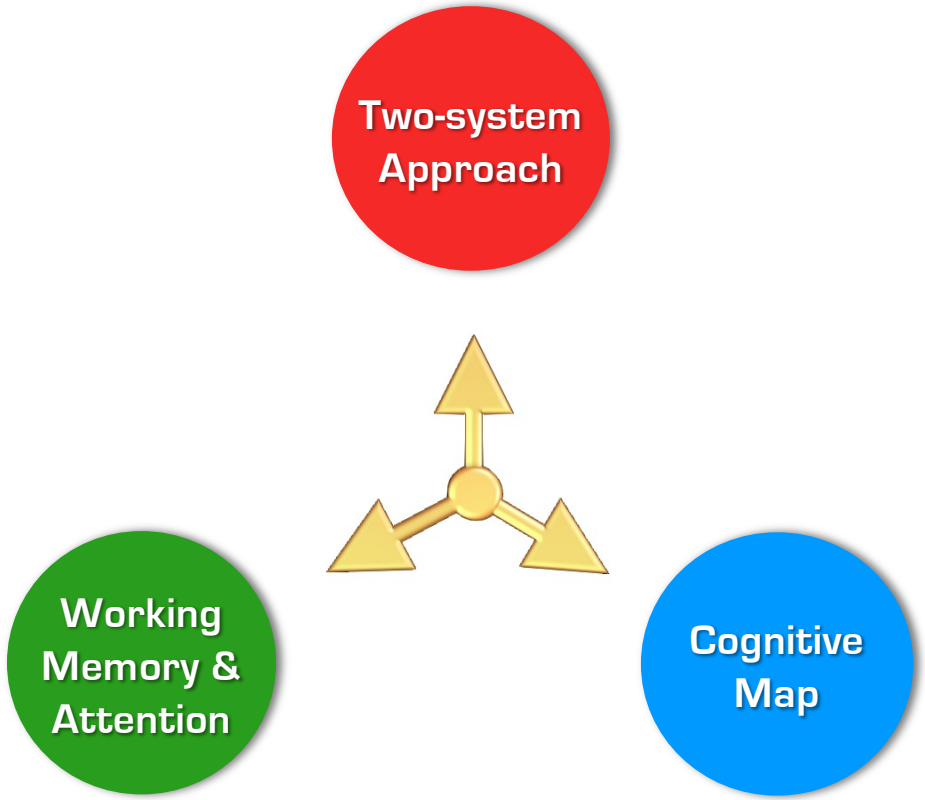
"Intended Behavioral Outcome"
(cf. goal-directed nature of actions)

Perception of the action outcome

Captures both spatial and temporal aspects

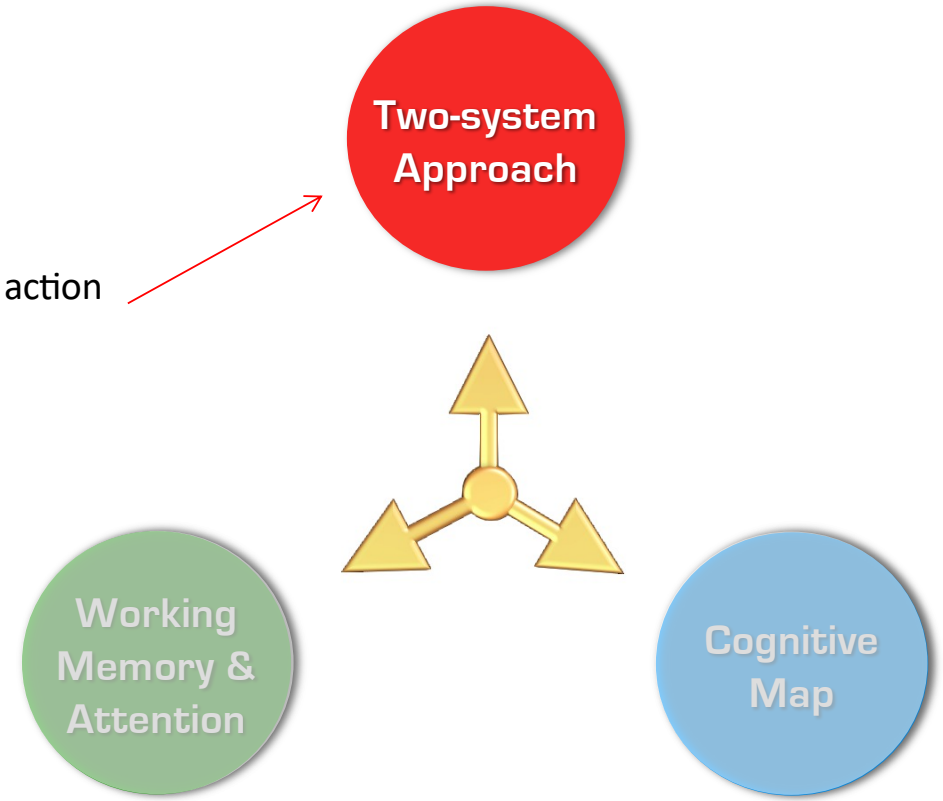
Causal relationships

The Situation Model Framework

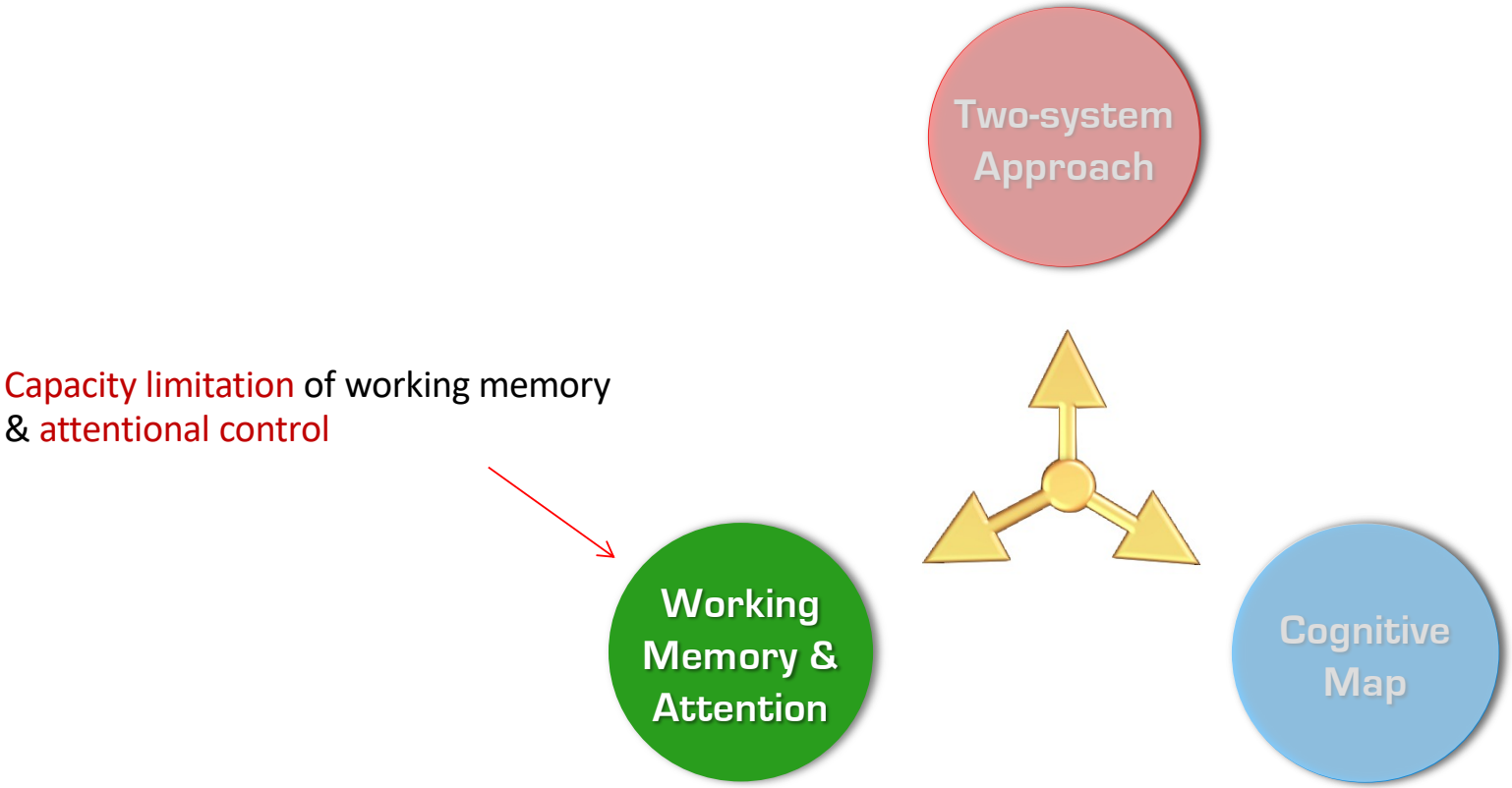


The Situation Model Framework

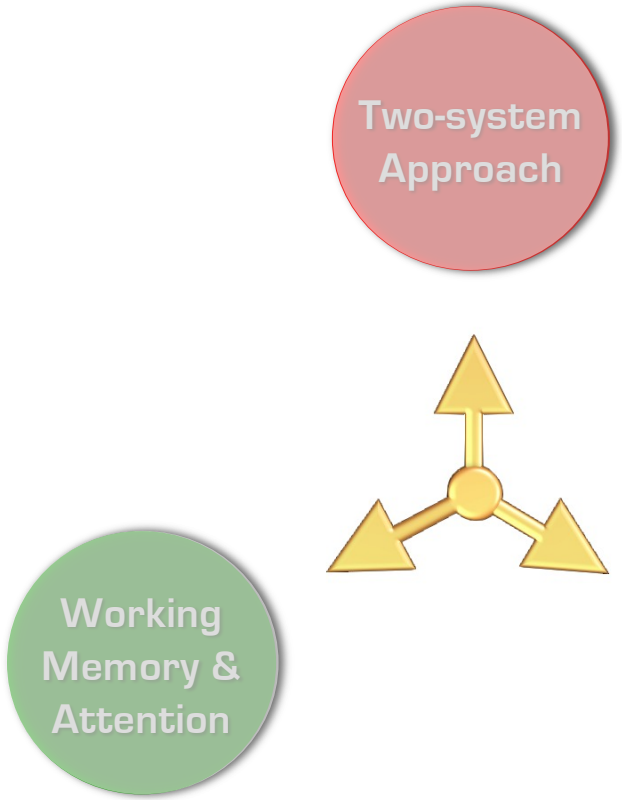
Two-system approach to thought and action
(cf. D. Kahneman, Thinking, Fast and Slow)



The Situation Model Framework



The Situation Model Framework



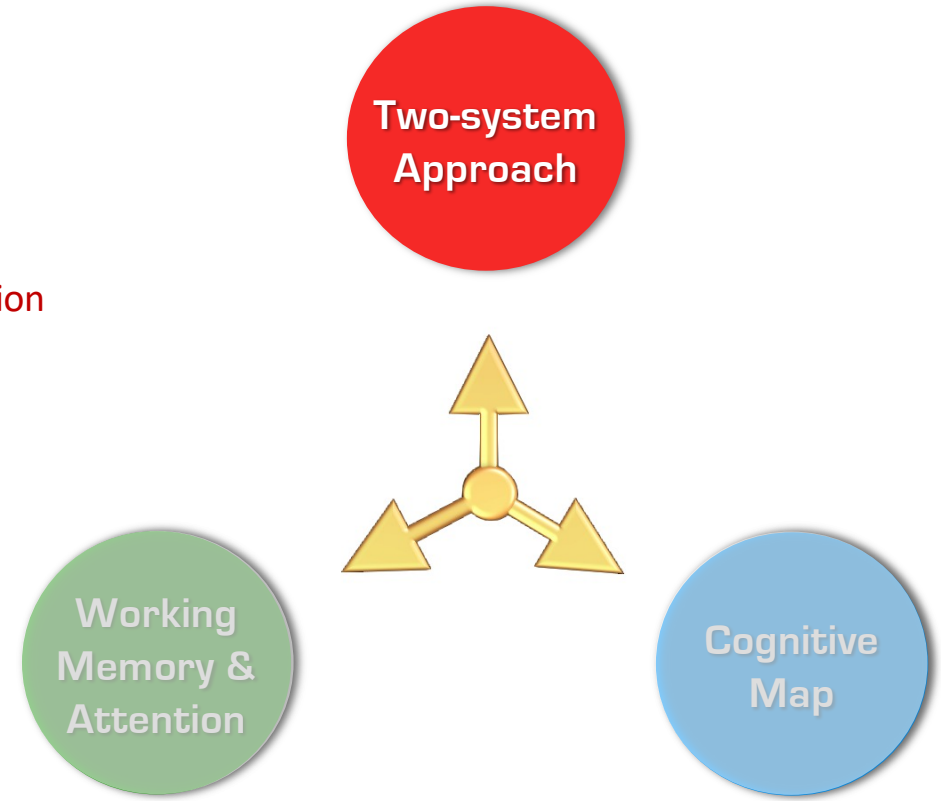
Cognitive map: extended form of behavioural episode
(and hence joint action-perception representation with both spatial and temporal characteristics)

The Situation Model Framework

Two classes of behaviour:

1. Routine habitual
   ... handled by system 1

2. Actions requiring deliberation
   ... handled by system 2



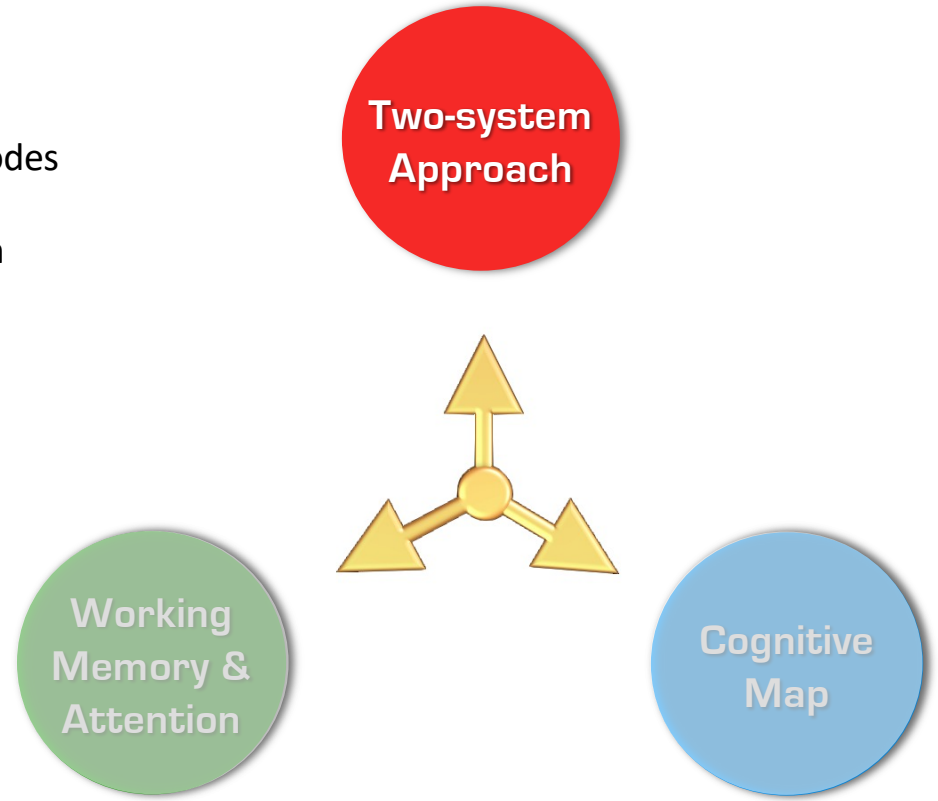
The Situation Model Framework

System 1

- Retrieves n behavioral episodes

- Winner-take-all competition

- Executes the winner



The Situation Model Framework

System 1

- Retrieves n behavioral episodes

- Winner-take-all competition

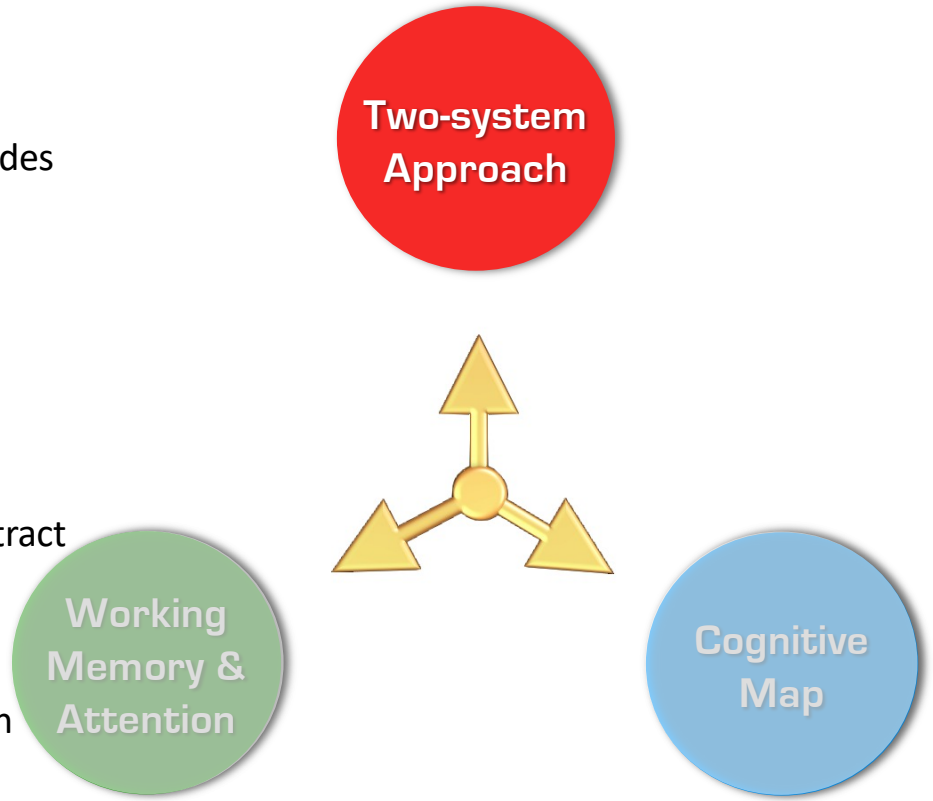
- Executes the winner

But ...

Behavioural episodes are abstract

So ...

Sensor and motor information is resolved in real-time.



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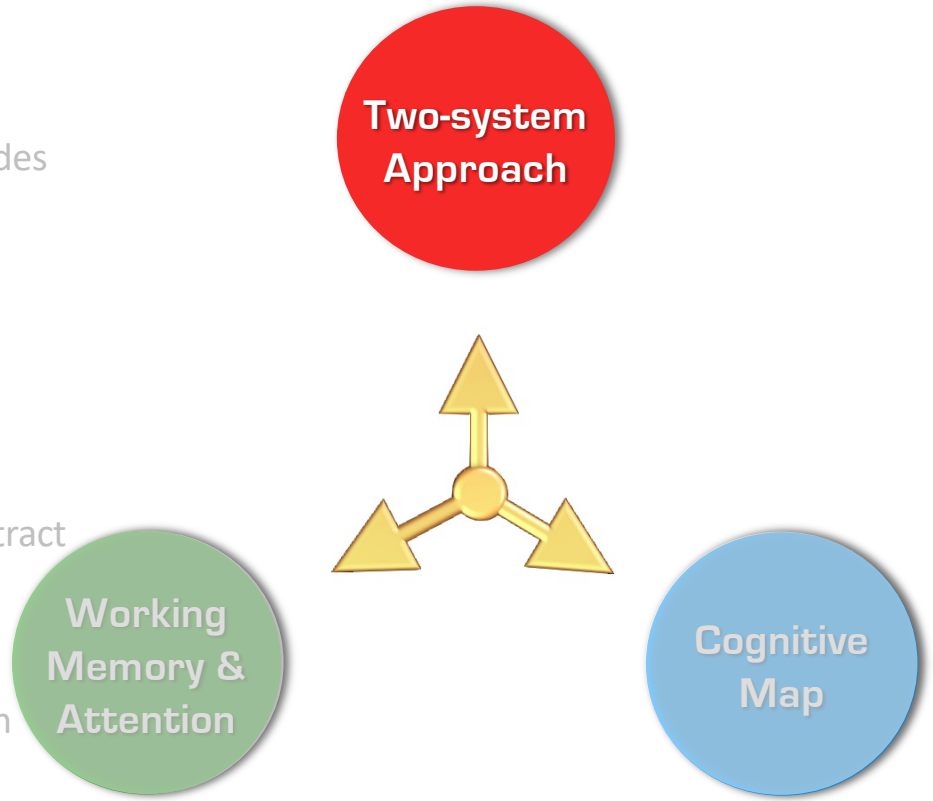

System 2

Has additional mechanisms in **working memory** to

- Construct novel episodes

- Predict outcome using internal simulation (or enact in reality)

- Refine

- Assimilate in LTM

The Situation Model Framework

System 1

- Retrieves n behaviour episodes

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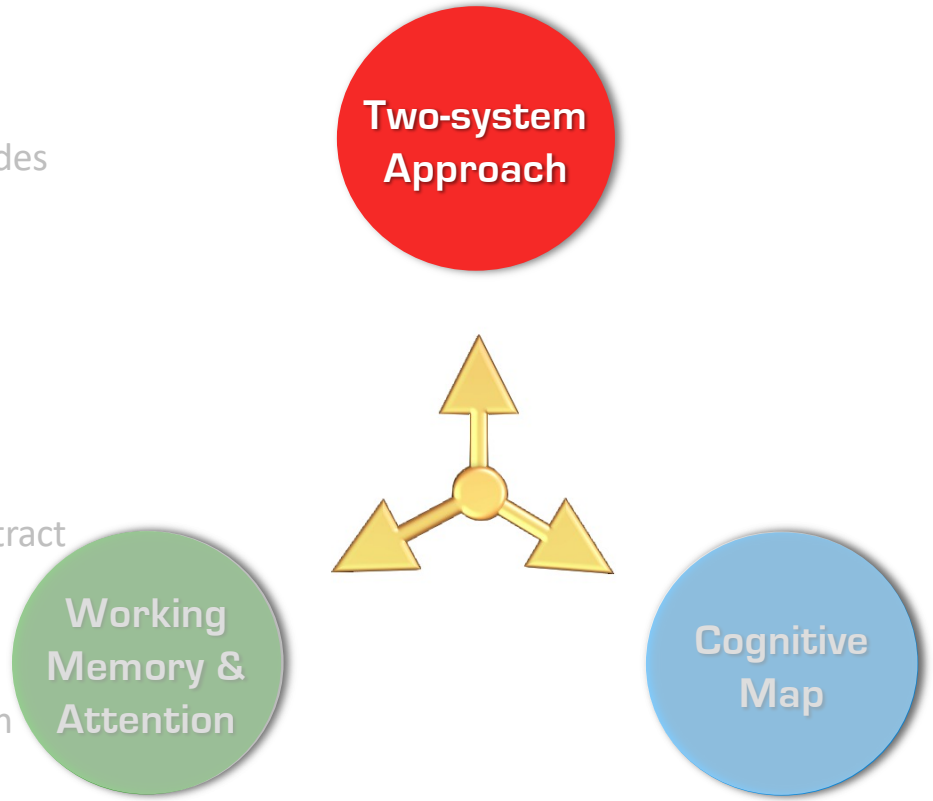


System 2

Has additional mechanisms in **working memory** to

- Construct novel episodes

- Predict outcome using internal simulation (or enact in reality)

- Refine

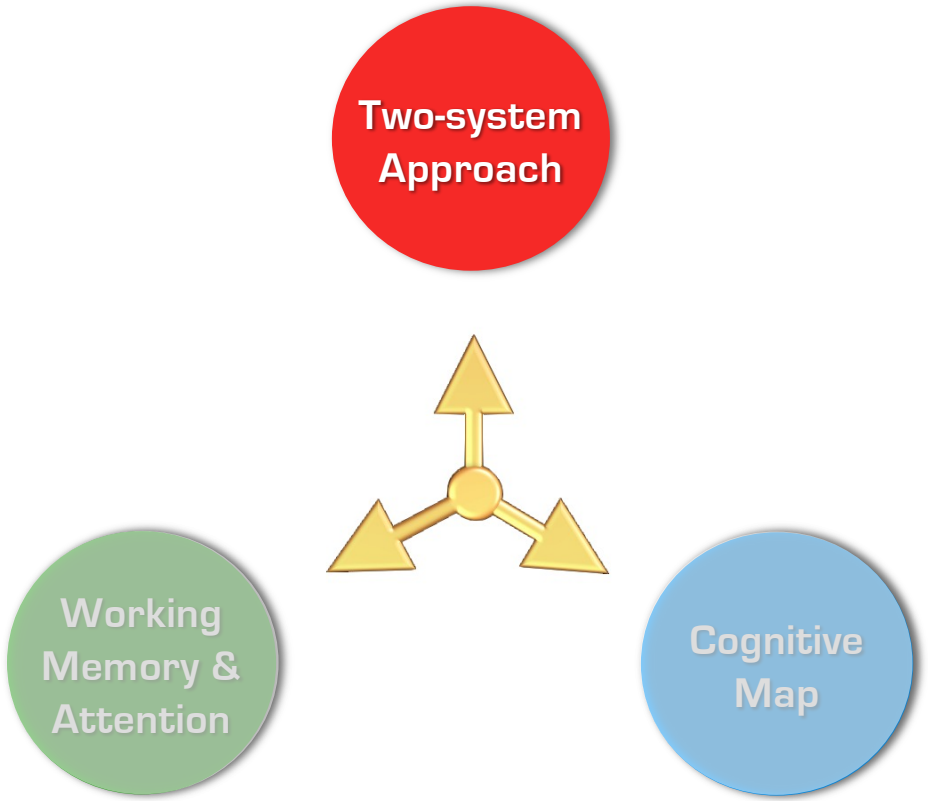
- Assimilate in LTM

⇒ FLEXIBILITY

The Situation Model Framework

System 1

Reactive control of action

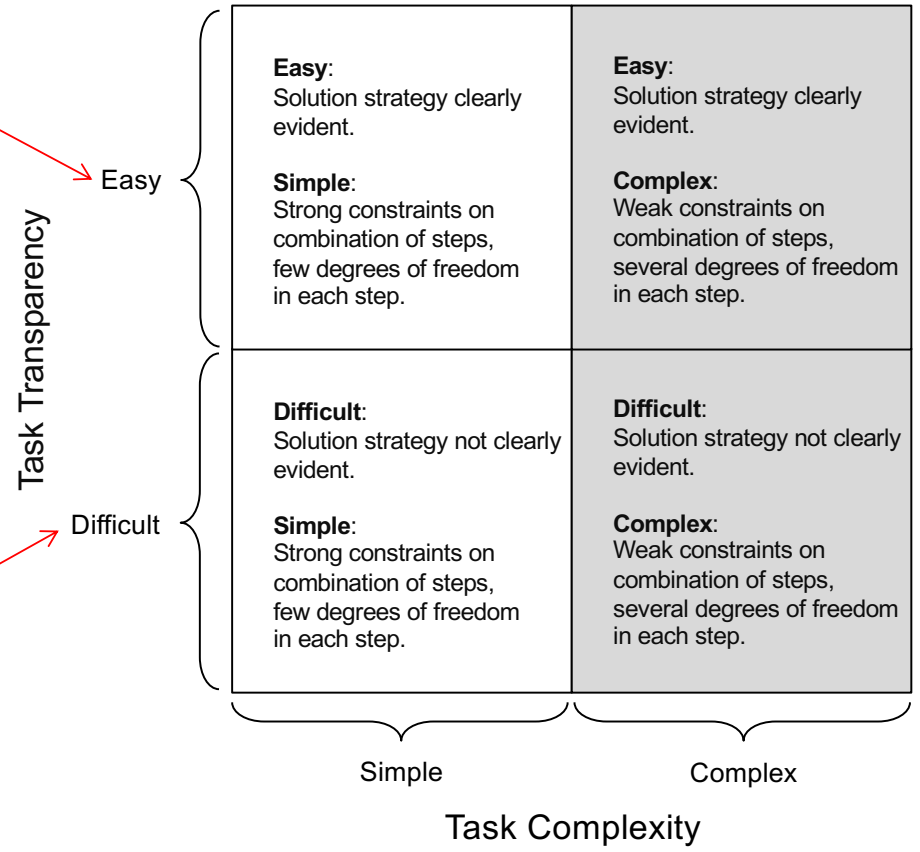


System 2

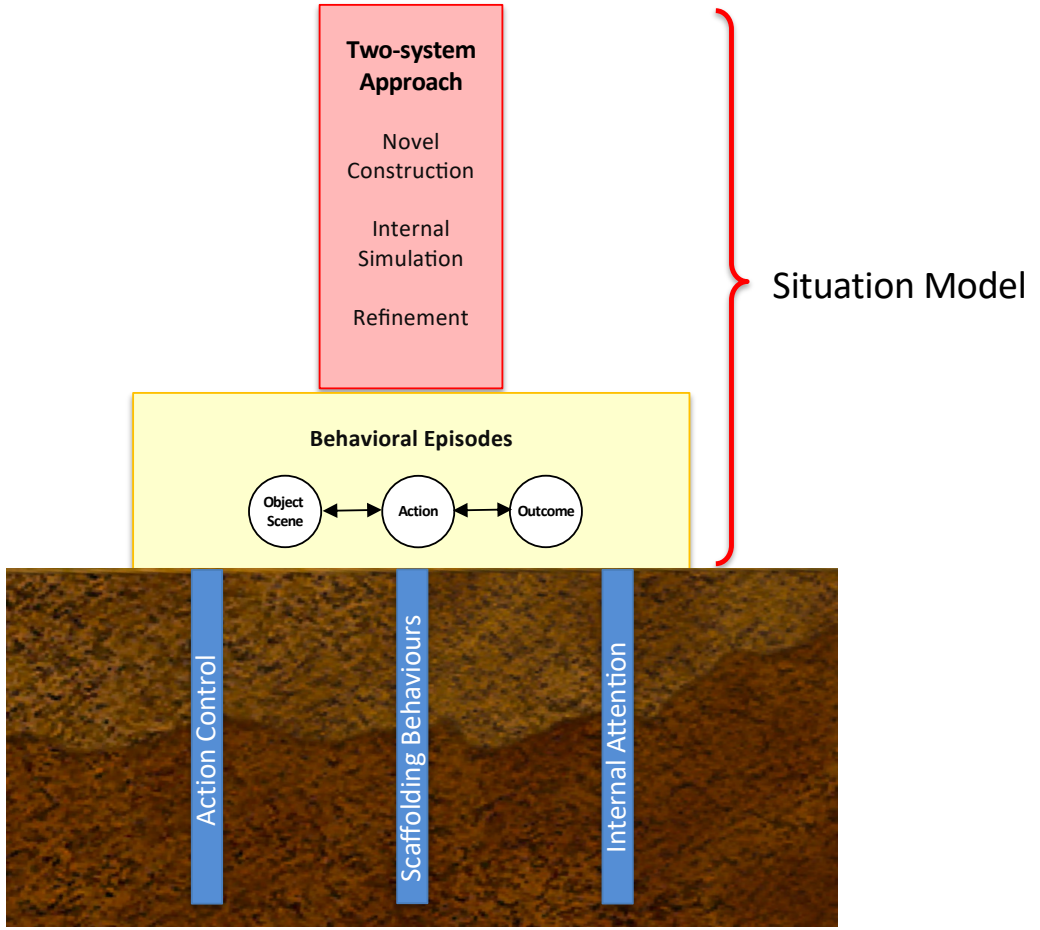
Prospective control of action

System 1: Habitual

System 2: Deliberative

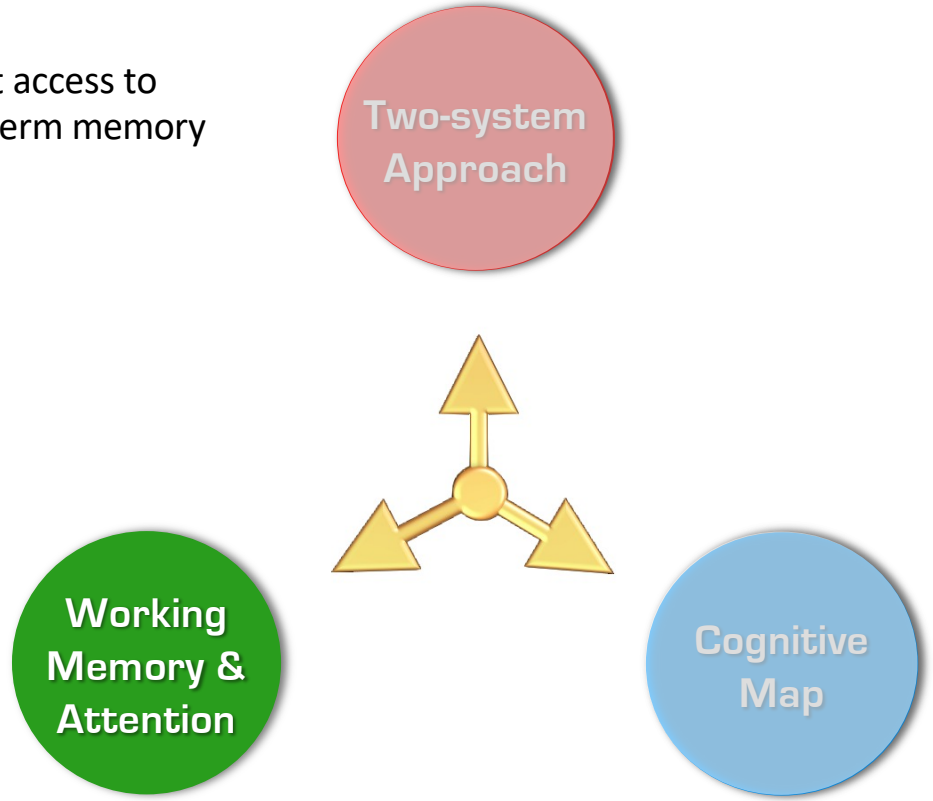


The Situation Model Framework



The Situation Model Framework

Systems 1 and 2 need efficient access to behavioural episodes in long-term memory



The Situation Model Framework

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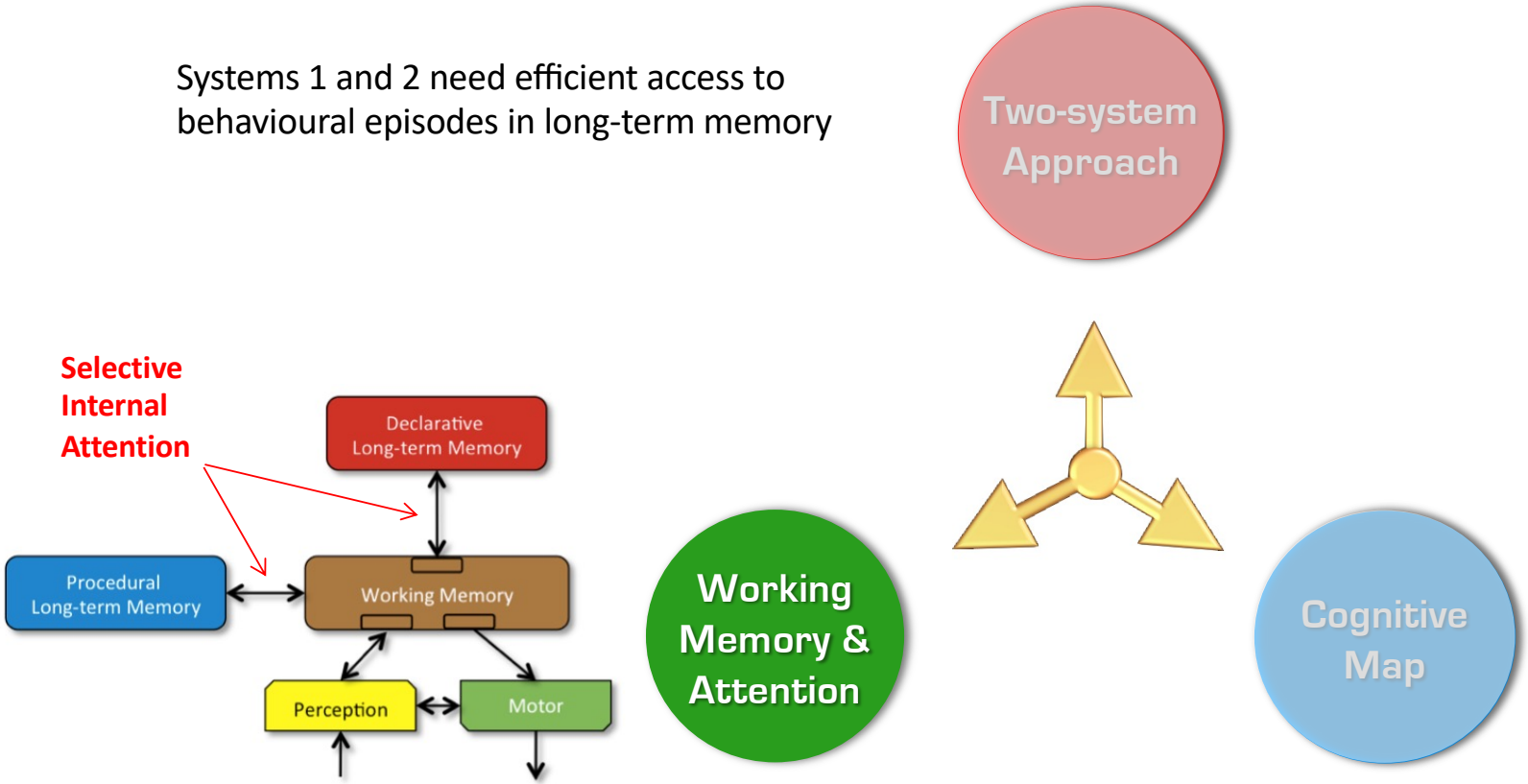


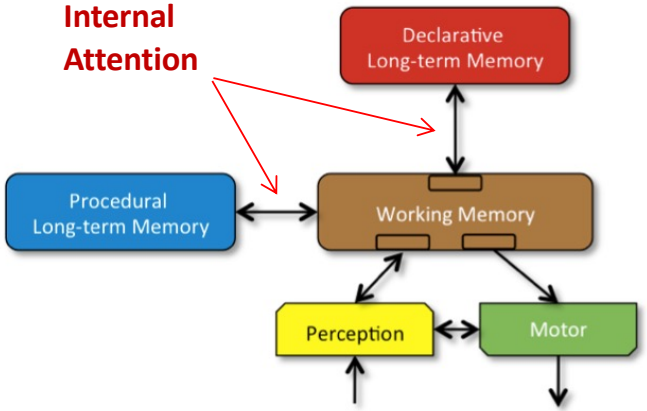
Laird, J. E., Lebiere, C. & Rosenbloom, P. S. . A Standard Model of the Mind: Toward a Common Computational Framework across Artificial Intelligence, Cognitive Science, Neuroscience, and Robotics. AI Magazine, 2017.

The Situation Model Framework

Systems 1 and 2 need efficient access to behavioural episodes in long-term memory

⇒ CONTEXT SENSITIVITY

Selective Internal Attention



Two-system Approach

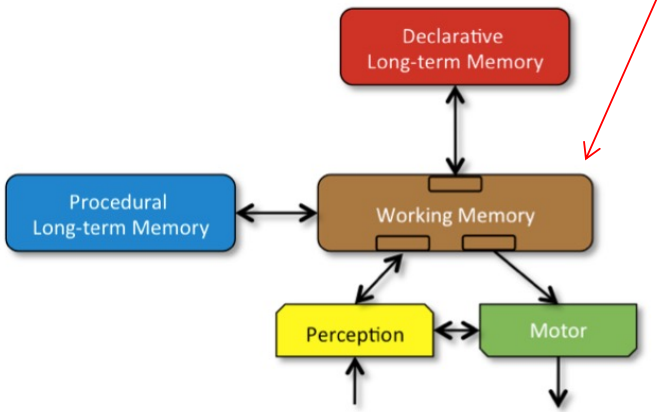
Working Memory & Attention

Cognitive Map

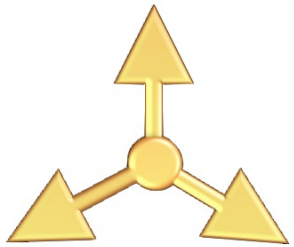
The Situation Model Framework

Two-system Approach

Mechanisms to setup novel behavioural episodes
Predict (covertly) by simulation the outcome
& refine through fast learning

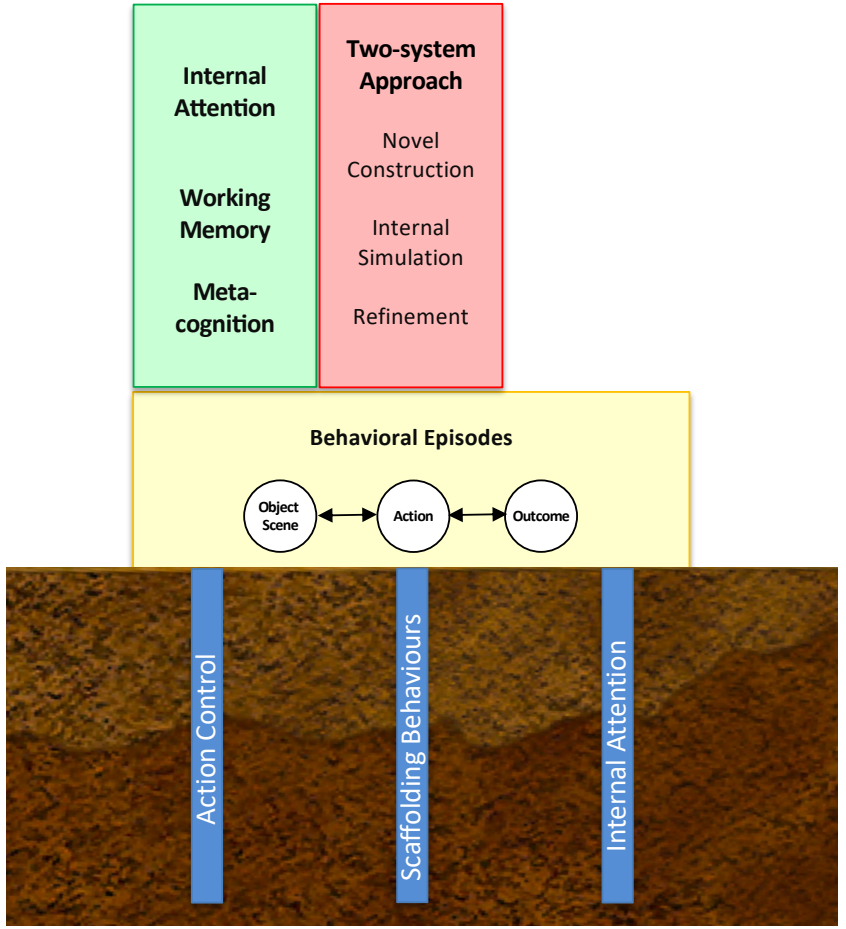


Working Memory & Attention

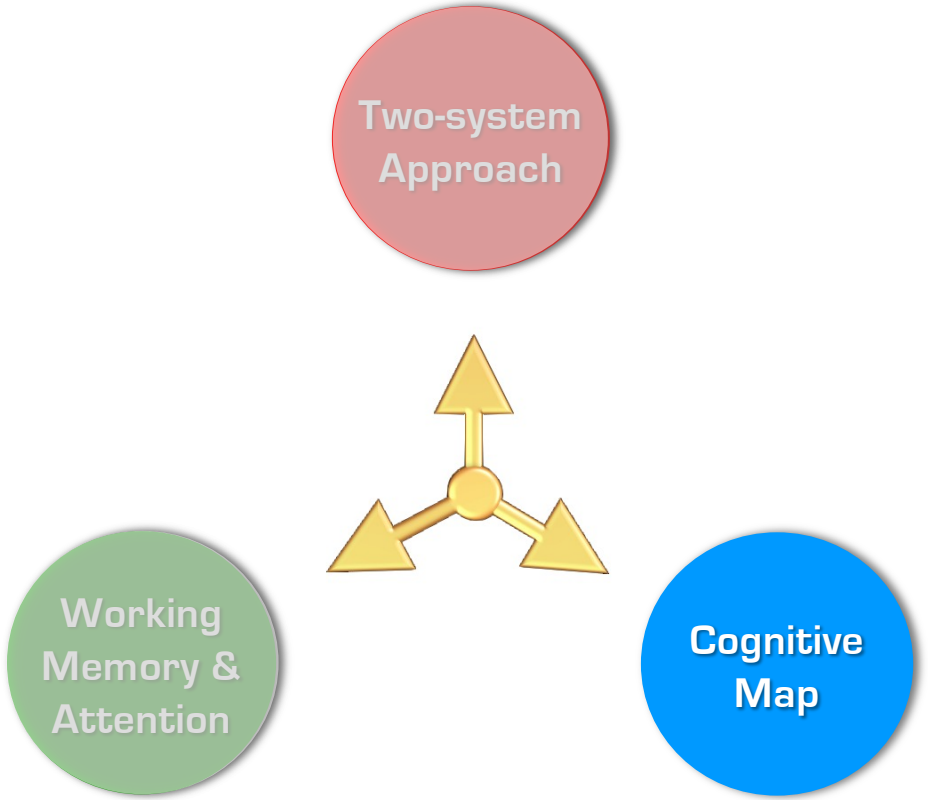


Cognitive Map

The Situation Model Framework



The Situation Model Framework

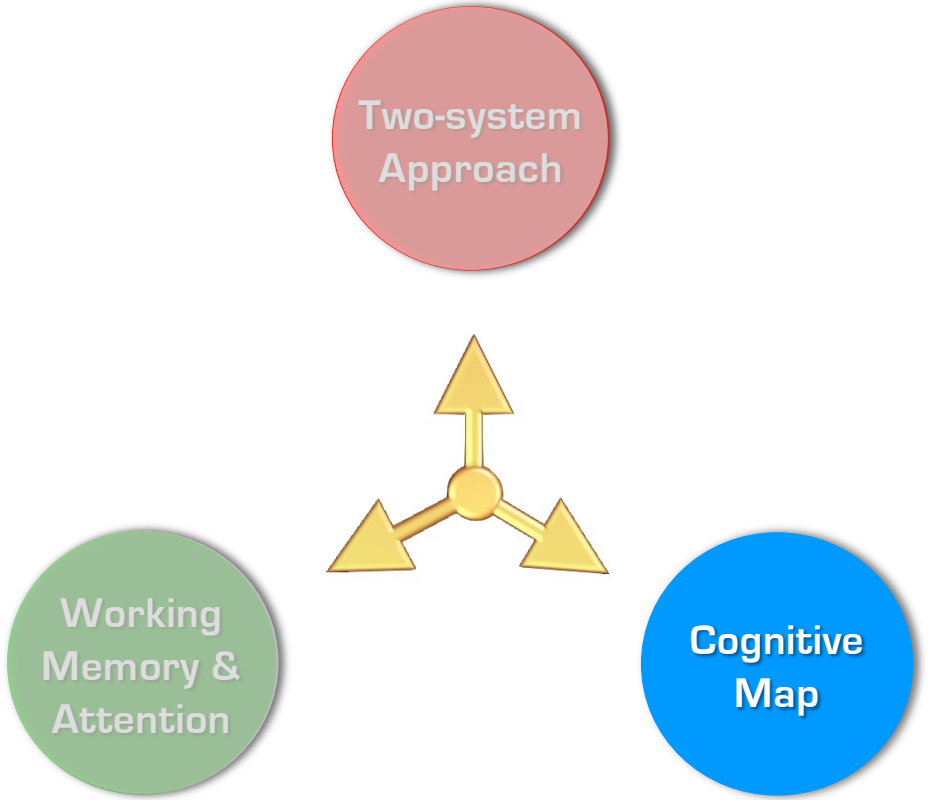


Extended form of behavioural episode:

