Prospection

David Vernon
Institute for Artificial Intelligence
University of Bremen

International Foundation of Robotics Research Robotics Global Colloquia

Robotics Colloquia

IFRR

Prospection

The capacity to anticipate the future

Prospection

Anticipation
Prediction
Intention
Planning
Simulation
Episodic future thinking
Future oriented cognition

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.

"The brain constantly attempts to anticipate future events"

Schulkin J. (2011). Social allostasis: anticipatory regulation of the internal milieu. *Frontiers in evolutionary neuroscience*, *2*, 111.

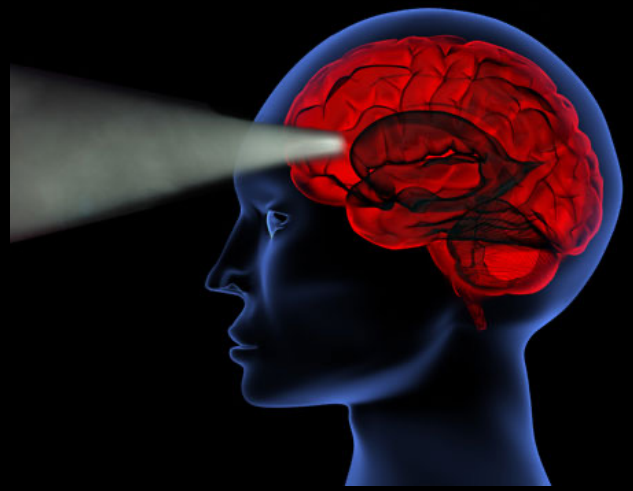
The Future

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

Timescale increases through cognitive development

Episodic Memory

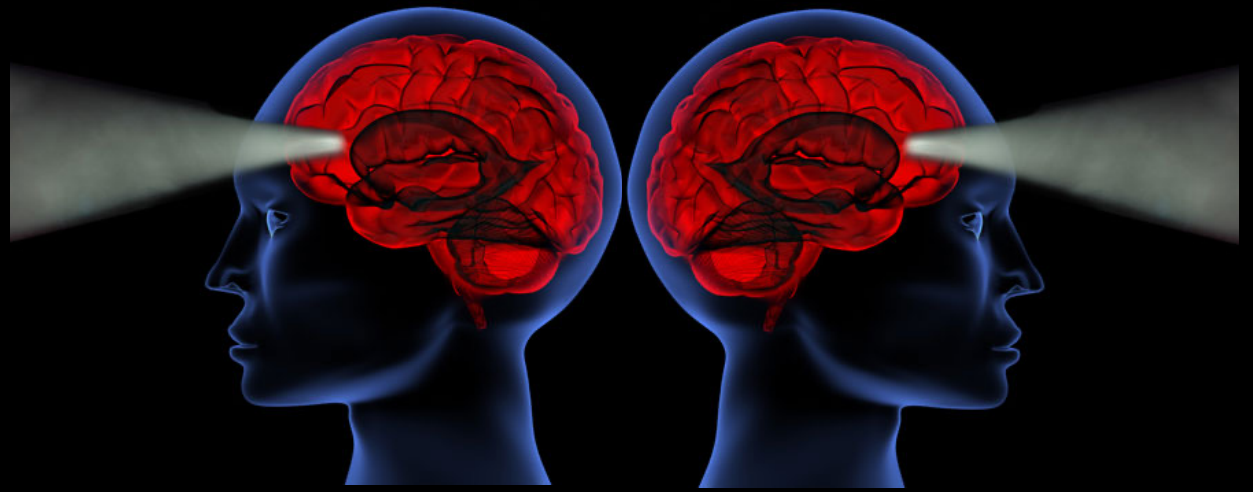
The Past



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
reconstructed ...

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

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

Constructive Episodic Simulation Hypothesis

The Past

The Future

Past events are
reconstructed ...

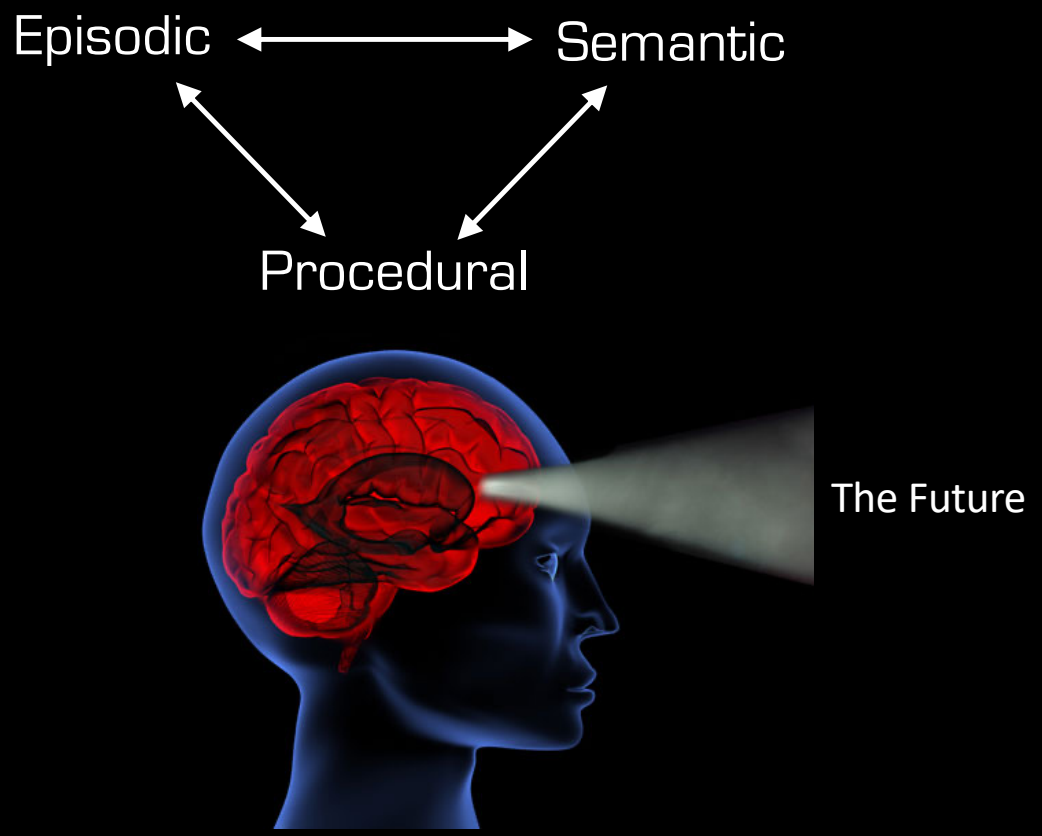
To allow the agent
to **pre-experience** the future

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.

Episodic ⟷ Semantic

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.

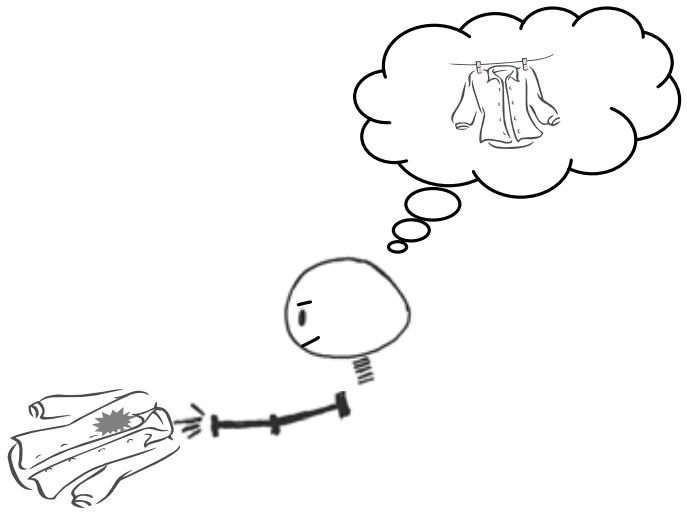


K. K. Szpunar, R. N. Spreng, and D. L. Schacter, A taxonomy of prospection: introducing an organizational framework for future-oriented cognition, PNAS 111(52), 18414–18421, 2014.