- Joint perception-action spatio-temporal representation

- Causal link between scene, object, action, outcome

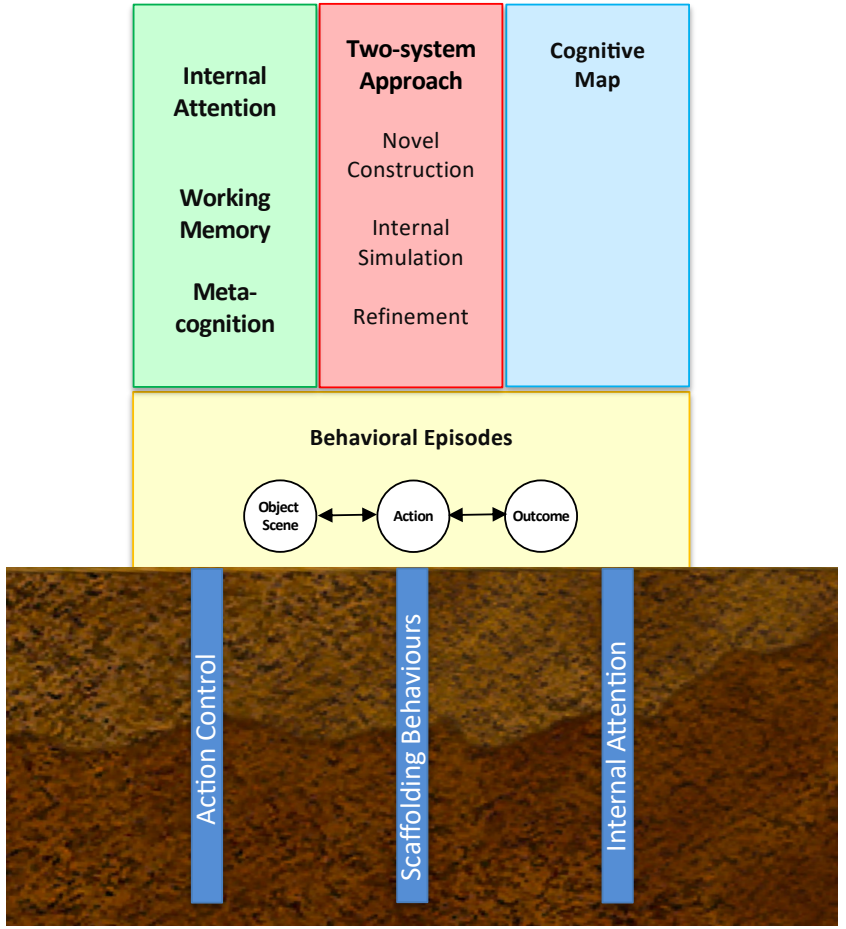
The Situation Model Framework



A way of organizing knowledge in all domains of behavior in a systematic manner
(Behrens et al. 2018)

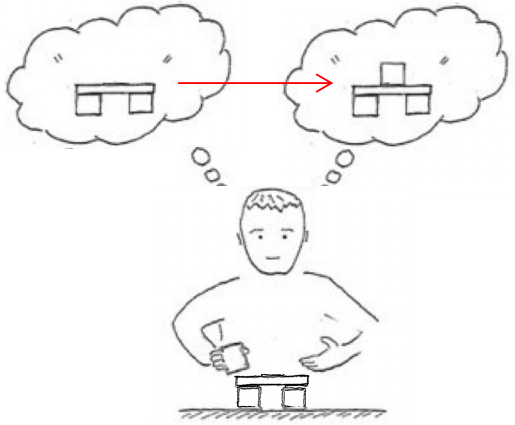
An abstract map of causal relationships in the world

The Situation Model Framework



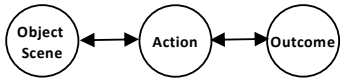
The Situation Model Framework

Mechanisms for
constructing, simulating, enacting, refining, and assimilating
behavioural episodes



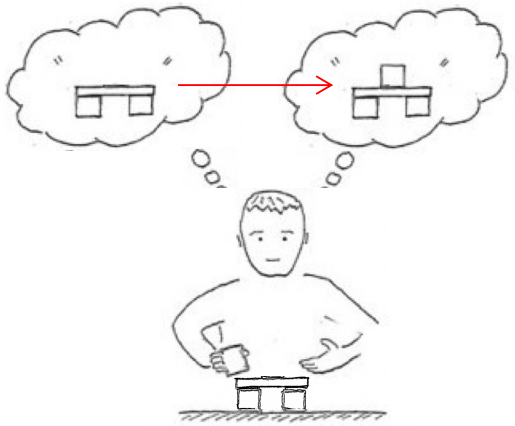
Behavioural episode

- Joint **perception-action** representation
- Captures causal relationships between objects, scenes, actions, action outcomes



The Situation Model Framework

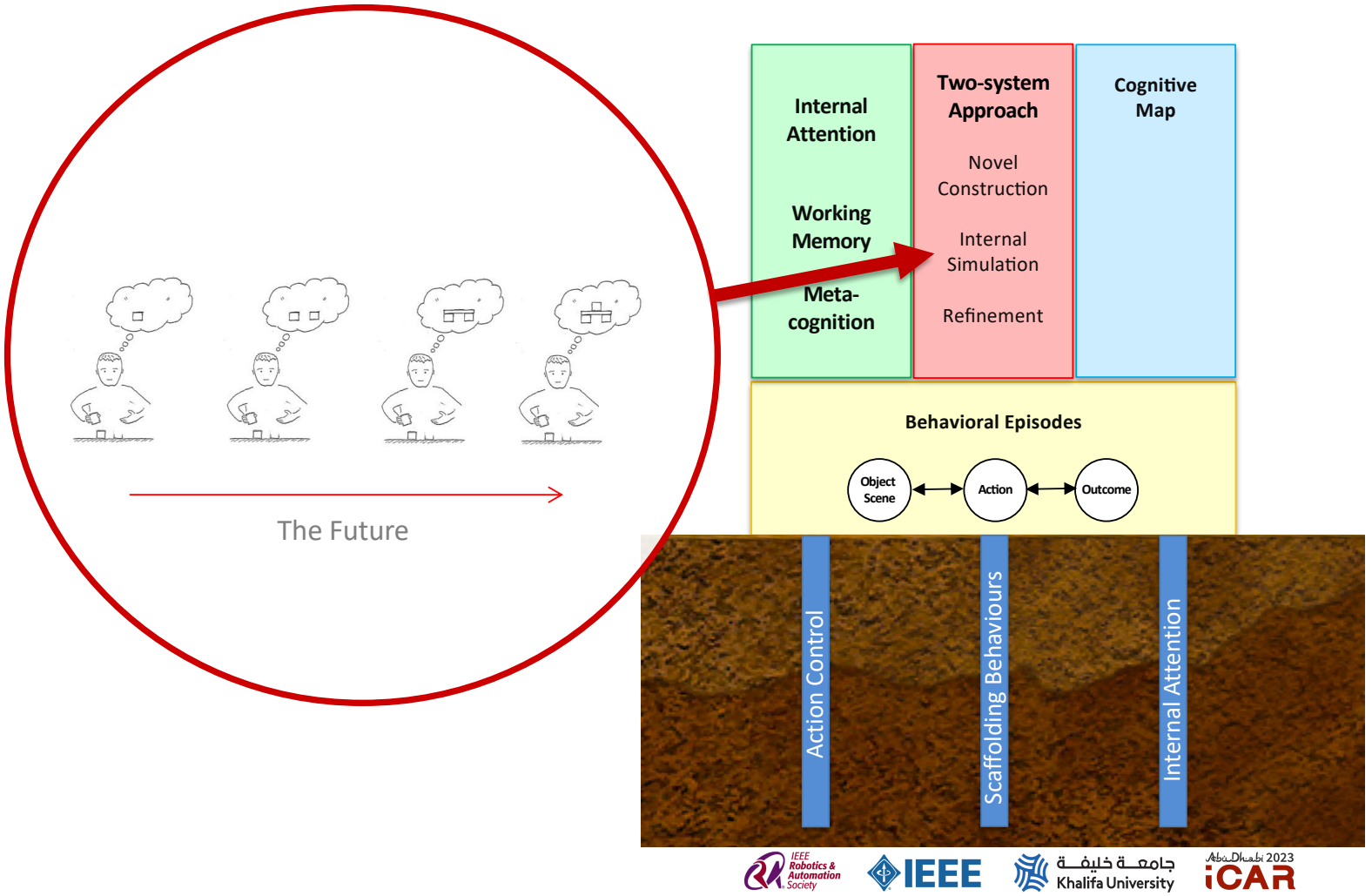
Probehandeln



Trial treatment: mental execution of an action or consideration of alternative actions to reach a decision

https://www.spektrum.de/lexikon/psychologie/probehandeln-internes/11849

The Situation Model Framework



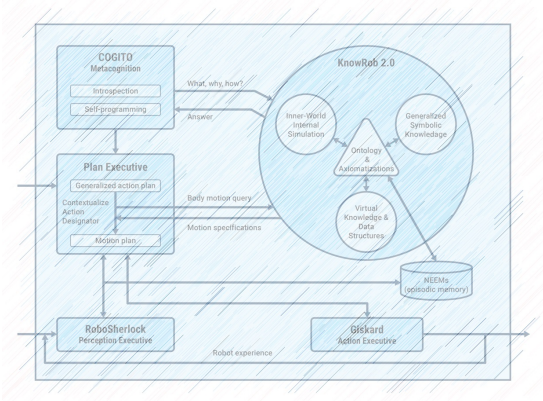
The CRAM Cognitive Architecture

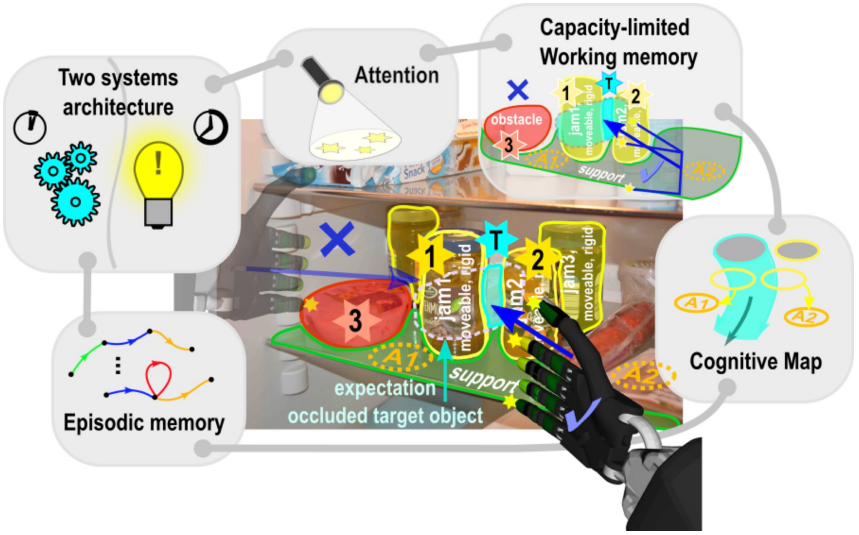
Flexible, Versatile, Context-sensitive Cognitive Behavior

Fetching something **inaccessible** from a fridge or
Placing something on a **cluttered** table ...

Requires **flexibility** to rearrange things first
& infer consequences of the rearrangement

CRAM 2.0





The CRAM Cognitive Architecture

Flexible, Versatile, Context-sensitive Cognitive Behavior

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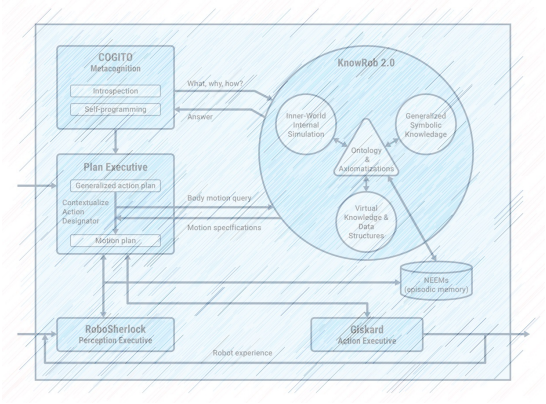


Exploiting multiple affordances of several objects

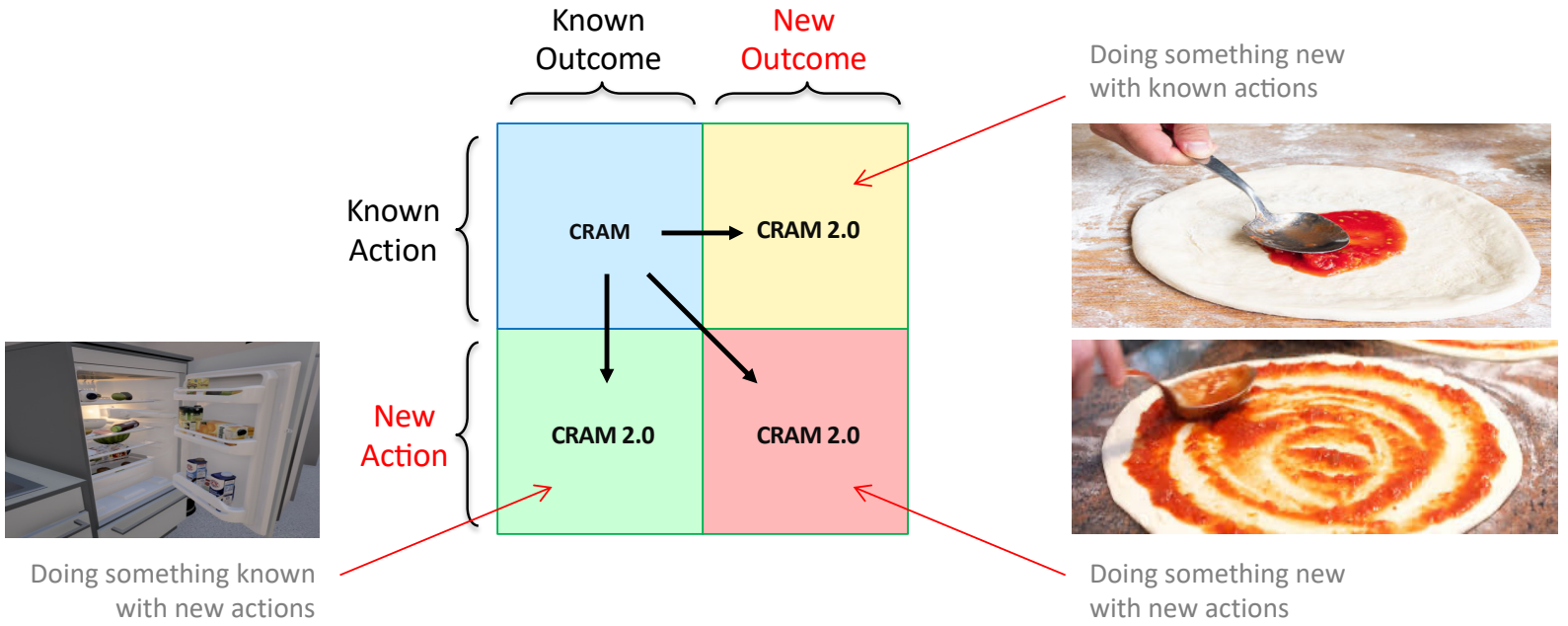
Transporting with a **spoon**
Spreading with a **spoon**
Levering a lid with a **spoon**

Transporting with a **fork**
Spreading with a **fork**
Levering a lid with a **fork**

Requires **flexibility** to infer the outcome or action
& **context-sensitivity** to select the appropriate affordance

The CRAM Cognitive Architecture

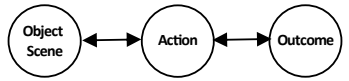
Flexible, Versatile, Context-sensitive Cognitive Behavior



Challenges for implementation of the situation model framework

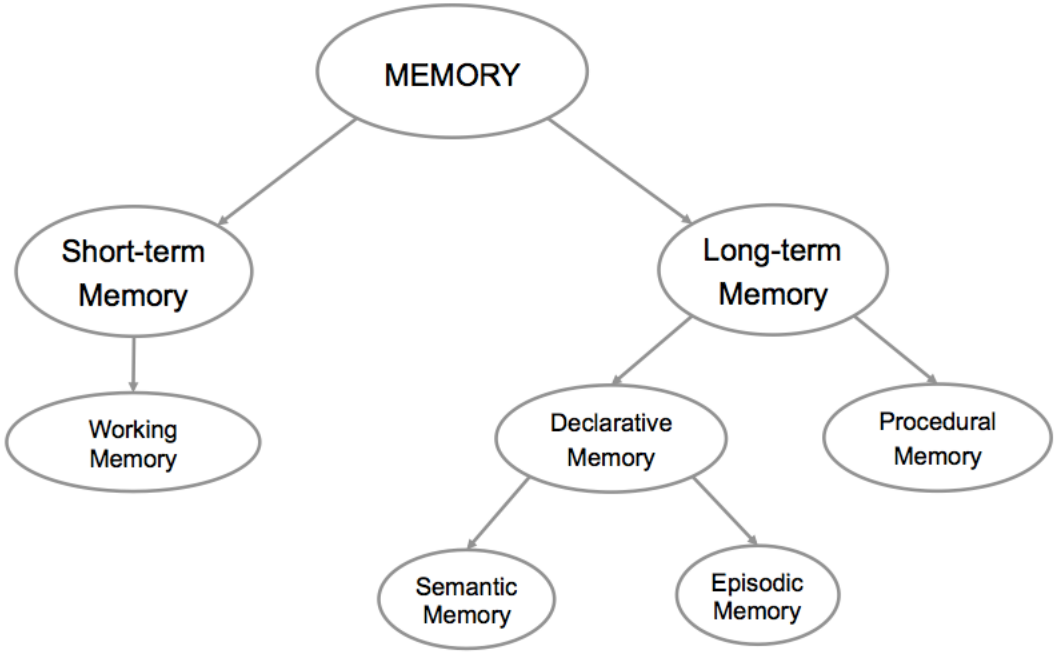
1. Decomposition, reconstruction, and recombination of behavioural episodes
2. Hierarchical behavioural episodes
3. Networks of behavioural episodes
4. Multiple levels of abstraction in internal simulation
5. Multiple timescales in internal simulation
6. Situation models vs. cognitive maps
7. Context sensitivity: what criteria are used for attention?
8. Autonomy: extrinsic vs. intrinsic goals

They all hinge on the perceptuomotor representation: the behavioural episode



Types of Memory

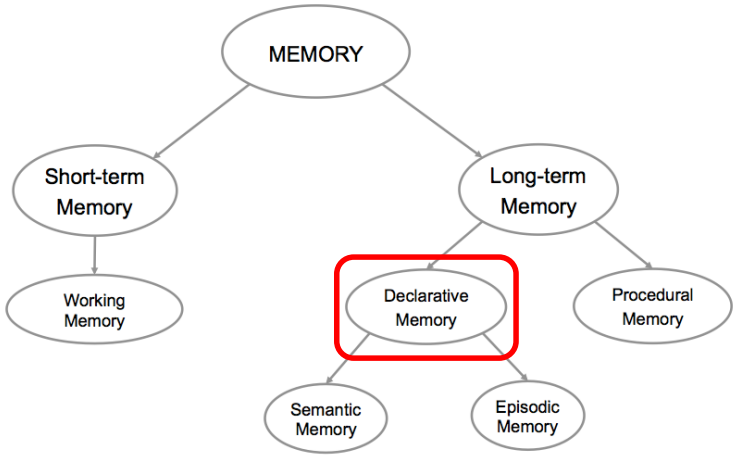
- Declarative
- Procedural
- Semantic
- Episodic
- Long-term
- Short-term
- Working
- Modal
- Amodal
- Symbolic
- Sub-symbolic
- Hetero-associative
- Auto-associative



Types of Memory

Declarative

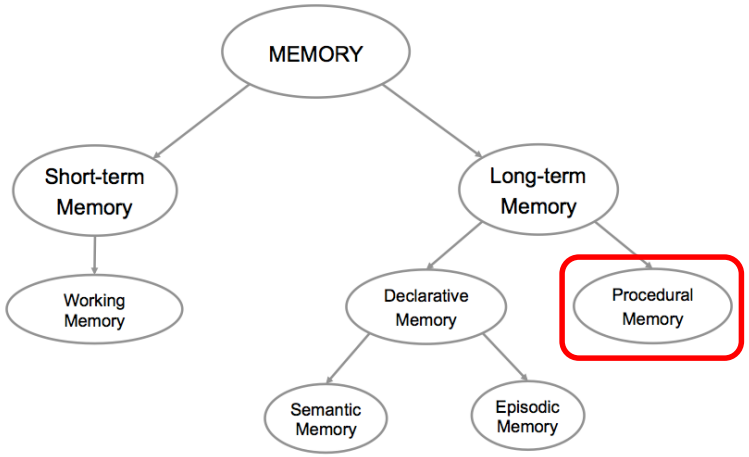
- Knowledge of things / facts
- **"Knowing that"**
- Propositional memory (true or false)
- Can be communicated from one agent to another through language
- Can be acquired in a single act of perception or cognition
- Accessible to conscious recall
- Explicit memory



Types of Memory

Procedural

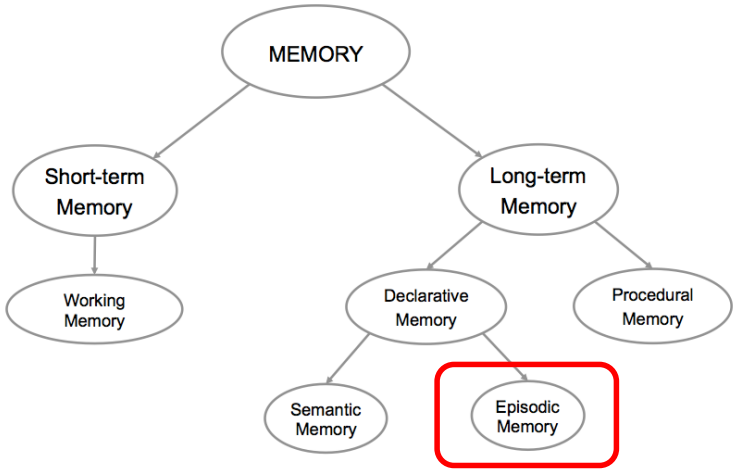
- Skill-oriented memory of actions
- "**Knowing how**"
- Can only be demonstrated
- Acquired progressively and may require an element of practice
- Not accessible to conscious recall
- Implicit memory
- **Non-declarative memory**



Types of Memory

Episodic

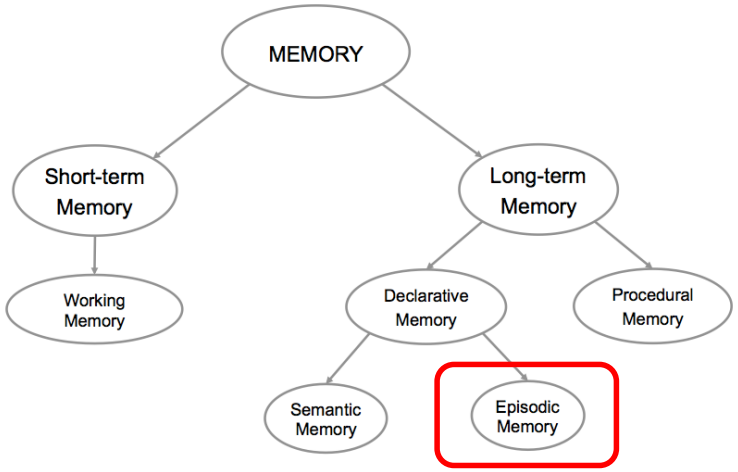
- Specific instances in the agent's experience: autobiographical
- Explicit spatial and temporal context
  - what happened, where it happened, and when it happened
  - This temporal sequencing is the only element of structure in episodic memory
- Sub-symbolic



Types of Memory

Episodic

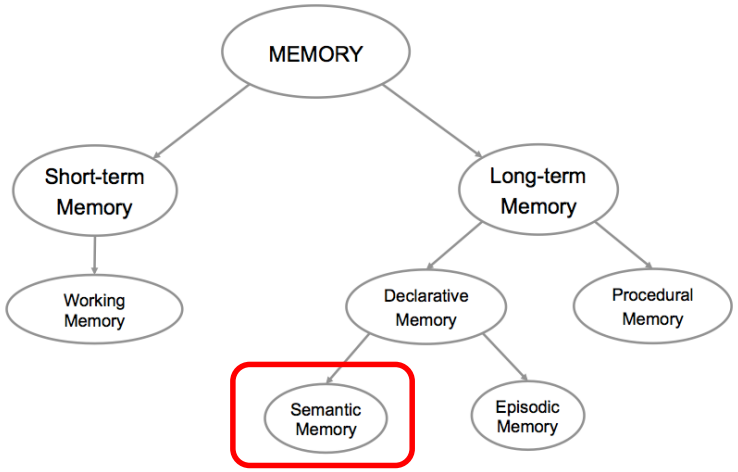
- Episodic memory is a constructive process
  - Each time an event is assimilated into episodic memory, past episodes are re- constructed a little differently each time
  - Related to the role that episodic memory plays in the process of internal simulation that forms the basis of prospection



Types of Memory

Semantic

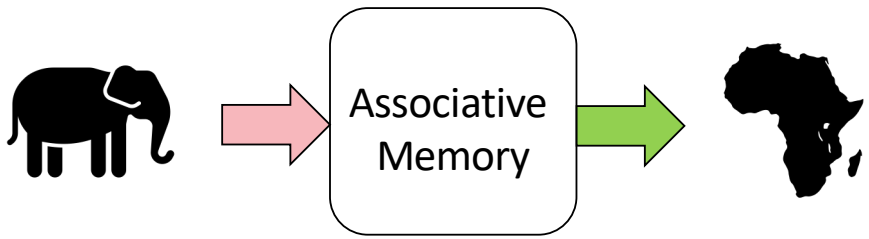
- General knowledge about the agent's world: facts, ideas, and concepts
- May be independent of the agent's specific experiences
- Memory necessary for the use of language
- Derived from episodic memory through a process of generalization and consolidation
- Symbolic



Types of Memory

Associative memory

- An element of information or some pattern is linked to another
- The first element or pattern is used to recall the second, by association



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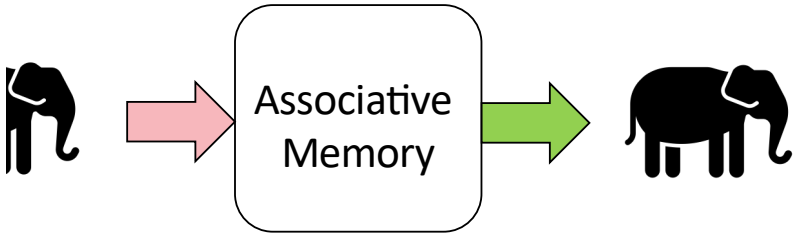

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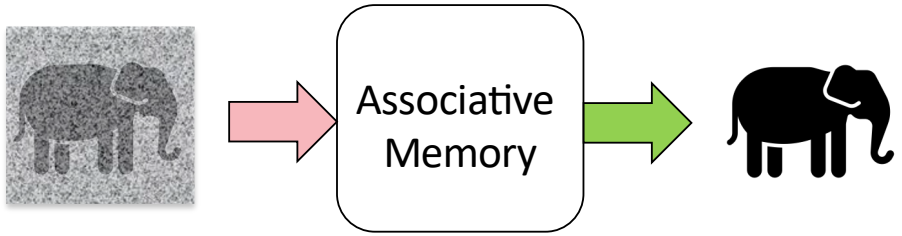
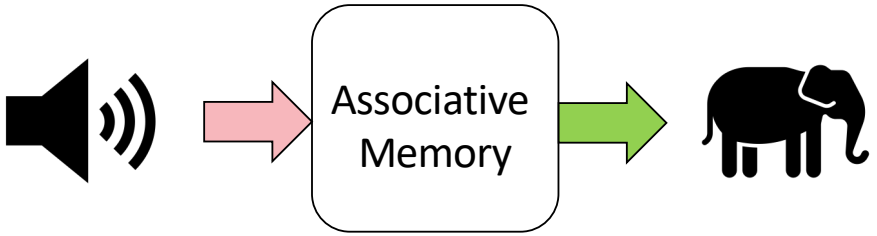


Types of Memory

Hetero-associative memory

- Recalls a memory that is different in character from the input
- A particular smell or sound, for example, might evoke a visual memory of some past event



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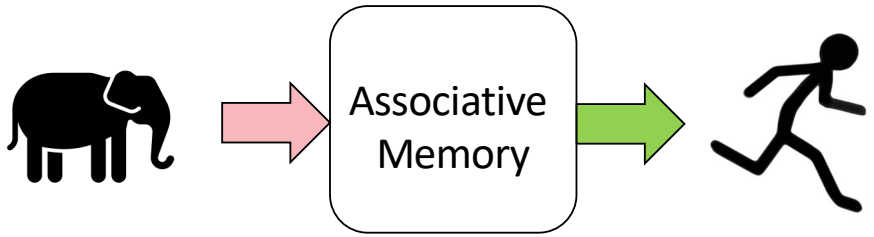
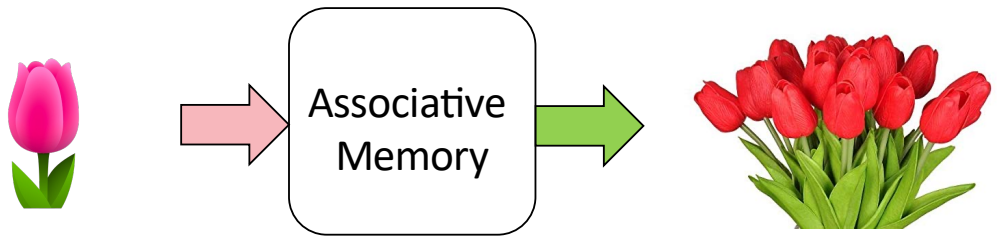


Types of Memory

Auto-associative memory

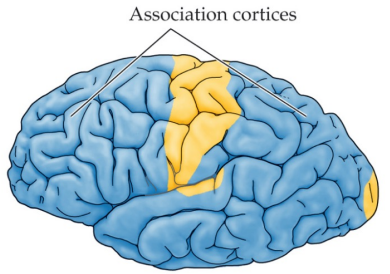
- Recalls a memory of the same modality as the one that evoked it
- A picture of a favourite object might evoke a mental image of that object in vivid detail

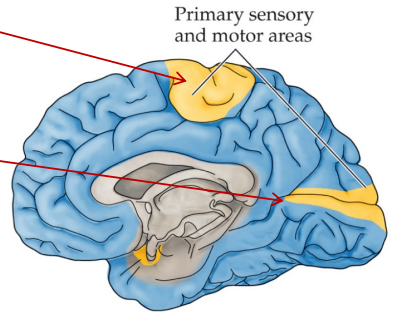


Types of Memory

Cortical structures

- Primary motor cortex
  - Innervates muscles to cause movement
- Primary sensory cortex
  - Extracts features in stimuli
  - Primary visual cortex
  - Primary auditory cortex

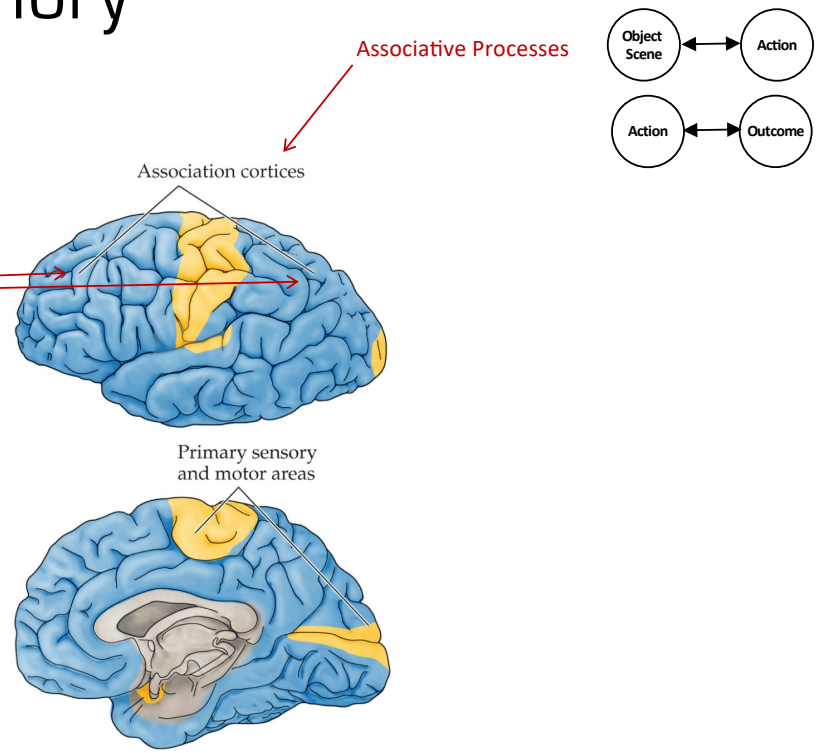




Types of Memory

Cortical structures

- Association cortices
  - Multimodal
  - Integrate signals from primary & secondary sensory cortex
  - Generate activity in the motor cortex



Role of Memory

"It's a poor sort of memory that only works backwards"

Remarks of the White Queen to Alice
in Lewis Carroll's *Through the Looking Glass*

Memory is Prospective

Role of Memory

“It’s a poor sort of memory that only remembers what has actually happened”

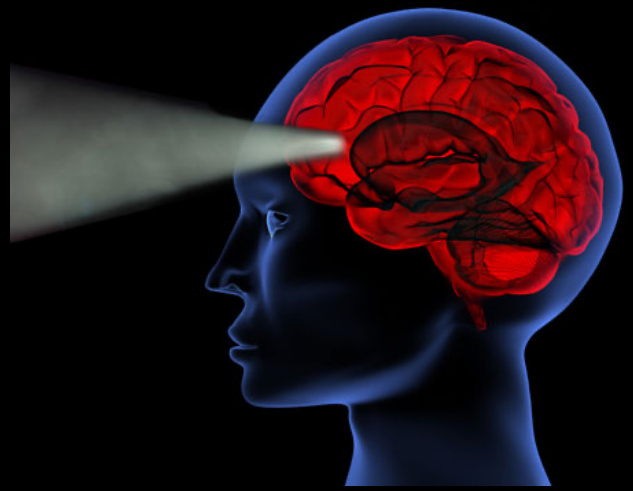
Remarks by Tom Ziemke

Memory is Constructive

Episodic Memory

Specific instances of
the agent's experience

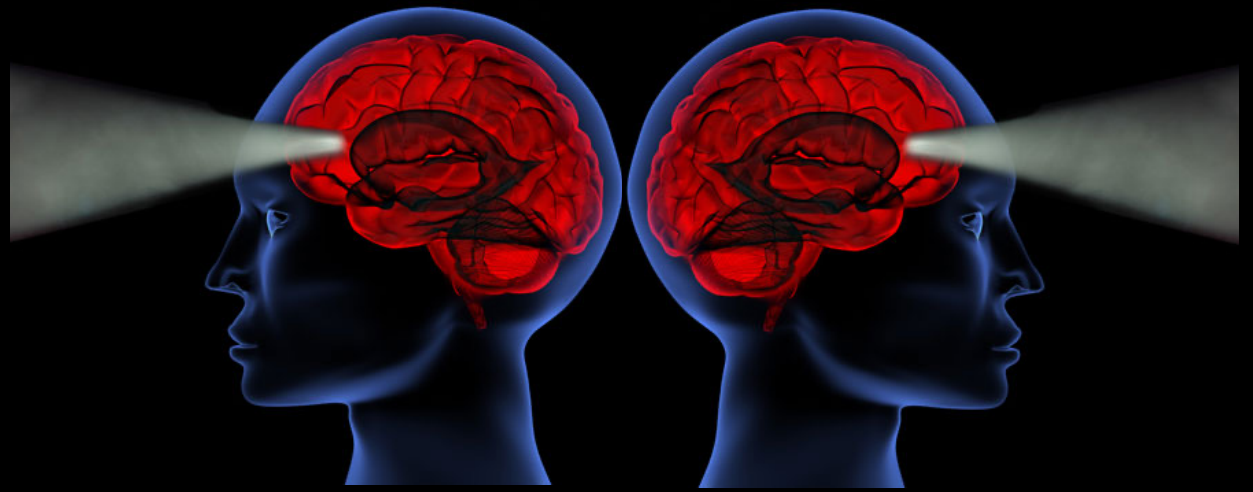
The Past



Past events are
reconstructed ...

Episodic Memory

The Past



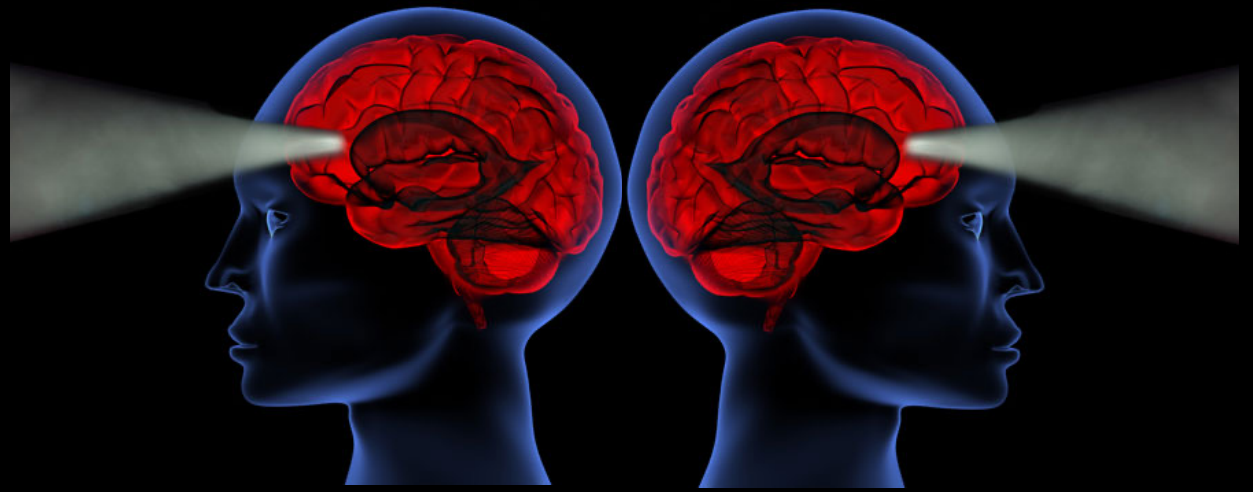
The Future

Past events are
reconstructed ...

To allow the agent
to **pre-experience** the future

Episodic Future Thinking

The Past



The Future

Past events are
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To allow the agent
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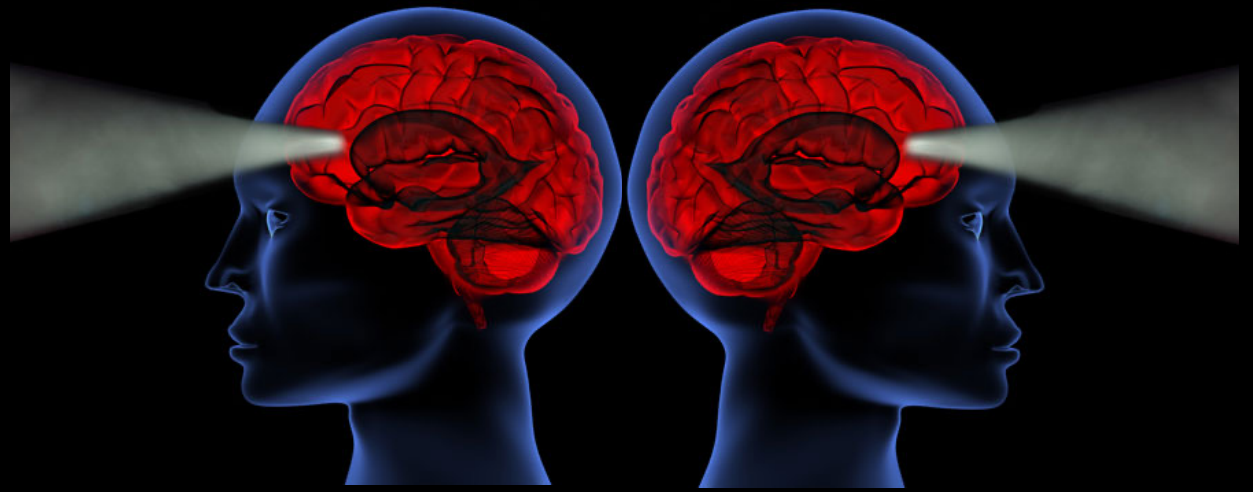
C. M. Atance and D. K. O'Neill, "Episodic future thinking," Trends in Cognitive Sciences, vol. 5, no. 12, pp. 533–539, 2001.

The constructive episodic simulation hypothesis

The Past



Future A
Future B
Future C
...

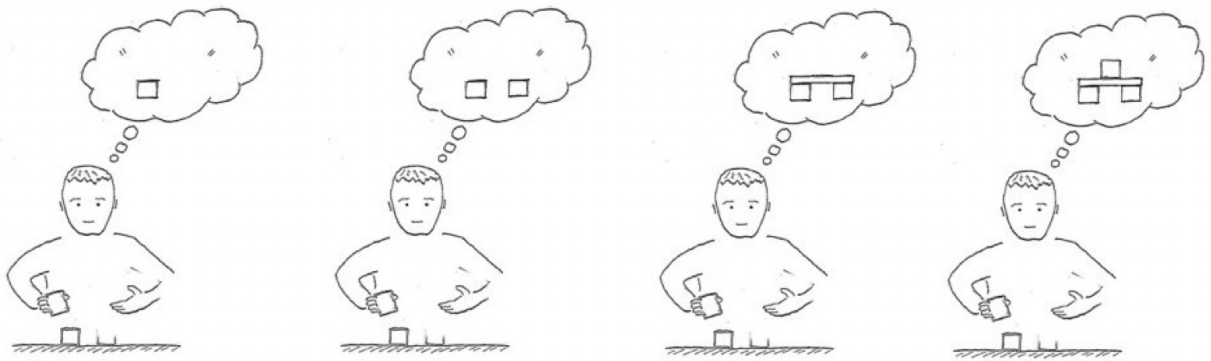
Past events are
reconstructed ...

To allow the agent
to **pre-experience** the future

D. L. Schacter and D. R. Addis, "The cognitive neuroscience of constructive memory: Remembering the past and imagining the future," Philosophical Transactions of the Royal Society B, vol. 362, pp. 773–786, 2007.

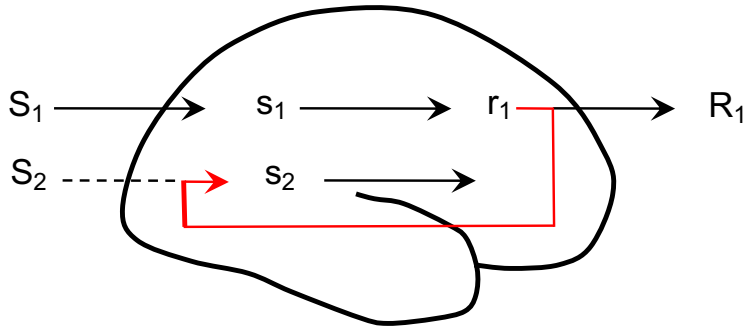
Role of Memory

- Episodic memory is not an exact and perfect record of experience
- It captures the **essence of an event** and is **open to recombination**



The Future

Internal Simulation

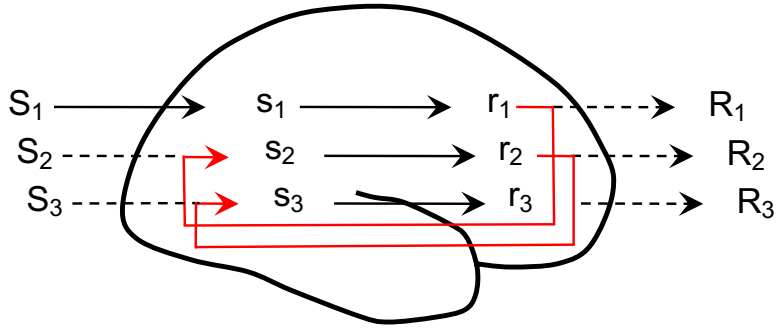


Internal Simulation Hypothesis

(Hesslow, 2002, 2012)

A motor response to an input stimulus causes the internal simulation of an associated perception …

Internal Simulation



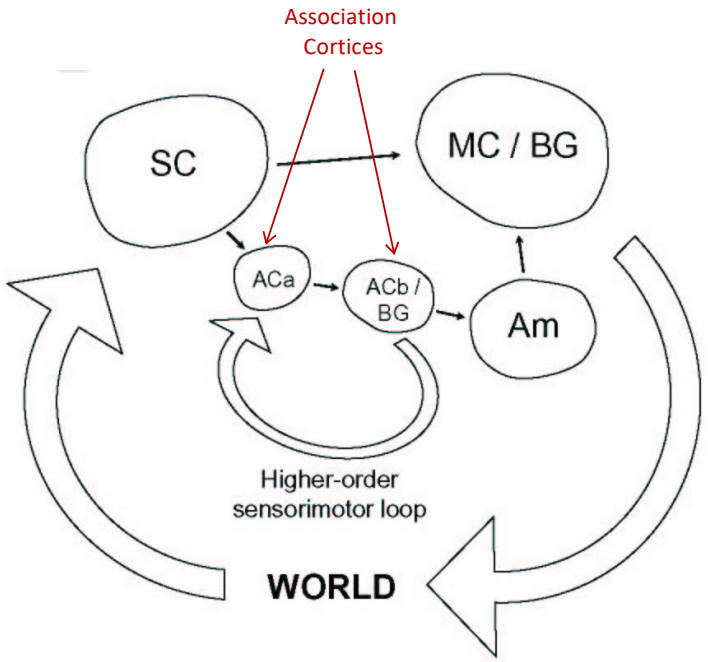
Internal Simulation Hypothesis
(Hesslow, 2002, 2012)

This elicits a covert action which in turn elicits a simulated perception and a consequent covert action

Internal Simulation

Global Workspace cognitive architecture

- Modelled on the anatomy and operation of the brain
  - SC: Sensory Cortex
  - MC: Motor Cortex
  - BG: Basal Ganglia (action selection)
  - AC: Association Cortex
  - Am: Amygdala (affect)



- Implemented using G-RAMS (generalized random access memories)

M. P. Shanahan, 2006. A Cognitive Architecture that Combines Internal Simulation with a Global Workspace, Consciousness and Cognition, 15, pp. 433-449.

Internal Simulation

The HAMMER cognitive architecture

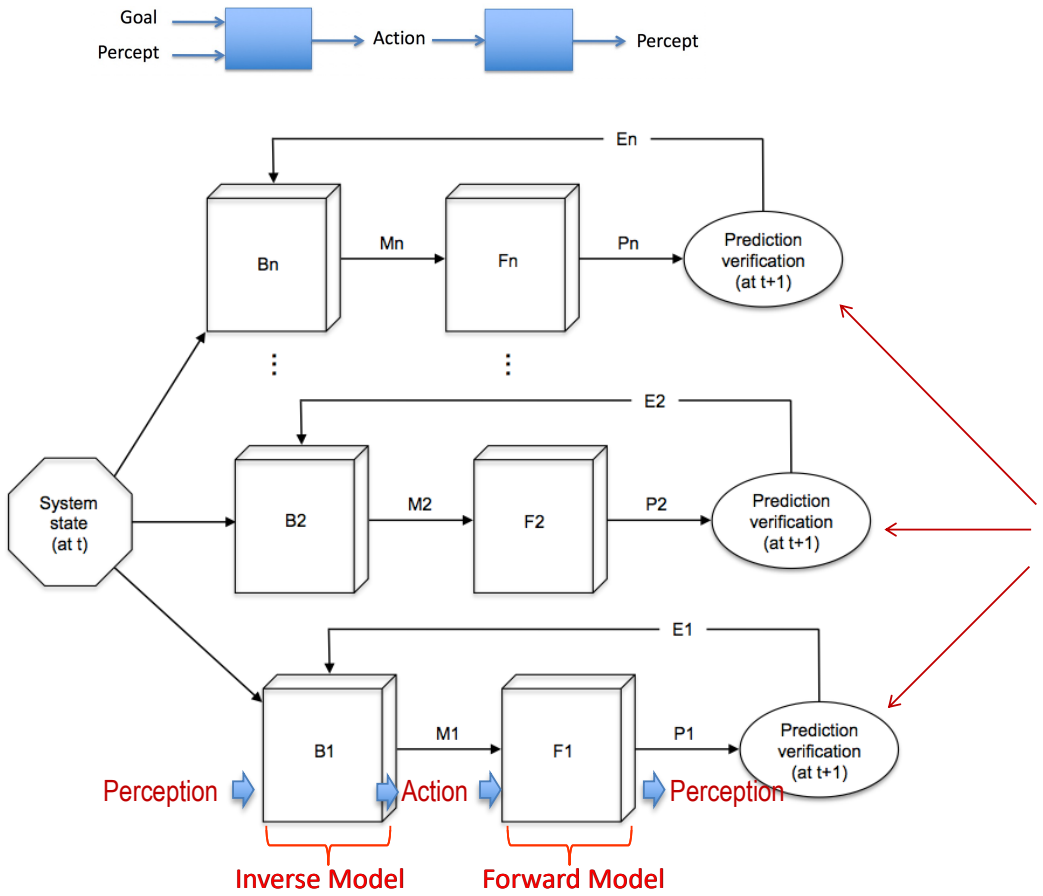
– The inverse model

- Input the current state of the system and the desired goal
- Outputs the motor commands necessary to achieve that goal

– The forward model

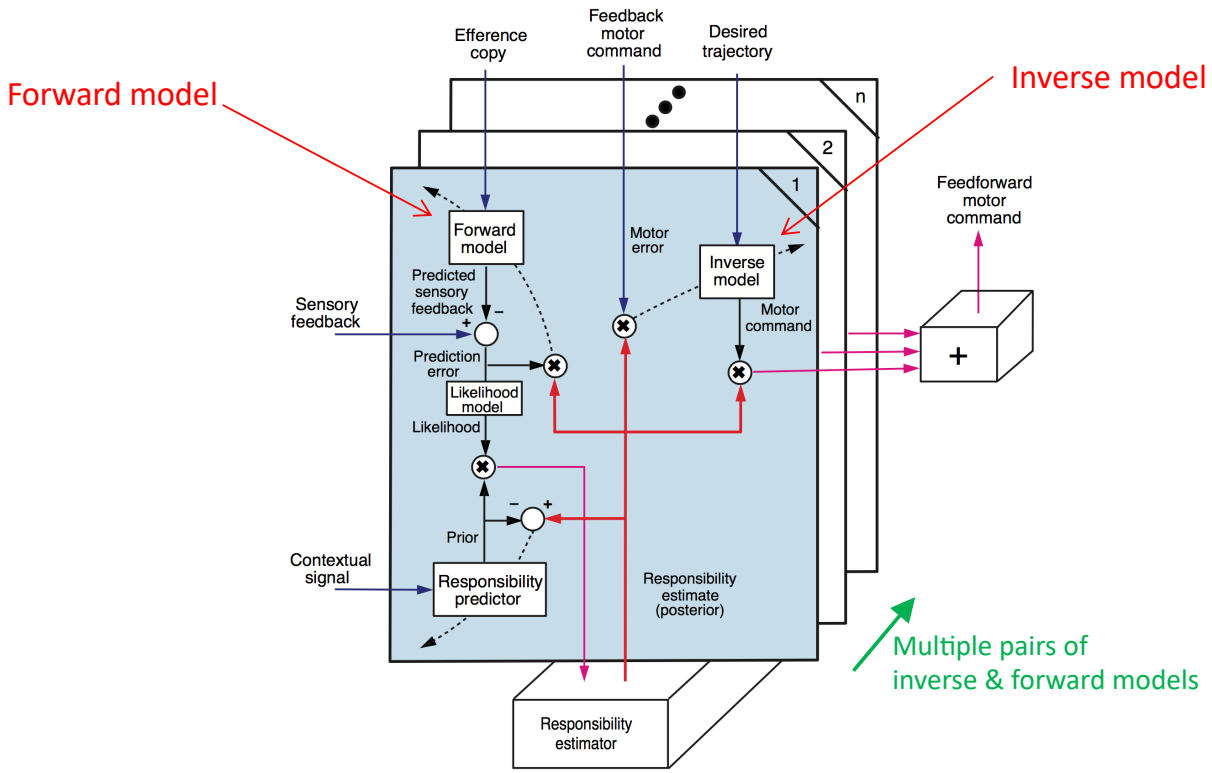
- Input the motor commands
- Output simulated perception that would arise if this motor command were to be executed

Y. Demiris and B. Khadhouri. Hierarchical attentive multiple models for execution and recognition (HAMMER). Robotics and Autonomous Systems, 54:361– 369, 2006.



The choice of inverse/forward model pair is made by **an internal attention process** based on how close the predicted outcome is to the desired one

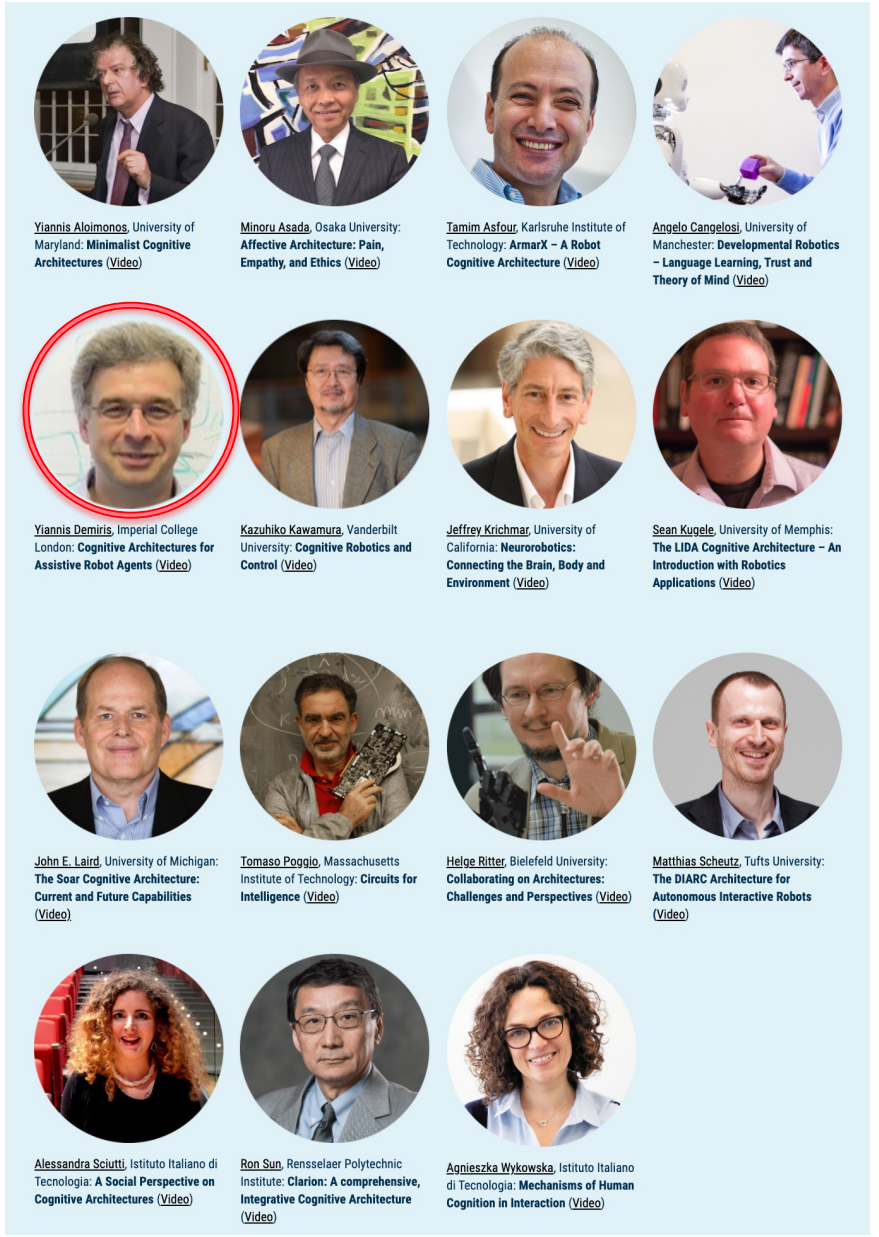
Y. Demiris and B. Khadhouri. Hierarchical attentive multiple models for execution and recognition (HAMMER). Robotics and Autonomous Systems, 54:361– 369, 2006.



D.M. Wolpert, M. Kawato, Multiple paired forward and inverse models for motor control, Neural Networks 11 (1998) 1317–1329.

A short video by Yiannis Demiris on HAMMER can be found at the 2021 TransAIR Workshop on Cognitive Architectures for Robot Agents

https://transair-bridge.org/workshop-2021/



Yiannis Aloimonos, University of Maryland: **Minimalist Cognitive Architectures** (Video)

Minoru Asada, Osaka University: **Affective Architecture: Pain, Empathy, and Ethics** (Video)

Tamim Asfour, Karlsruhe Institute of Technology: **ArmarX – A Robot Cognitive Architecture** (Video)

Angelo Cangelosi, University of Manchester: **Developmental Robotics – Language Learning, Trust and Theory of Mind** (Video)

Yiannis Demiris, Imperial College London: **Cognitive Architectures for Assistive Robot Agents** (Video)

Kazuhiko Kawamura, Vanderbilt University: **Cognitive Robotics and Control** (Video)

Jeffrey Krichmar, University of California: **Neurorobotics: Connecting the Brain, Body and Environment** (Video)

Sean Kugele, University of Memphis: **The LIDA Cognitive Architecture – An Introduction with Robotics Applications** (Video)

John E. Laird, University of Michigan: **The Soar Cognitive Architecture: Current and Future Capabilities** (Video)

Tomaso Poggio, Massachusetts Institute of Technology: **Circuits for Intelligence** (Video)

Helge Ritter, Bielefeld University: **Collaborating on Architectures: Challenges and Perspectives** (Video)

Matthias Scheutz, Tufts University: **The DIARC Architecture for Autonomous Interactive Robots** (Video)

Alessandra Sciutti, Istituto Italiano di Tecnologia: **A Social Perspective on Cognitive Architectures** (Video)

Ron Sun, Rensselaer Polytechnic Institute: **Clarion: A comprehensive, Integrative Cognitive Architecture** (Video)

Agnieszka Wykowska, Istituto Italiano di Tecnologia: **Mechanisms of Human Cognition in Interaction** (Video)

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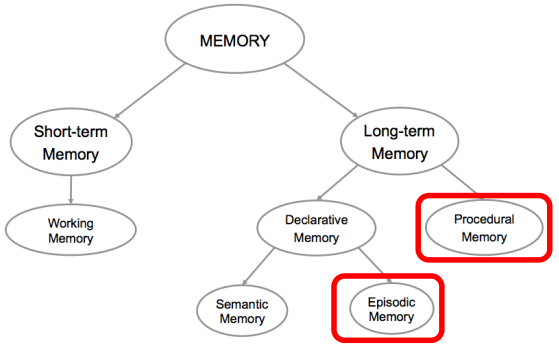
Situation Model Framework

Internal Simulation &
Episodic and Procedural Memory



Internal Attention

Working Memory

Meta-cognition

Two-system Approach

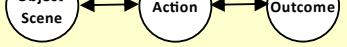
Novel Construction

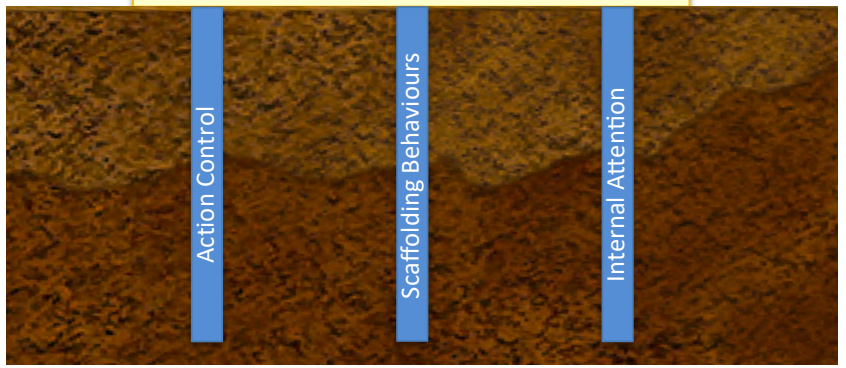
Internal Simulation

Refinement

Cognitive Map

Behavioral Episodes





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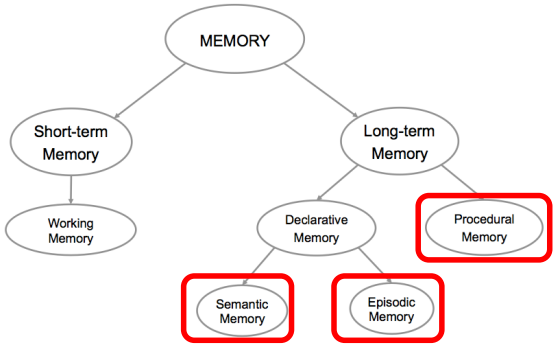
Episodic memory and episodic future thinking can be modulated by semantic memory

D. L. Schacter, D. R. Addis, D. Hassabis, V. C. Martin, R. N. Spreng, and K. K. Szpunar, “The future of memory: Remembering, imagining, and the brain,” Neuron, vol. 76, pp. 677–694, 2012.

Situation Model Framework

Internal Simulation &
Episodic and Procedural Memory



Internal Attention

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Internal Simulation

Refinement

Cognitive Map

Behavioral Episodes

Object Scene → Action → Outcome

Action Control

Scaffolding Behaviours

Internal Attention

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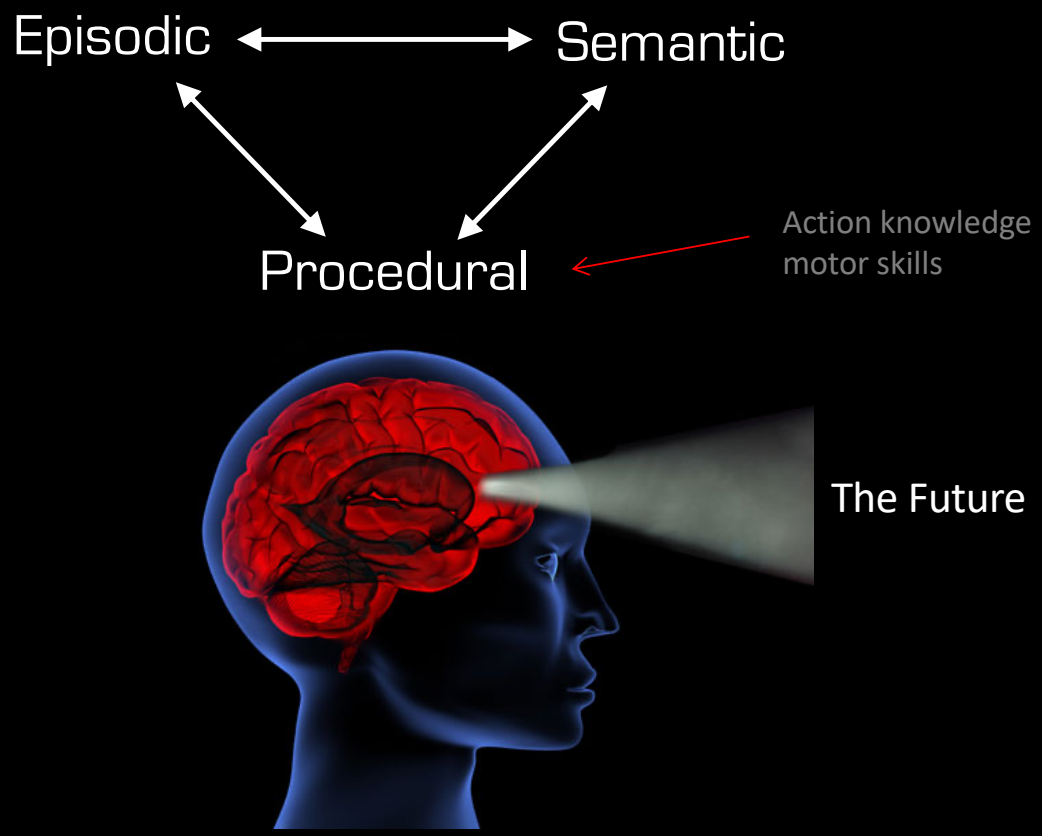
Episodic ⟷ Semantic

General knowledge
about the agent's world

The Future

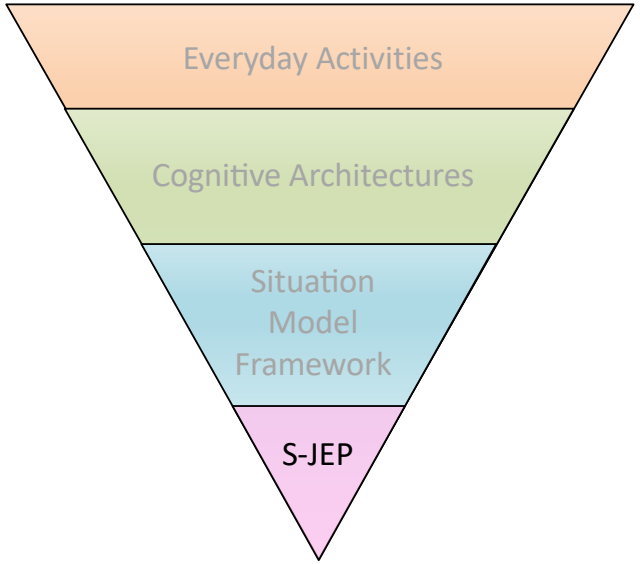
K. K. Szpunar, R. N. Spreng, and D. L. Schacter, A taxonomy of prospection: introducing an organizational framework for future-oriented cognition, PNAS 111(52), 18414–18421, 2014.



K. K. Szpunar, R. N. Spreng, and D. L. Schacter, A taxonomy of prospection: introducing an organizational framework for future-oriented cognition, PNAS 111(52), 18414–18421, 2014.

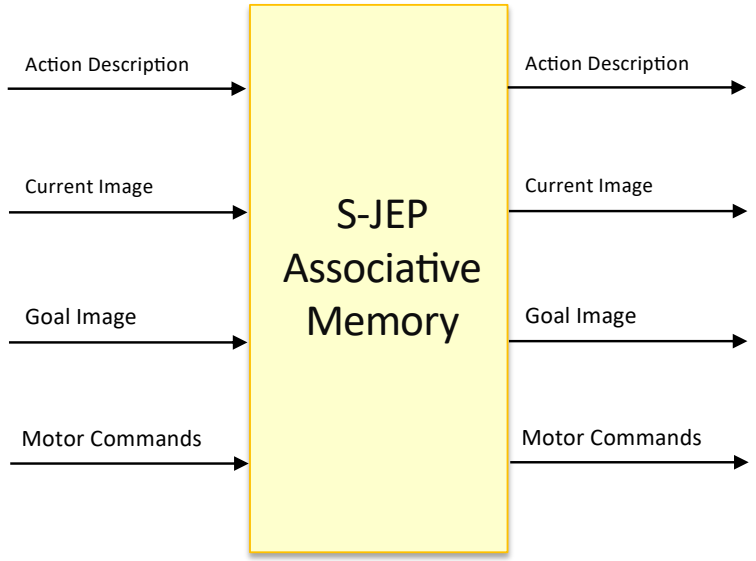
Overview

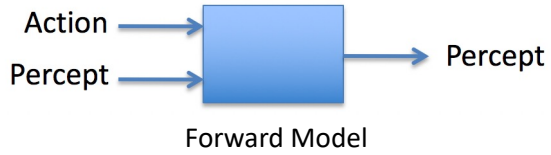
1. Everyday activities: easy & difficult vs. simple vs complex
2. Cognitive Architectures
   - Introduction to cognitive architectures
   - CRAM
   - Extending CRAM
3. The Situation Model Framework (SMF)
   - Behavioral episodes
   - Two-system approach
4. Semantically-Modulated Joint Episodic-Procedural Memory (S-JEP)

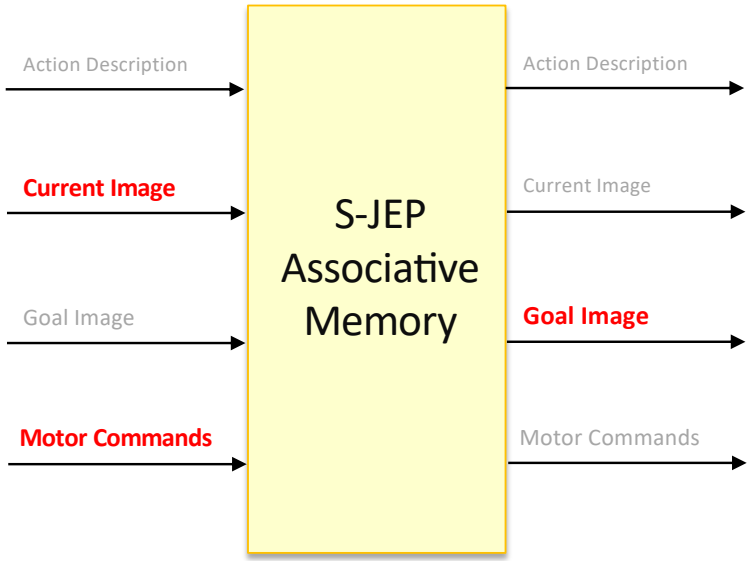


Joint Episodic-Procedural Memory

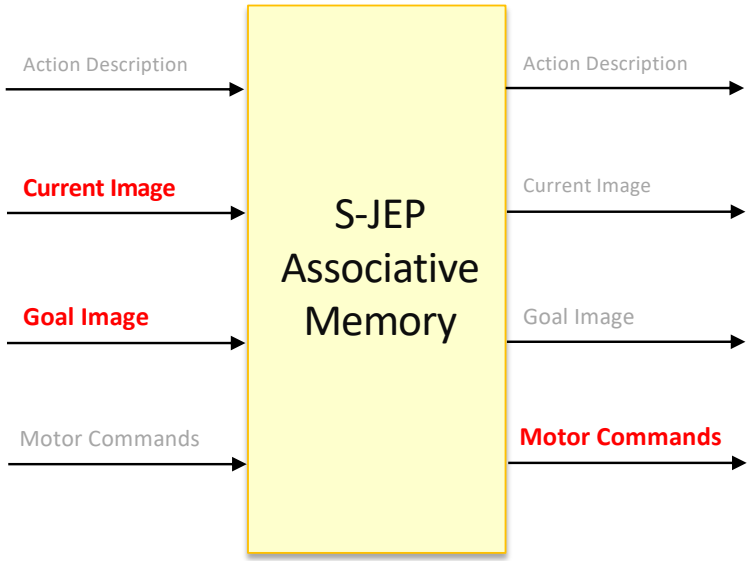
Multimodal Hetero-associative Memory

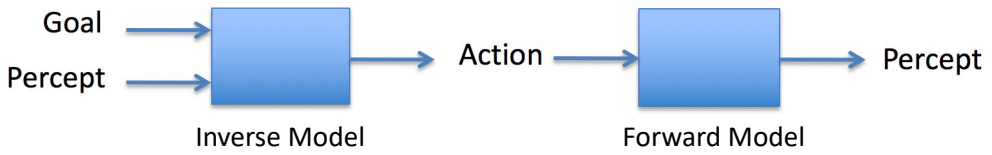



Action
Percept
Percept
Forward Model

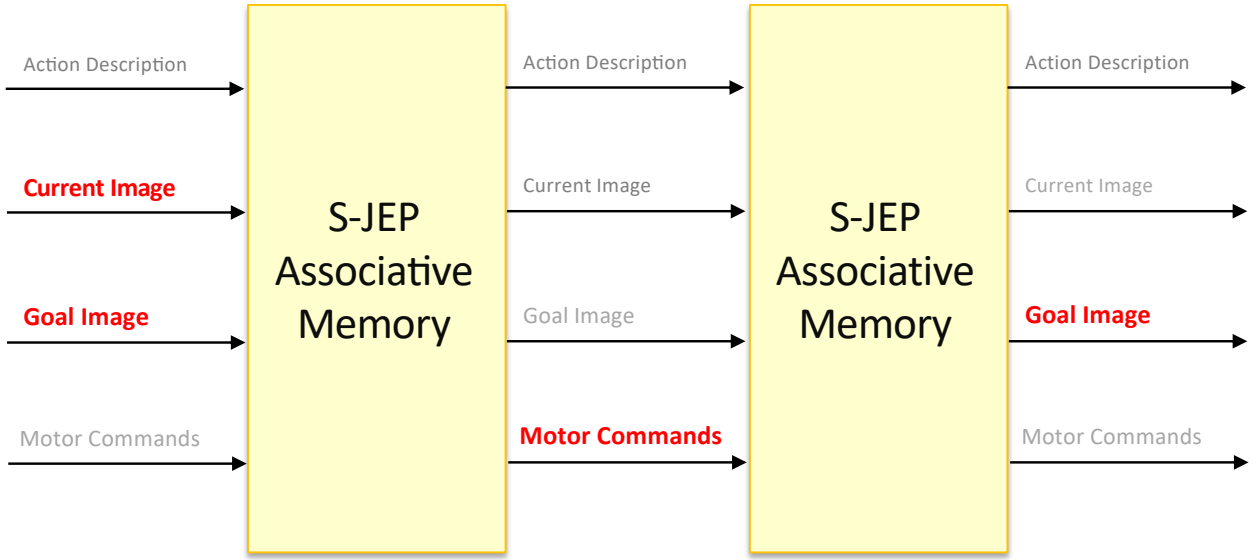

Action Description
Current Image
Goal Image
Motor Commands
S-JEP
Associative
Memory
Action Description
Current Image
Goal Image
Motor Commands

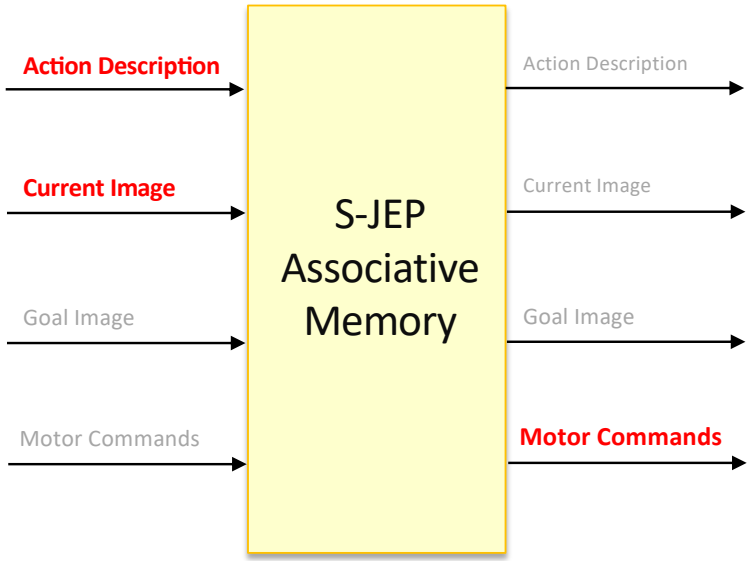
Inverse Model

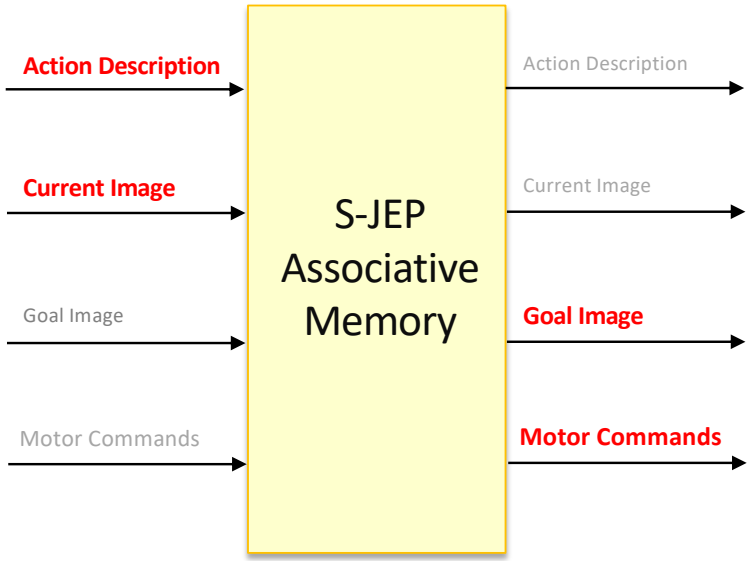




Y. Demiris
M. Shanahan
G. Hesslow
D. Wolpert
...




Action Description
Current Image
Goal Image
Motor Commands
S-JEP
Associative
Memory
Action Description
Current Image
Goal Image
Motor Commands


Action Description
Current Image
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Associative
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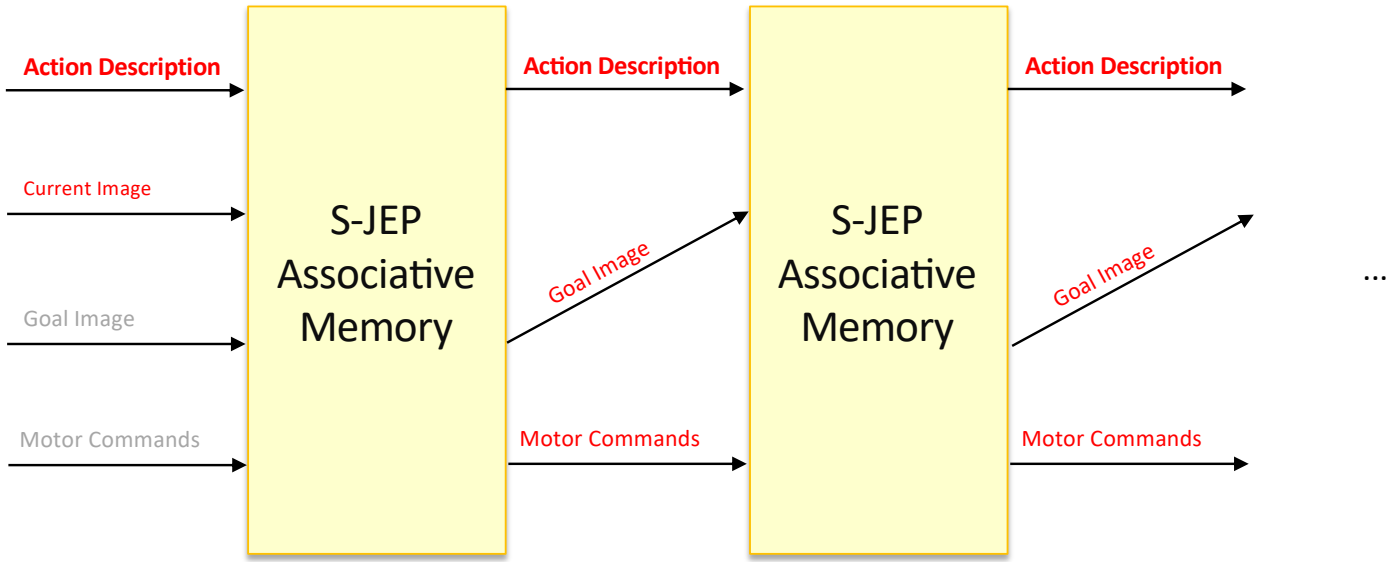
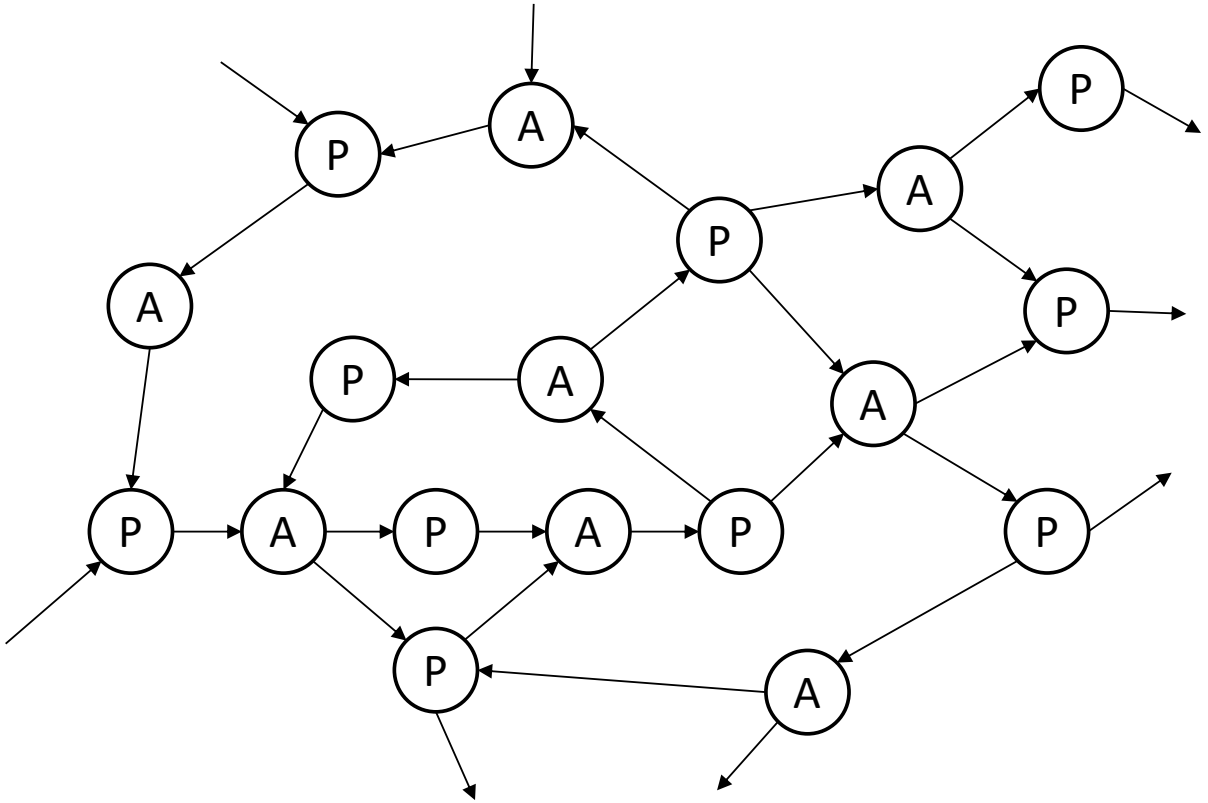
Action Description
Current Image
Goal Image
Motor Commands


Action Description
Current Image
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Goal Image
Motor Commands
...

Joint Episodic-Procedural Memory



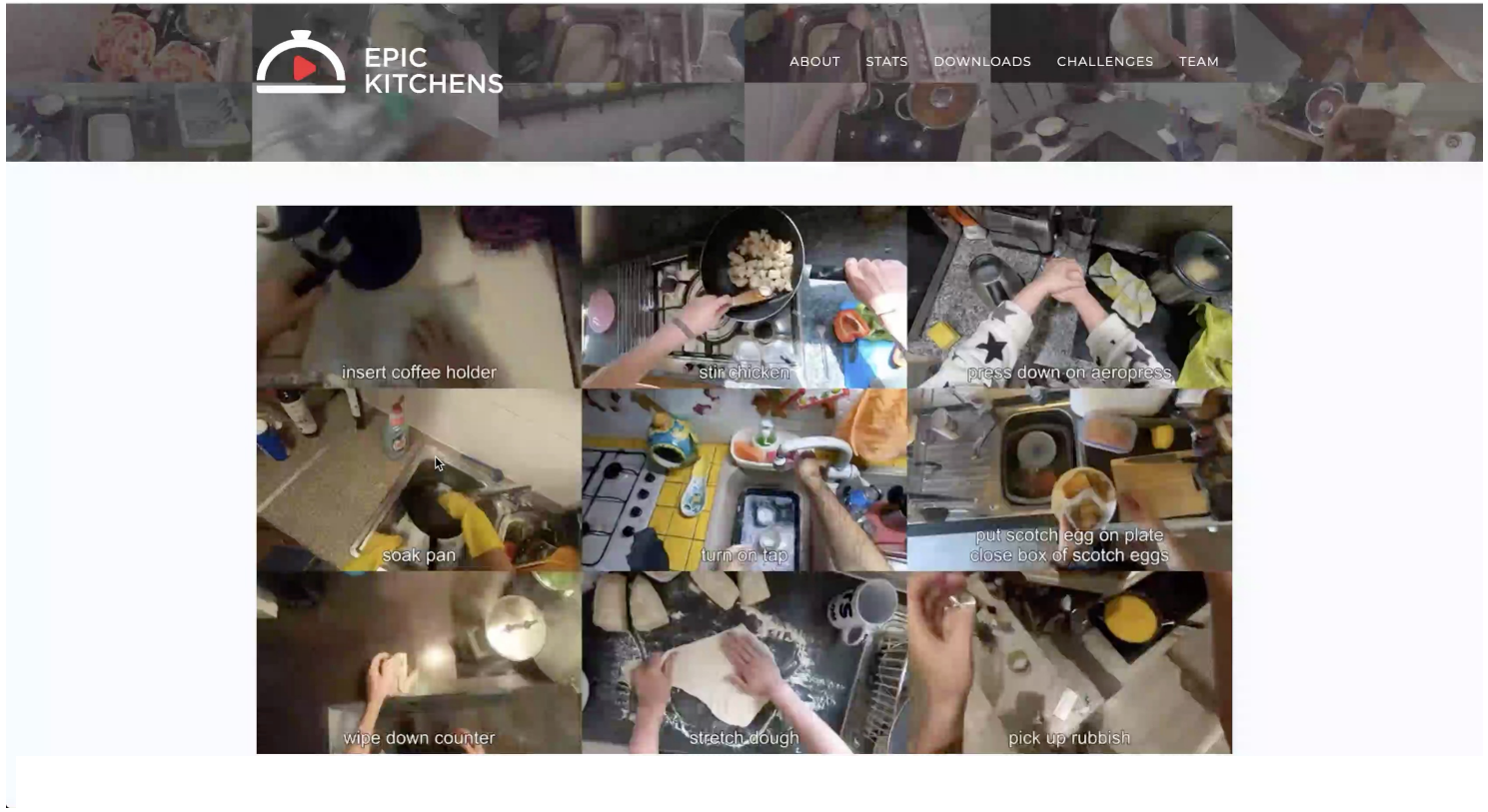
D. Vernon, M. Beetz, and G. Sandini. Prospection in cognitive robotics: The case for joint episodic-procedural memory. Frontiers in Robotics and AI, 2 (Article 19):1–14, 2015.

Candidate Training Data Sets

Candidate Training Data Sets

Epic kitchens data set

https://epic-kitchens.github.io/2022



Candidate Training Data Sets

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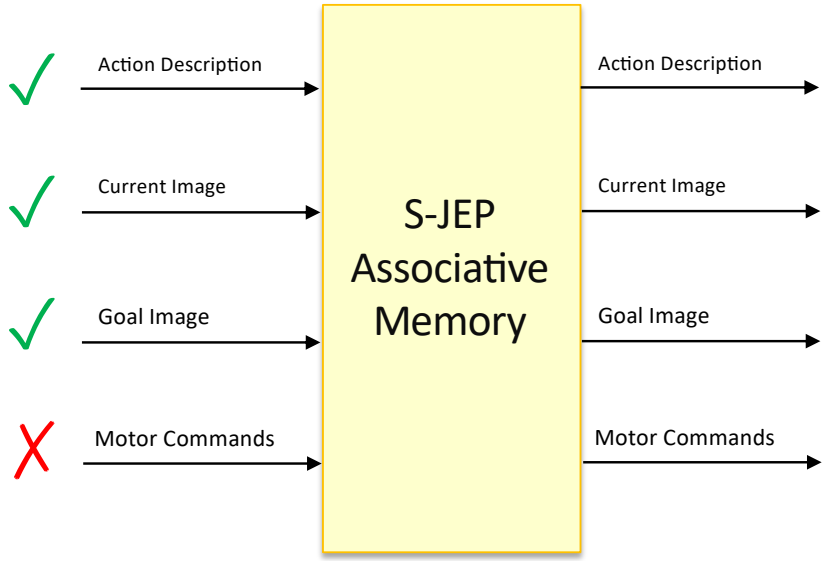


Candidate Training Data Sets

Epic kitchens data set

https://epic-kitchens.github.io/2022

Something-something data set

https://paperswithcode.com/dataset/something-something-v2

Something-Something V2 (20BN-Something-Something Dataset V2)

Edit

Introduced by Goyal et al. in The "something something" video database for learning and evaluating visual common sense

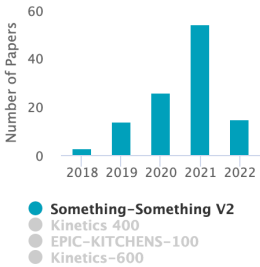
The 20BN-SOMETHING-SOMETHING V2 dataset is a large collection of labeled video clips that show humans performing pre-defined basic actions with everyday objects. The dataset was created by a large number of crowd workers. It allows machine learning models to develop fine-grained understanding of basic actions that occur in the physical world. It contains 220,847 videos, with 168,913 in the training set, 24,777 in the validation set and 27,157 in the test set. There are 174 labels.