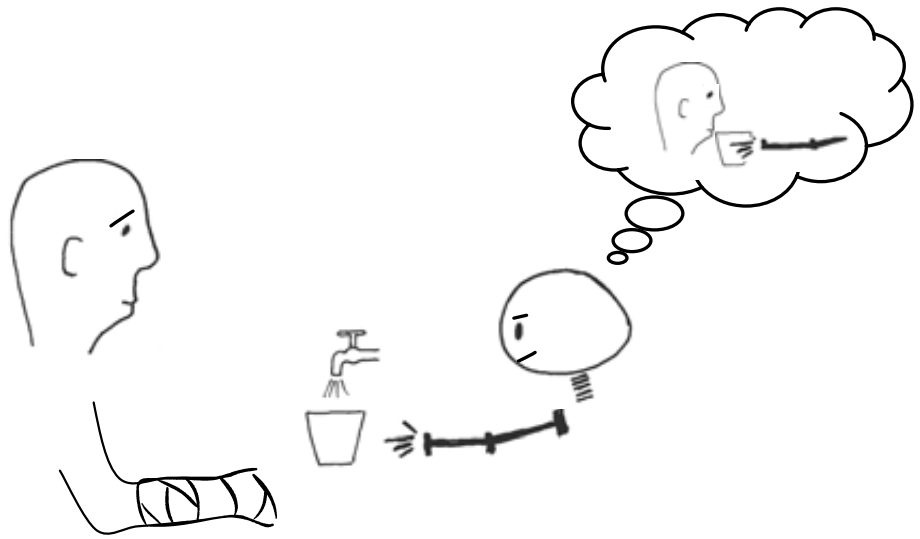
Cognitive systems continually predict

The need for action
(self and others)

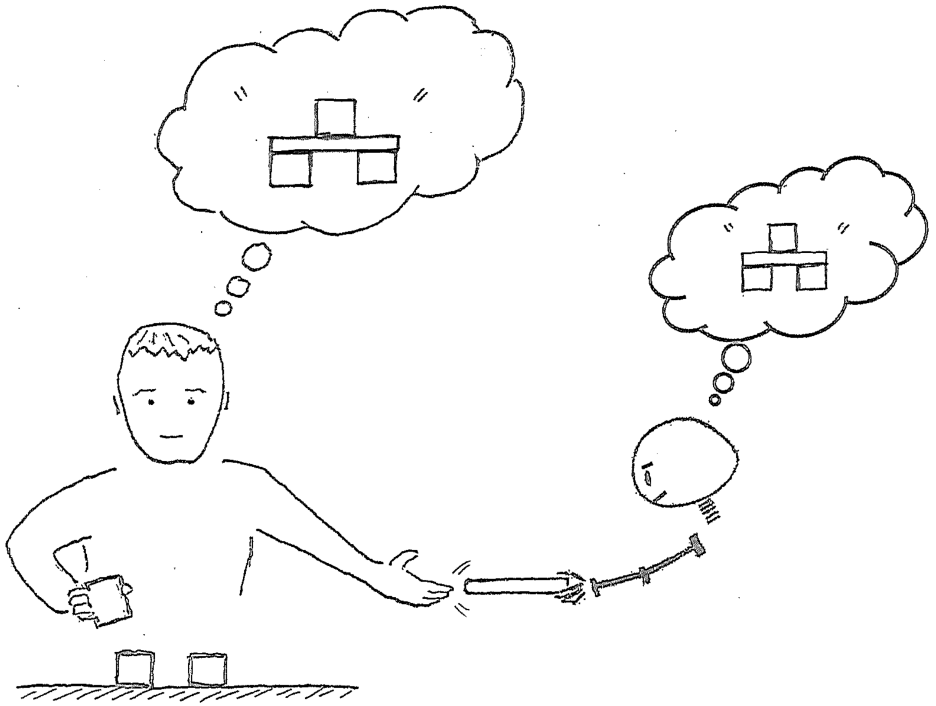
The outcome of those actions



Everyday activities: apparently routine but often complex and demanding



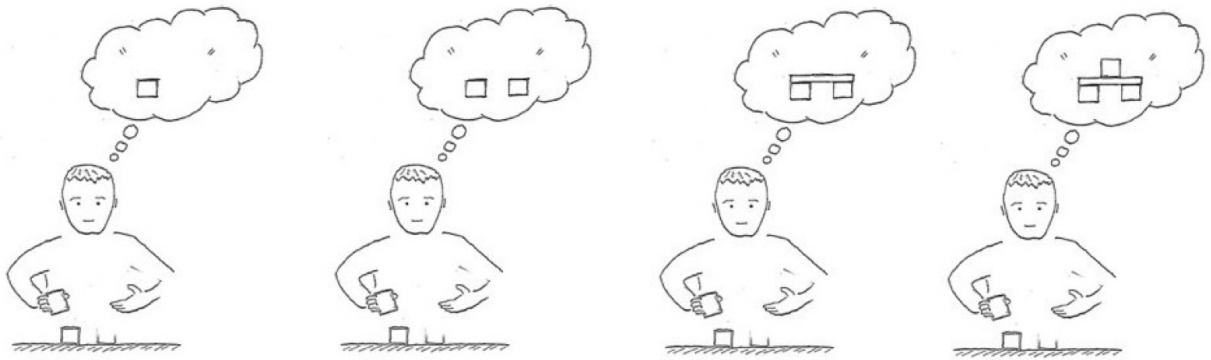
Anticipate the needs of others



Interact, assist, and collaborate with others

"Actions are goal-directed
and
are guided by prospective information"

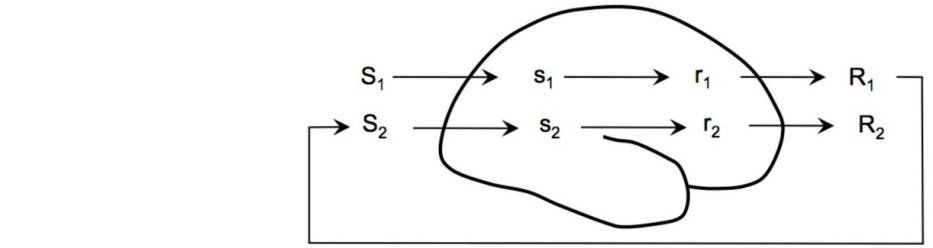
Claes von Hofsten

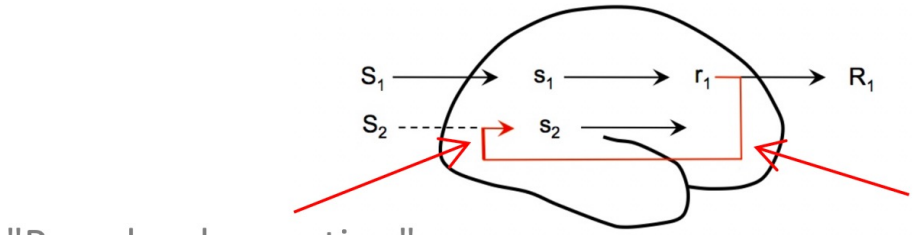


The Future

How do we accomplish this?