Source

Image Source

Homepage

Usage



Benchmarks

Edit

Trend	Task	Dataset Variant	Best Model	Paper	Code
	Action Recognition	Something-Something V2	VideoMAE		
	General Action Video Anomaly Detection	Something-Something V2	Pooled Image Level kNN		
	Video Classification	Something-Something V2	MSNet-R50En		

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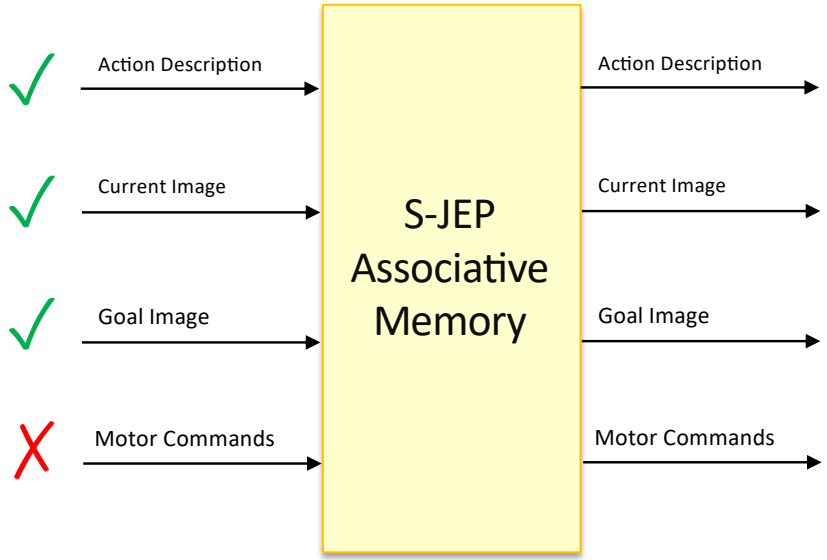

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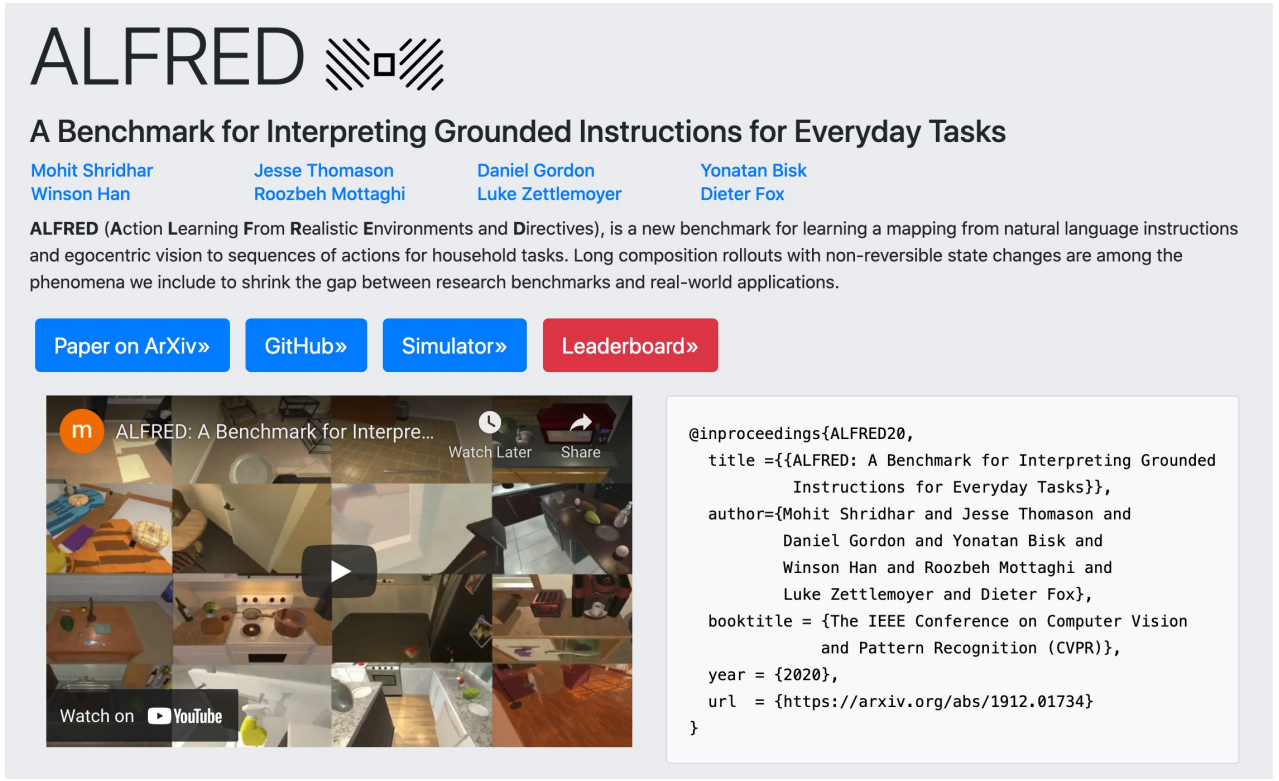
Alfred data set

https://askforalfred.com/



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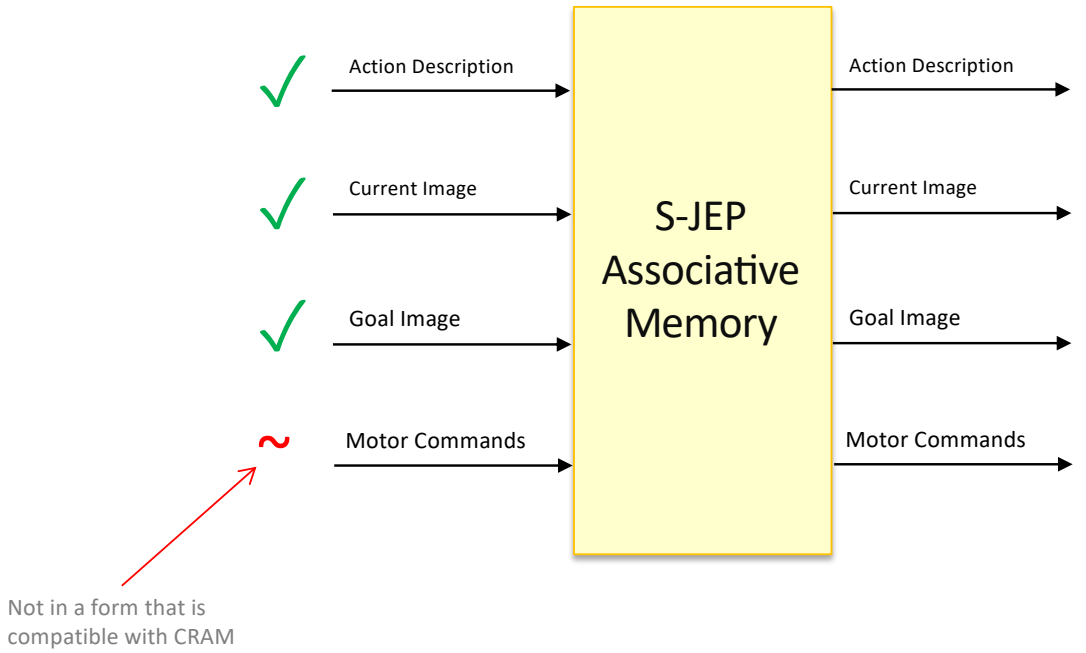
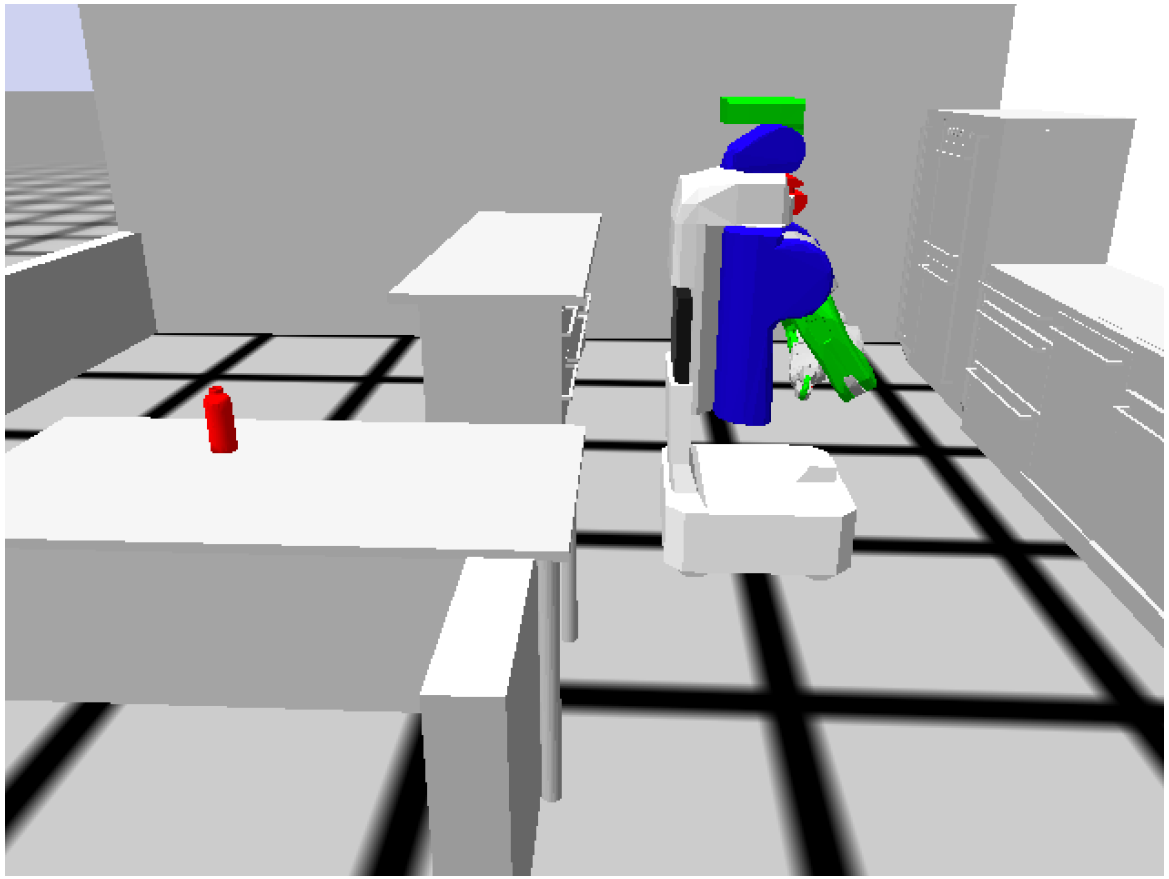
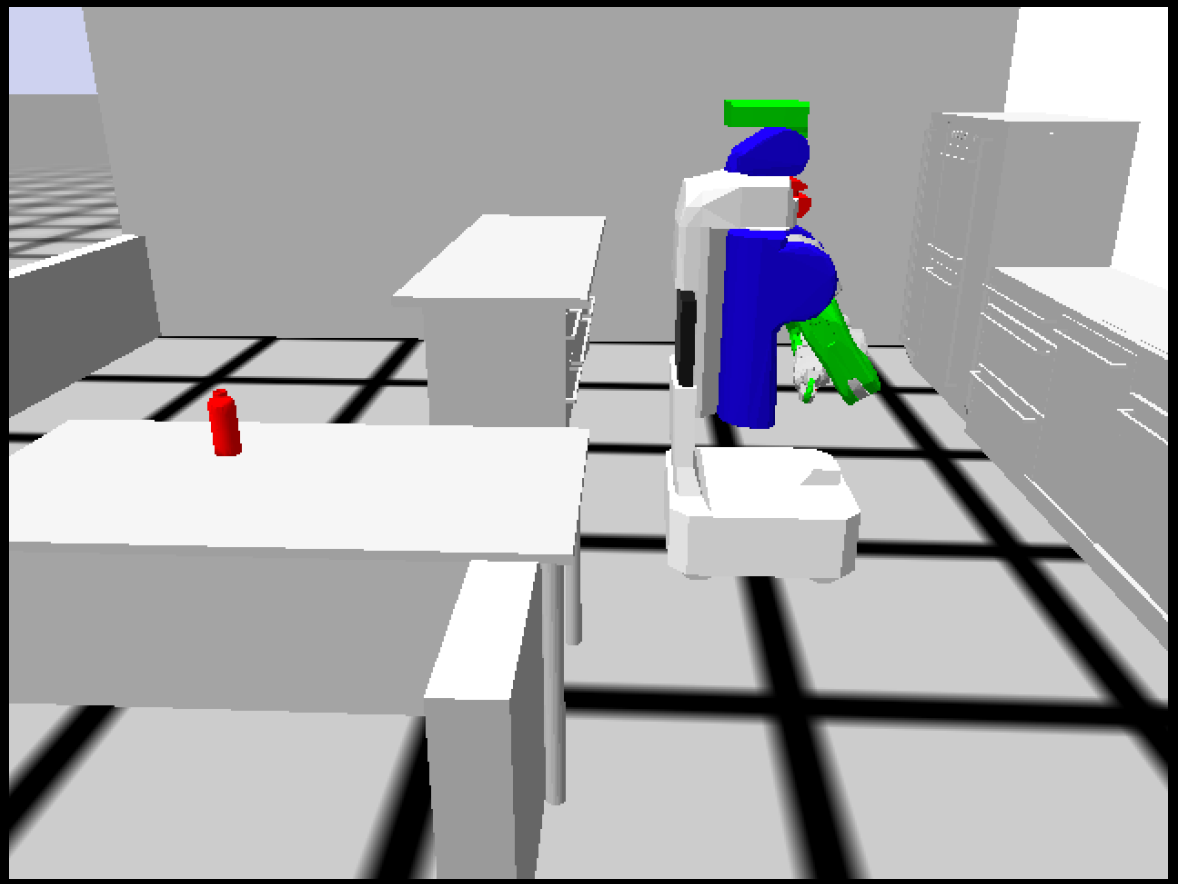


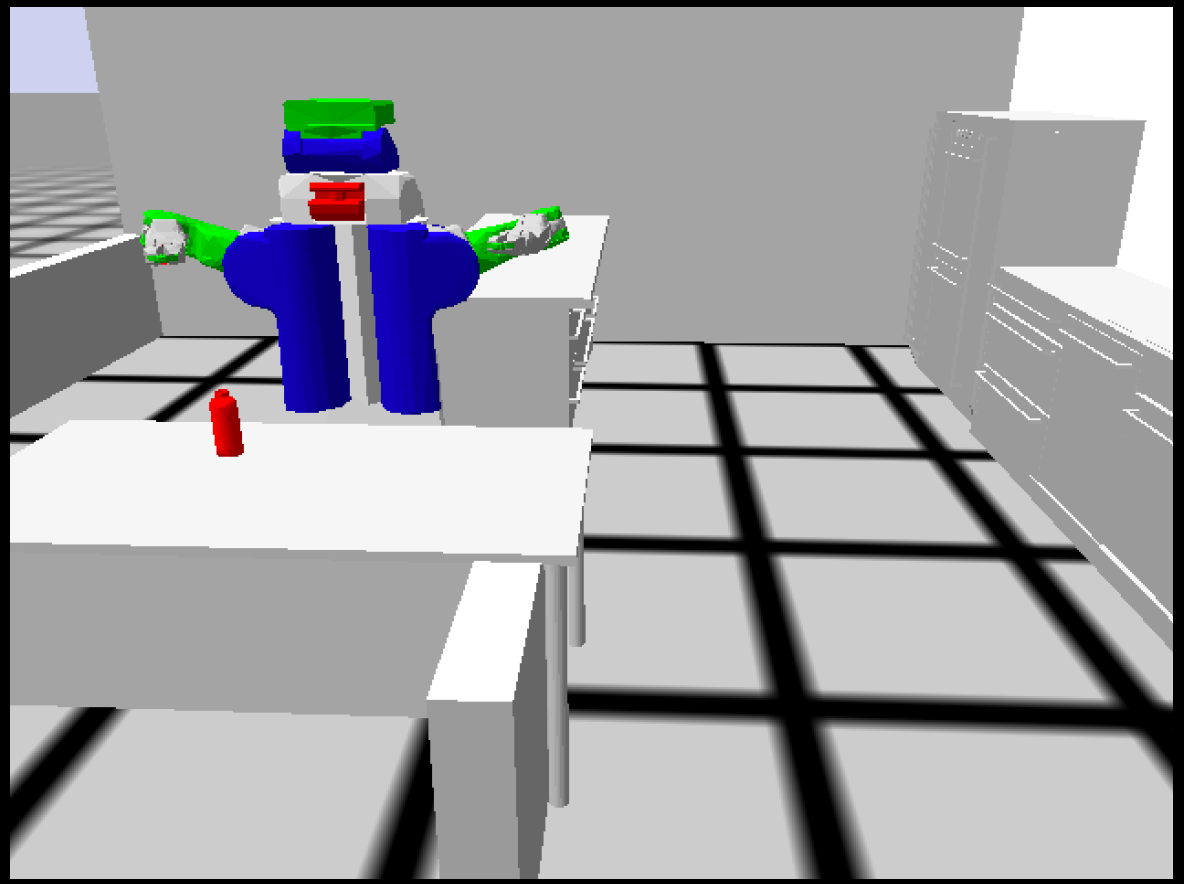
Simulation in the Bullet World

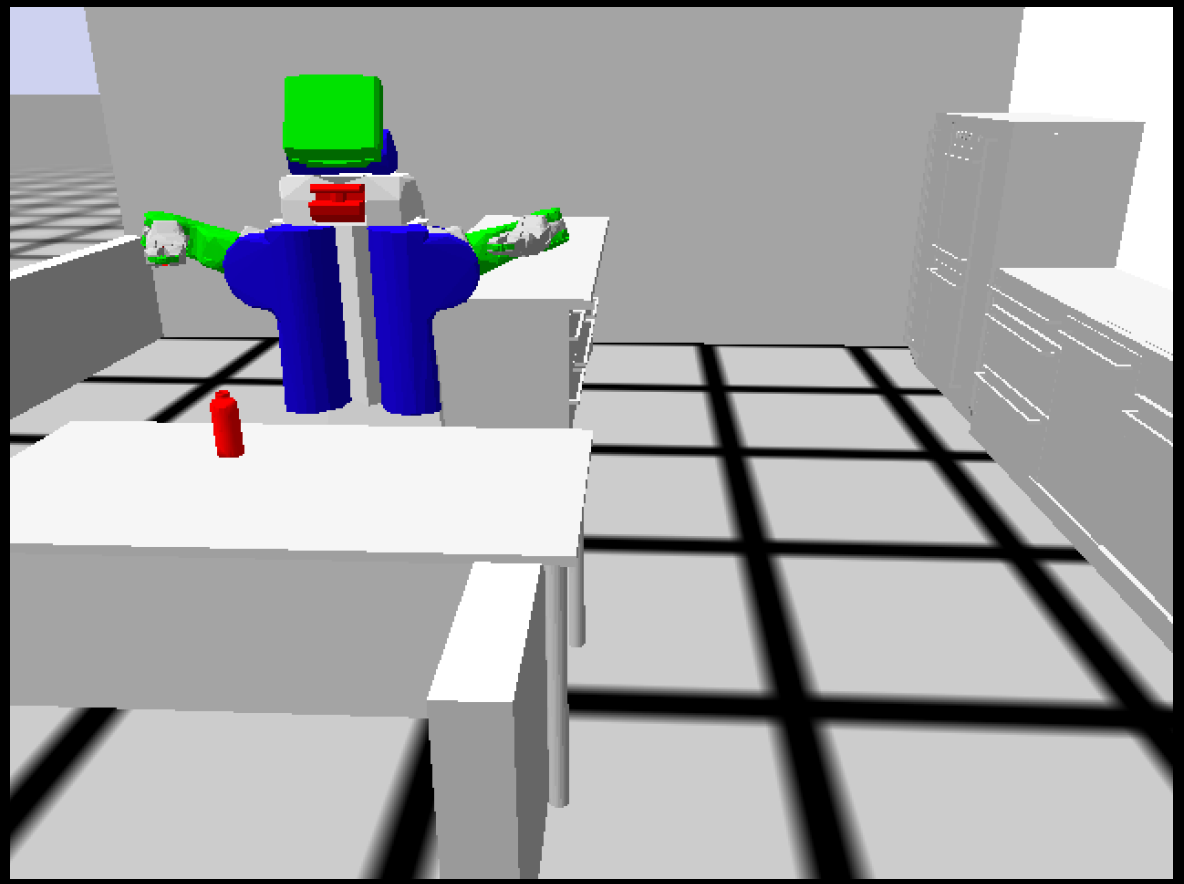


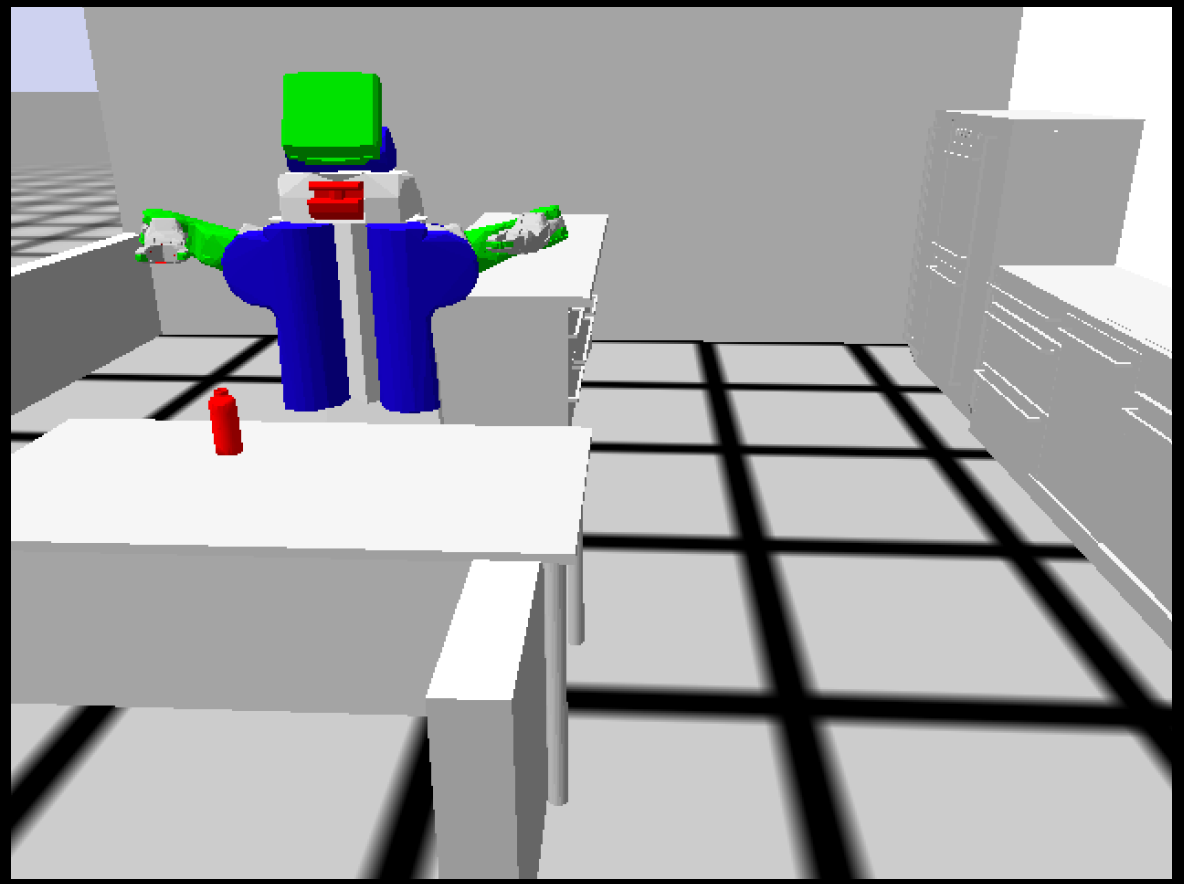
```
(defun move-bottle (bottle-spawn-pose)
  (spawn-object bottle-spawn-pose)
  (with-simulated-robot
    (let ((?navigation-goal *base-pose-near-table*))
      (cpl:par
        ;; Moving the robot near the table.
        (perform (an action
                     (type going)
                     (target (a location
                                 (pose ?navigation-goal)))))
        (perform (a motion
                    (type moving-torso)
                    (joint-angle 0.3)))
        (park-arms)))
    ;; Looking towards the bottle before perceiving.
    (let ((?looking-direction *downward-look-coordinate*))
      (perform (an action
                   (type looking)
                   (target (a location
                               (pose ?looking-direction))))))
    ;; Detect the bottle on the table.
    (let ((?grasping-arm :right)
          (?perceived-bottle (perform (an action
                                          (type detecting)
                                          (object (an object
                                                      (type bottle)))))))
      ;; Pick up the bottle
      (perform (an action
                   (type picking-up)
                   (arm ?grasping-arm)
                   (grasp left-side)
                   (object ?perceived-bottle)))
      (park-arm ?grasping-arm)
      ;; Moving the robot near the counter.
      (let ((?nav-goal *base-pose-near-counter*))
        (perform (an action
                     (type going)
                     (target (a location
                                 (pose ?nav-goal))))))
      ;; Setting the bottle down on the counter
      (let ((?drop-pose *final-object-destination*))
        (perform (an action
                     (type placing)
                     (arm ?grasping-arm)
                     (object ?perceived-bottle)
                     (target (a location
                                 (pose ?drop-pose))))))
      (park-arm ?grasping-arm))))
```

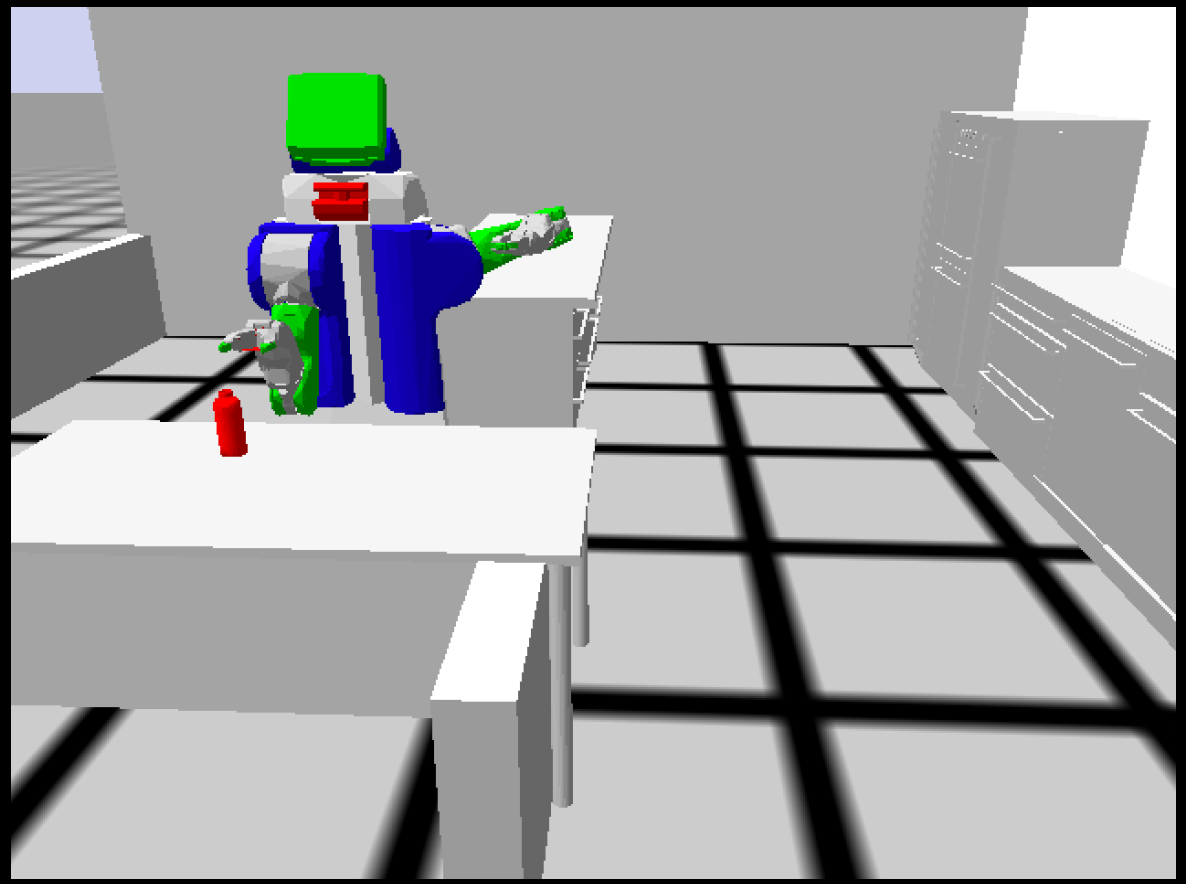
CRAM Plan to fetch and place a bottle

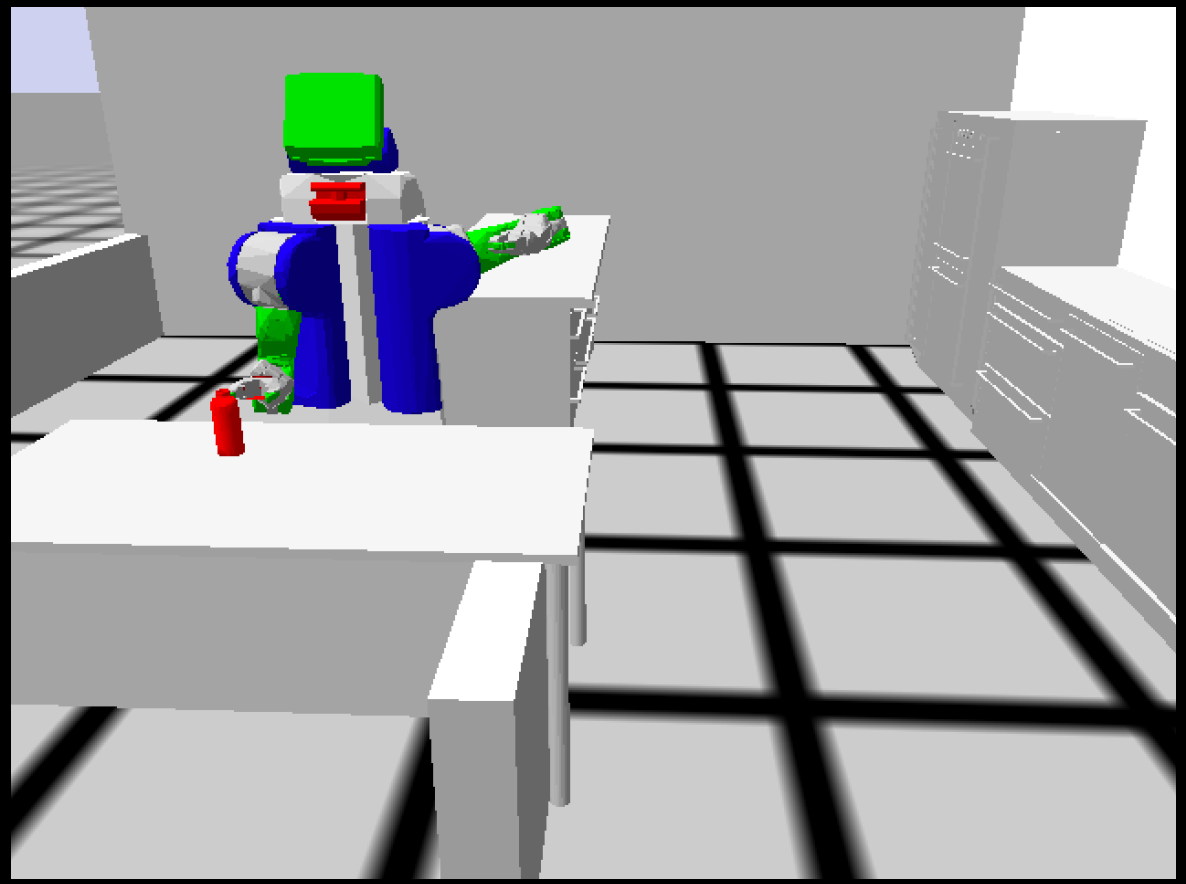


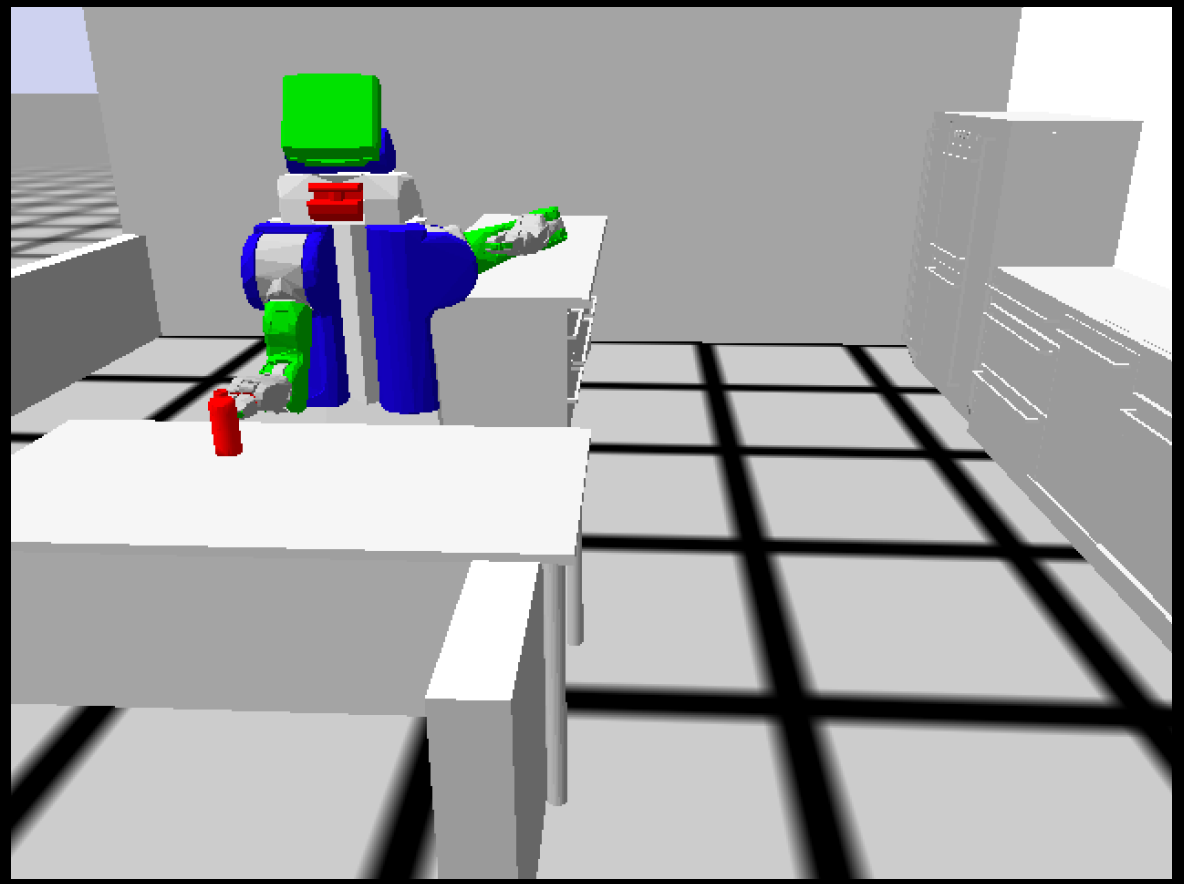


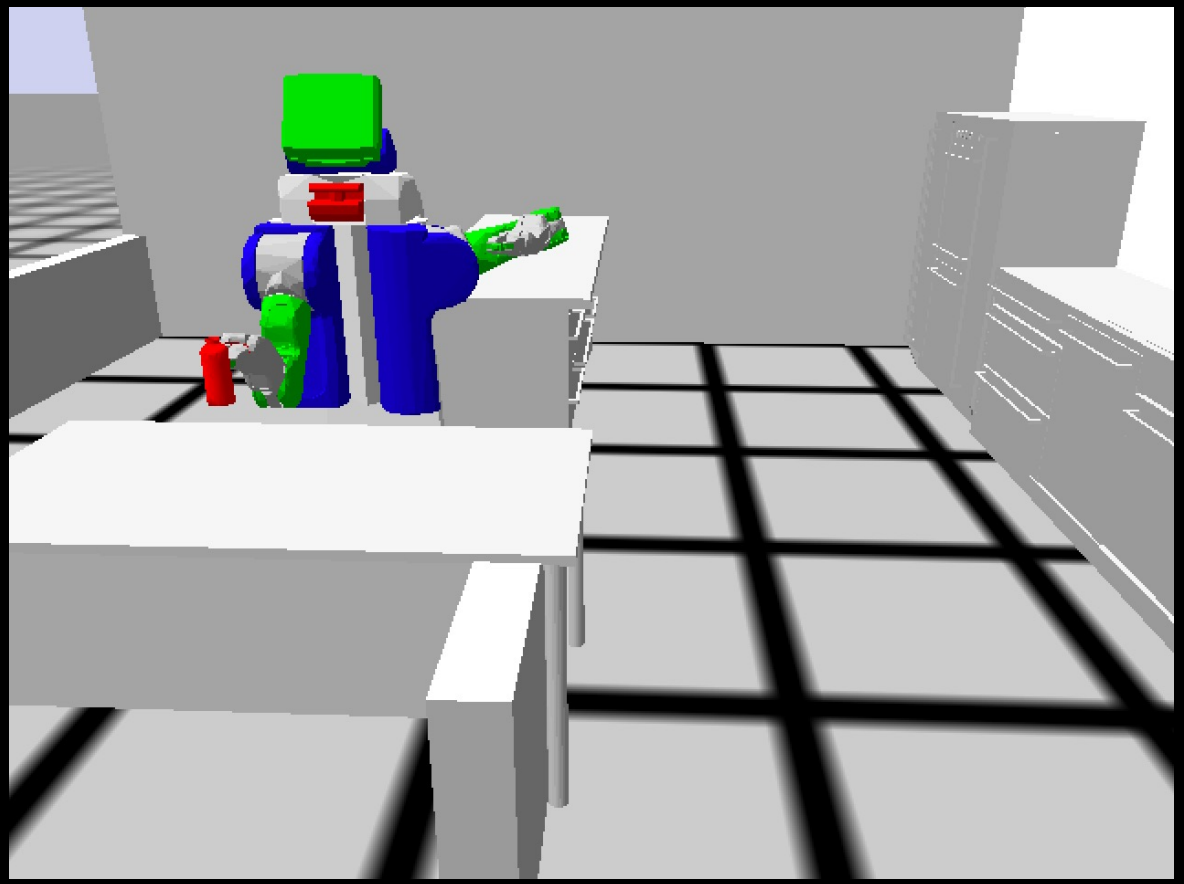


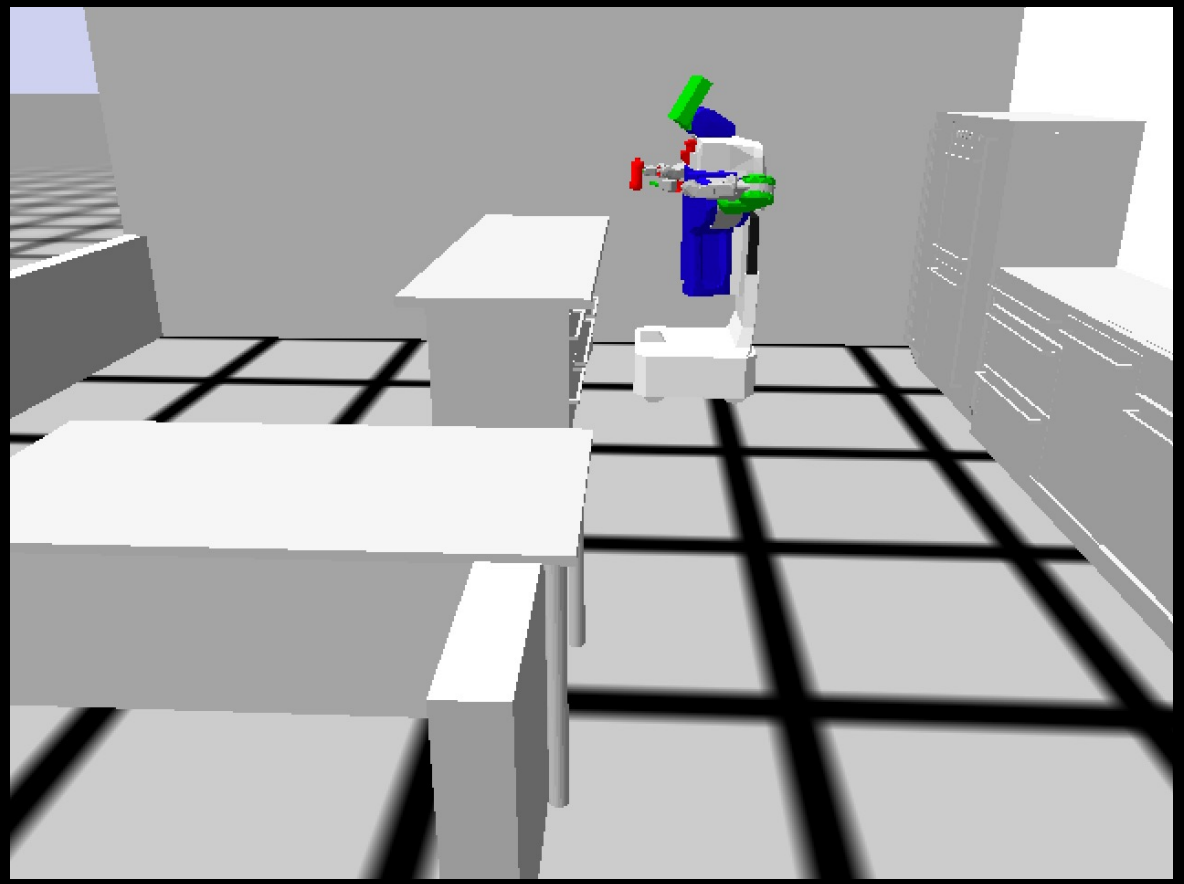


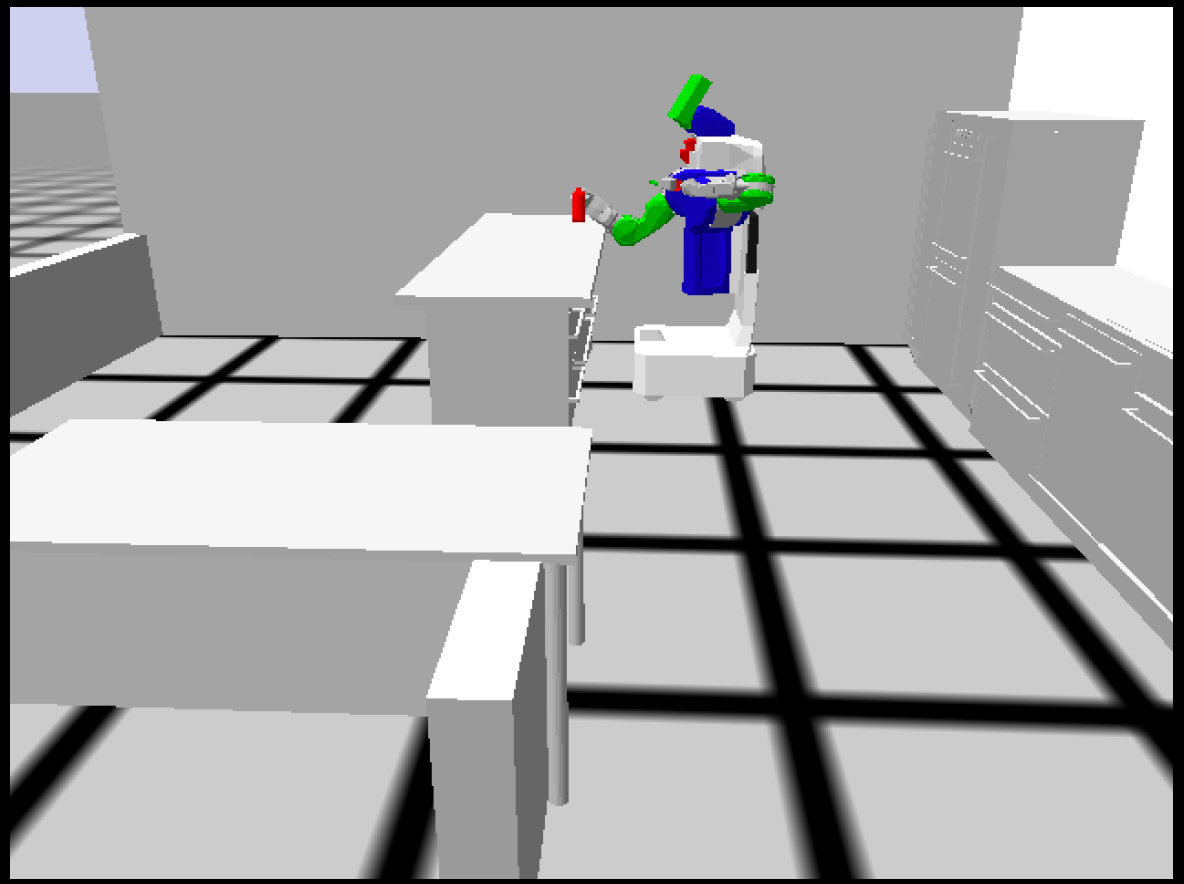


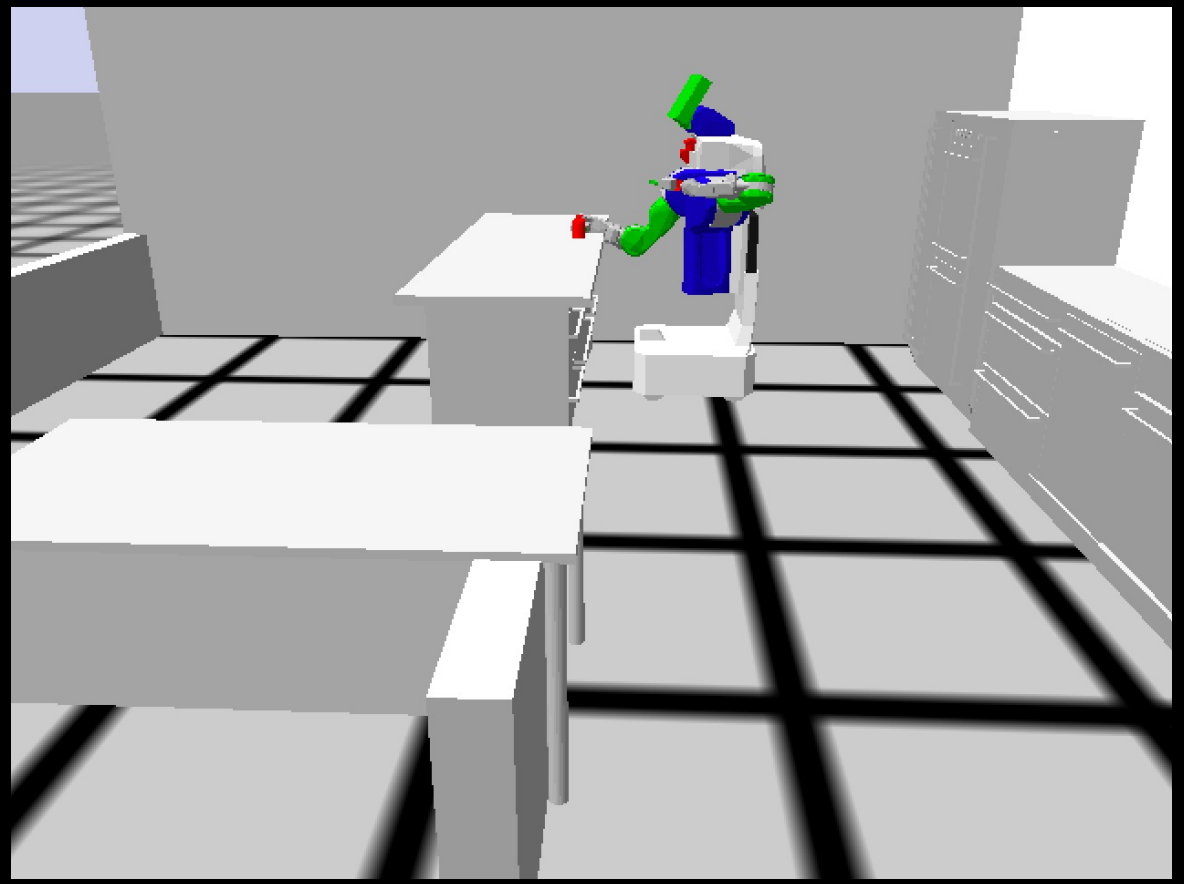


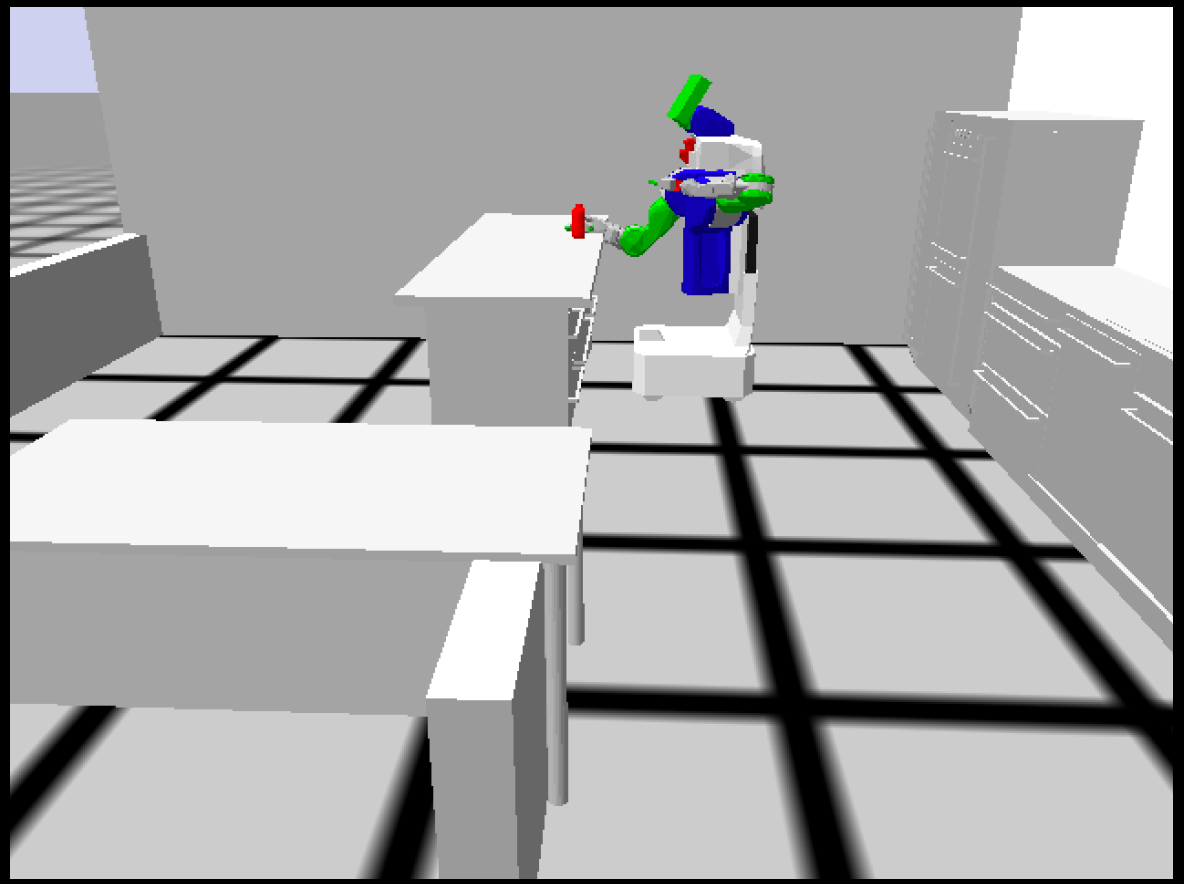


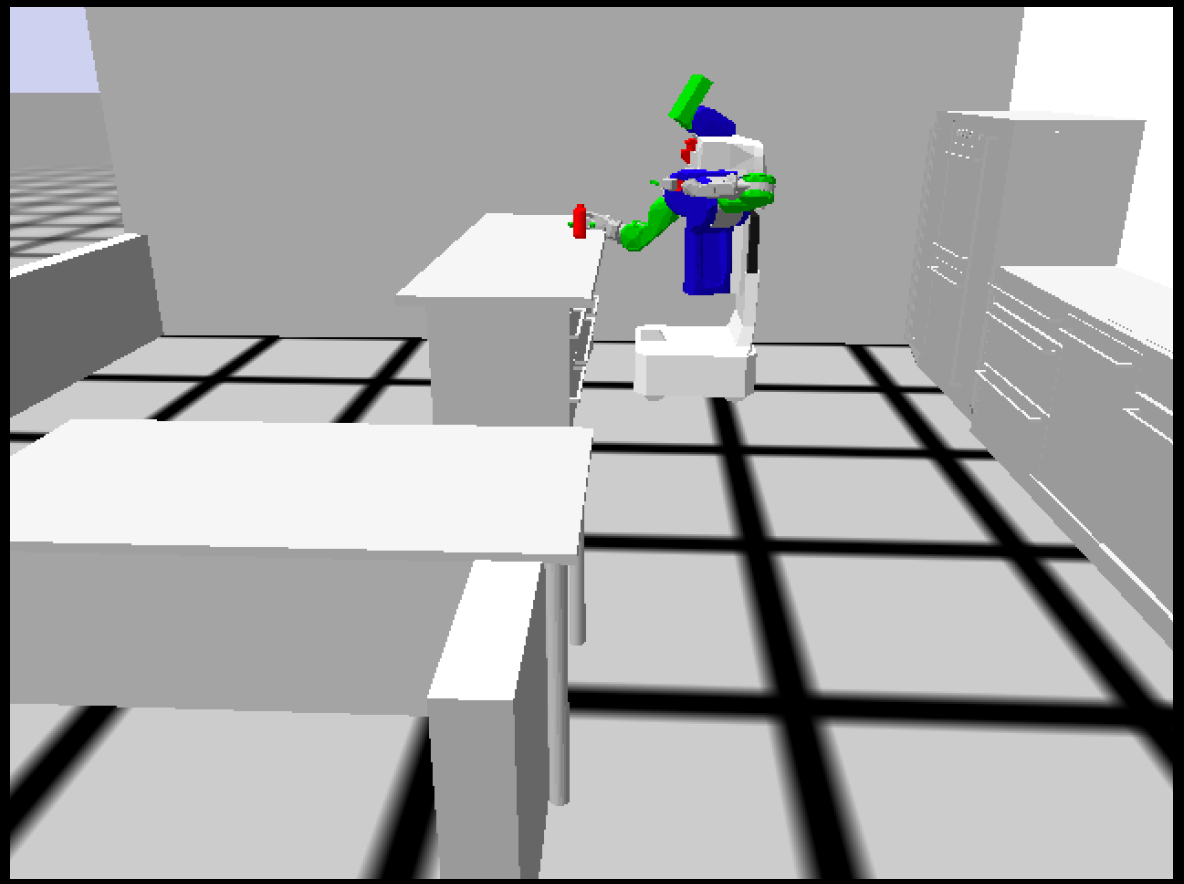


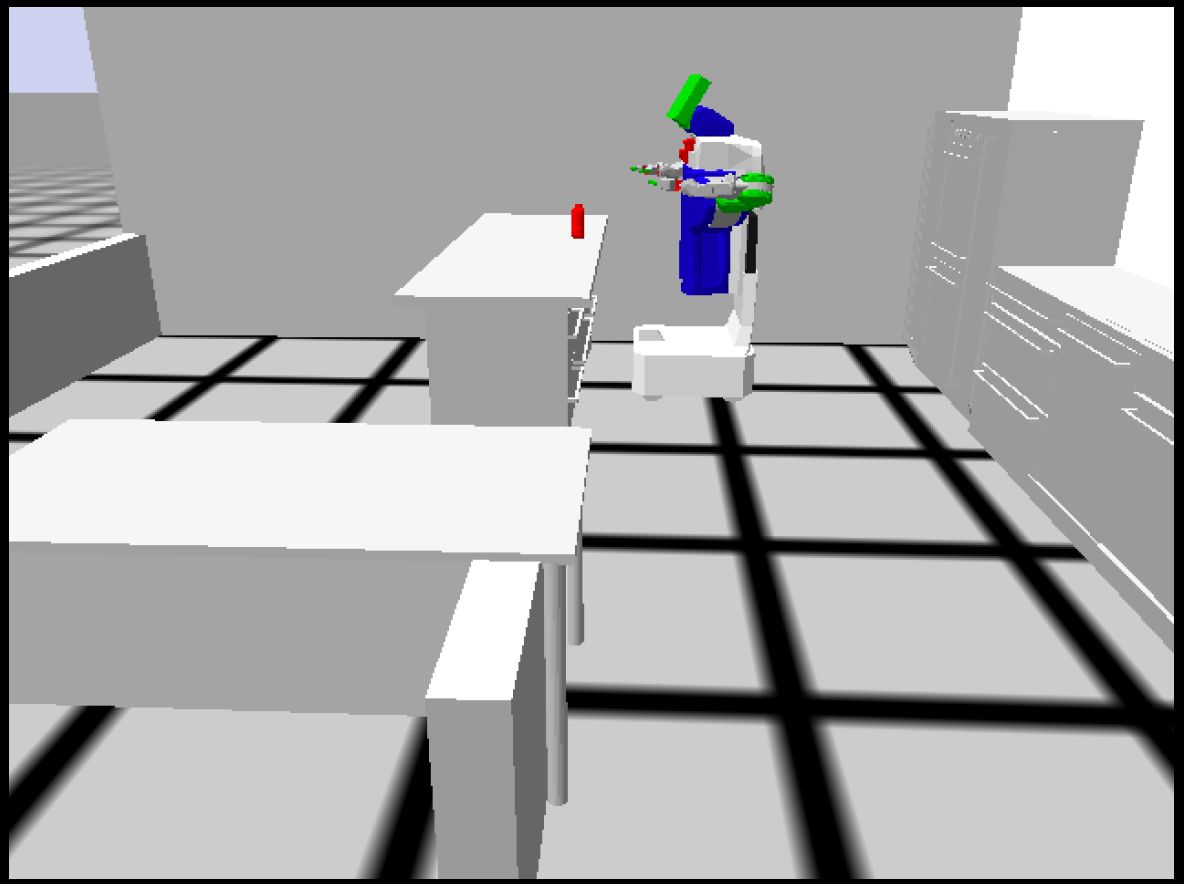






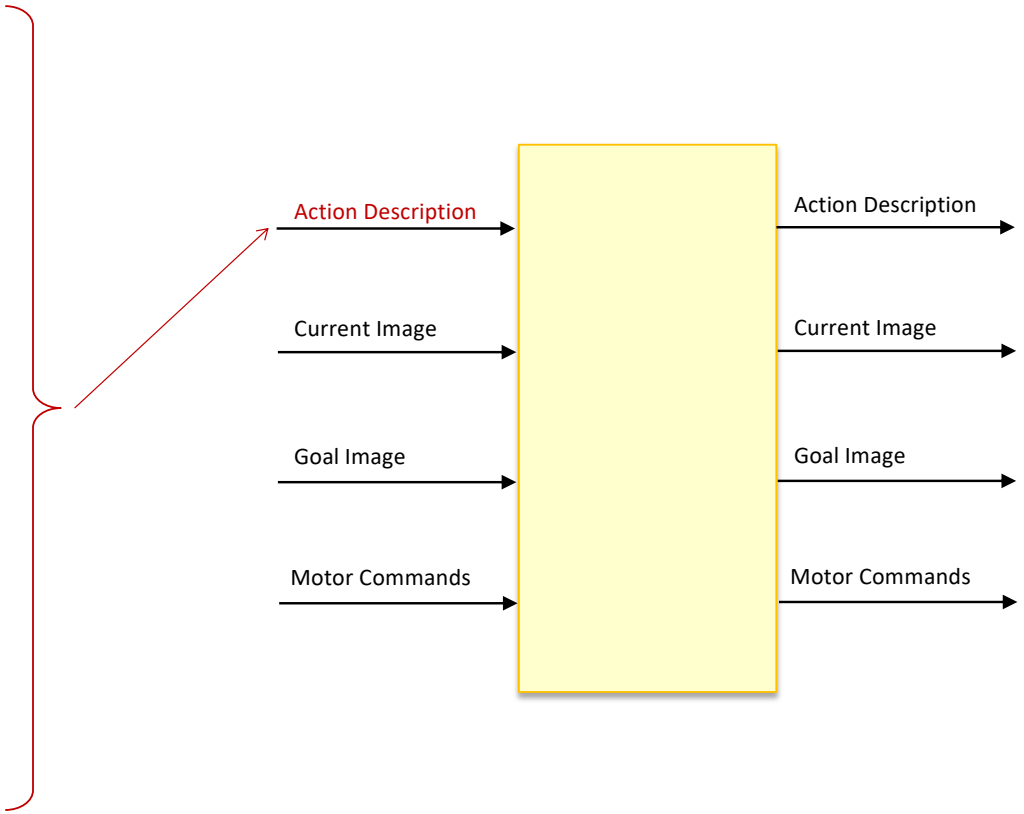






<action_description> ::= <transport_phrase>|<reposition_phrase>
<transport_phrase > ::= <transport_verb><noun_phrase><preposition_phrase><noun_phrase >
<reposition_phrase > ::= <reposition_verb><noun_phrase ><adverb_phrase>
<noun_phrase> ::= <article>{<adjective>} <object>
<transport_verb > ::= “put”
<reposition_verb > ::= “move” | “shift”
<article > ::= “a” | “an” | “the”
<preposition_phrase> ::= “behind” | “beside” | “in” | “in front of” | “on” | “on top of” | “to the left of” | “to the right of”
<adverb_phrase> ::= “backwards” | “forwards” | “left” | “right”
<object> ::= “bottle” | “bowl” | “cereal” | “cup” | “fork” | “knife” | “milk” | “plate”
<adjective> ::= “blue” | “green” | “red”

“Put the red bottle behind the plate”
“Put the fork beside the plate”
“Put the cup in front of the cereal”
“Put the bowl on the red plate”
“Move the bottle left”
“Move the cup backwards”
“Shift the fork right”



<motor_program> ::= “(motor-program `(”{<object_specification>} “)”
<object_type><transformation><object_type>“)”
<object_specification> ::= “(” <object_type><object_color><object_pose>“)”
<object_type> ::= “:bottle” | “:bowl” | “:cereal” | “:cup” | “:fork’’ | “:knife” | “:milk” | “:plate”
<object_pose> ::= “,*pose-1*” | “,*pose-2*” | “,*pose-3*” | “,*pose-4*” | “,*pose-5*”
<object_color> ::= “red” | “blue” | “green” | “default_color’’
<transformation> ::= “#'*backward-transformation*” | #'*forward-transformation*’ | “#'*leftward-transformation*’ | “#'*rightward-transformation*’ | “#'*on-transformation*”

This grammar generates a syntactically-correct CPL function call but only the keywords are used when training the JEPS memory (the function call is generated after recalling the keywords)

“Put the red bottle behind the plate” →
```
:bottle red *pose-1* plate default_color *pose-2* :bottle #'*backward-transformation* :plate
```

“Put the fork beside the plate” →
```
:fork default_color *pose-1* :plate default_color *pose-2* :fork *leftward-transformation* :plate)
```

“Put the cup in front of the cereal” →
```
:cup default_color *pose-1* :cereal default_color *pose-2* :cup *forward-transformation* :cereal
```

“Put the bowl on the red plate” →
```
:bowl default_color *pose-1* :plate red ,*pose-2* :bowl *on-transformation* :plate
```

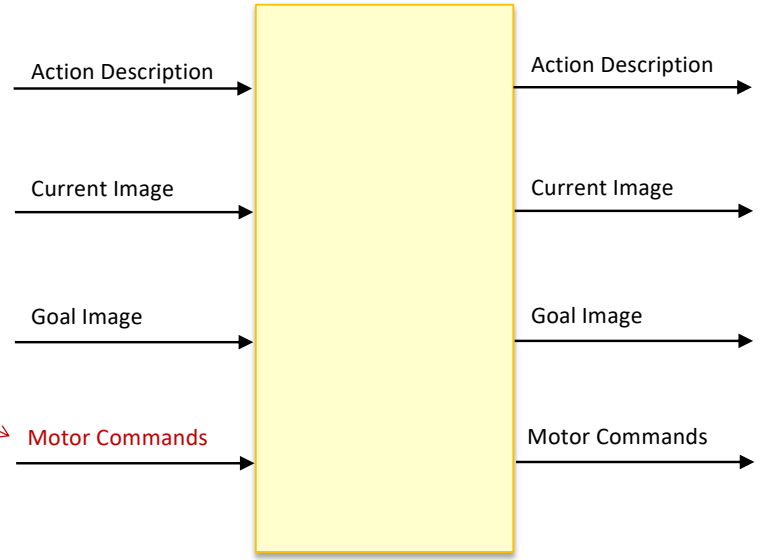
“Move the bottle left” →
```
:bottle default_color *pose-2* :bottle *leftward-transformation* :bottle
```

“Move the cup backwards” →
```
:cup default_color *pose-1* :cup *backward-transformation* :cup
```

“Shift the fork right” →
```
:fork default_color *pose-1* :fork *rightward-transformation* :fork
```

The last keyword triple defines the transformation of an object , e.g, cup with respect to another object, e.g., :cereal

The first *n* keyword triples instantiate *n* objects, e.g., cup and :cereal



0@ move the :BOTTLE left
1@ put the :BOTTLE in front of :CUP
2@ put the :BOTTLE behind :WEISSWURST
3@ put the :CUP on top of :MUG
4@ put the :BOTTLE to the right of :MUG
5@ put the :CUP to the left of :MILK
6@ put the :CUP to the right of :CAP
7@ shift the :BOTTLE left
8@ move the :CUP left
9@ shift the :CUP right
10@ put the :BOTTLE to the right of :GLASSES
11@ put the :CUP in front of :CEREAL
12@ move the :BOTTLE forwards
13@ move the :CUP forwards
14@ put the :BOTTLE in front of :POT
15@ put the :BOTTLE to the left of :BOWL
16@ put the :BOTTLE on top of :WEISSWURST
17@ put the :BOTTLE behind :FORK
18@ shift the :CUP right
19@ move the :CUP backwards
20@ shift the :BOTTLE forwards
21@ put the :BOTTLE in front of :MUG
22@ put the :CUP to the right of :MUG
23@ move the :CUP right
24@ put the :BOTTLE to the left of :CUP
25@ put the :CUP in front of :BREAKFAST-CEREAL
26@ put the :BOTTLE on top of :WEISSWURST
27@ put the :CUP on top of :MUG
28@ put the :BOTTLE to the right of :MUG
29@ put the :CUP to the left of :MILK
30@ put the :CUP to the right of :CAP
31@ shift the :BOTTLE left
32@ move the :CUP left
33@ shift the :CUP right
34@ put the :BOTTLE to the right of :GLASSES
35@ shift the :BOTTLE backwards
36@ put the :BOTTLE behind :BOTTLE
37@ put the :CUP to the left of :CUBE
38@ put the :BOTTLE to the right of :PLATE
39@ put the :BOTTLE to the right of :RED-METAL-PLATE
40@ shift the :BOTTLE right
41@ put the :BOTTLE in front of :MONDAMIN
42@ put the :CUP behind :WEISSWURST
43@ move the :BOTTLE backwards
44@ put the :BOTTLE on top of :BLUE-METAL-PLATE
45@ put the :BOTTLE to the right of :GLASSES
46@ move the :BOTTLE left
47@ move the :CUP right
48@ put the :CUP to the left of :KNIFE
49@ put the :BOTTLE to the left of :RED-METAL-PLATE
50@ put the :BOTTLE behind :CUP
51@ put the :BOTTLE behind :WEISSWURST
52@ put the :CUP on top of :MUG
53@ put the :BOTTLE to the right of :MUG
54@ put the :CUP to the left of :MILK
55@ put the :CUP to the right of :CAP
56@ shift the :BOTTLE left
57@ move the :CUP left
58@ shift the :CUP right
59@ put the :BOTTLE to the right of :GLASSES
60@ shift the :BOTTLE backwards
61@ put the :BOTTLE behind :BOTTLE
62@ put the :CUP to the left of :CUBE
63@ move the :BOTTLE backwards
64@ put the :CUP in front of :POT
65@ put the :BOTTLE on top of :FORK
66@ shift the :CUP backwards
67@ shift the :BOTTLE forwards
68@ move the :BOTTLE left
69@ put the :BOTTLE on top of :GLASSES
70@ shift the :BOTTLE right
71@ put the :CUP in front of :KNIFE
72@ put the :BOTTLE to the right of :GLOVE
73@ shift the :CUP left
74@ put the :CUP on top of :MILK
75@ put the :BOTTLE in front of :GLASSES
76@ move the :CUP backwards

Action Descriptions

```
0@  :BOTTLE BLUE POSE-4 :BOTTLE  #'*leftward-transformation*  :BOTTLE
1@  :BOTTLE BLUE POSE-6 :CUP BLUE POSE-1 :BOTTLE  #'*forward-transformation*  :CUP
2@  :BOTTLE GREEN POSE-7 :WEISSWURST GREEN POSE-2 :BOTTLE  #'*backward-transformation*  :WEISSWURST
3@  :CUP GREEN POSE-8 :MUG BLUE POSE-3 :CUP NIL :MUG
4@  :BOTTLE BLUE POSE-7 :MUG BLUE POSE-5 :BOTTLE  #'*rightward-transformation*  :MUG
5@  :CUP BLUE POSE-9 :MILK RED POSE-3 :CUP  #'*leftward-transformation*  :MILK
6@  :CUP BLUE POSE-6 :CAP GREEN POSE-5 :CUP  #'*rightward-transformation*  :CAP
7@  :BOTTLE GREEN POSE-3 :BOTTLE  #'*leftward-transformation*  :BOTTLE
8@  :CUP GREEN POSE-1 :CUP  #'*leftward-transformation*  :CUP
9@  :CUP GREEN POSE-4 :CUP  #'*rightward-transformation*  :CUP
10@  :BOTTLE GREEN POSE-6 :GLASSES BLUE POSE-1 :BOTTLE  #'*rightward-transformation*  :GLASSES
11@  :CUP RED POSE-7 :CEREAL GREEN POSE-3 :CUP  #'*forward-transformation*  :CEREAL
12@  :BOTTLE BLUE POSE-1 :BOTTLE  #'*forward-transformation*  :BOTTLE
13@  :CUP GREEN POSE-2 :CUP  #'*forward-transformation*  :CUP
14@  :BOTTLE BLUE POSE-7 :POT GREEN POSE-5 :BOTTLE  #'*forward-transformation*  :POT
15@  :BOTTLE RED POSE-7 :BOWL BLUE POSE-4 :BOTTLE  #'*leftward-transformation*  :BOWL
16@  :BOTTLE GREEN POSE-9 :WEISSWURST RED POSE-3 :BOTTLE NIL :WEISSWURST
17@  :BOTTLE GREEN POSE-8 :FORK RED POSE-2 :BOTTLE  #'*backward-transformation*  :FORK
18@  :CUP GREEN POSE-2 :CUP  #'*rightward-transformation*  :CUP
19@  :CUP RED POSE-4 :CUP  #'*backward-transformation*  :CUP
20@  :BOTTLE GREEN POSE-4 :BOTTLE  #'*forward-transformation*  :BOTTLE
21@  :BOTTLE RED POSE-6 :MUG GREEN POSE-2 :BOTTLE  #'*forward-transformation*  :MUG
22@  :CUP GREEN POSE-6 :MUG RED POSE-1 :CUP  #'*rightward-transformation*  :MUG
23@  :CUP RED POSE-1 :CUP  #'*rightward-transformation*  :CUP
24@  :BOTTLE GREEN POSE-6 :CUP RED POSE-5 :BOTTLE  #'*leftward-transformation*  :CUP
25@  :CUP BLUE POSE-9 :BREAKFAST-CEREAL GREEN POSE-4 :CUP  #'*forward-transformation*  :BREAKFAST-CEREAL
26@  :BOTTLE GREEN POSE-7 :WEISSWURST GREEN POSE-3 :BOTTLE NIL :WEISSWURST
27@  :CUP GREEN POSE-8 :MUG BLUE POSE-3 :CUP NIL :MUG
28@  :BOTTLE BLUE POSE-7 :MUG BLUE POSE-5 :BOTTLE  #'*rightward-transformation*  :MUG
29@  :CUP BLUE POSE-9 :MILK RED POSE-3 :CUP  #'*leftward-transformation*  :MILK
30@  :CUP BLUE POSE-6 :CAP GREEN POSE-5 :CUP  #'*rightward-transformation*  :CAP
31@  :BOTTLE GREEN POSE-3 :BOTTLE  #'*leftward-transformation*  :BOTTLE
32@  :CUP GREEN POSE-1 :CUP  #'*leftward-transformation*  :CUP
33@  :CUP GREEN POSE-4 :CUP  #'*rightward-transformation*  :CUP
34@  :BOTTLE GREEN POSE-6 :GLASSES BLUE POSE-1 :BOTTLE  #'*rightward-transformation*  :GLASSES
35@  :BOTTLE RED POSE-5 :BOTTLE  #'*backward-transformation*  :BOTTLE
36@  :BOTTLE RED POSE-9 :BOTTLE GREEN POSE-5 :BOTTLE  #'*backward-transformation*  :BOTTLE
37@  :CUP RED POSE-6 :CUBE RED POSE-2 :CUP  #'*leftward-transformation*  :CUBE
38@  :BOTTLE BLUE POSE-7 :PLATE RED POSE-5 :BOTTLE  #'*rightward-transformation*  :PLATE
39@  :BOTTLE BLUE POSE-6 :RED-METAL-PLATE GREEN POSE-5 :BOTTLE  #'*rightward-transformation*  :RED-METAL-PLATE
40@  :BOTTLE RED POSE-1 :BOTTLE  #'*rightward-transformation*  :BOTTLE
41@  :BOTTLE GREEN POSE-8 :MONDAMIN RED POSE-2 :BOTTLE  #'*forward-transformation*  :MONDAMIN
42@  :CUP GREEN POSE-10 :WEISSWURST GREEN POSE-4 :CUP  #'*backward-transformation*  :WEISSWURST
43@  :BOTTLE BLUE POSE-4 :BOTTLE  #'*backward-transformation*  :BOTTLE
44@  :BOTTLE BLUE POSE-6 :BLUE-METAL-PLATE BLUE POSE-3 :BOTTLE NIL :BLUE-METAL-PLATE
45@  :BOTTLE RED POSE-7 :GLASSES GREEN POSE-4 :BOTTLE  #'*rightward-transformation*  :GLASSES
46@  :BOTTLE BLUE POSE-4 :BOTTLE  #'*leftward-transformation*  :BOTTLE
47@  :CUP RED POSE-1 :CUP  #'*rightward-transformation*  :CUP
48@  :CUP GREEN POSE-6 :KNIFE GREEN POSE-1 :CUP  #'*leftward-transformation*  :KNIFE
49@  :BOTTLE RED POSE-6 :RED-METAL-PLATE RED POSE-4 :BOTTLE  #'*leftward-transformation*  :RED-METAL-PLATE
50@  :BOTTLE BLUE POSE-6 :CUP BLUE POSE-4 :BOTTLE  #'*backward-transformation*  :CUP
51@  :BOTTLE GREEN POSE-7 :WEISSWURST GREEN POSE-2 :BOTTLE  #'*backward-transformation*  :WEISSWURST
52@  :CUP GREEN POSE-8 :MUG BLUE POSE-3 :CUP NIL :MUG
53@  :BOTTLE BLUE POSE-7 :MUG BLUE POSE-5 :BOTTLE  #'*rightward-transformation*  :MUG
54@  :CUP BLUE POSE-9 :MILK RED POSE-3 :CUP  #'*leftward-transformation*  :MILK
55@  :CUP BLUE POSE-6 :CAP GREEN POSE-5 :CUP  #'*rightward-transformation*  :CAP
56@  :BOTTLE GREEN POSE-3 :BOTTLE  #'*leftward-transformation*  :BOTTLE
57@  :CUP GREEN POSE-1 :CUP  #'*leftward-transformation*  :CUP
58@  :CUP GREEN POSE-4 :CUP  #'*rightward-transformation*  :CUP
59@  :BOTTLE GREEN POSE-6 :GLASSES BLUE POSE-1 :BOTTLE  #'*rightward-transformation*  :GLASSES
60@  :BOTTLE RED POSE-5 :BOTTLE  #'*backward-transformation*  :BOTTLE
61@  :BOTTLE RED POSE-9 :BOTTLE GREEN POSE-5 :BOTTLE  #'*backward-transformation*  :BOTTLE
62@  :CUP RED POSE-6 :CUBE RED POSE-2 :CUP  #'*leftward-transformation*  :CUBE
63@  :BOTTLE RED POSE-1 :BOTTLE  #'*backward-transformation*  :BOTTLE
64@  :CUP GREEN POSE-8 :POT RED POSE-1 :CUP  #'*forward-transformation*  :POT
65@  :BOTTLE BLUE POSE-6 :FORK RED POSE-2 :BOTTLE NIL :FORK
66@  :CUP RED POSE-4 :CUP  #'*backward-transformation*  :CUP
67@  :BOTTLE BLUE POSE-1 :BOTTLE  #'*forward-transformation*  :BOTTLE
68@  :BOTTLE BLUE POSE-1 :BOTTLE  #'*leftward-transformation*  :BOTTLE
69@  :BOTTLE BLUE POSE-10 :GLASSES RED POSE-4 :BOTTLE NIL :GLASSES
70@  :BOTTLE BLUE POSE-5 :BOTTLE  #'*rightward-transformation*  :BOTTLE
71@  :CUP BLUE POSE-6 :KNIFE BLUE POSE-4 :CUP  #'*forward-transformation*  :KNIFE
72@  :BOTTLE BLUE POSE-6 :GLOVE RED POSE-5 :BOTTLE  #'*rightward-transformation*  :GLOVE
73@  :CUP BLUE POSE-1 :CUP  #'*leftward-transformation*  :CUP
74@  :CUP RED POSE-10 :MILK RED POSE-1 :CUP NIL :MILK
75@  :BOTTLE RED POSE-7 :GLASSES GREEN POSE-4 :BOTTLE  #'*forward-transformation*  :GLASSES
76@  :CUP GREEN POSE-4 :CUP  #'*backward-transformation*  :CUP
```

Motor Commands

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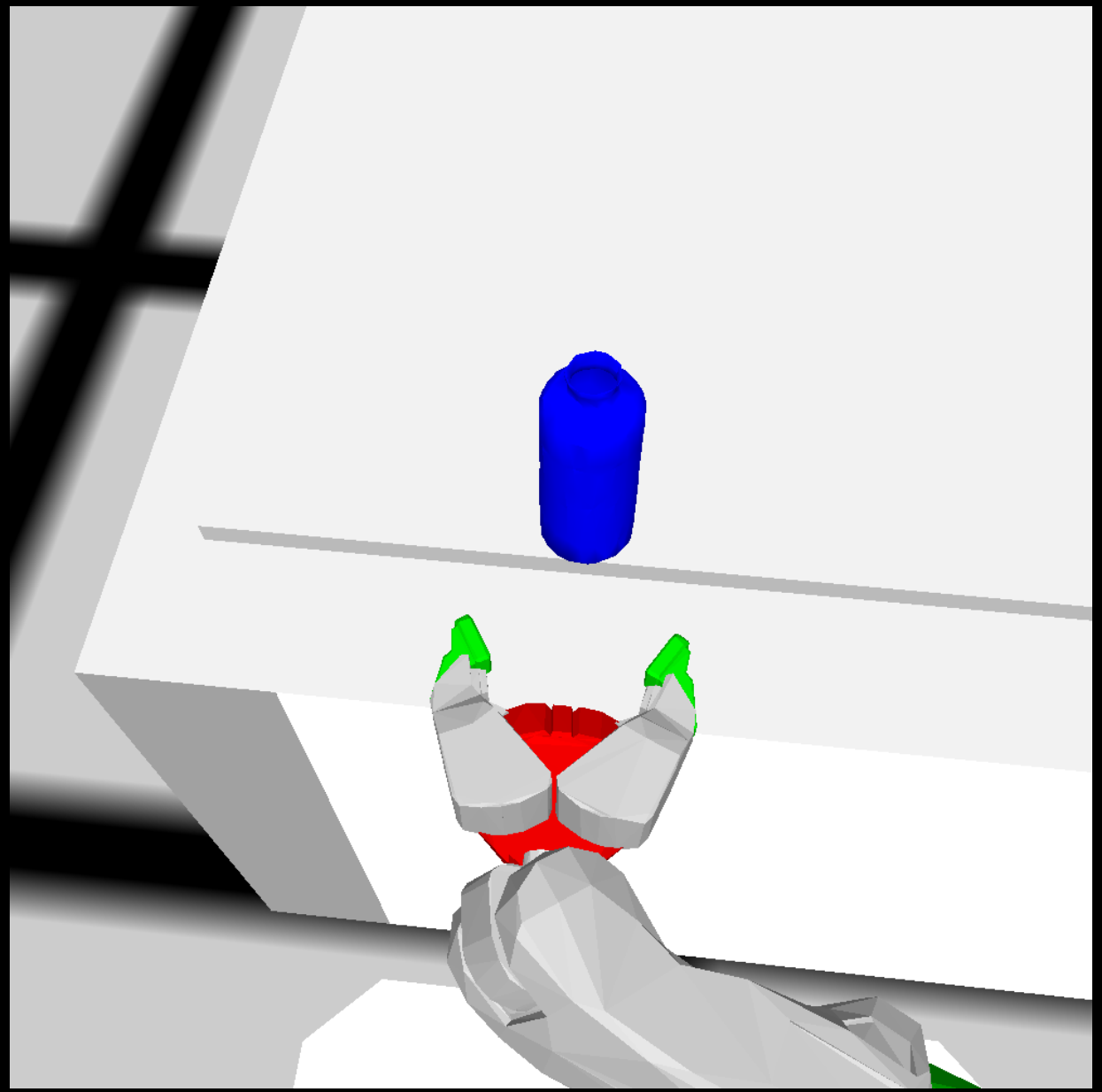