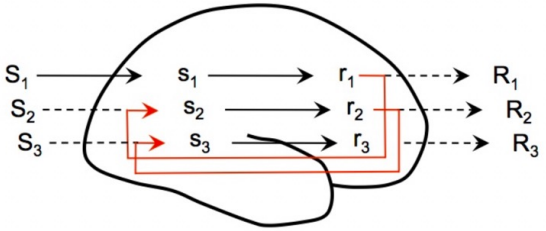
Internal Simulation Hypothesis





"Pseudo-observation"

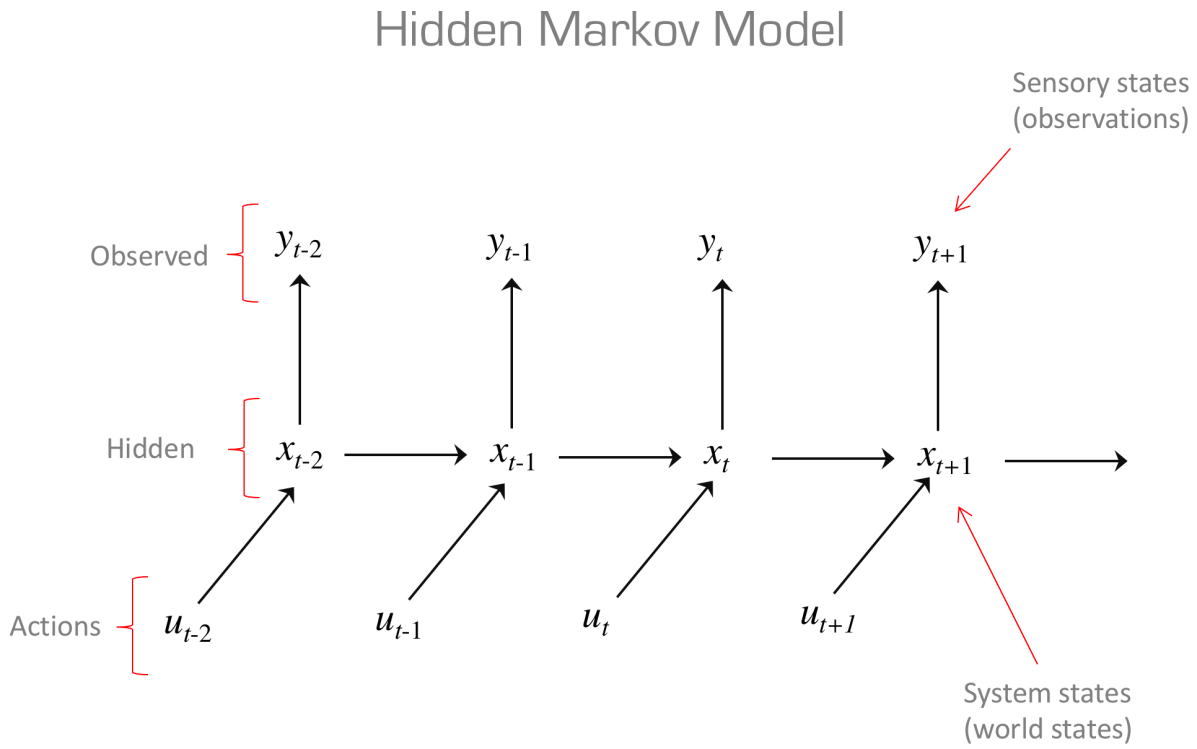
Efference copy



G. Hesslow. Conscious thought as simulation of behaviour and perception. Trends in Cognitive Sciences, 6(6):242–247, 2002.
G. Hesslow.The current status of the simulation theory of cognition. BrainResearch, 1428:71– 79, 2012.

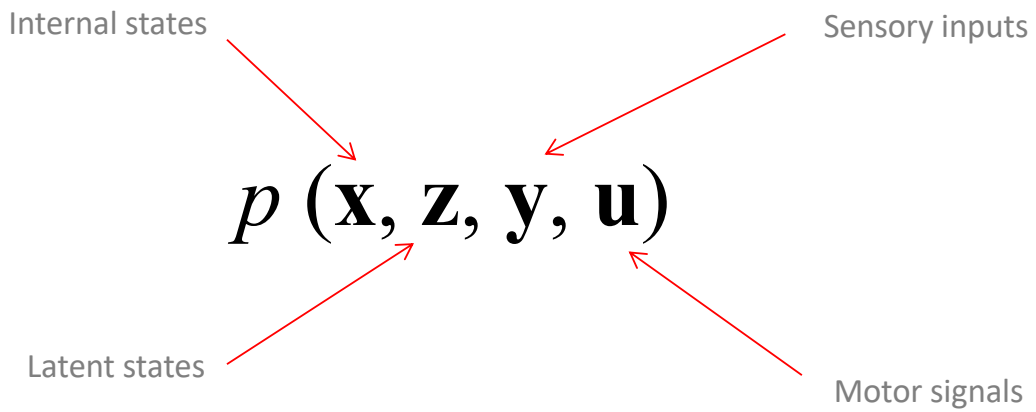
Construct generative internal models

Internal Generative Models



Internal Generative Models

Joint distribution of time series of sensory inputs $\mathbf{y}$, latent states $\mathbf{z}$, internal states $\mathbf{x}$, and motor signals $\mathbf{u}$.



D. McNamee and D. M. Wolpert. Internal models in biological control. Annual Review of Control, Robotics, and Autonomous Systems, 2:339–364, 2019.

Internal Generative Models

Inverse Model

$$p_{\text{inv}}(\mathbf{u} \mid \mathbf{g})$$

Infer an action ...

... from a "pseudo-observation" of **desired** outcome

Adapted from D. McNamee and D. M. Wolpert. Internal models in biological control. Annual Review of Control, Robotics, and Autonomous Systems, 2:339–364, 2019.

Internal Generative Models

Forward Model

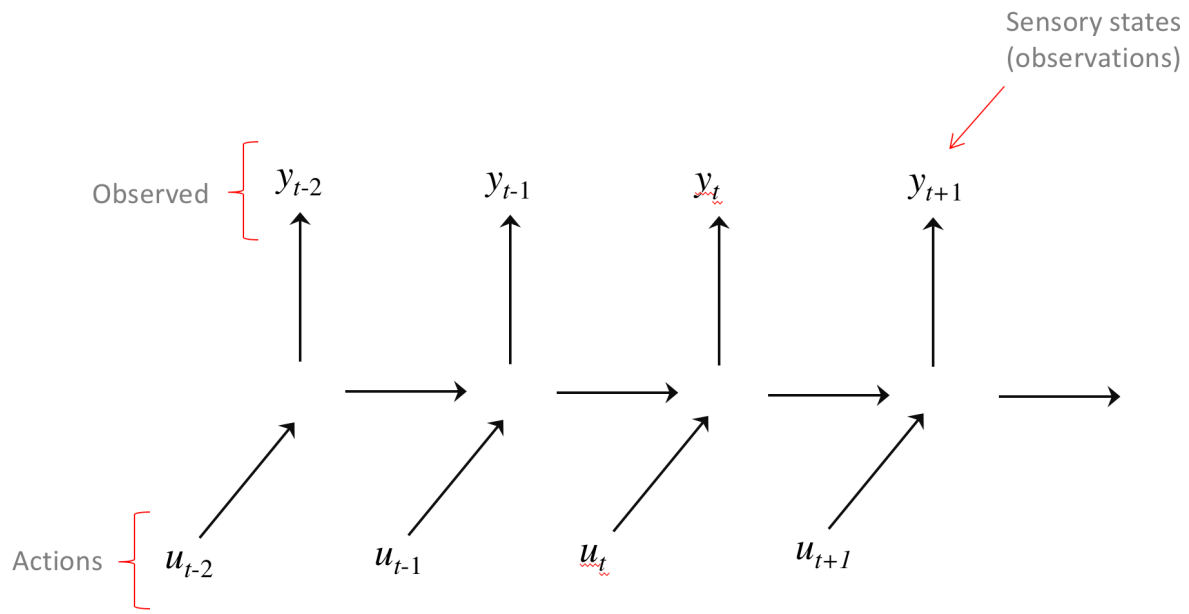
$$p_{\text{fw}}(\mathbf{y} \mid \mathbf{y}_0, \mathbf{u})$$