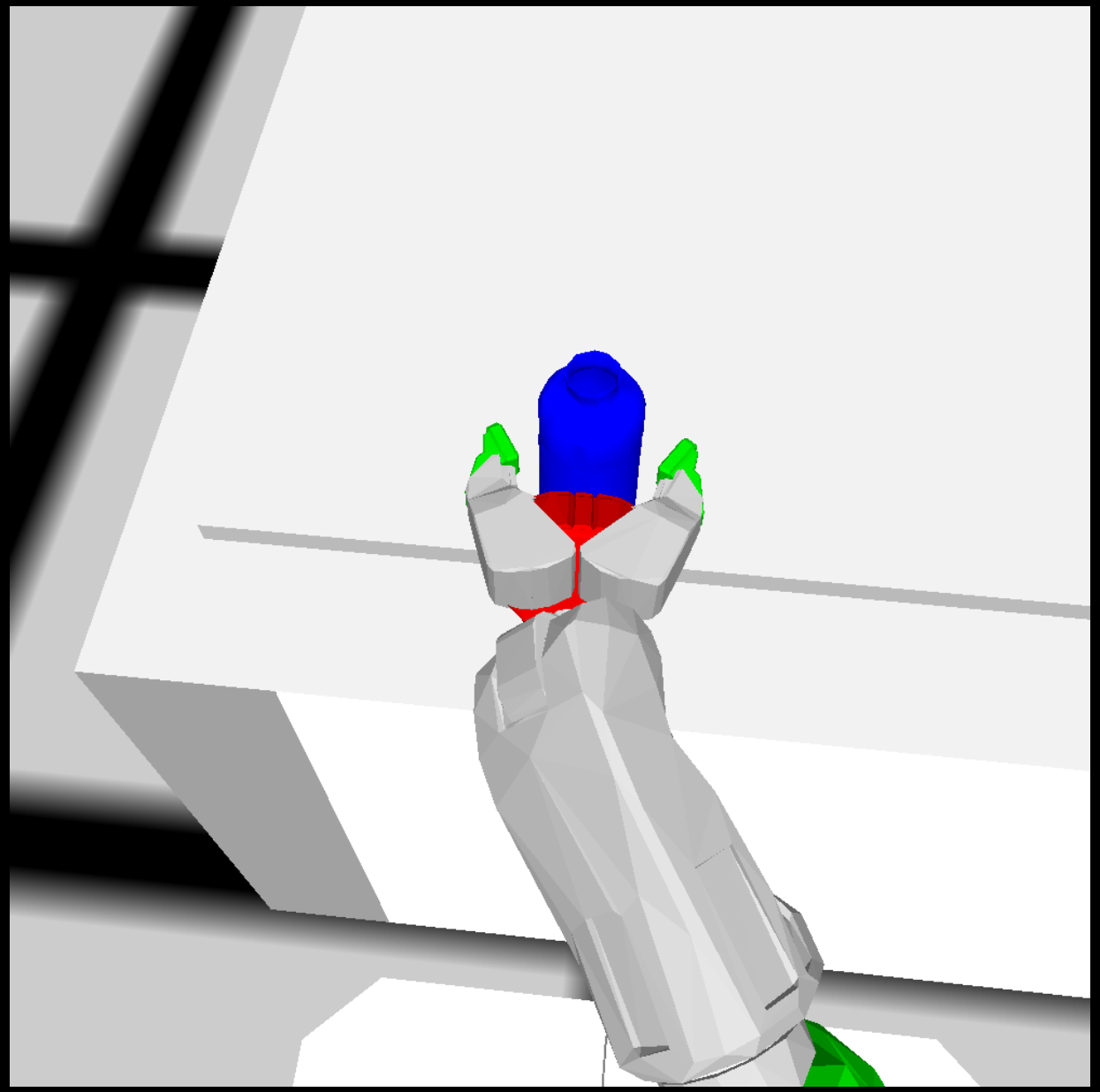

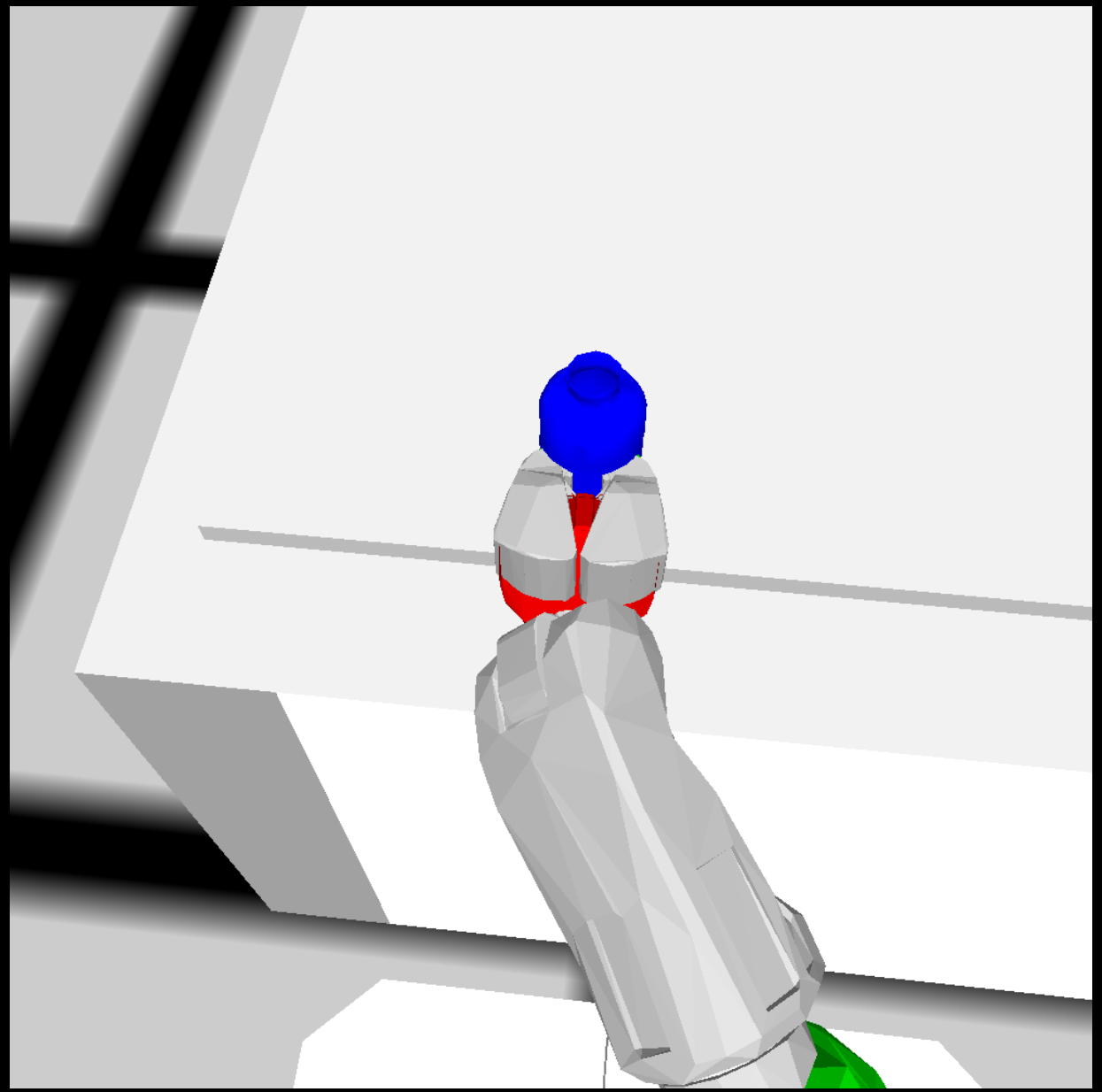

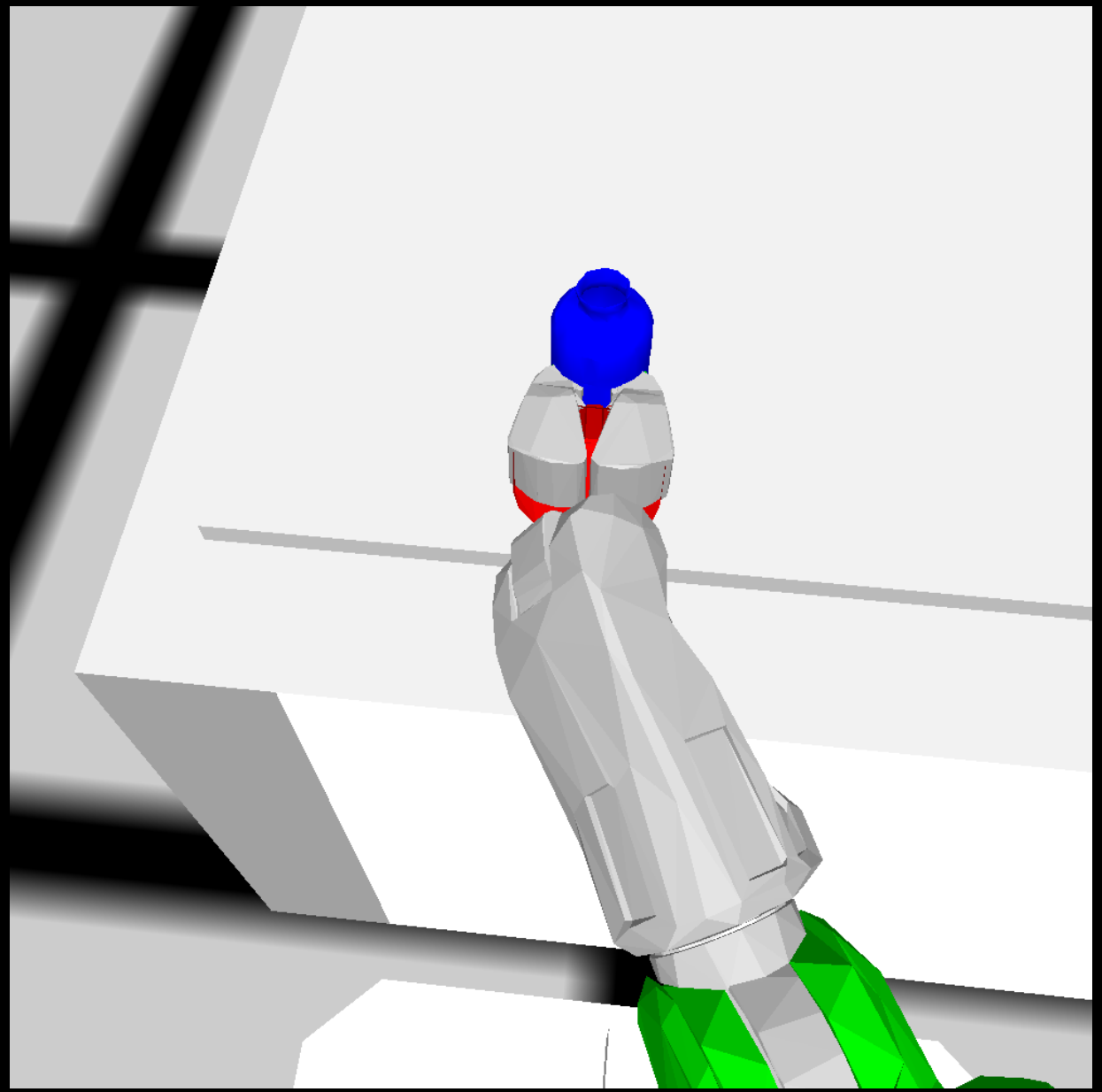

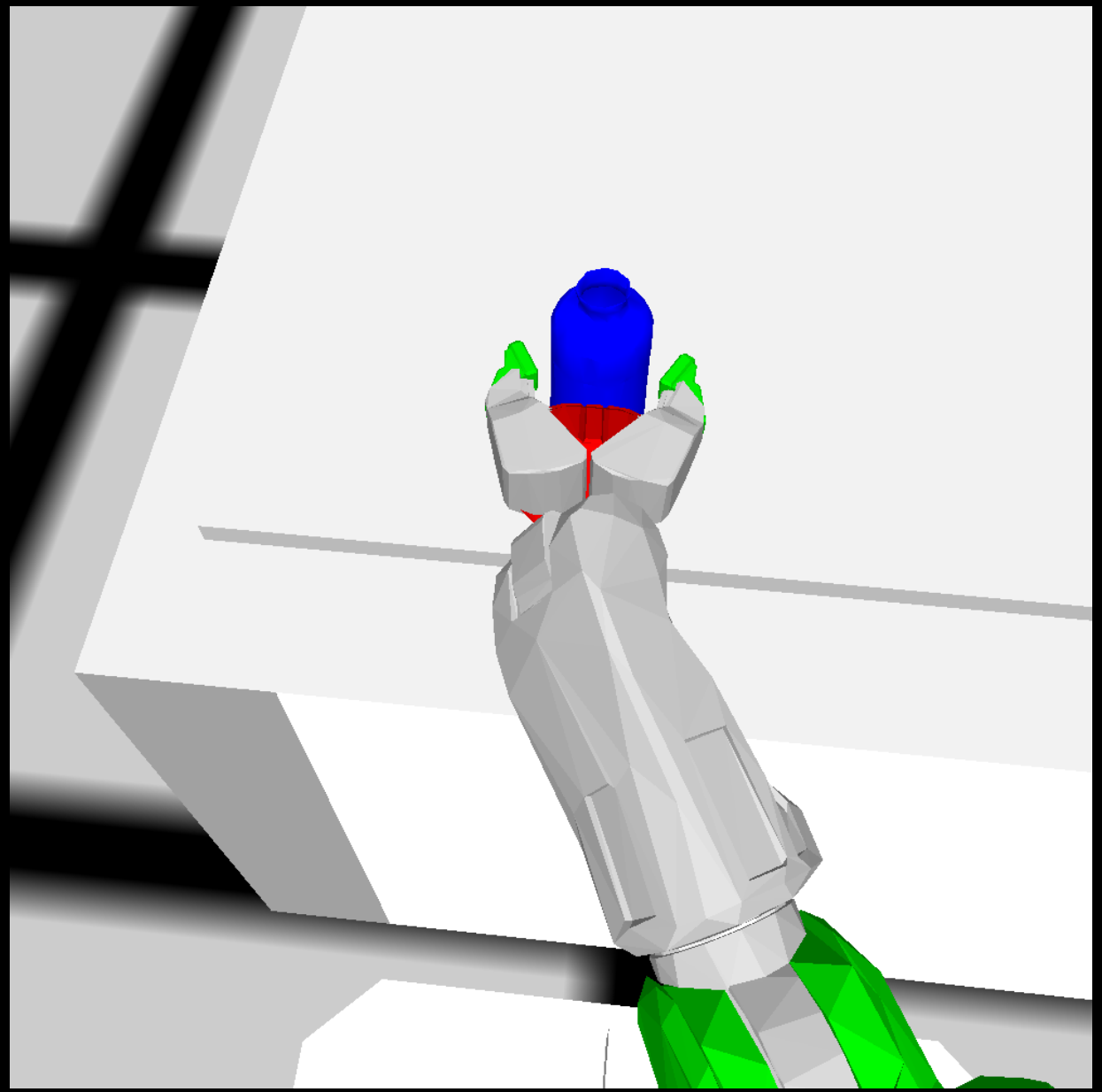

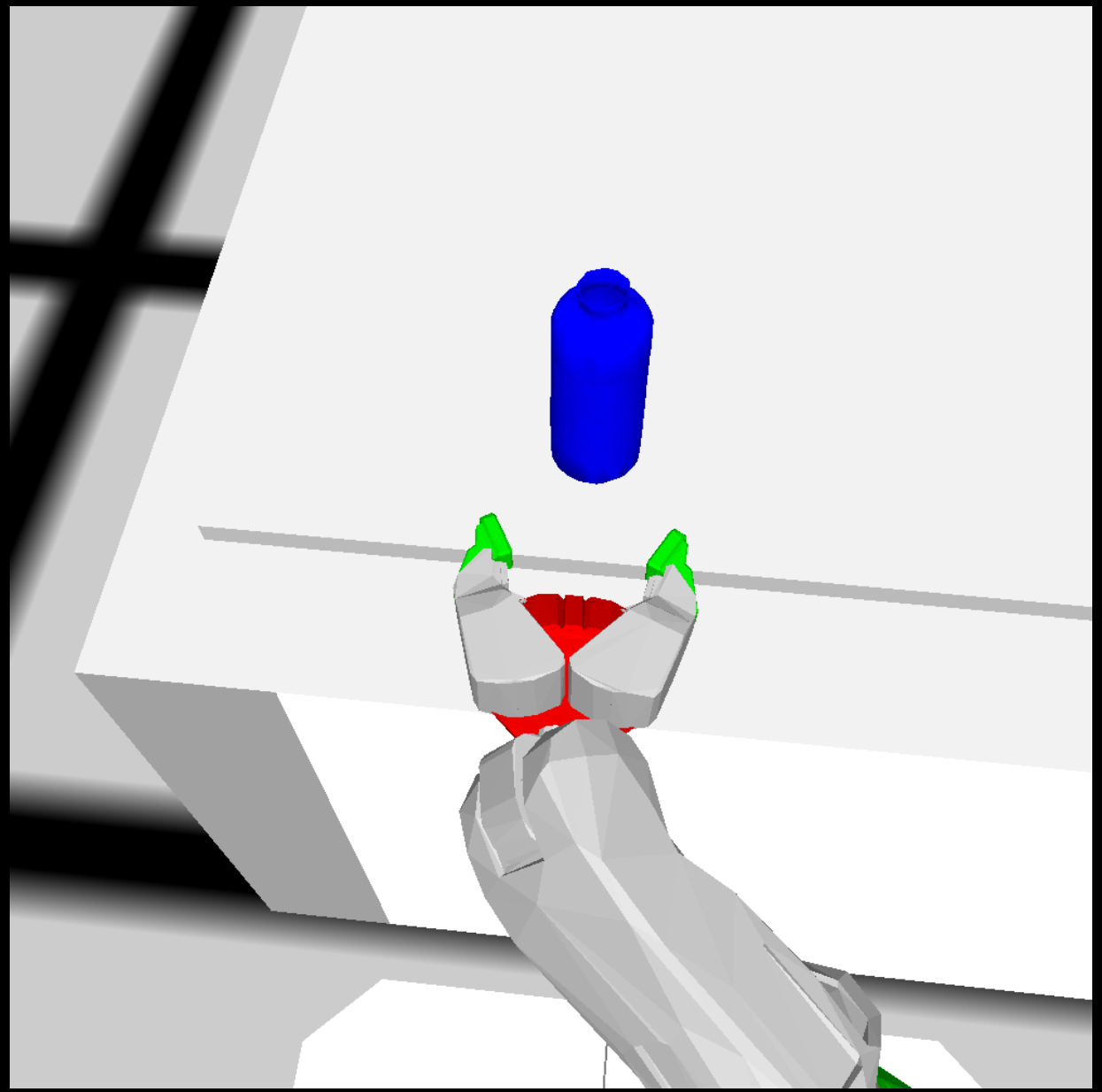

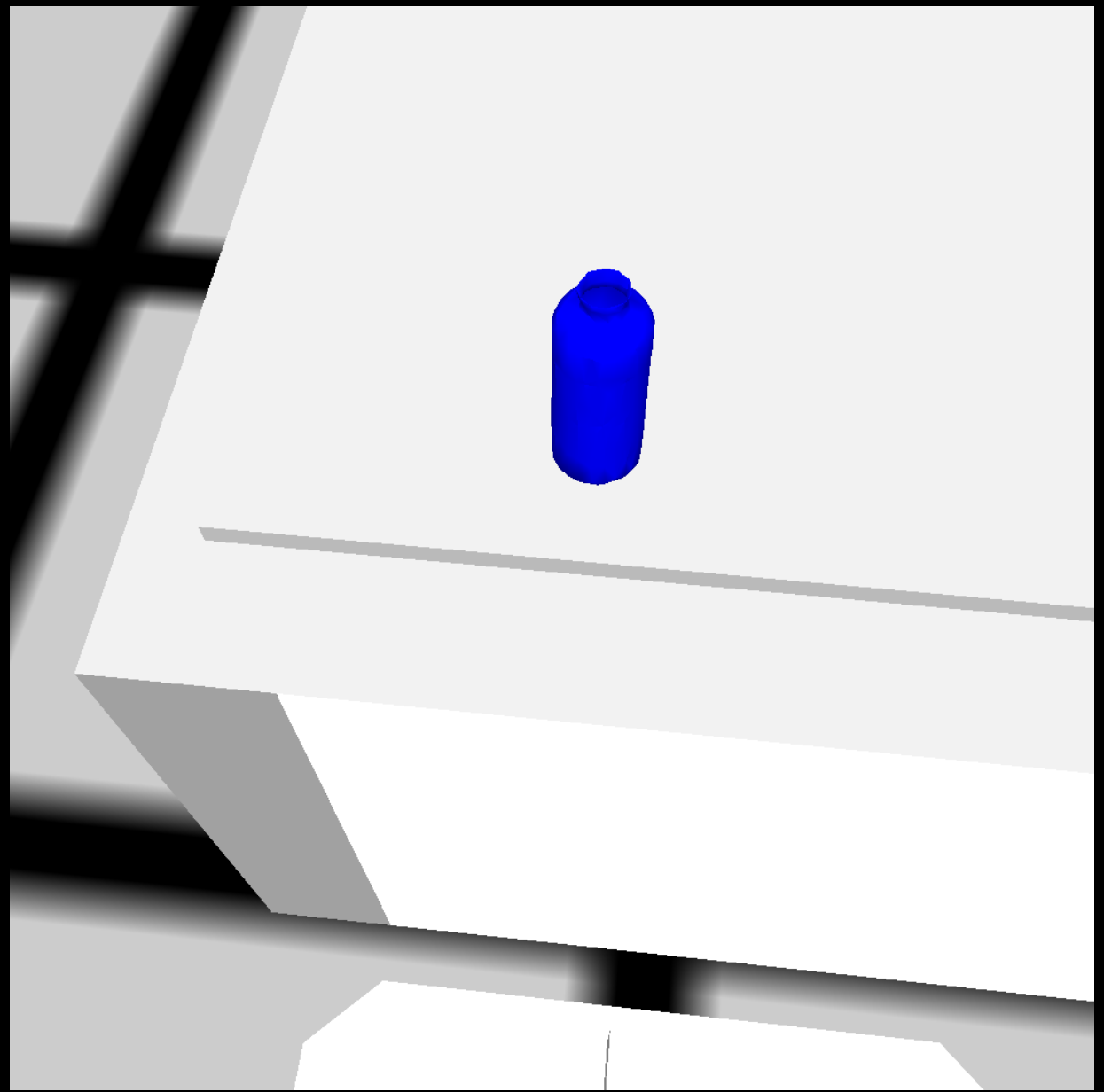

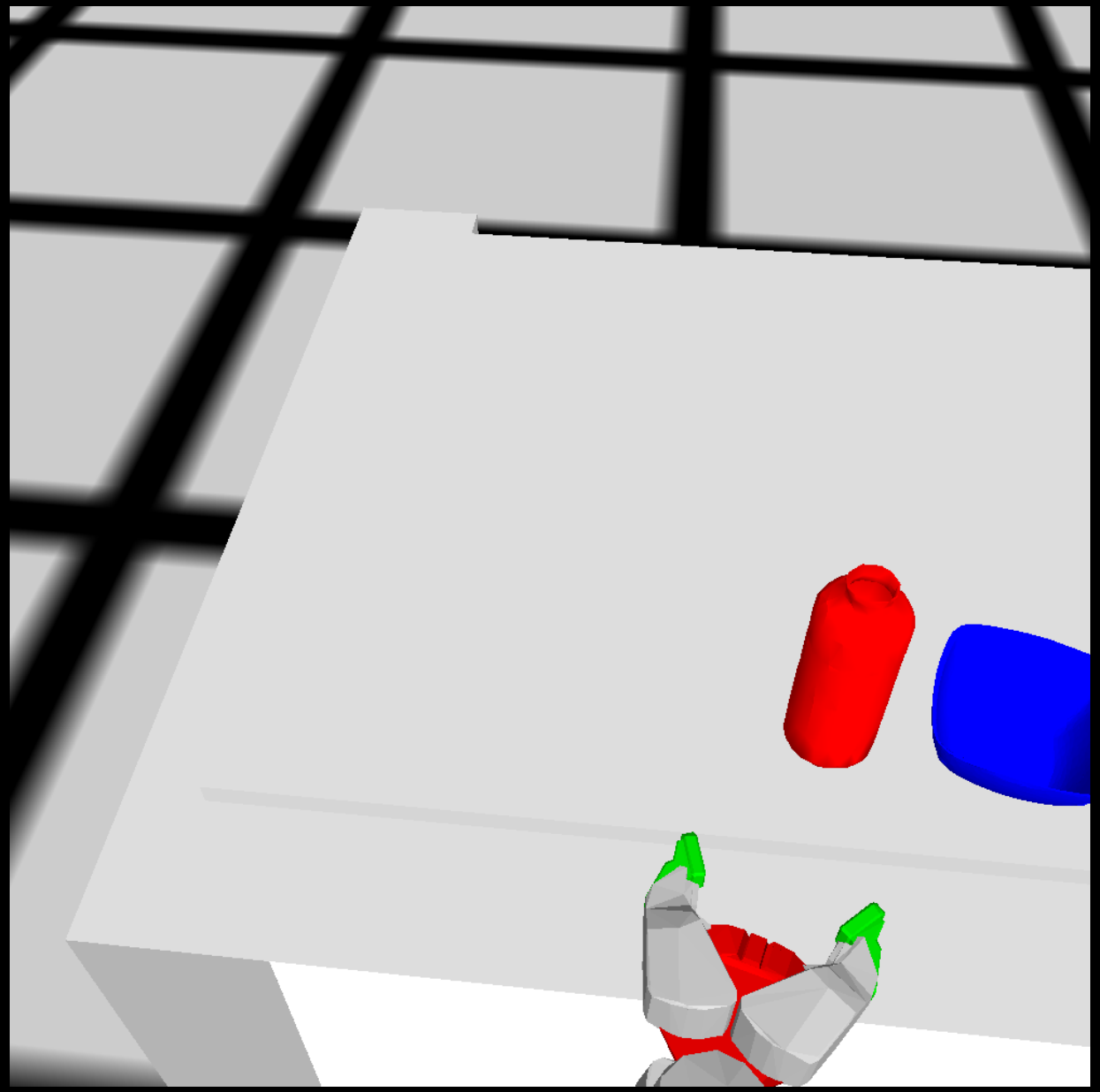

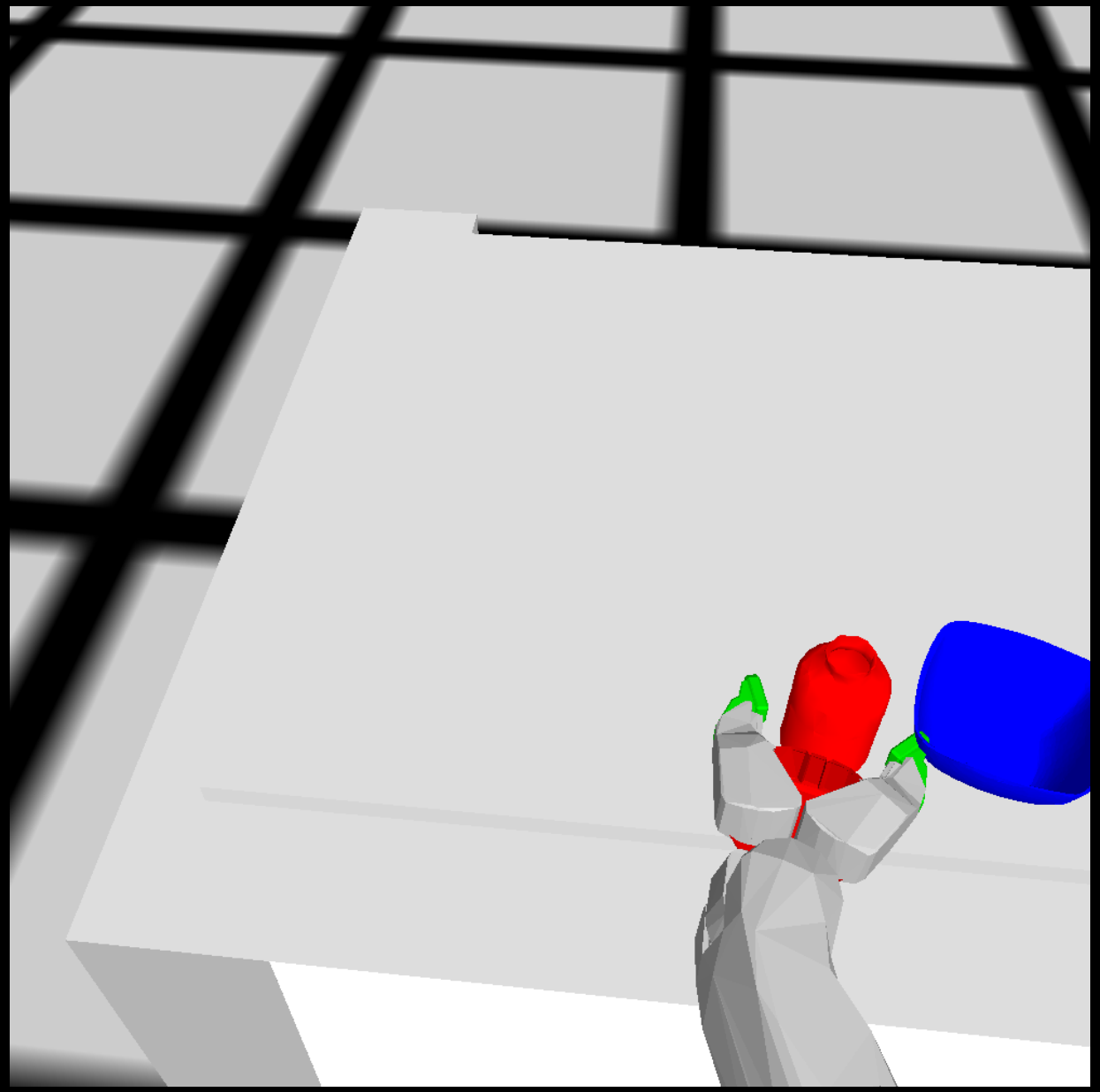

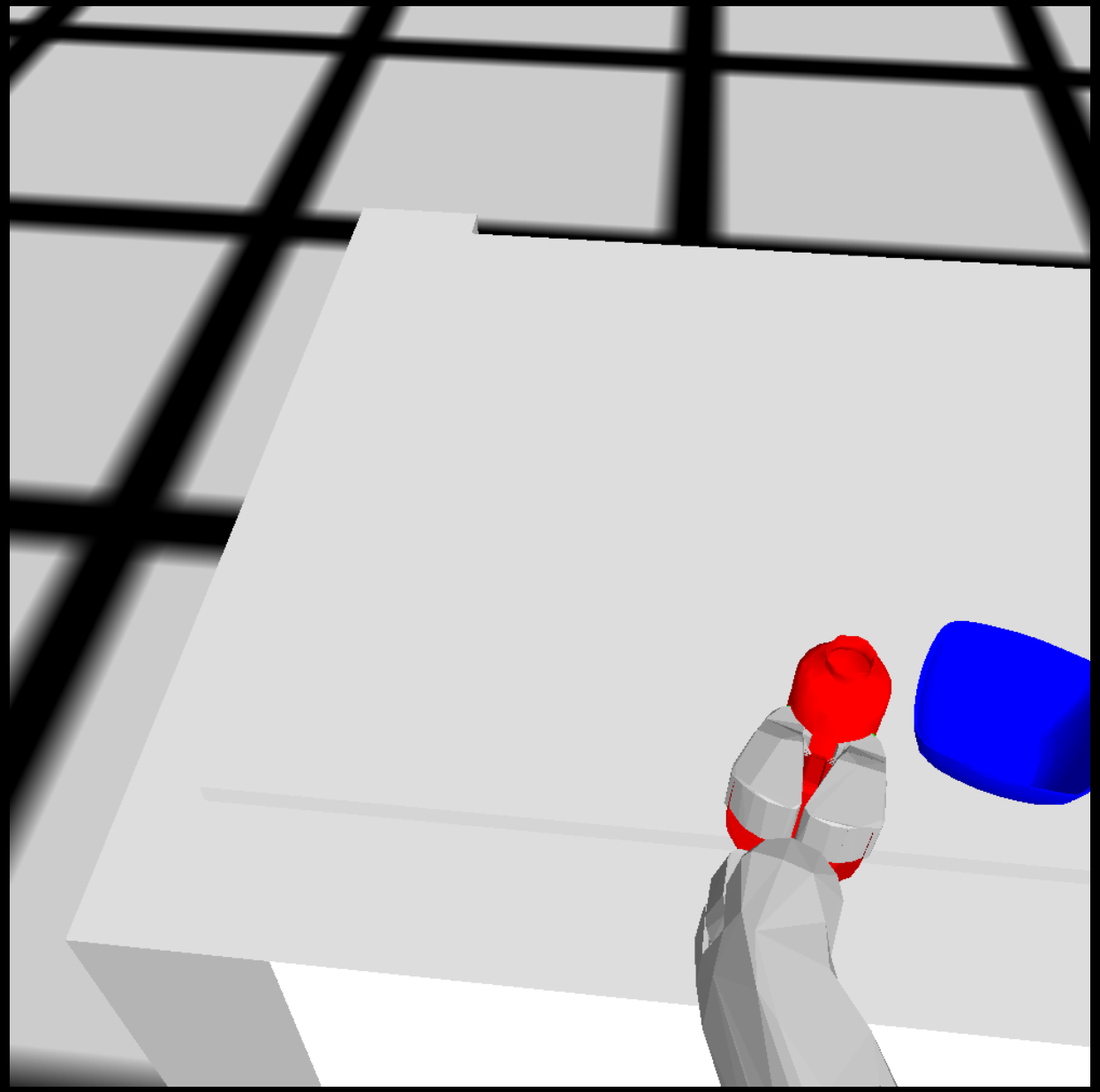

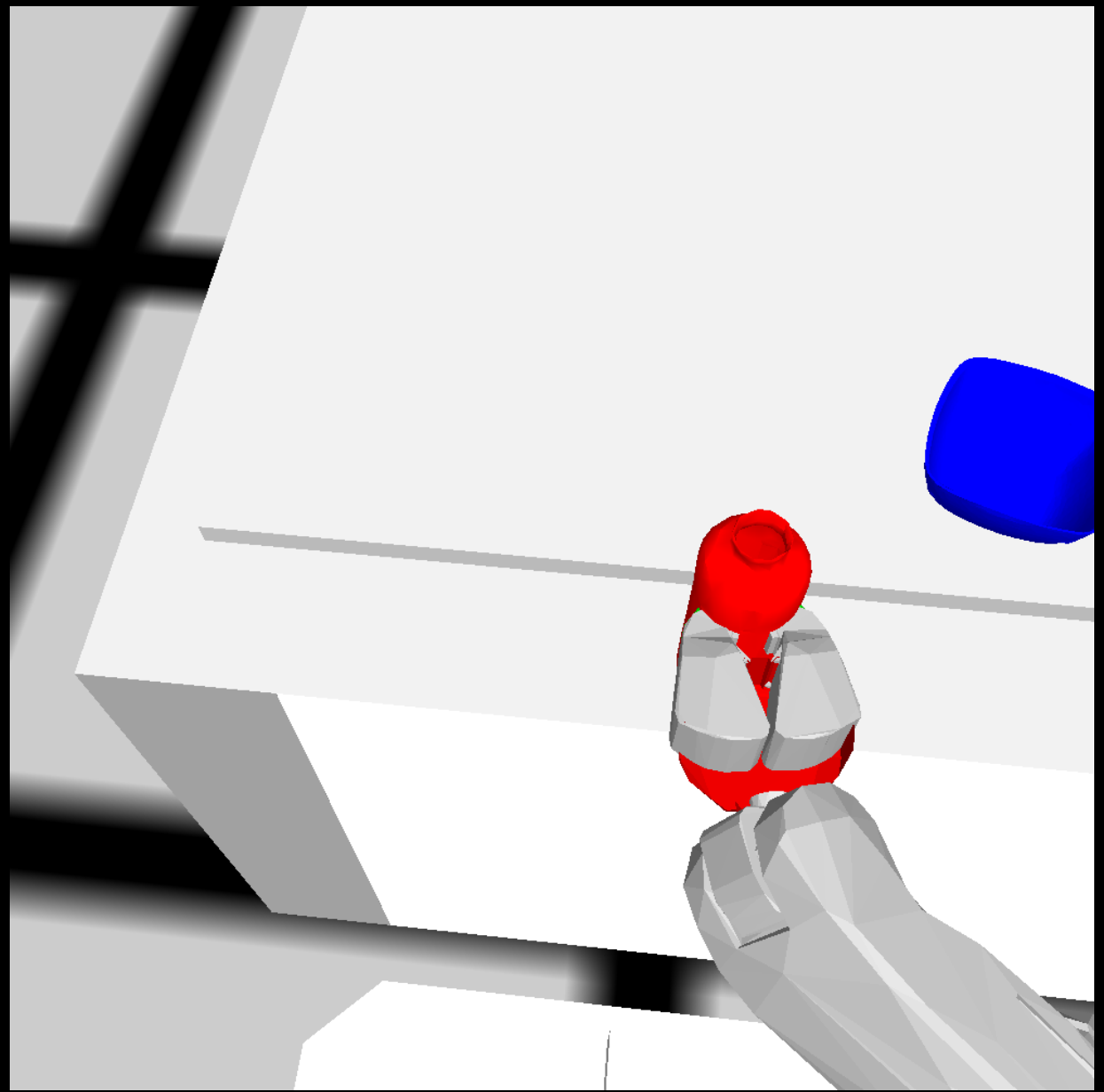

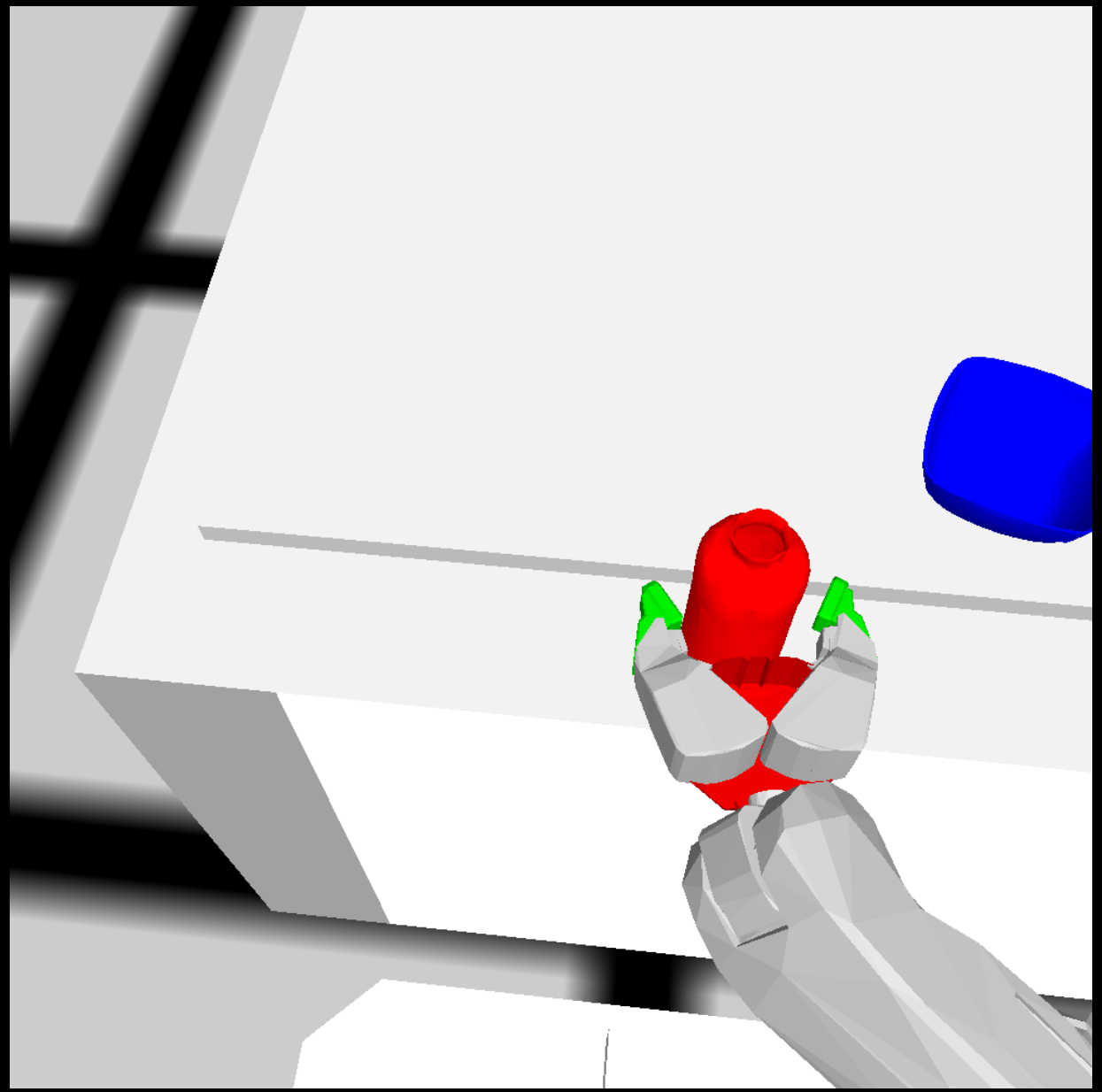

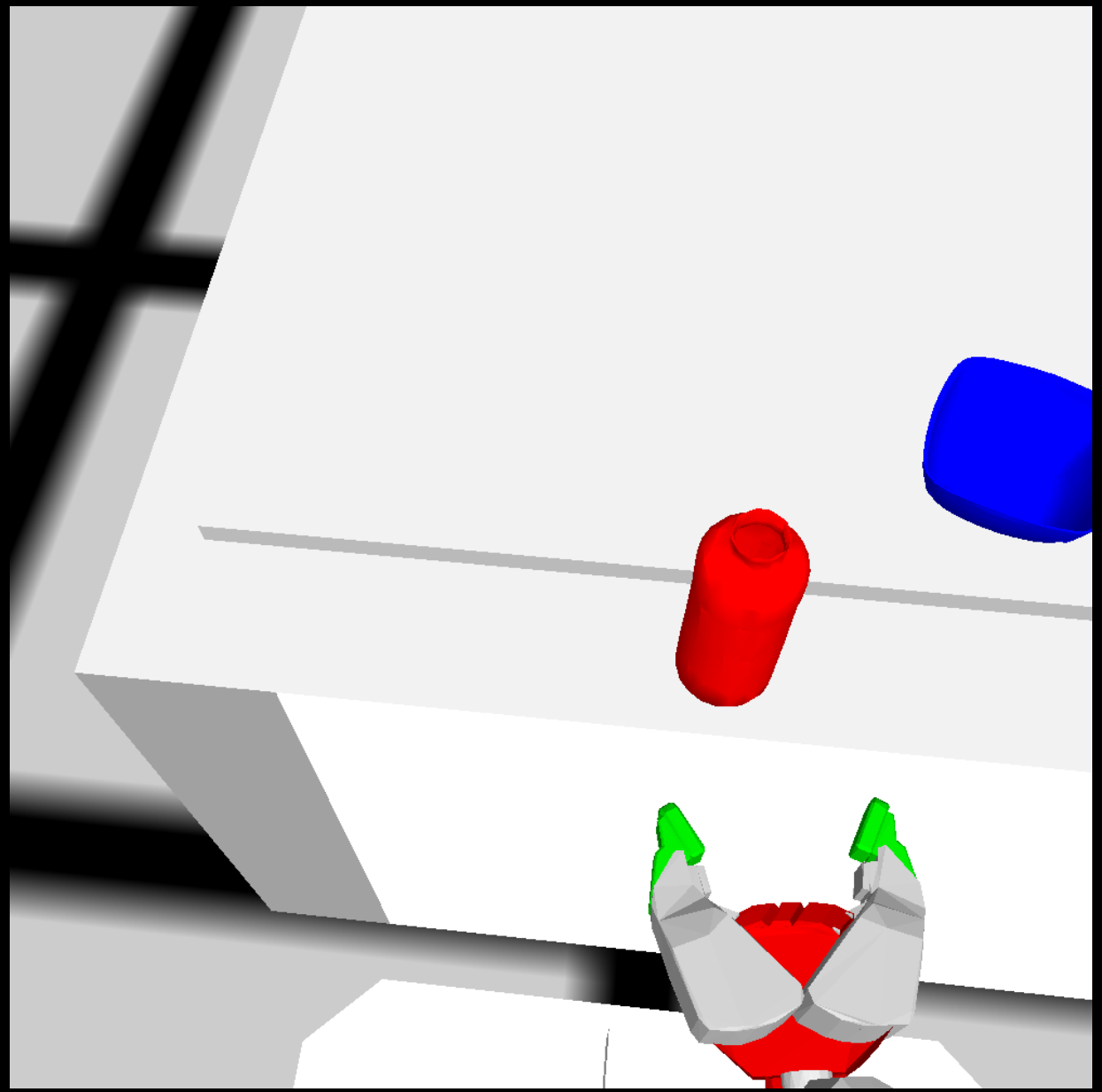

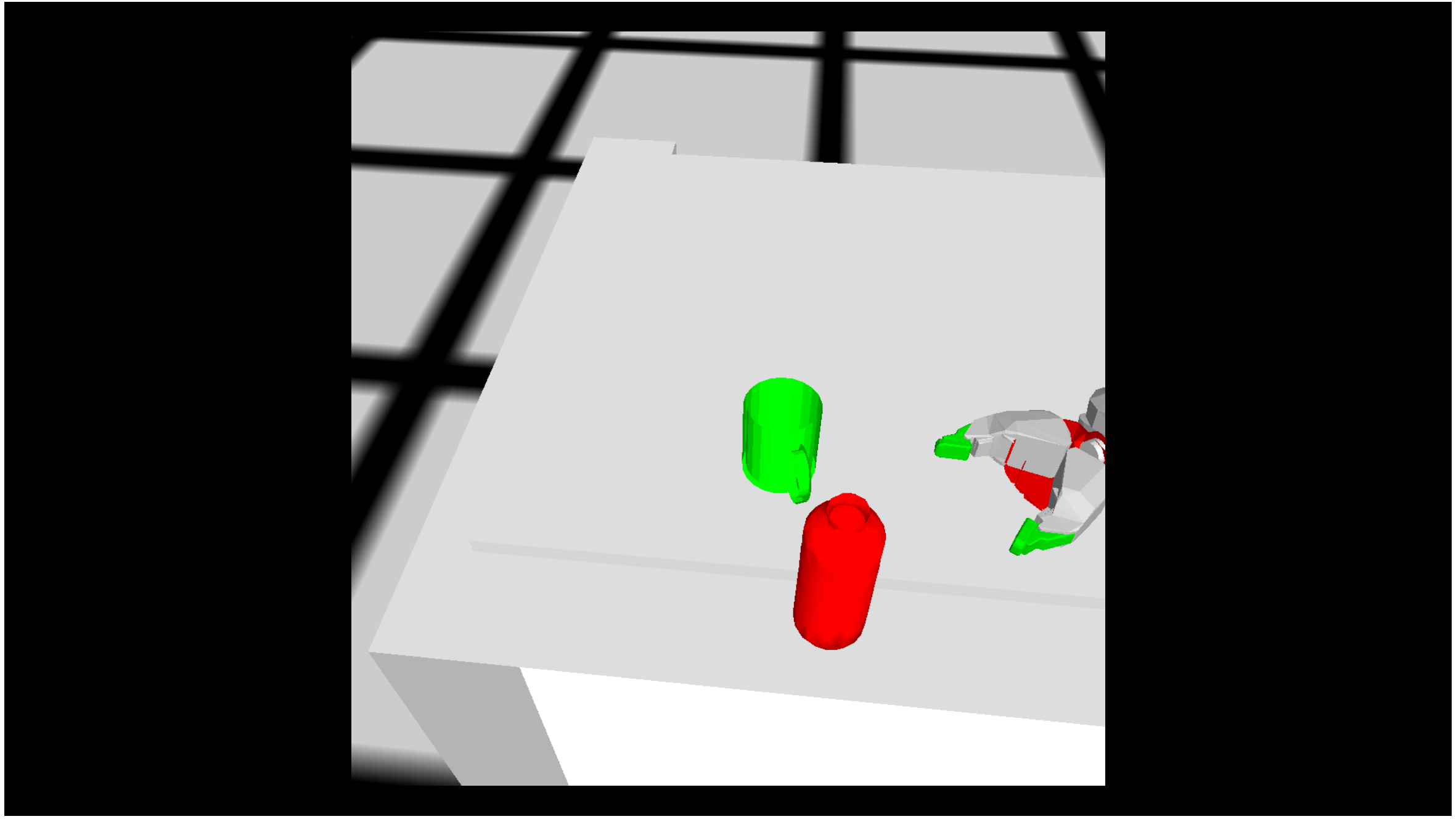

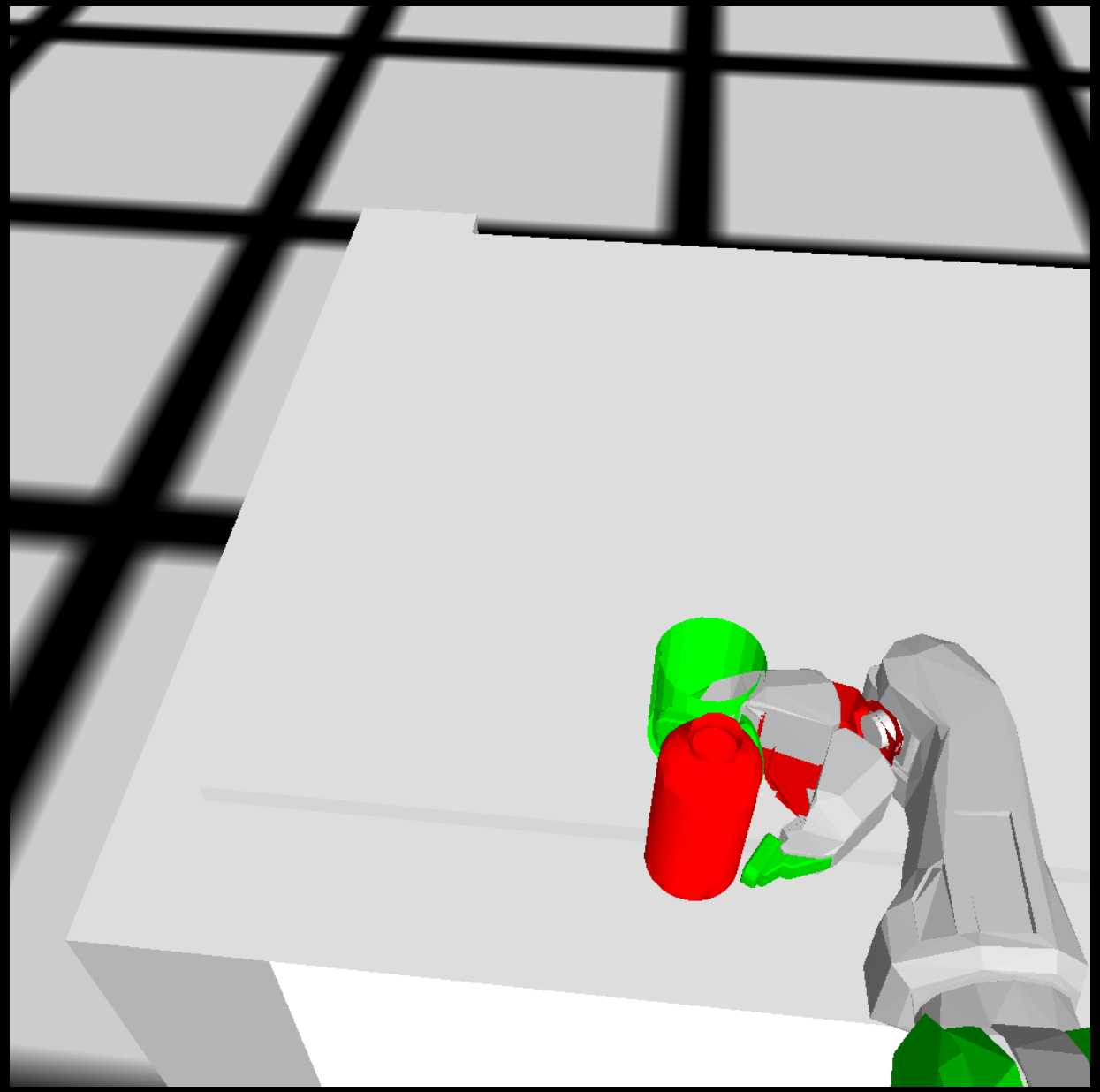

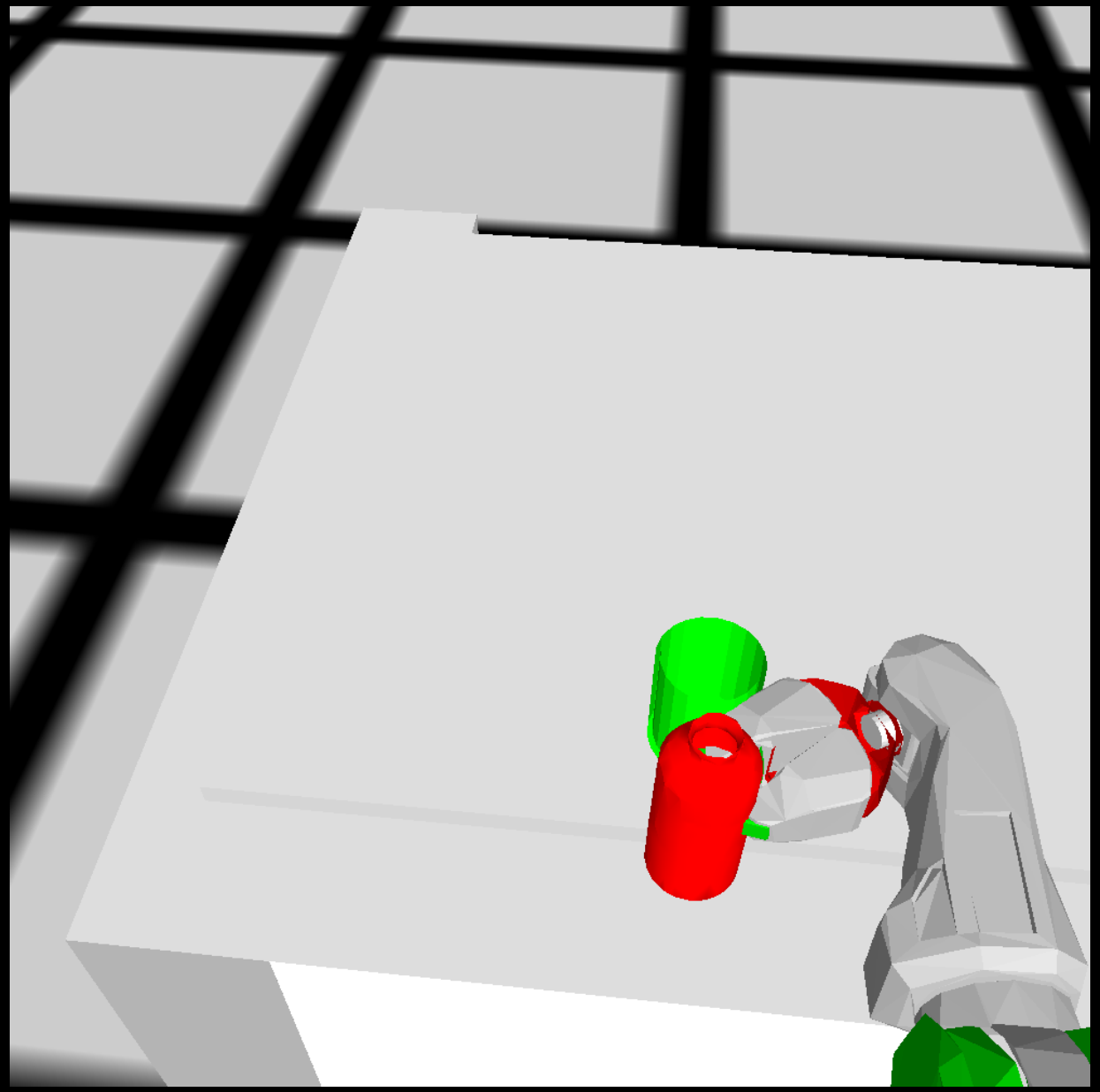

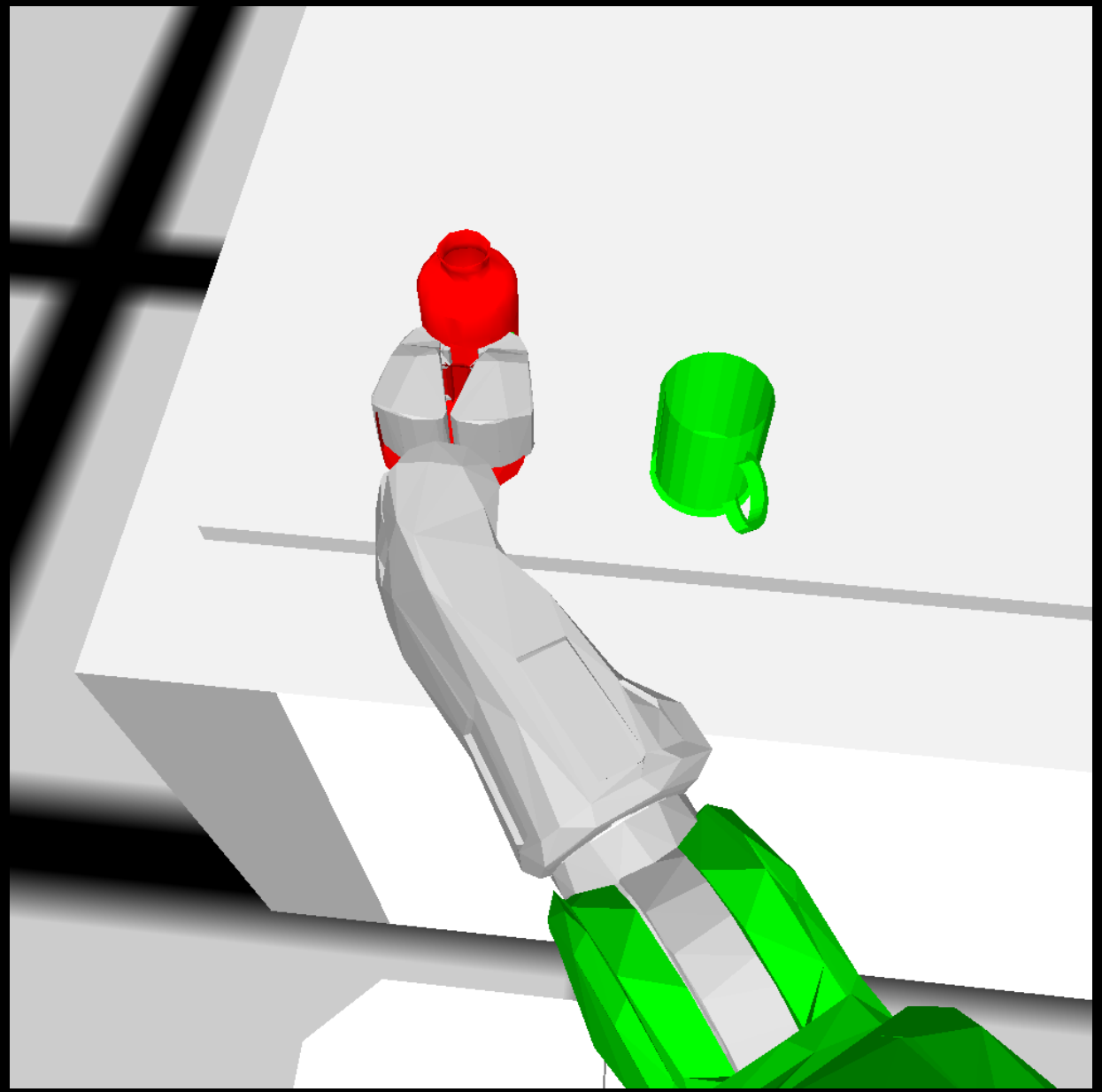

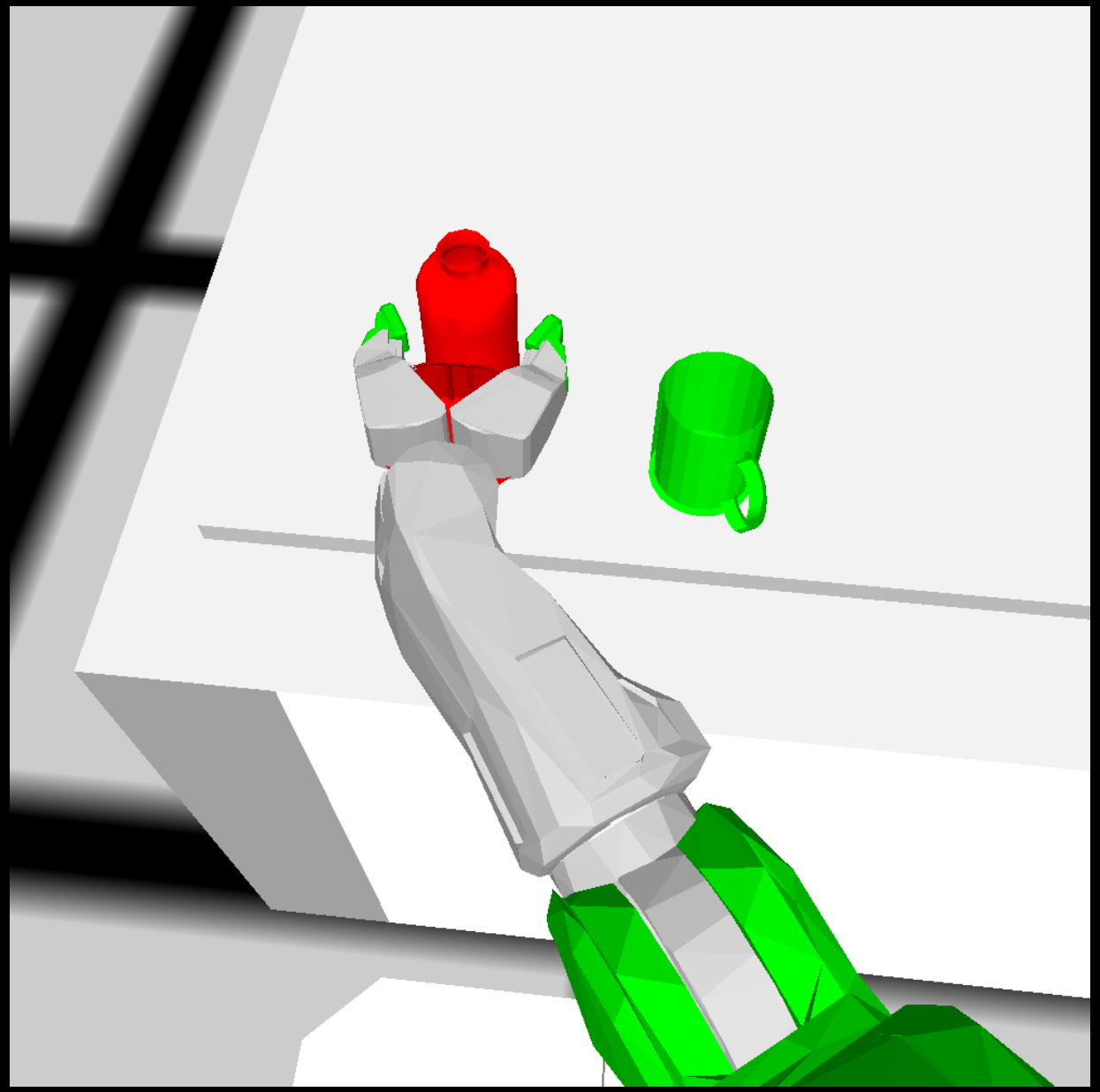

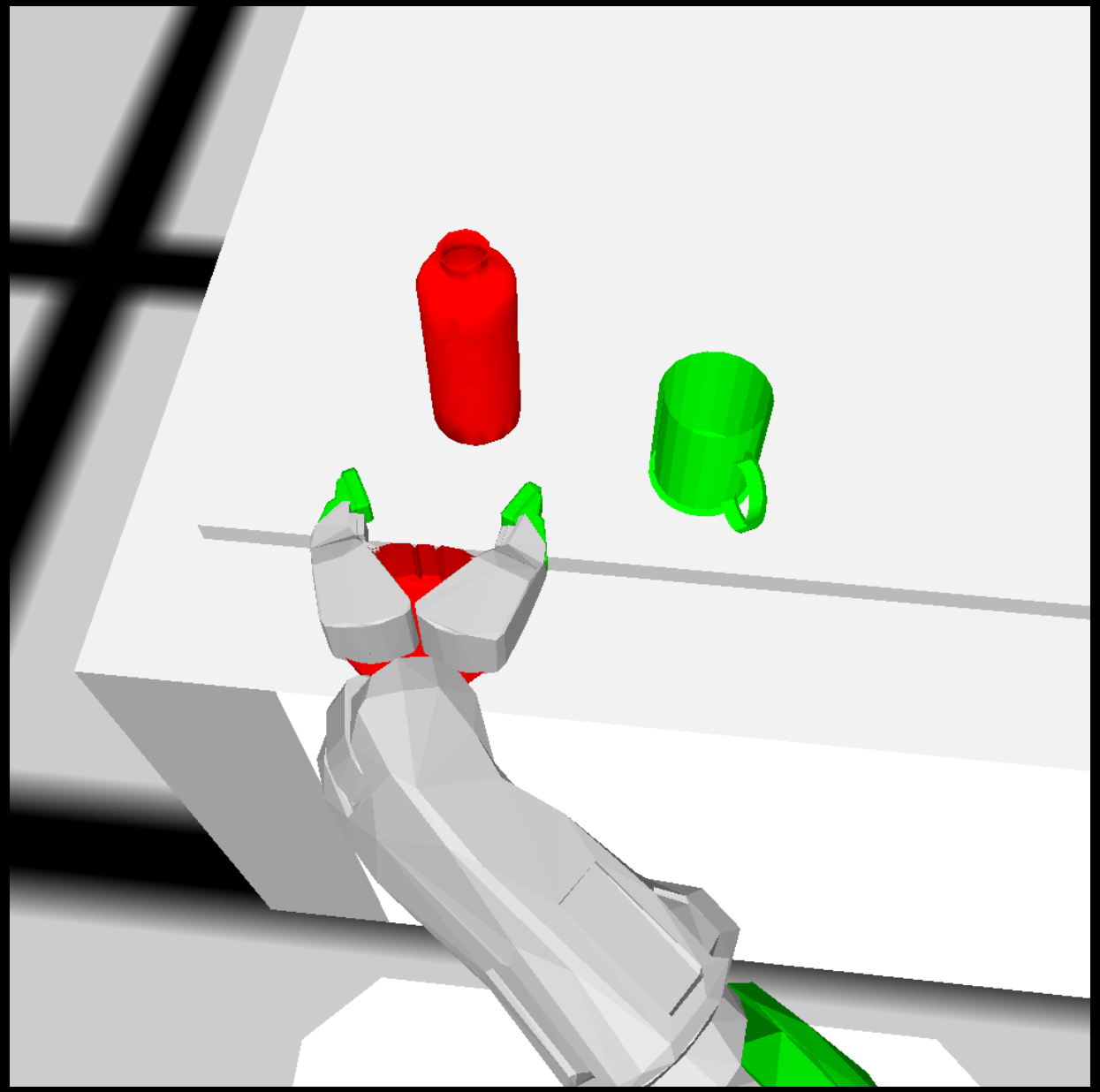

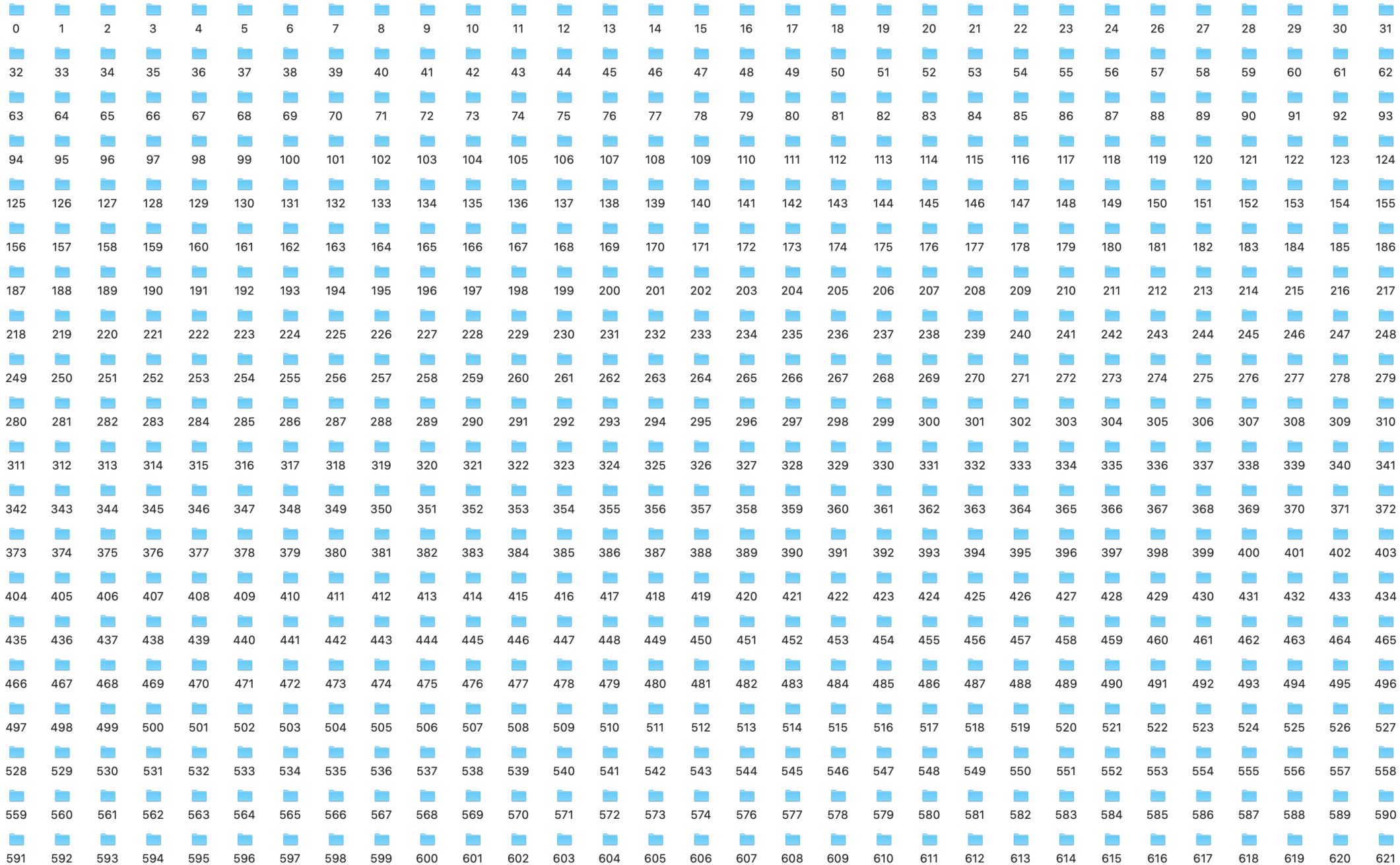
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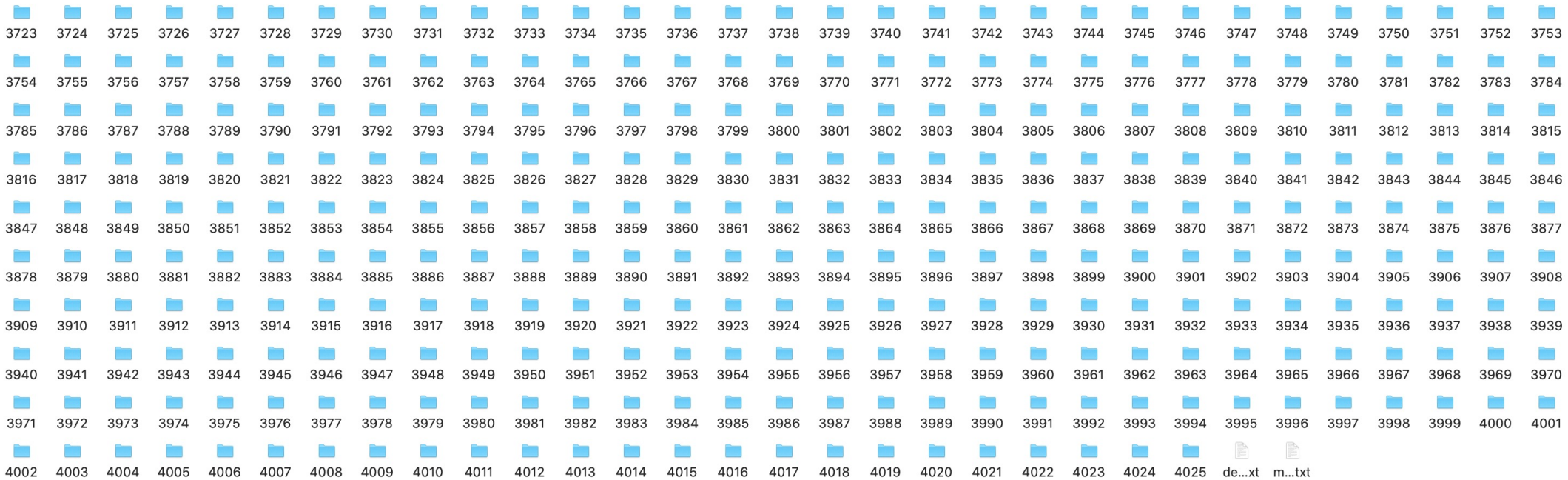
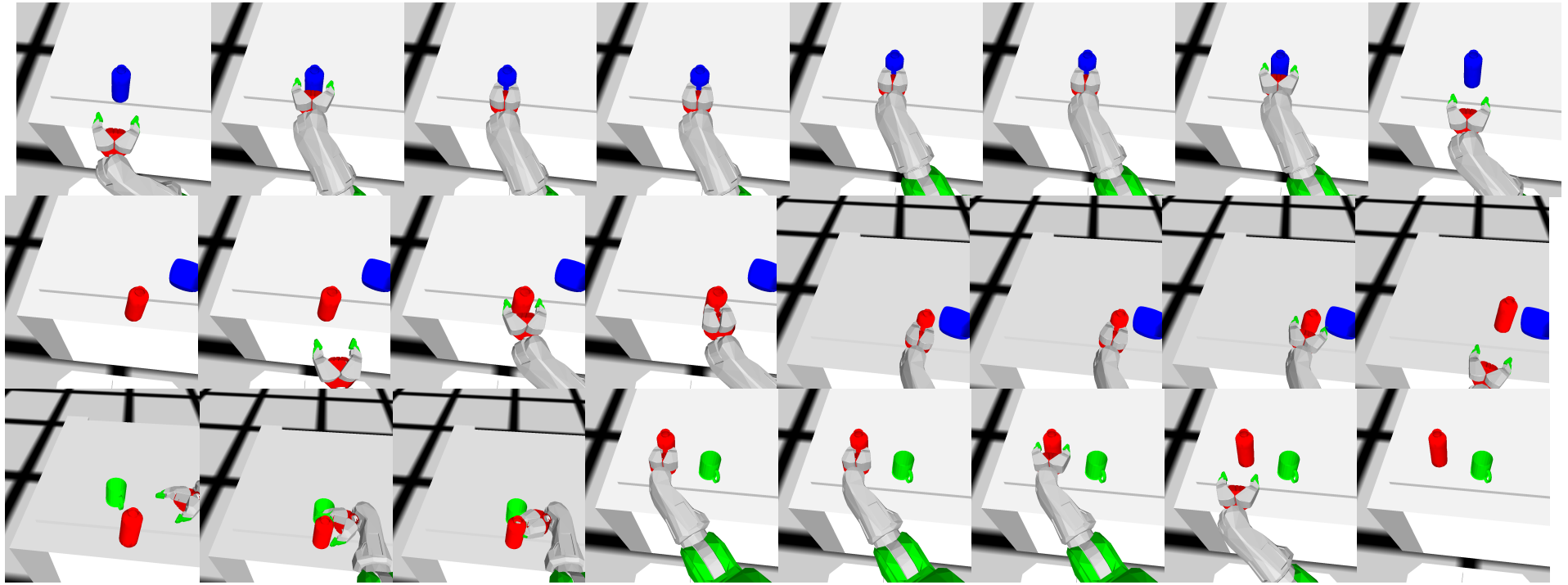