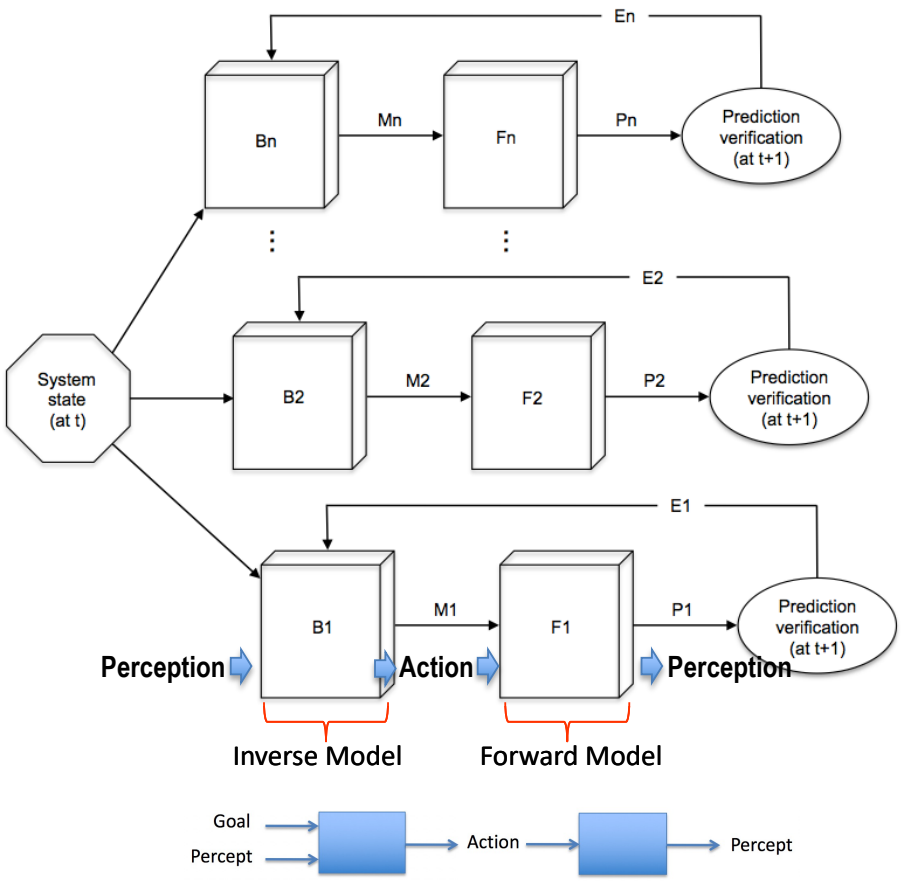
Infer an observed outcome ...

... from an observed initial state and action

Adapted from D. McNamee and D. M. Wolpert. Internal models in biological control. Annual Review of Control, Robotics, and Autonomous Systems, 2:339–364, 2019.

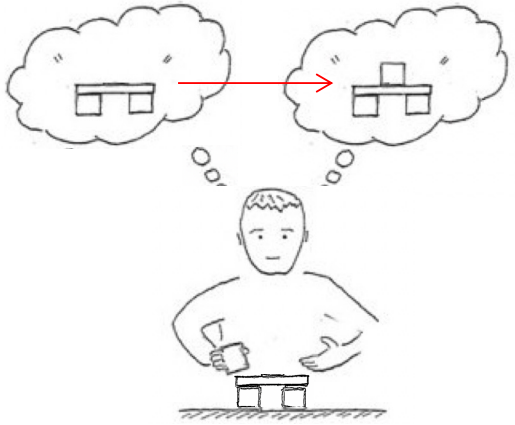
Internal Generative Models





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

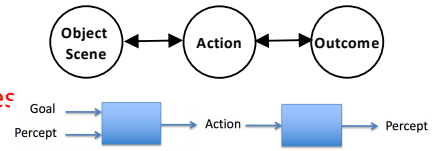
The Situation Model Framework



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

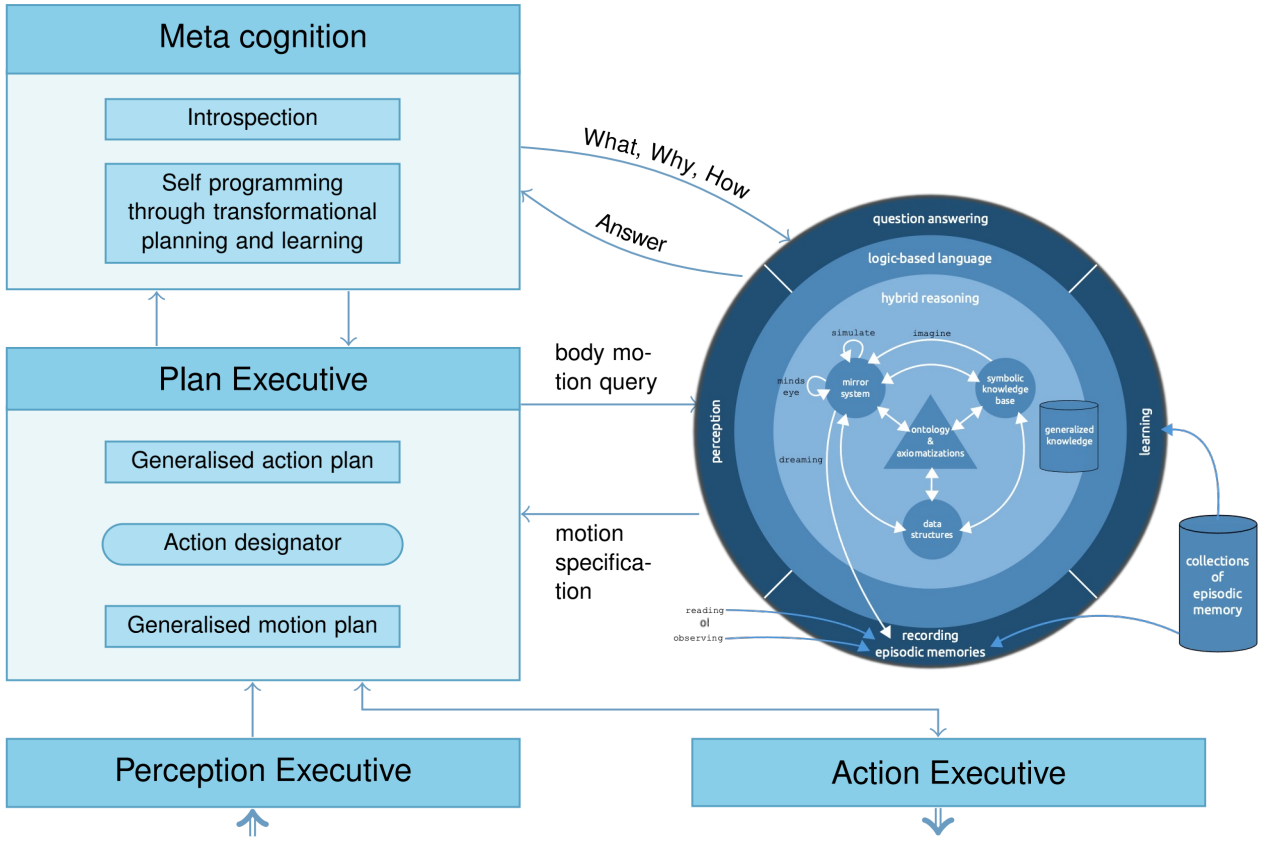


W. X. Schneider, J. Albert, and H. Ritter. Enabling cognitive behavior of humans, animals, and machines: A situation model framework. ZiF-Mitteilungen, pages 21–34, 2020.

What formalisms should we use?

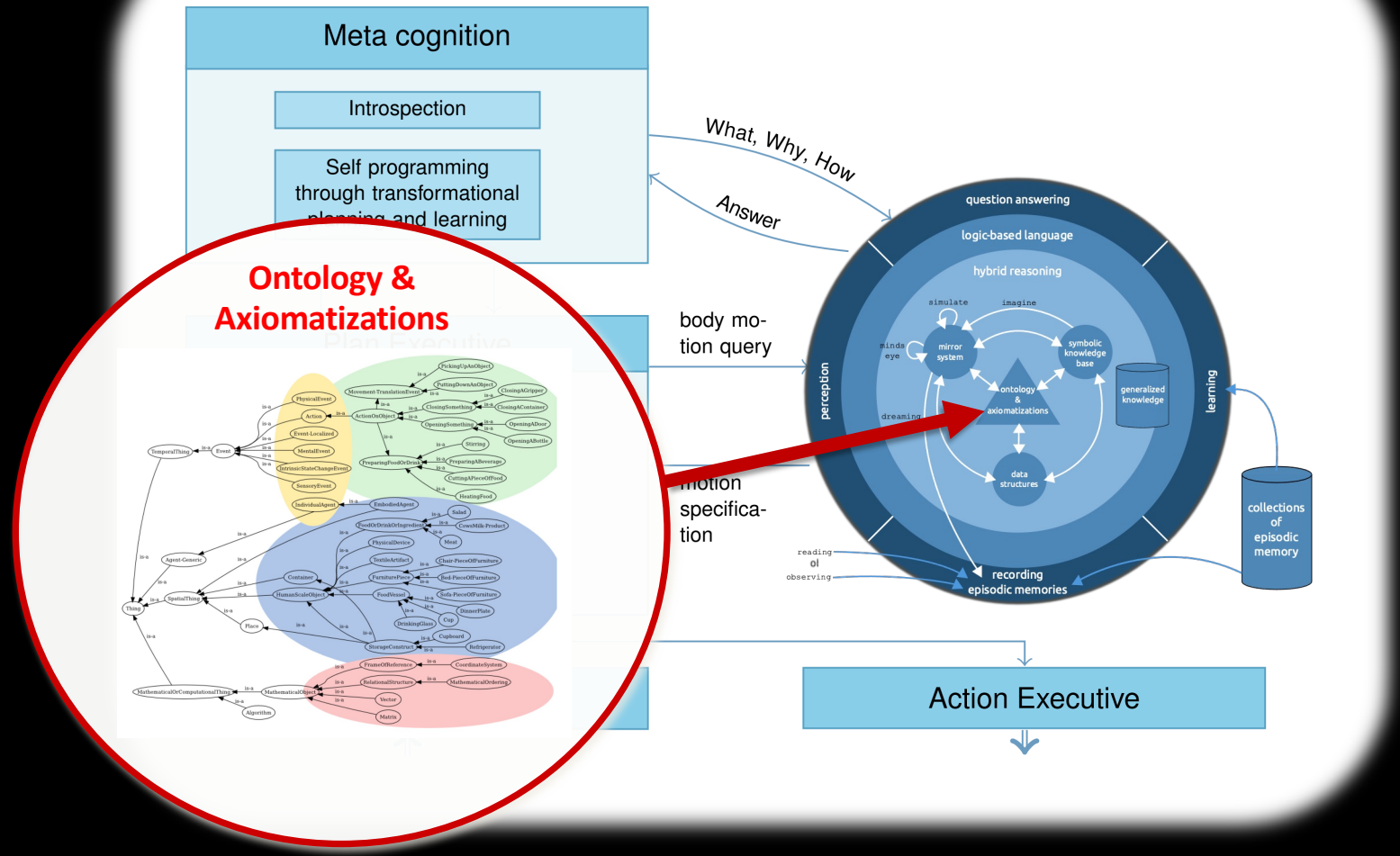
Reasoning with Knowledge vs. Associative Mechanisms

The CRAM Cognitive Architecture



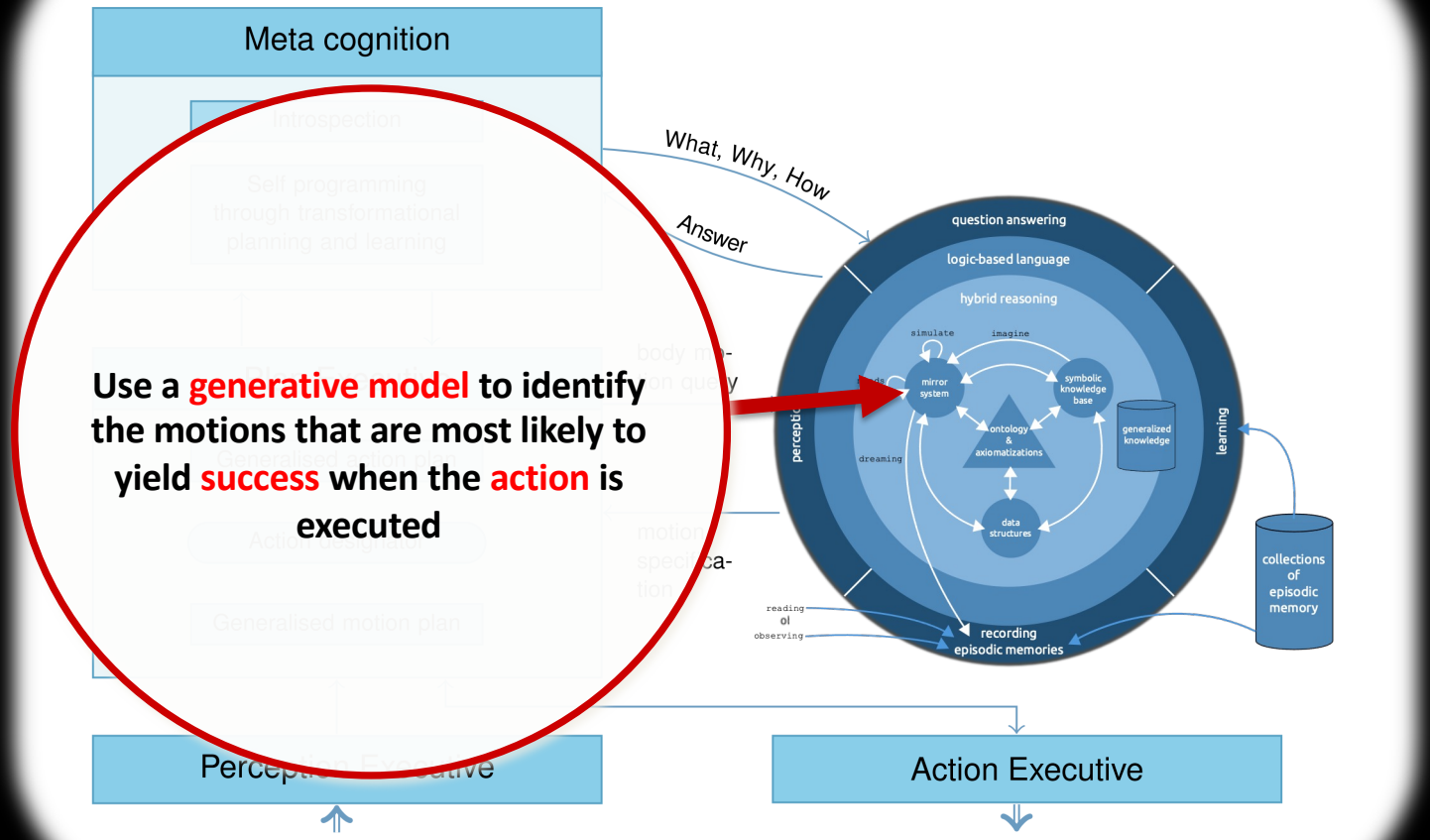
M. Beetz, D. Jain, L. Mösenlechner, and M. Tenorth. Towards Performing Everyday Manipulation Activities. Robotics and Autonomous Systems, 58(9):1085–1095, 2010.