~5000 sequences in the training set



Simulation in the Unreal Engine

Semantically-Modulated Joint Episodic-Procedural Associative Memory,
"Three Ways"

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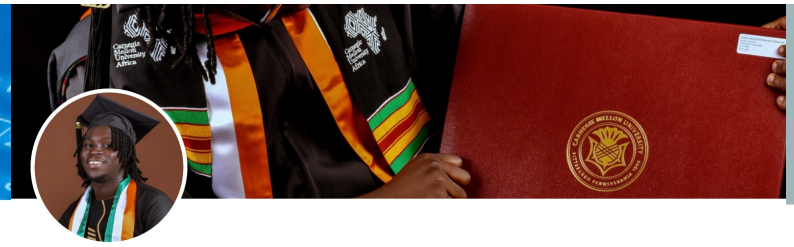

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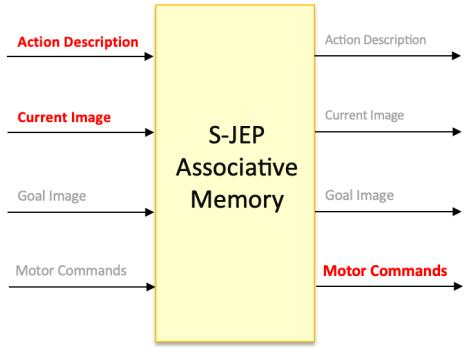
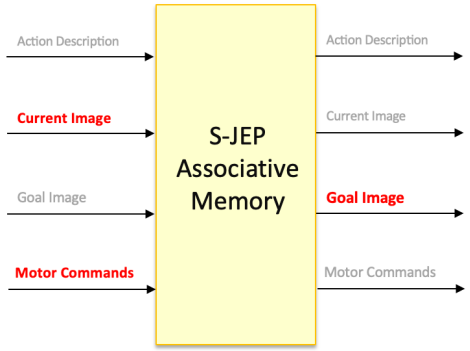
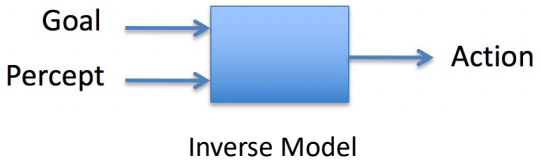
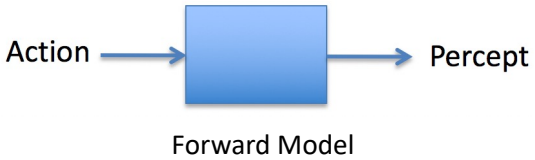
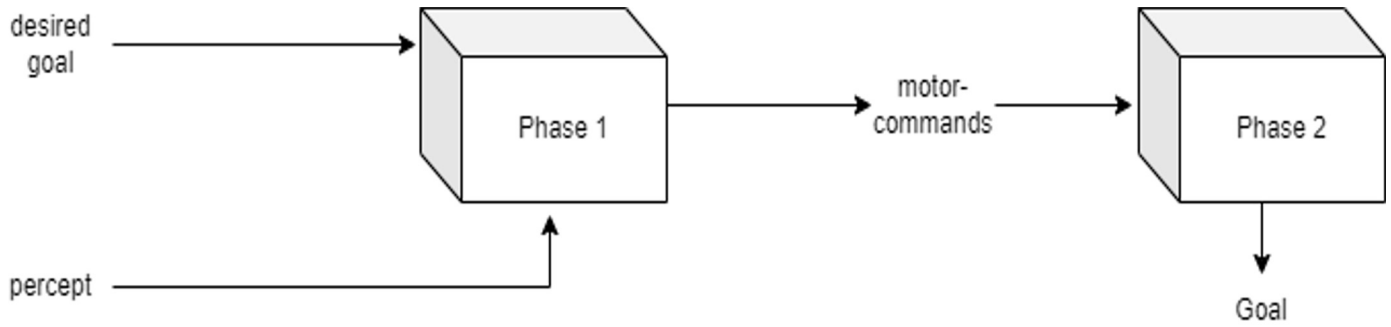
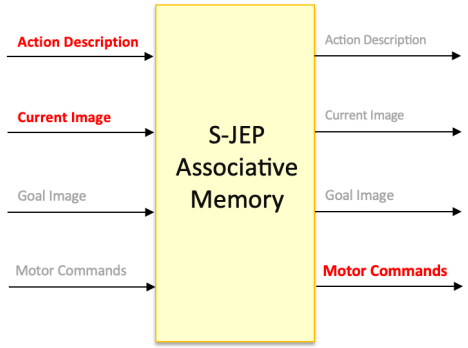




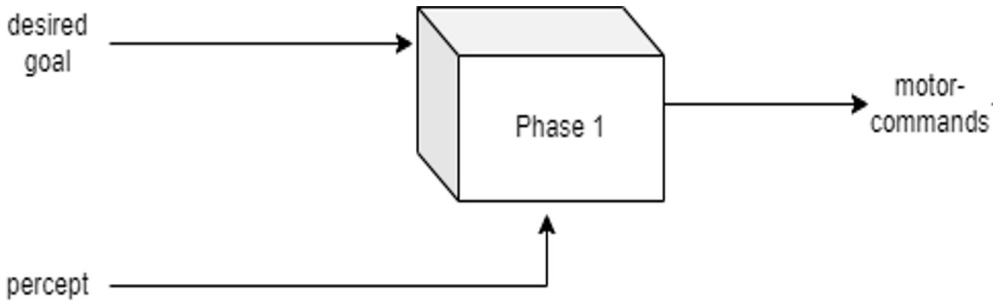








Inverse Model



Based on LAS (Listen, Attend, Spell) model (Chan et al. 2015)

and RT-1 Robotics Transformer (Brohan et al., 2022)

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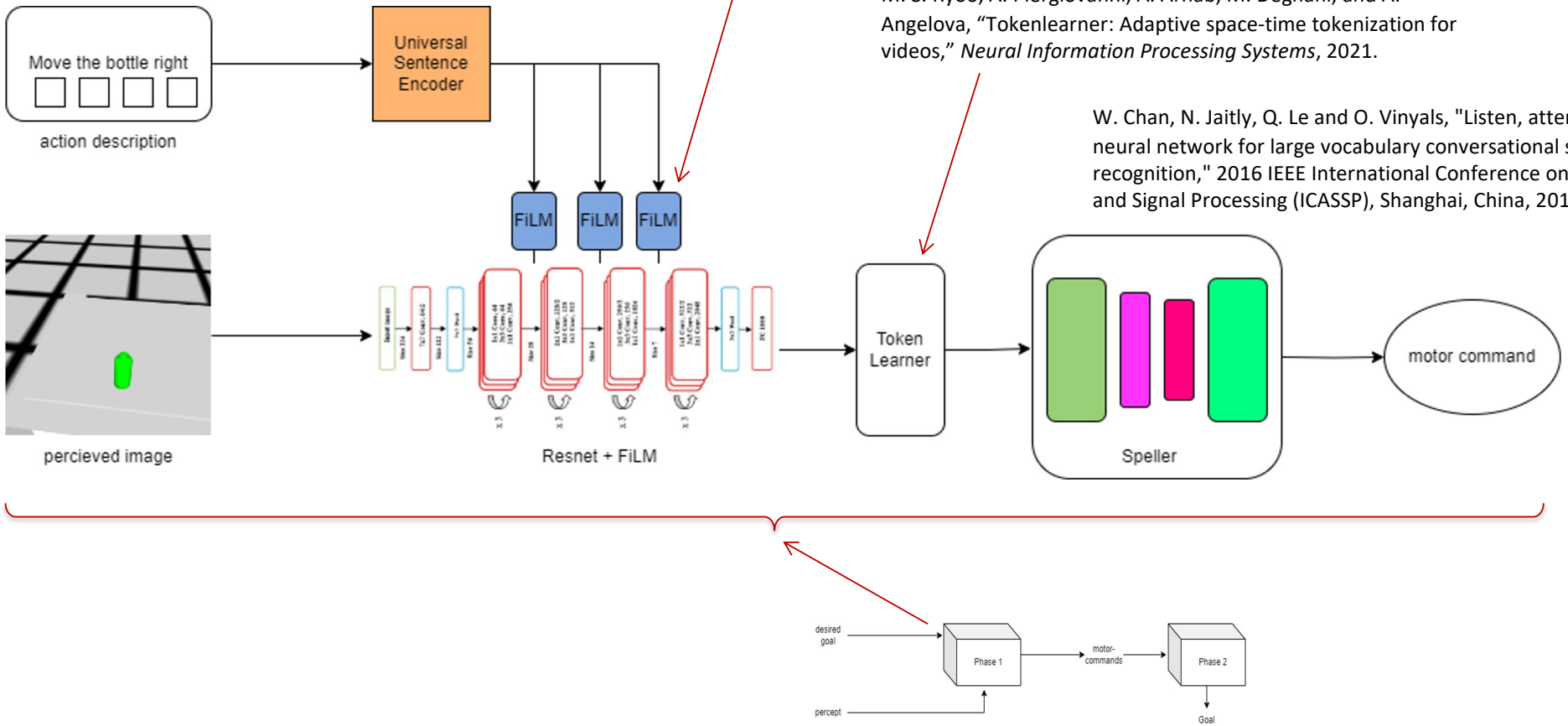
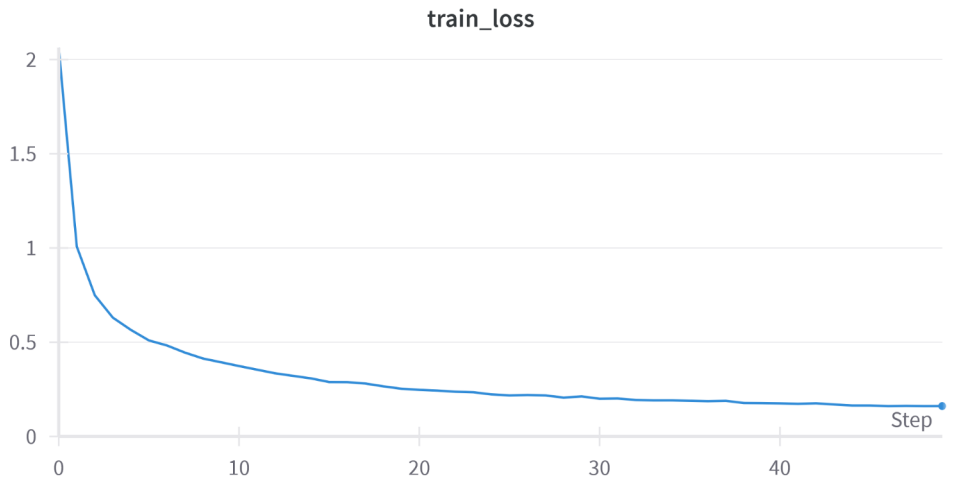
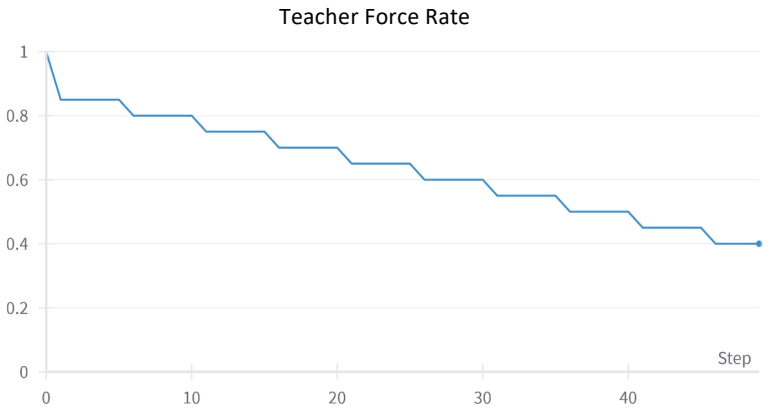
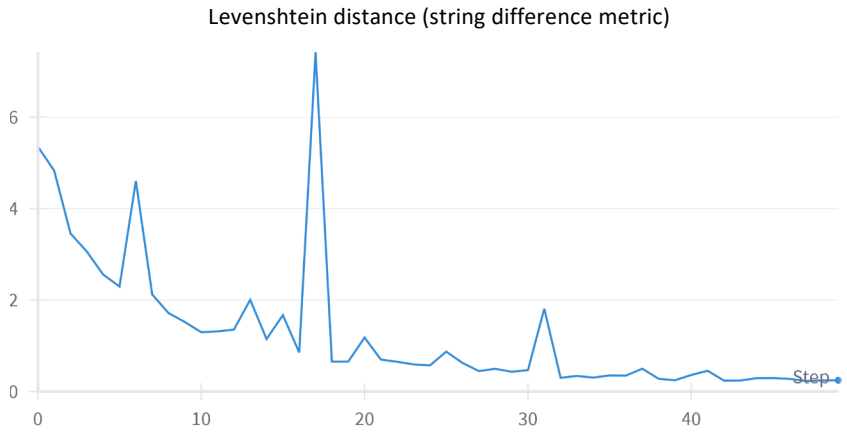