The CRAM Cognitive Architecture



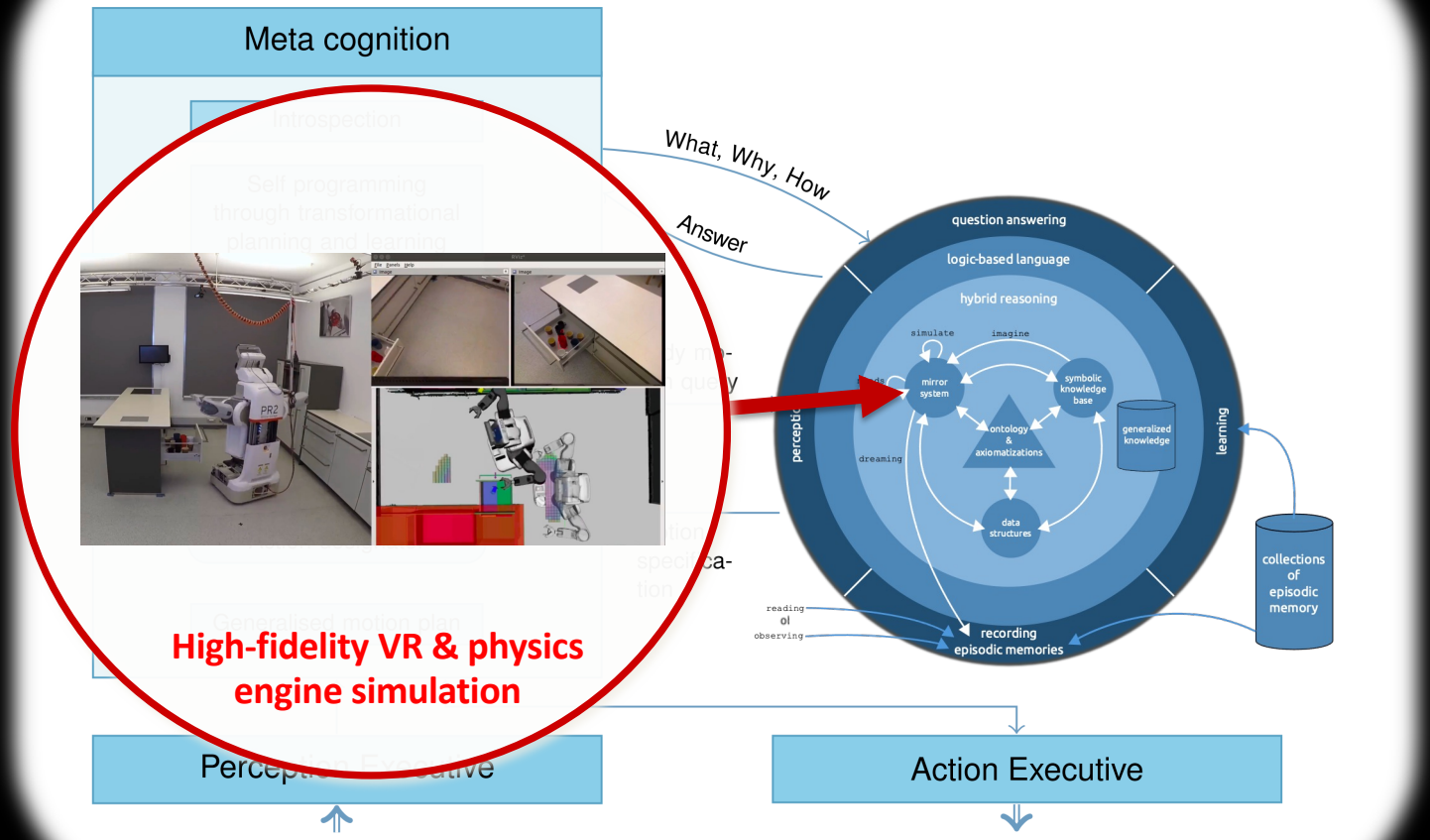
M. Beetz, D. Jain, L. Mösenlechner, and M. Tenorth. Towards Performing Everyday Manipulation Activities. Robotics and Autonomous Systems, 58(9):1085–1095, 2010.

The CRAM Cognitive Architecture



M. Beetz, D. Jain, L. Mösenlechner, and M. Tenorth. Towards Performing Everyday Manipulation Activities. Robotics and Autonomous Systems, 58(9):1085–1095, 2010.

The CRAM Cognitive Architecture

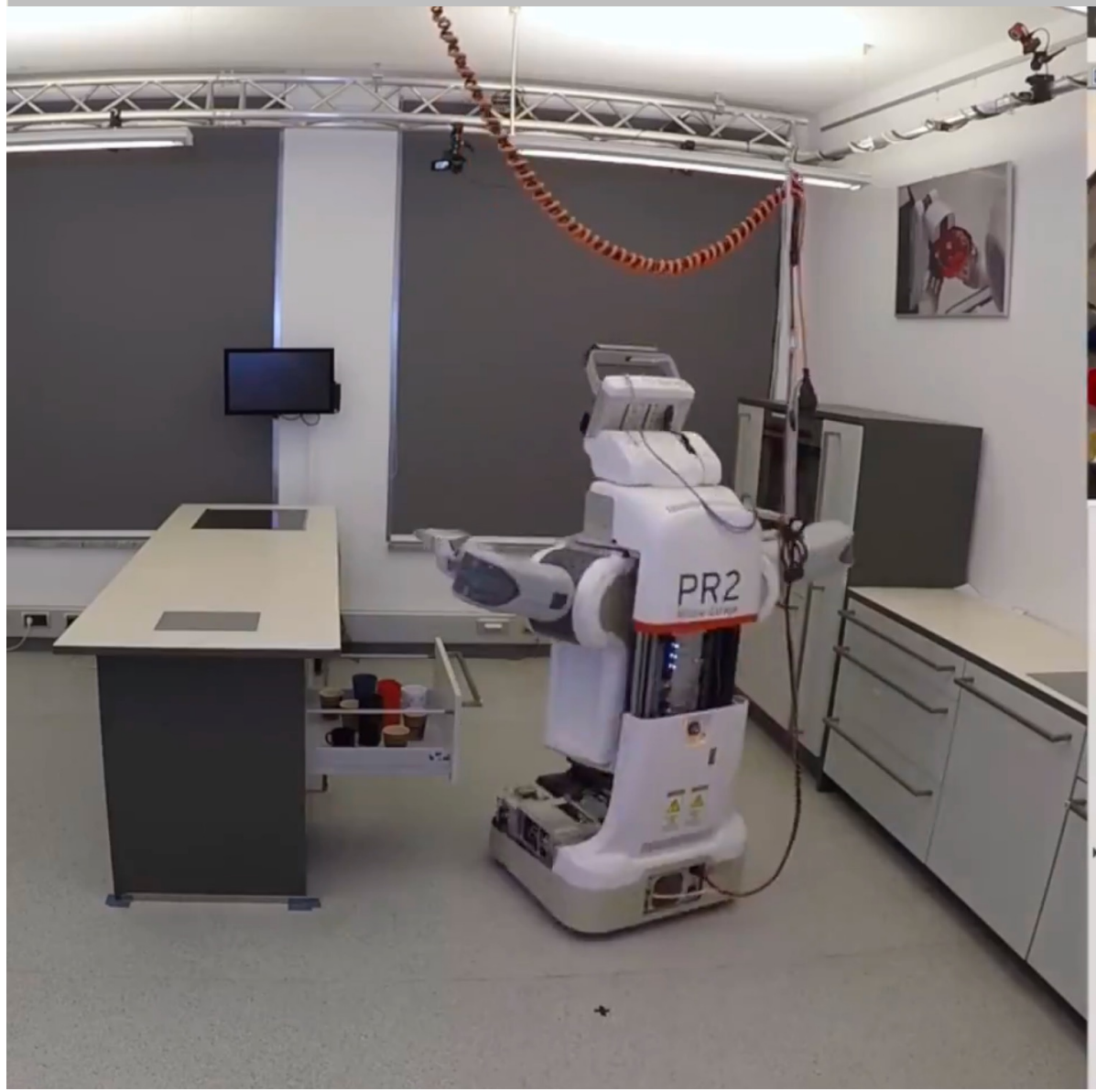


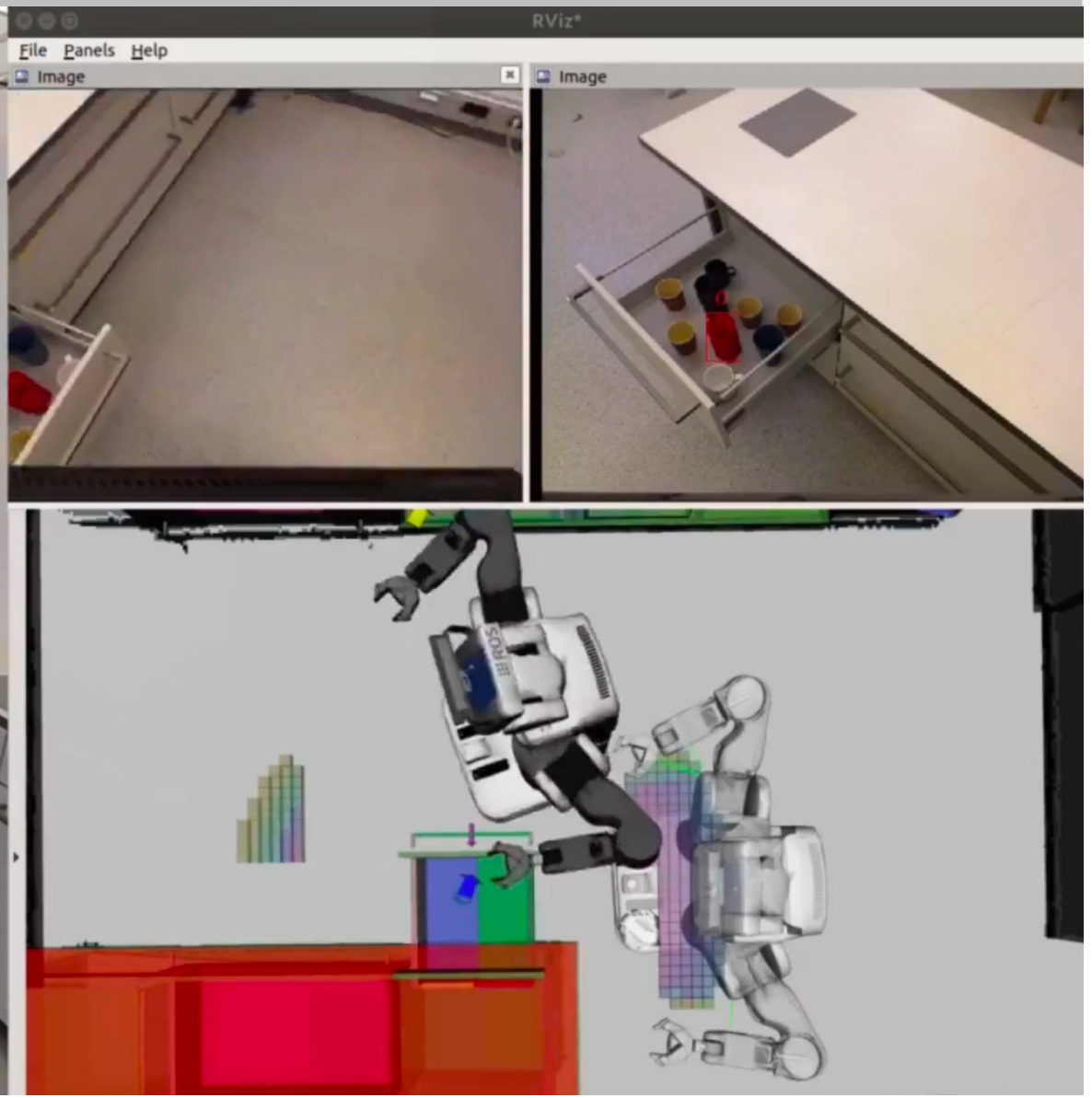
M. Beetz, D. Jain, L. Mösenlechner, and M. Tenorth. Towards Performing Everyday Manipulation Activities. Robotics and Autonomous Systems, 58(9):1085–1095, 2010.

CRAM Cognitive Architecture

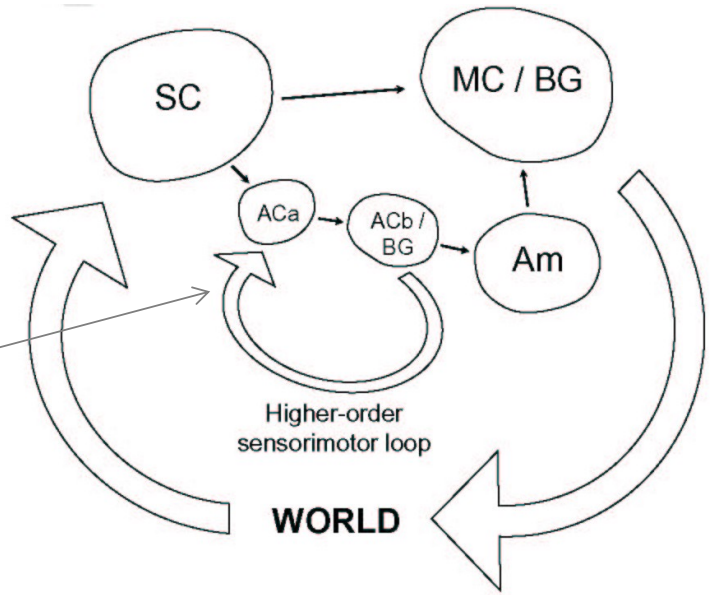
[Beetz et al. 2010], et seq.

KnowRob2





Global Workspace Cognitive Architecture

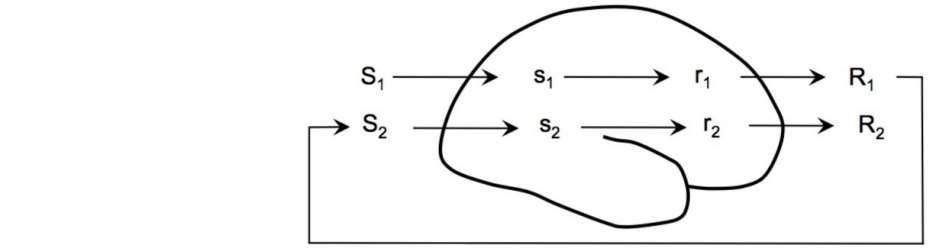


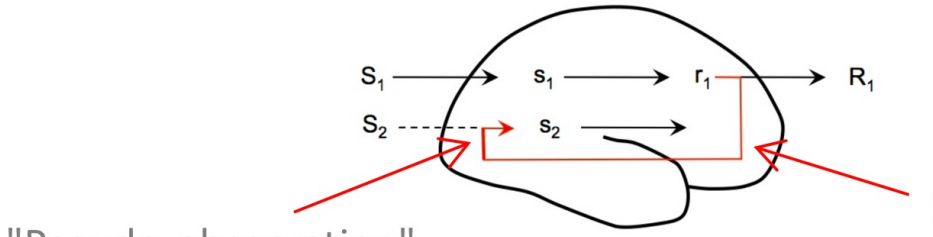
Internal simulation

SC Sensory Cortex
MC Motor Cortex
BG Basal Ganglia
(action selection)
AC Association Cortex
Am Amygdala (affect)

M. P. Shanahan. Cognition, action selection, and inner rehearsal. In Proceedings IJCAI Workshop on Modelling Natural Action Selection, pages 92–99, 2005.
M. P. Shanahan. A cognitive architecture that combines internal simulation with a global workspace. Consciousness and Cognition, 15:433–449, 2006.