5000 data samples: 4750 samples for training, 250 samples for validation





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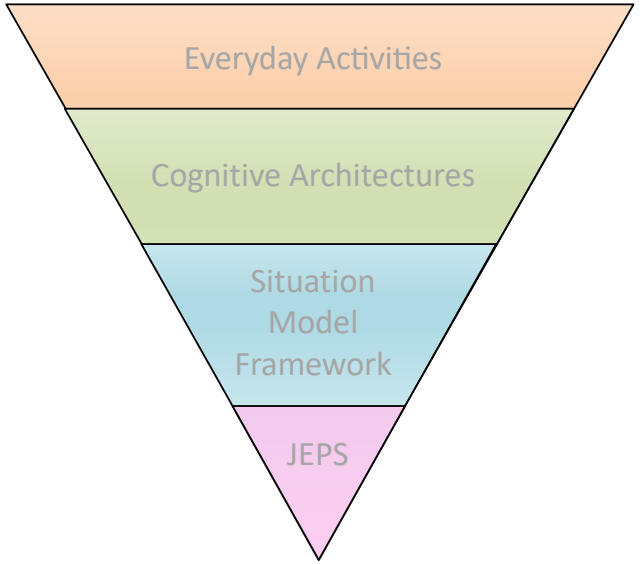
<object_specification>   ::=  “(” <object_type><object_color><object_pose>“)”
<object_type>            ::=  “:bottle” | “:bowl” | “:cereal” | “:cup” | “:fork’’ | “:knife” | “:milk” |
                              “:plate”
<object_pose>            ::=  “,*pose-1*” | “,*pose-2*” | “,*pose-3*” | “,*pose-4*” | “,*pose-5*”
<object_color>           ::=  “red” | “blue” | “green” | “default_color’’
<transformation>         ::=  “#'*backward-transformation*” | #'*forward-transformation*’ |
                              “#'*leftward-transformation*’ | “#'*rightward-transformation*’ |
                              “#'*on-transformation*”
```

truth	pred
:CUPREDPOSE-10:GLOVEREDPOSE-1:CUP#'*forward-transformation*:GLOVE	:CUPREDPOSE-10:GLOVEREDPOSE-1:CUP#'*forward-transformation*:GLOVE
:CEREALGREENPOSE-10:CEREAL#'*rightward-transformation*:CEREAL	:CEREALGREENPOSE-10:CEREAL#'*rightward-transformation*:CEREAL
:KNIFEREDPOSE-14:SPATULABLUEPOSE-11:KNIFE#'*forward-transformation*:SPATULA	:KNIFEREDPOSE-14:SPATULABLUEPOSE-11:KNIFE#'*forward-transformation*:SPATULA
:KNIFEGREENPOSE-8:SPATULABLUEPOSE-1:KNIFE#'*rightward-transformation*:SPATULA	:KNIFEGREENPOSE-8:SPATULABLUEPOSE-1:KNIFE#'*rightward-transformation*:SPATULA
:KNIFEGREENPOSE-13:FORKREDPOSE-12:KNIFE#'*backward-transformation*:FORK	:KNIFEGREENPOSE-13:FORKREDPOSE-12:KNIFE#'*backward-transformation*:FORK
:BOTTLEREDPOSE-6:POTBLUEPOSE-2:BOTTLE#'*backward-transformation*:POT	:BOTTLEREDPOSE-6:POTBLUEPOSE-2:BOTTLE#'*backward-transformation*:POT
:FORKGREENPOSE-13:MONDAMINBLUEPOSE-11:FORK#'*backward-transformation*:MONDAMIN	:FORKGREENPOSE-13:MONDAMINBLUEPOSE-11:FORK#'*backward-transformation*:MONDAMIN
:MILKGREENPOSE-8:FORKBLUEPOSE-5:MILK#'*backward-transformation*:FORK	:MILKGREENPOSE-8:FORKBLUEPOSE-5:MILK#'*backward-transformation*:FORK
:FORKBLUEPOSE-7:BLUE-METAL-PLATEGREENPOSE-3:FORK#'*forward-transformation*:BLUE-METAL-PLATE	:FORKBLUEPOSE-7:BLUE-METAL-PLATEGREENPOSE-3:FORK#'*forward-transformation*:BLUE-METAL-PLATE
:CEREALREDPOSE-10:BOWLGREENPOSE-2:CEREAL#'*forward-transformation*:BOWL	:CEREALREDPOSE-10:BOWLGREENPOSE-2:CEREAL#'*forward-transformation*:BOWL

Overview

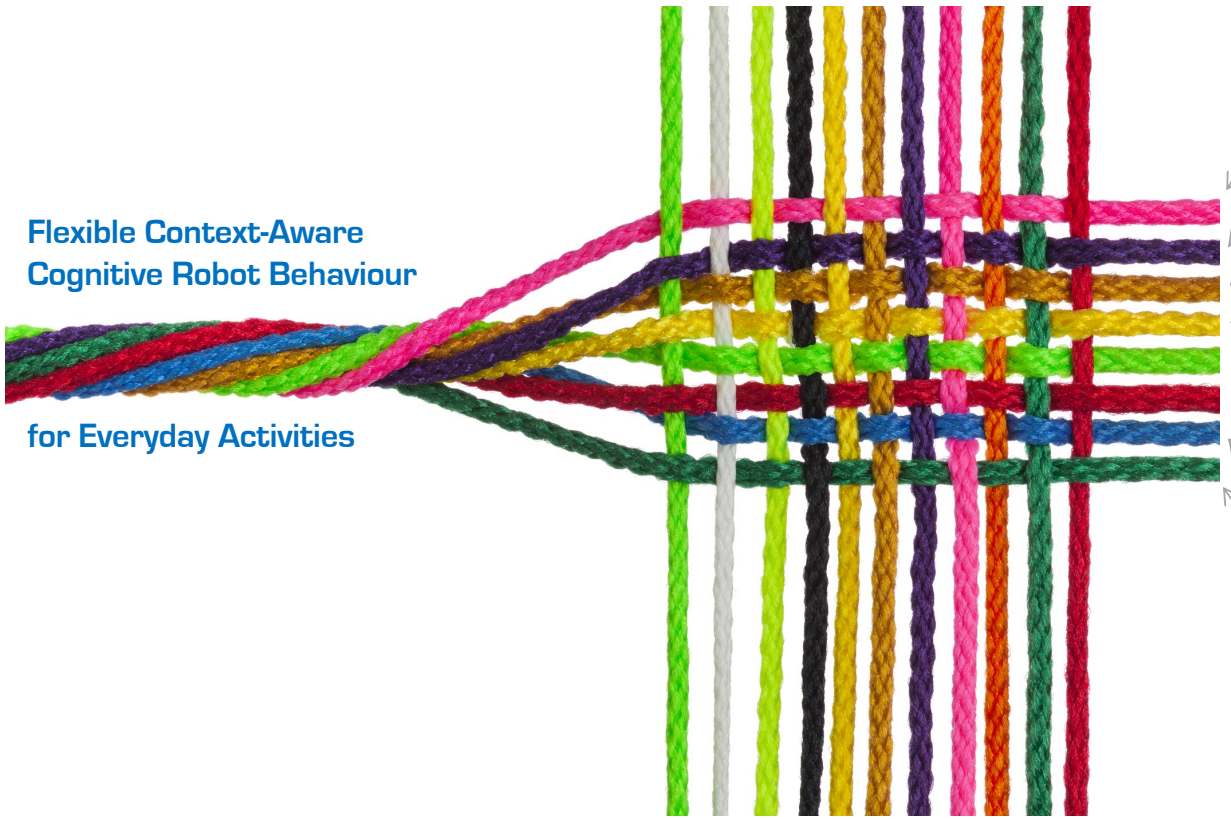
1. Everyday activities: easy & difficult vs. simple vs complex
2. Cognitive Architectures
   - CRAM
   - Extending CRAM
3. The Situation Model Framework (SMF)
   - Behavioral episodes
   - Two-system approach
4. Joint Episodic-Procedural-Semantic Memory (JEPS)



We're there!

Robot Cognitive Architectures

Flexible Context-Aware Cognitive Robot Behaviour for Everyday Activities



https://fashion-history.lovetoknow.com/fabrics-fibers/weave-types

- System 1 for Habitual Action
- System 2 for Deliberative Action
- Working Memory (for Recombination)
- Internal Attention (for Recall)
- Internal Simulation (for Prospection)
- Factorized Motor Commands
- Semantic Modulation (for Goals and Recombination)
- Episodic-Procedural Associative Memory

Acknowledgements

Special thanks to

Favour Aderinto[5]
Josefine Albert[2, 3]
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Abrham Gebreselasie[5]
Medhin Hadush[5]
Gayane Kazhoyan[1]
Cédric Manouan[5]
Arisema Mihretu[5]
Denis Musinguzi[5]
Helge Ritter[4]
Werner X. Schneider[2, 3]

1. Institute for Artificial Intelligence, University of Bremen, Germany
2. Center for Interdisciplinary Research (ZiF), Bielefeld University, Germany
3. Neuro-cognitive Psychology, Department of Psychology, Bielefeld University, Germany
4. Center for Cognitive Interaction Technology (CITEC), Bielefeld University, Germany
5. Carnegie Mellon University Africa, Rwanda

Cognitive Robotics

An introductory course for the IEEE Robotics and Automation Society Technical Committee for Cognitive Robotics

Instructors: send an email to request the complete set of PowerPoint slides. Example code is available on Github.
If you already have a copy, check the Version History to make sure you have the most recent version. If you don't, please send an email to request it.

A PR2 robot pours popcorn from a saucepan (left) and sets a table (right) during demonstrations of cognitively-enabled robot manipulation using CRAM.
Image courtesy of the Everyday Activity Science and Engineering (EASE) interdisciplinary research center at the University of Bremen, Germany.

Cognitive Robotics

"The word cognition derives from the Latin verb *cognosco*, a composition of *con* (meaning related to) and *gnosco* (to know). Cognitive robotics, then, is the branch of robotics where knowledge plays a central role in supporting action selection, execution, and understanding.

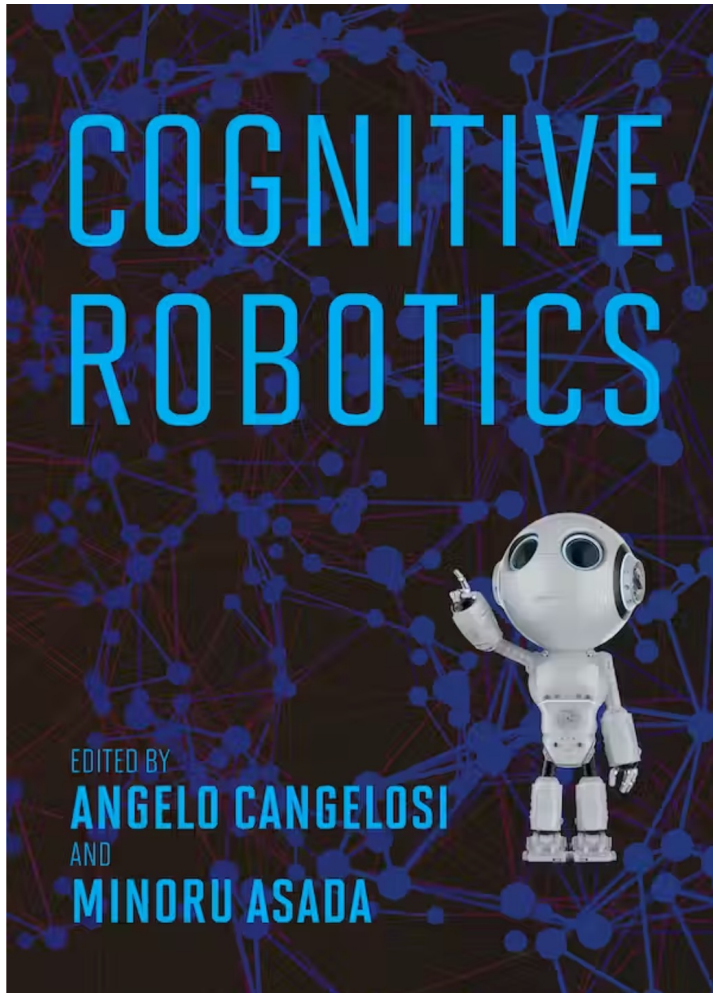
It focuses on designing and building robots that have the ability to learn from experience and from others, commit relevant knowledge and skills to memory, retrieve them as the context requires, and flexibly use this knowledge to select appropriate actions in the pursuit of their goals, while anticipating the outcome of those actions when doing so.

Cognitive robots can use their knowledge to reason about their actions and the actions of those with whom they are interacting, and thereby modify their behavior to improve their overall long-term effectiveness.

In short, cognitive robots are capable of flexible, context-sensitive action, knowing what they are doing and why they are doing it."

Sandini, G., Sciutti, A., and Vernon, D. (2021) "Cognitive Robotics", In Ang M., Khatib O., Siciliano B. (eds), *Encyclopedia of Robotics* . Springer, Berlin, Heidelberg.

www.CognitiveRobotics.net



A. Cangelosi and M. Asada (Eds.), Cognitive Robotics. MIT Press 2022.

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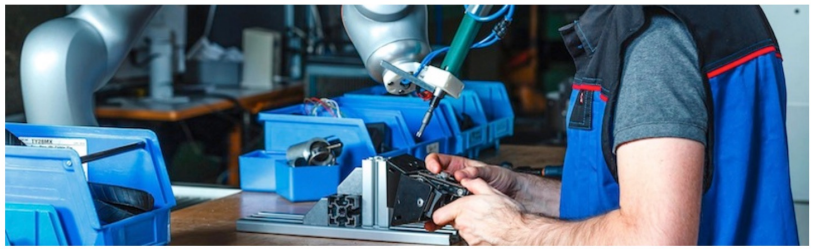
Scope

There is growing need for robots that can interact safely with people in everyday situations. These robots have to be able to anticipate the effects of their own actions as well as the actions and needs of the people around them.



(Image courtesy of Fraunhofer IPA)

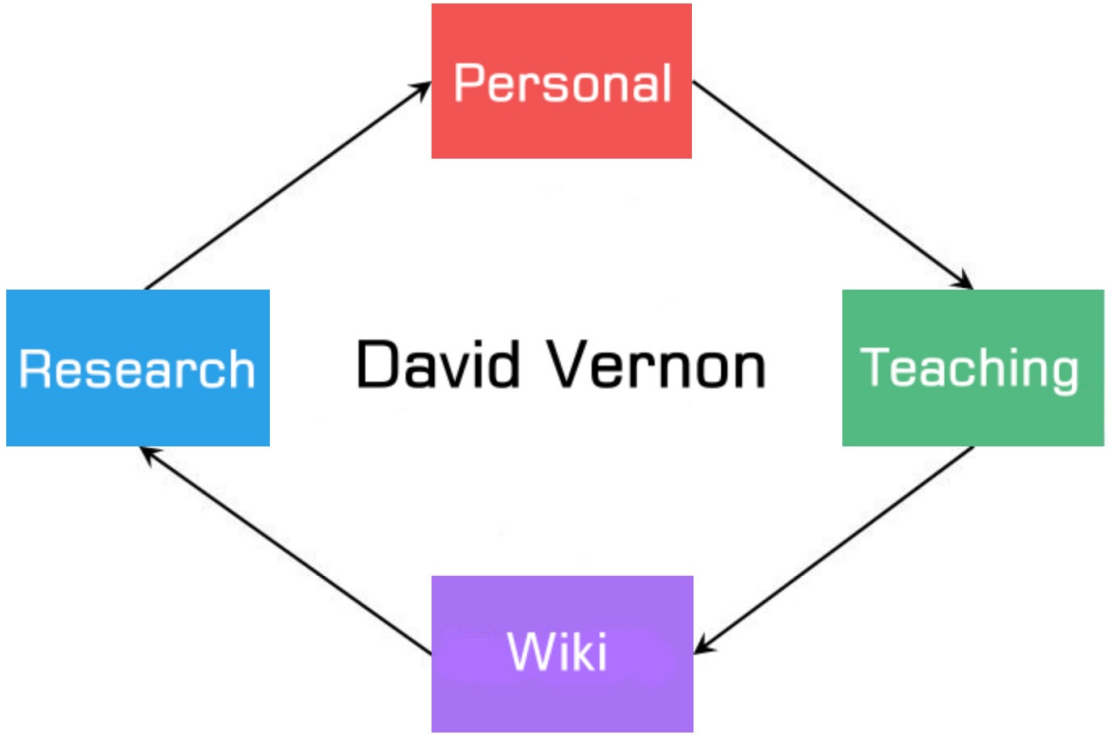
To achieve this, two streams of research need to merge, one concerned with physical systems specifically designed to interact with unconstrained environments and another focussing on control architectures that explicitly take into account the need to acquire and use experience.

The merging of these two areas has brought about the field of *Cognitive Robotics*. This is a multi-disciplinary science that draws on research in adaptive robotics as well as cognitive science and artificial intelligence, and often exploits models based on biological cognition.

Cognitive robots achieve their goals by perceiving their environment, paying attention to the events that matter, planning what to do, anticipating the outcome of their actions and the actions of other agents, and learning from the resultant interaction. They deal with the inherent uncertainty of natural environments by continually learning, reasoning, and sharing their knowledge.

Committee News

www.ieee-coro.org



david@vernon.eu
www.vernon.eu

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Abu Dhabi 2023
iCAR
21st International Conference on Advanced Robotics

Abu Dhabi, UAE
6th December 2023

The Situation Model Framework for Cognitive Behavior: Implications for the Design of Robot Cognitive Architectures

David Vernon
Carnegie Mellon University Africa

www.vernon.eu

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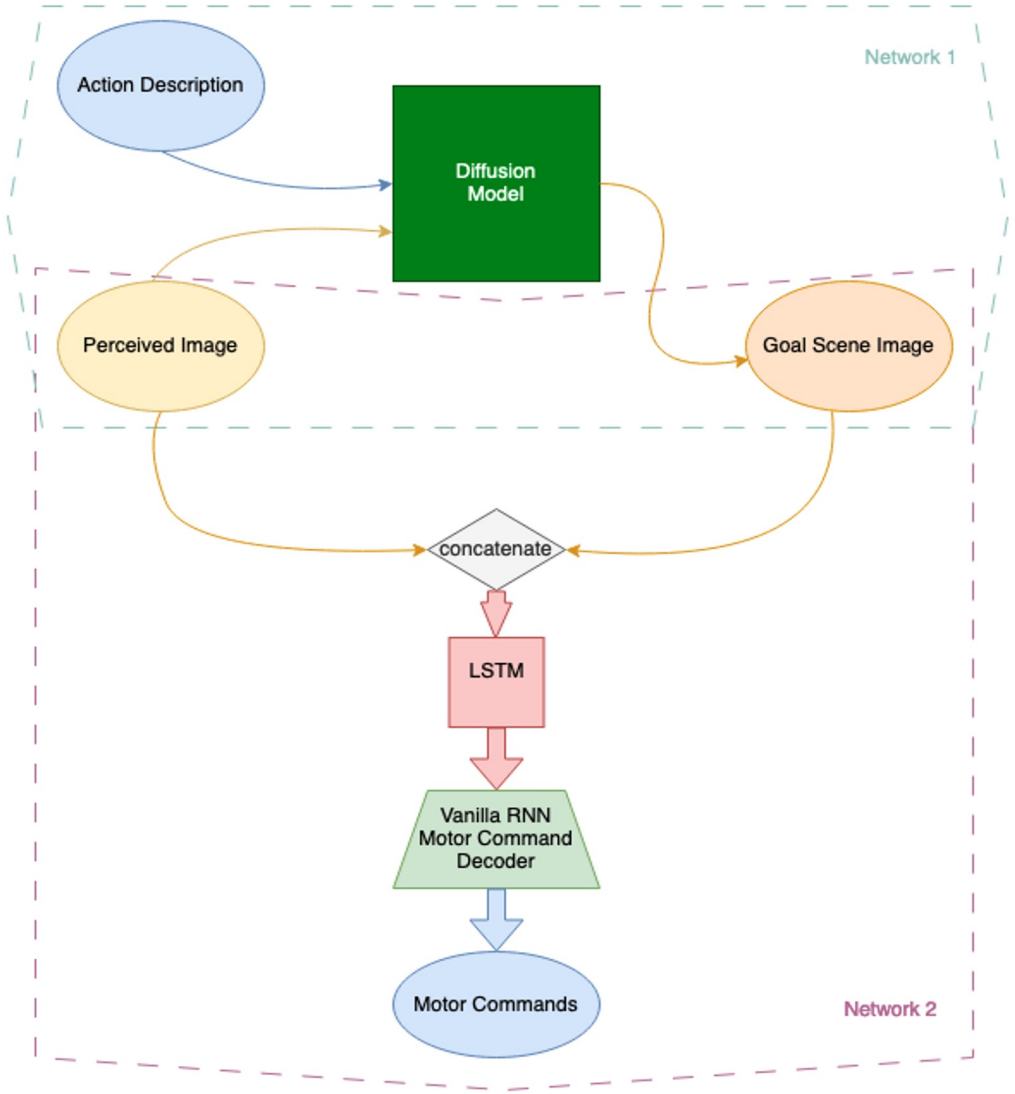
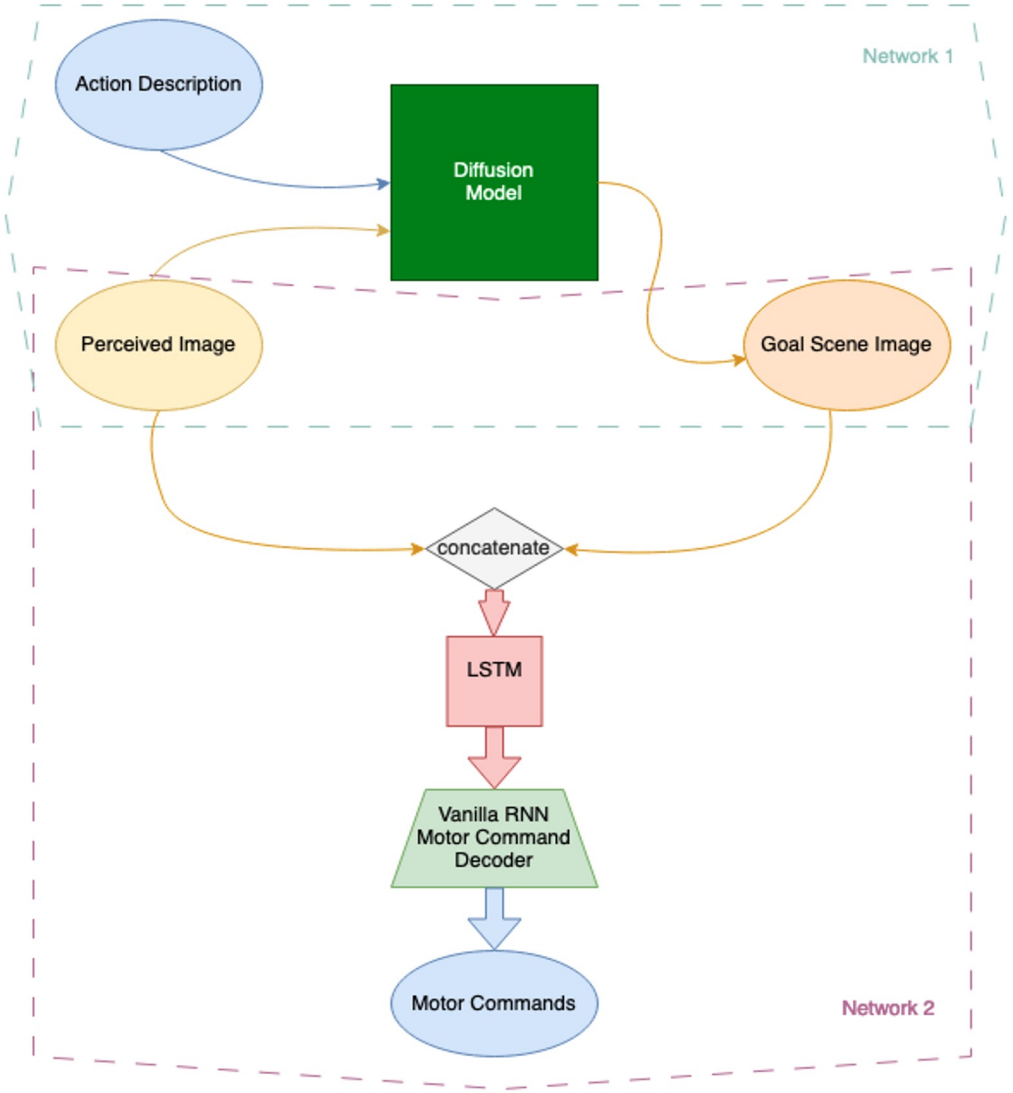
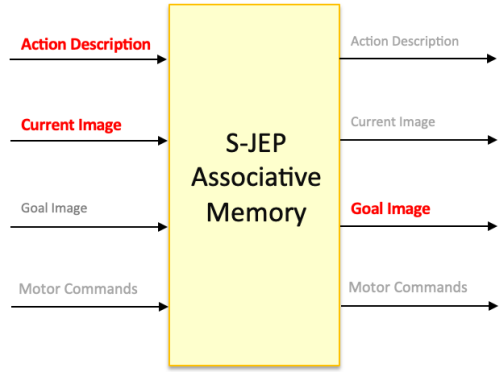
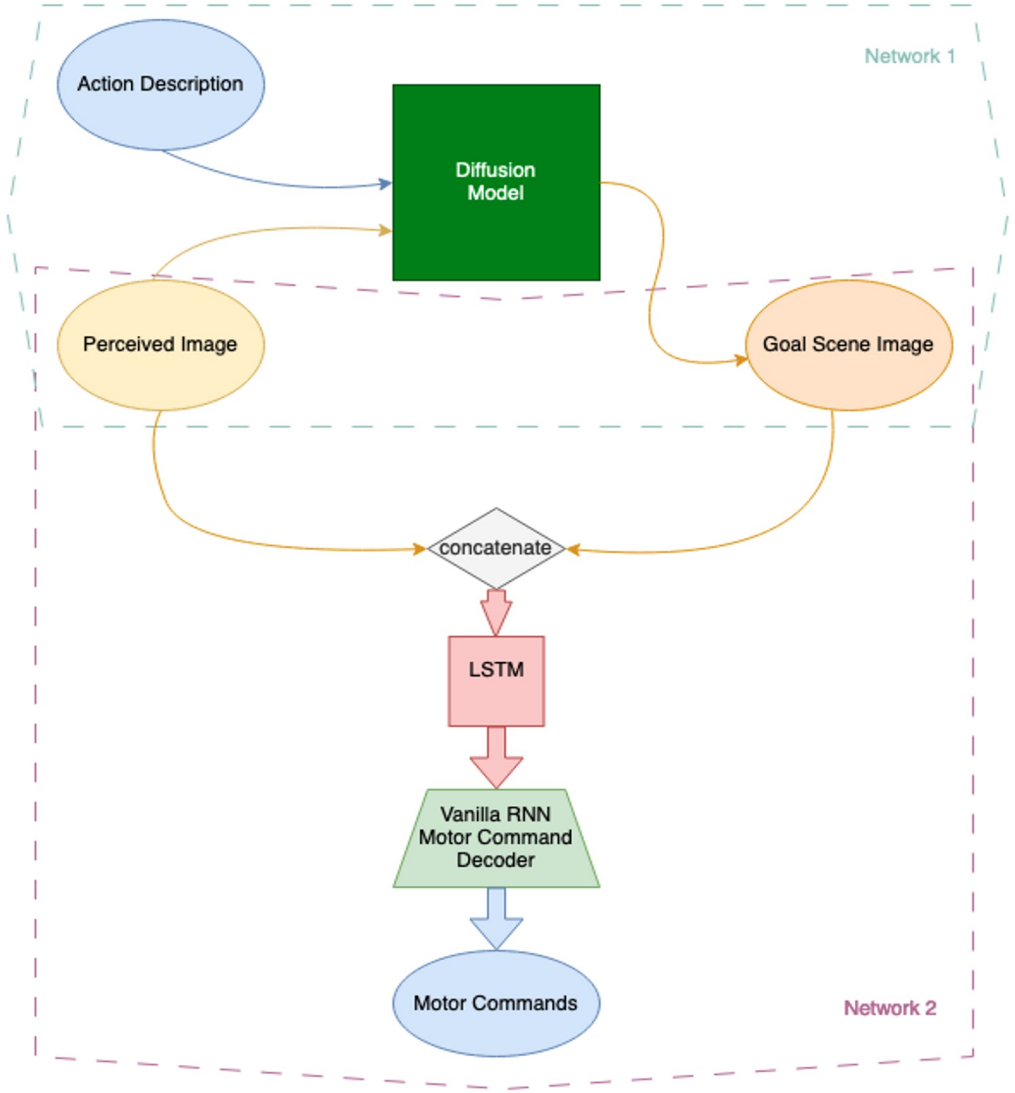

Network 1
Action Description
Diffusion Model
Perceived Image
Goal Scene Image
concatenate
LSTM
Vanilla RNN Motor Command Decoder
Motor Commands
Network 2


Network 1
Action Description
Diffusion Model
Perceived Image
Goal Scene Image
concatenate
LSTM
Vanilla RNN Motor Command Decoder
Motor Commands
Network 2

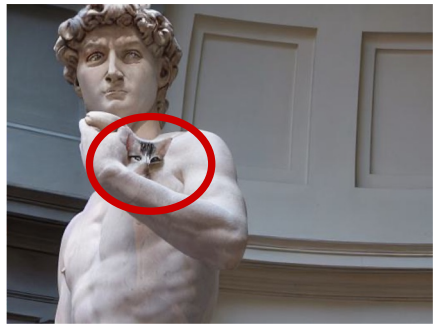

Action Description
Current Image
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Current Image
Goal Image
Motor Commands



Network 1: Instruct Pix2Pix

Based on Stable Diffusion model
Input: image & editing instruction
Output: edited image

Make David hold a cat



Stable Diffusion

First, the image x is encoded by a variational autoencoder into a latent representation z

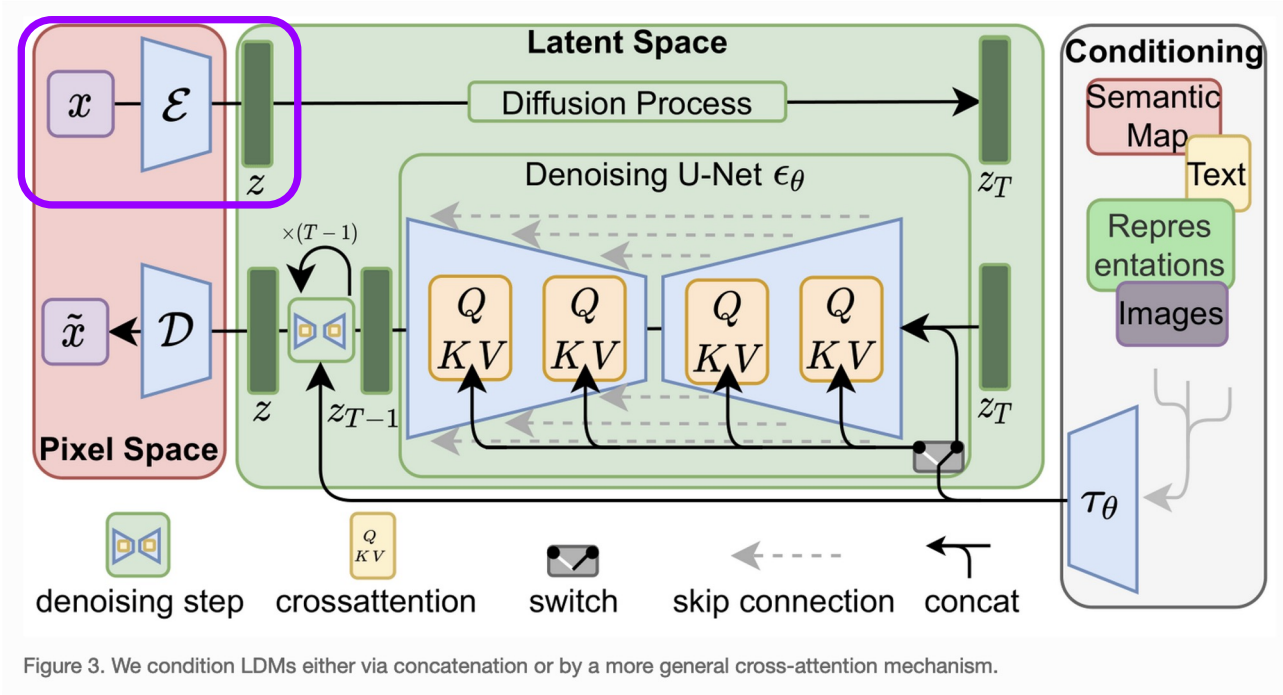


Figure 3. We condition LDMs either via concatenation or by a more general cross-attention mechanism.

Stable Diffusion

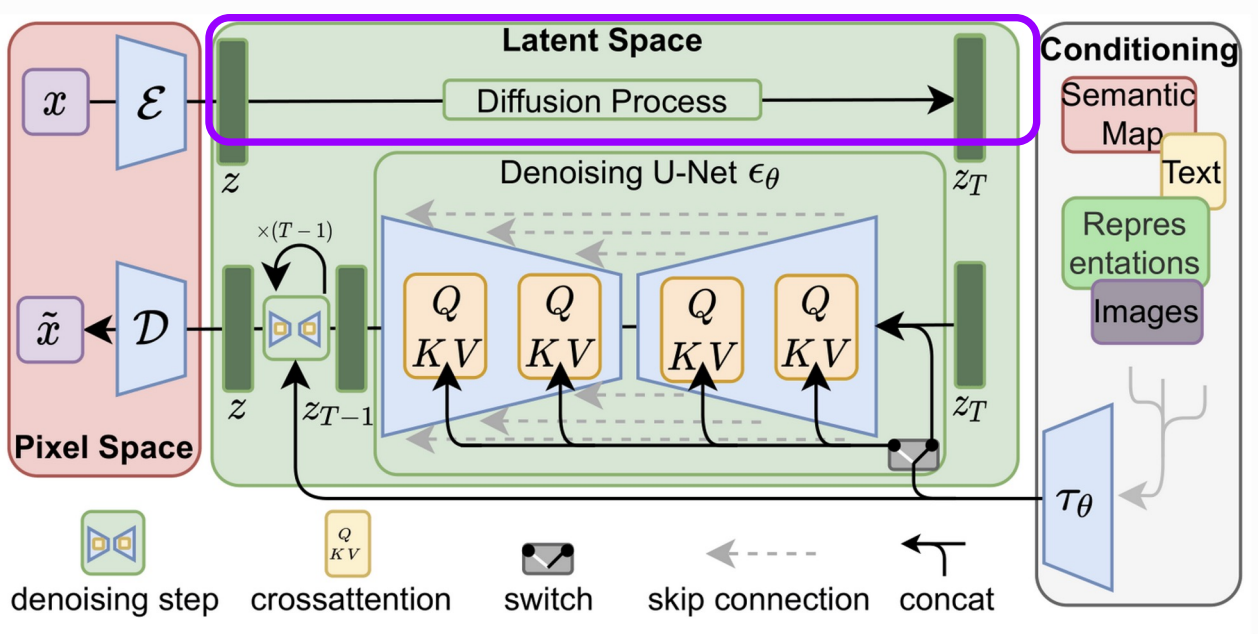


Figure 3. We condition LDMs either via concatenation or by a more general cross-attention mechanism.

The latent representation z then goes through a diffusion process which adds Gaussian noise incrementally for a total of T time steps to produce z_T the diffused version of z

Stable Diffusion

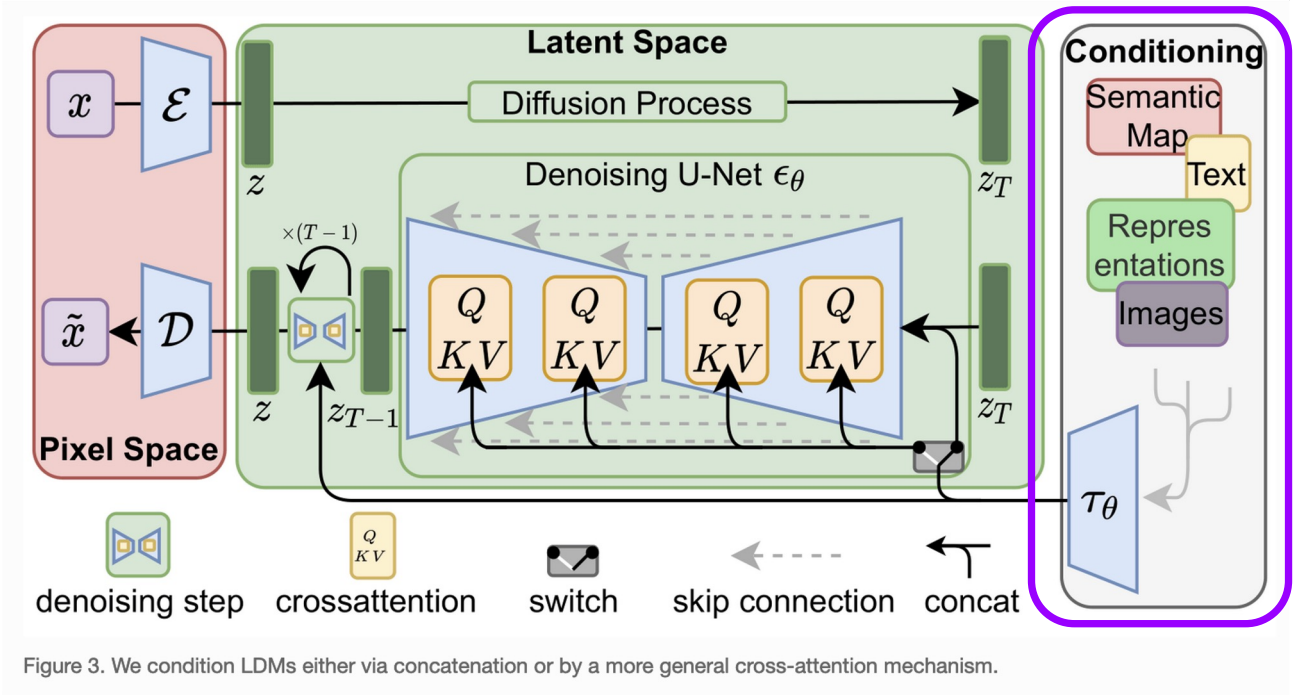


Figure 3. We condition LDMs either via concatenation or by a more general cross-attention mechanism.

The textual editing instructions in the Instruct Pix2Pix model is then encoded by a CLIP text model to obtain the text features that will condition the denoising process in the next step

SOURCE: R. Rombach, A. Blattmann, D. Lorenz, P. Esser, and B. Ommer, "High-resolution image synthesis with latent diffusion models," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2022. [Online]. Available: https://github.com/CompVis/latent-diffusionhttps://arxiv.org/abs/2112.10752

Stable Diffusion

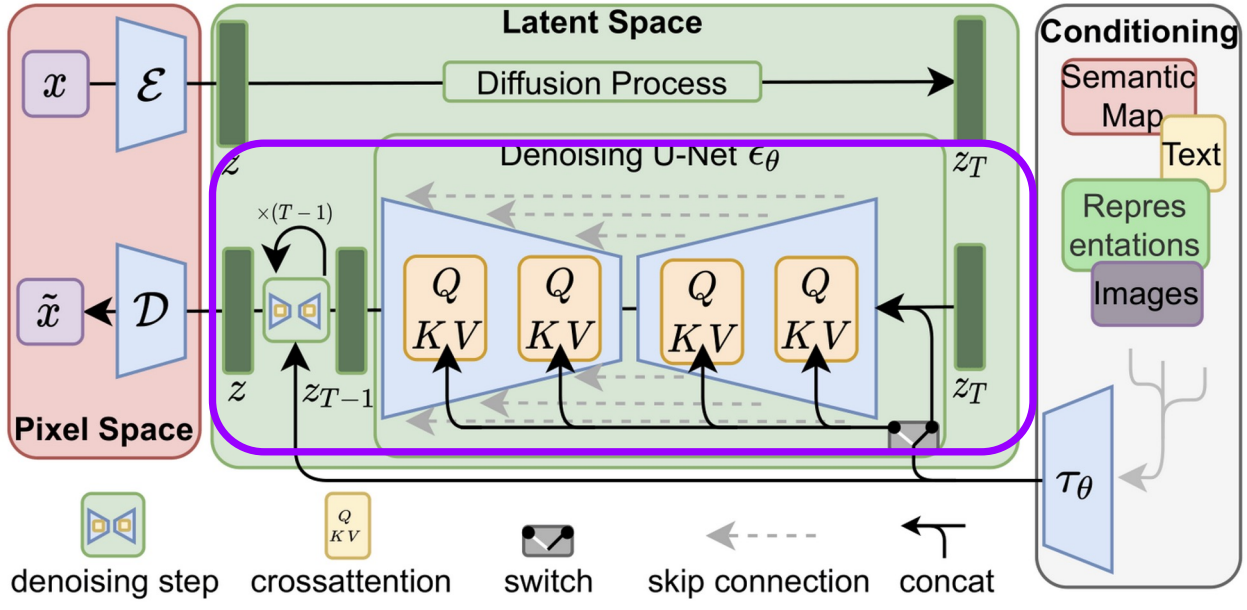


Figure 3. We condition LDMs either via concatenation or by a more general cross-attention mechanism.

The diffused latent space representation z_T, along with the tokenized conditioning text, is then processed through a U-net that denoises the latent space representation z_T conditioned by the extracted textual information, for a total T timesteps to produce the denoised latent representation z

Stable Diffusion

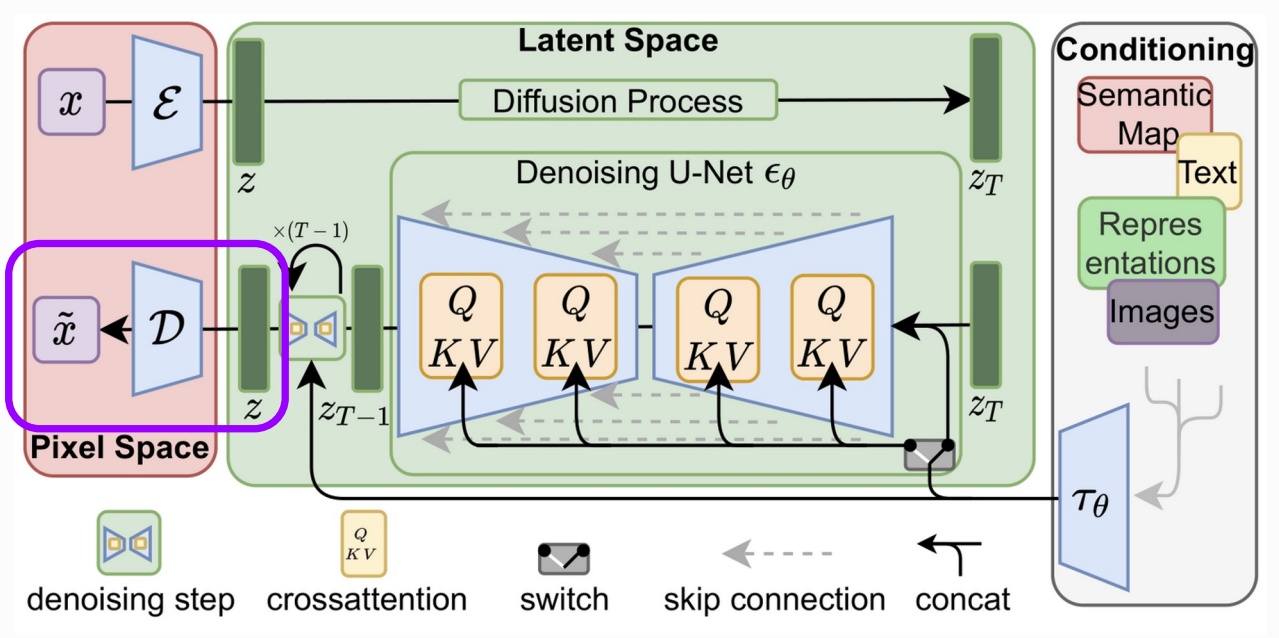
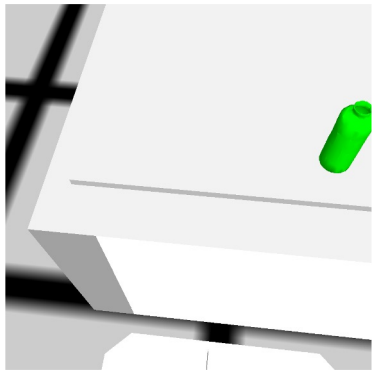


Figure 3. We condition LDMs either via concatenation or by a more general cross-attention mechanism.

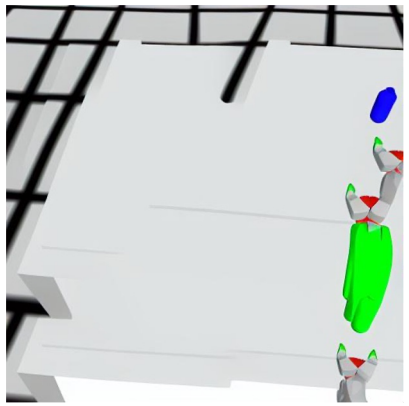
Finally, the denoised latent representation z is decoded by a Variational Autoencoder's decoder into the final image $\tilde{x}$

This final image is then compared to the goal image in our data and the error is back-propagated through the U-net model

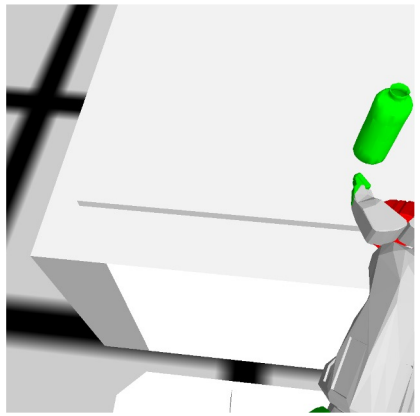
SOURCE: R. Rombach, A. Blattmann, D. Lorenz, P. Esser, and B. Ommer, "High-resolution image synthesis with latent diffusion models," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2022. [Online]. Available: https://github.com/CompVis/latent-diffusionhttps://arxiv.org/abs/2112.10752



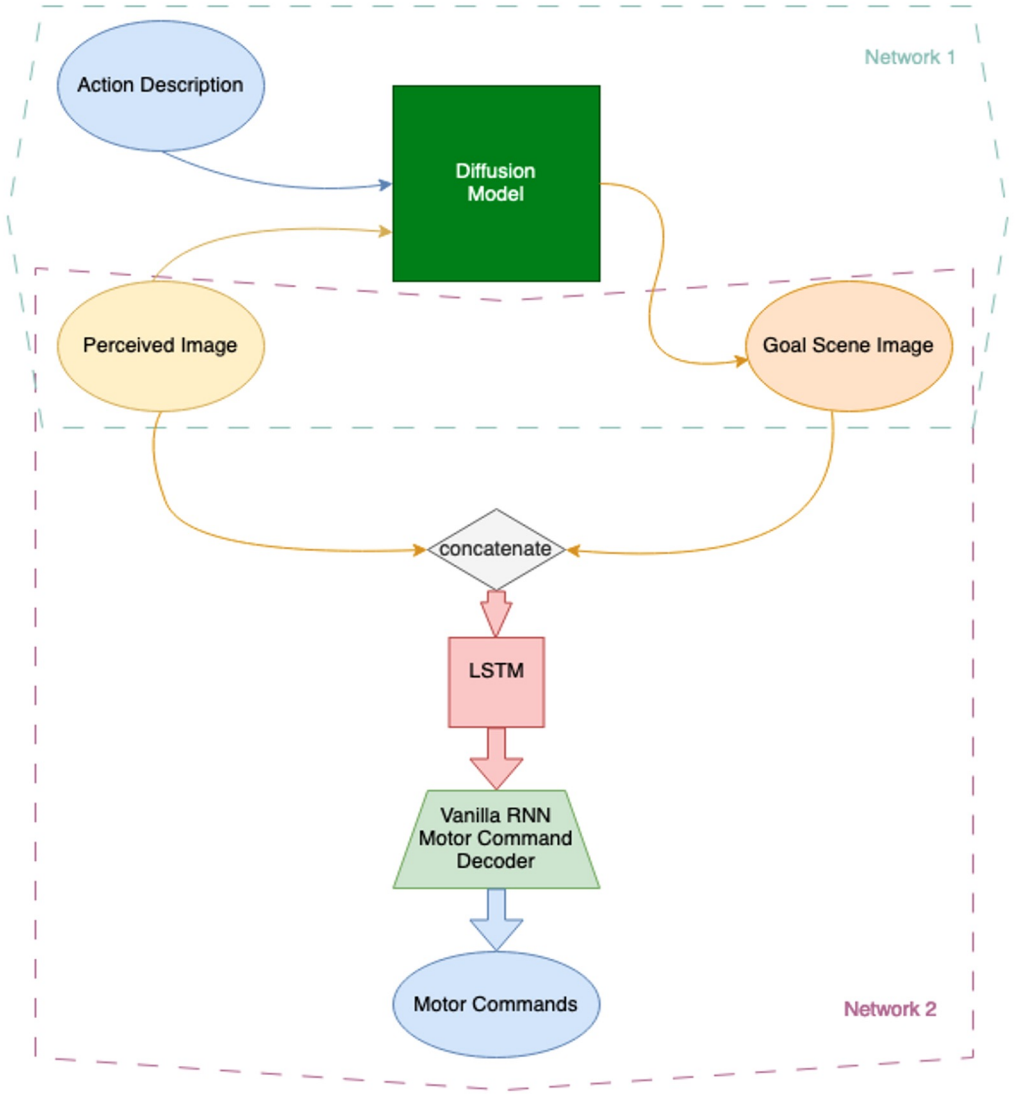
"Shift the bottle backwards"

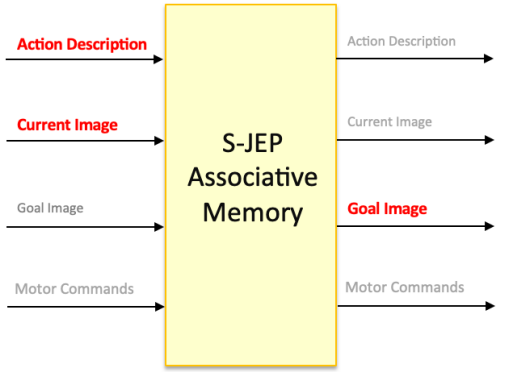


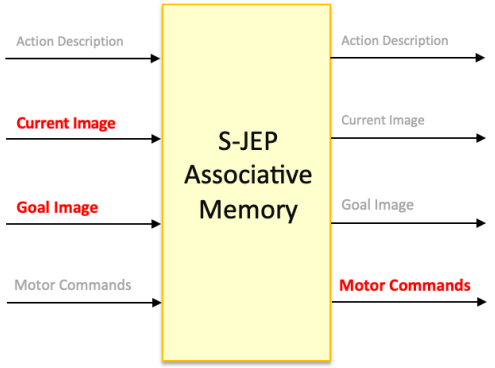
Generated Goal Scene

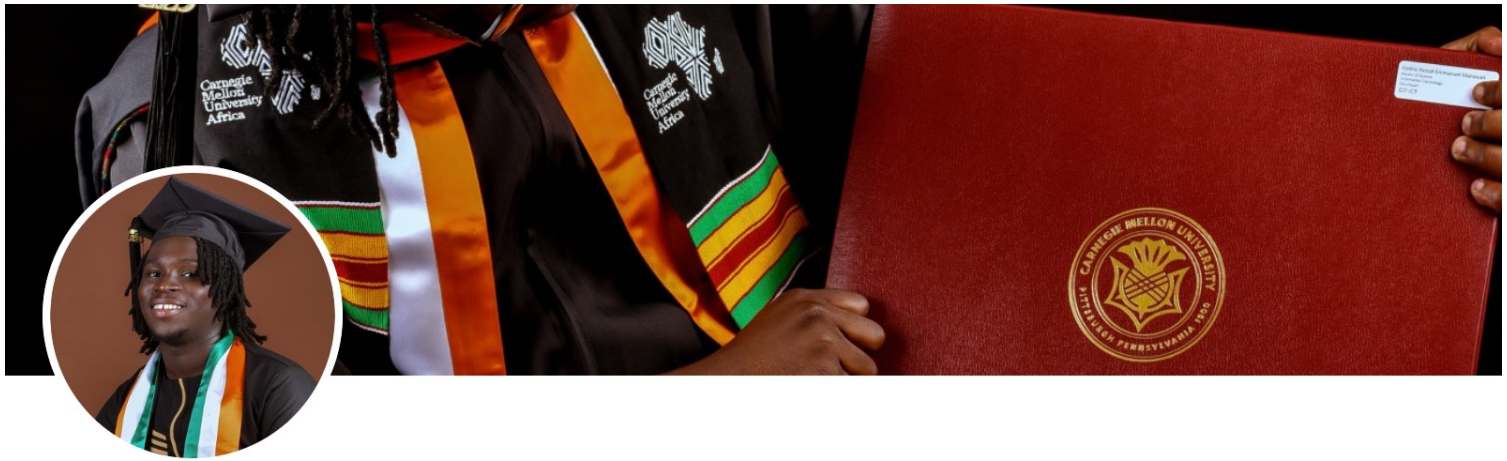


Original Goal Scene


Network 1
Action Description
Diffusion Model
Perceived Image
Goal Scene Image
concatenate
LSTM
Vanilla RNN Motor Command Decoder
Motor Commands
Network 2


Action Description
Current Image
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Current Image
Goal Image
Motor Commands


Action Description
Current Image
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Current Image
Goal Image
Motor Commands



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Deep Learning Research & Engineering | Language Technologies

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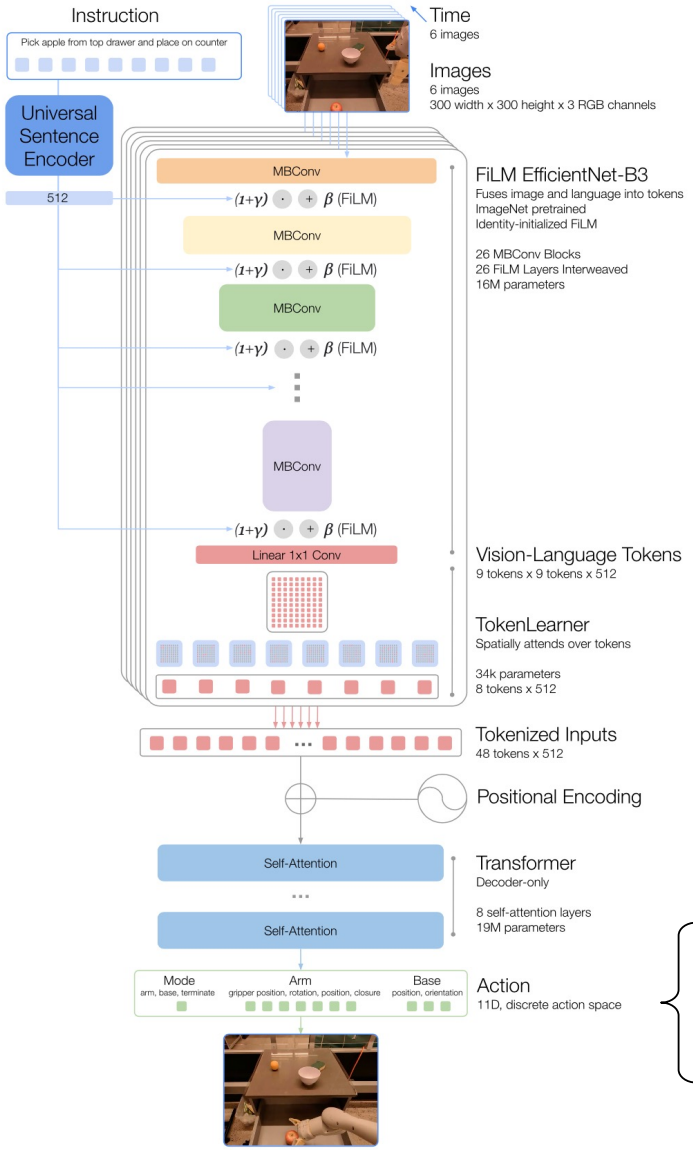
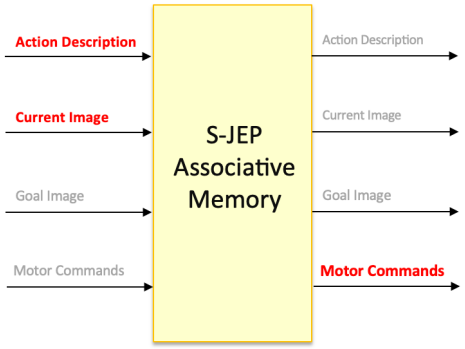
RT-1 Robotics Transformer
(Brohan et al., 2022)

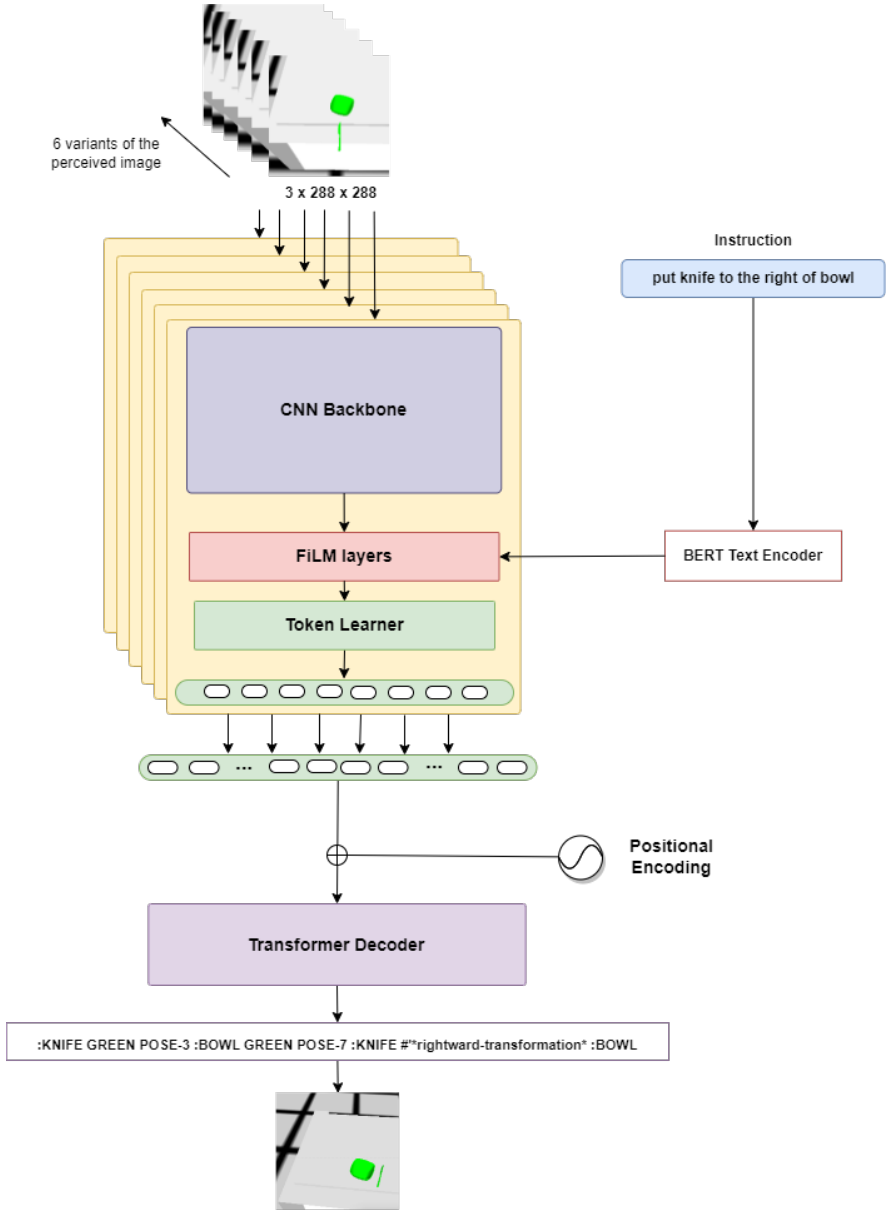
Also RT-2 (VLA) Vision-Language-Action model
(Brohan et al., 2023)



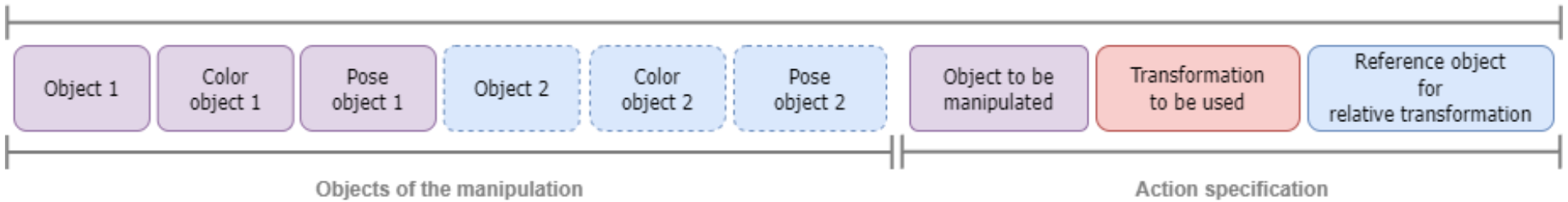
Arm: x, y, z, roll, pitch, yaw, opening of the gripper
Base: x, y, yaw
Mode: controlling the arm, the base, or terminating
(8 bits each)

RT1-CRAM


Action Description
Current Image
Goal Image
Motor Commands
S-JEP Associative Memory
Action Description
Current Image
Goal Image
Motor Commands


6 variants of the perceived image
3 x 288 x 288
Instruction
put knife to the right of bowl
CNN Backbone
FiLM layers
BERT Text Encoder
Token Learner
Positional Encoding
Transformer Decoder
:KNIFE GREEN POSE-3 :BOWL GREEN POSE-7 :KNIFE #"*rightward-transformation* :BOWL

<motor_program>	::=	“(motor-program `(”{<object_specification>} “)” <object_type><transformation><object_type>“)”
<object_specification>	::=	“(” <object_type><object_color><object_pose>“)”
<object_type>	::=	“:bottle” | “:bowl” | “:cereal” | “:cup” | “:fork’’ | “:knife” | “:milk” | “:plate”
<object_pose>	::=	“,*pose-1*” | “,*pose-2*” | “,*pose-3*” | “,*pose-4*” | “,*pose-5*”
<object_color>	::=	“red” | “blue” | “green” | “default_color’’
<transformation>	::=	“#'*backward-transformation*” | #'*forward-transformation*’ | “#'*leftward-transformation*’ | “#'*rightward-transformation*’ | “#'*on-transformation*”



Action description "Put the cup in front of the cereal"

Motor commands ":CUP DEFAULT_COLOR *POSE-1* :CEREAL DEFAULT_COLOR *POSE-2* :CUP #'*forward-transformation* :CEREAL"

Epoch #212

[Train]

Action desc : **put the knife on top of blue-metal-plate**

Predicted : :CUP BLUE <POSE> :BLUE-METAL-PLATE :PLATE RED POSE-1 :KNIFE #'*rightward-transformation* :BLUE-METAL-PLATE

Actual : :KNIFE BLUE POSE-7 :BLUE-METAL-PLATE RED POSE-1 :KNIFE #'*on-transformation* :BLUE-METAL-PLATE

[Val]

Action desc : **shift the bowl forwards**

Predicted : :BOWL BLUE POSE-11 :BOWL #'*leftward-transformation* :BOWL

Actual : :BOWL GREEN POSE-11 :BOWL #'*forward-transformation* :BOWL

Epoch #213

[Train]

Action desc **: put the bowl to the right of fork**

Predicted : :BOWL GREEN POSE-10 :FORK BLUE POSE-2 :BOWL #'*rightward-transformation* :FORK

Actual : :BOWL GREEN POSE-10 :FORK RED POSE-2 :BOWL #'*rightward-transformation* :FORK

[Val]

Action desc : **put the bottle to the right of plate**

Predicted : :BOWL BLUE POSE-11 :BOWL #'*leftward-transformation* :BOWL

Actual : :BOTTLE GREEN POSE-7 :PLATE BLUE POSE-3 :BOTTLE #'*rightward-transformation* :PLATE

Vision-Language-Action Models [edit]

(Also see Large Language Models and Limitations of AI)

RT-1: Robotics Transformer for Real-World Control at Scale arXiv article on RT-1

Supplementary video for RT-1: Robotics Transformer for Real-World Control at Scale Video

RT-2: Vision-Language-Action Models Transfer Web Knowledge to Robotic Control arXiv article on RT-2

RT-2: Vision-Language-Action Models RT-2 website

RT-2: New model translates vision and language into action Google DeepMind Blog

Do As I Can, Not As I Say: Grounding Language in Robotic Affordances arXiv article on SayCan

Do As I Can, Not As I Say: Grounding Language in Robotic Affordances SayCan website

Open X-Embodiment: Robotic Learning Datasets and RT-X Models arXiv article on Open X-Embodiment

Open X-Embodiment: Robotic Learning Datasets and RT-X Models Open X-Embodiment Website

Using an LLM to direct our robot Digit Agility Robotics video

ChatGPT for Robotics: Design Principles and Model Abilities Microsoft article

http://www.vernon.eu/wiki/Links#Vision-Language-Action_Models