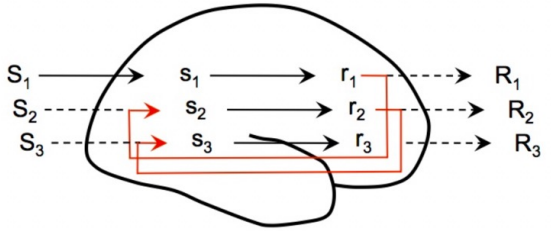
Internal Simulation Hypothesis





"Pseudo-observation"

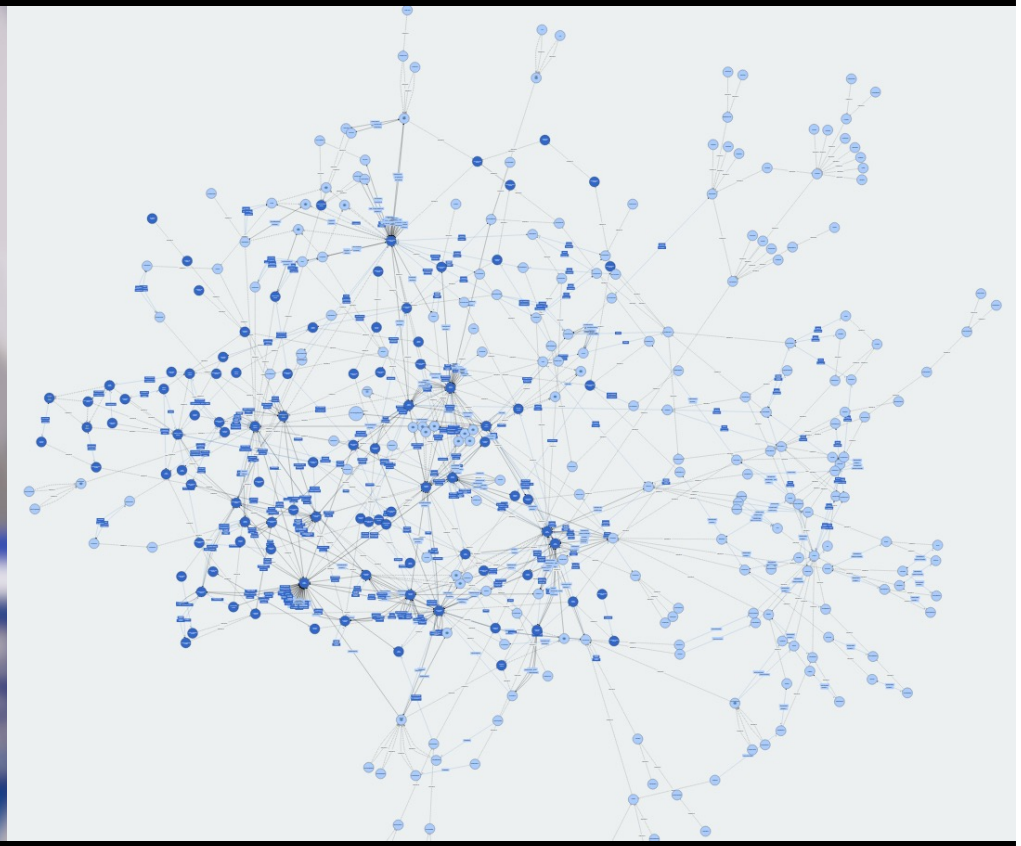
Efference copy



G. Hesslow. Conscious thought as simulation of behaviour and perception. Trends in Cognitive Sciences, 6(6):242–247, 2002.
G. Hesslow.The current status of the simulation theory of cognition. BrainResearch, 1428:71– 79, 2012.

How are these generative internal models organized?

Collaborative Research Center in Everyday Activity Science and Engineering (EASE)



A knowledge ontology grounded in experience and encapsulated in narrative-enabled episodic memories

https://ease-crc.github.io/soma/

Narrative-enabled Episodic Memory
NEEM

Symbolic description & sub-symbolic experiential knowledge

NEEM = experience + narrative

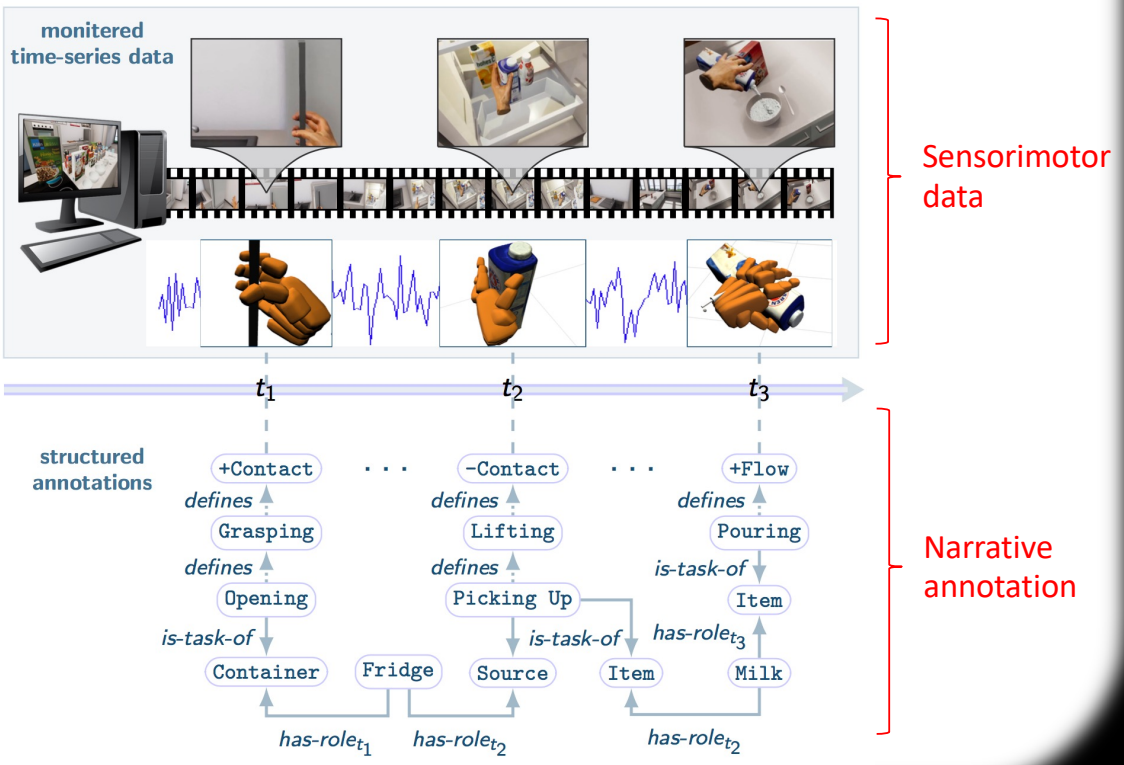
Sub-symbolic percepts based on exteroceptive and proprioceptive sensory data and sub-symbolic control signals

Symbolic description of the tasks, the context, the intended goals, and the observed outcome

Based on concepts defined in the SOMA ontology

- Organized in several hierarchies
- Describe the physical and the social context of an activity

Narrative-enabled Episodic Memory
NEEM



Reasoning with Knowledge vs. Associative Mechanisms

Reasoning with Knowledge vs. Associative Mechanisms

Hierarchical organization of
internal generative models

that can be

Constructed adaptively

Queried semantically

Navigated associatively

The Cybernetic Bayesian Brain:
From Interoceptive Inference to Sensorimotor Contingencies

"A rich repertoire of counterfactually explicit
probability densities encoding the mastery of SMCs"

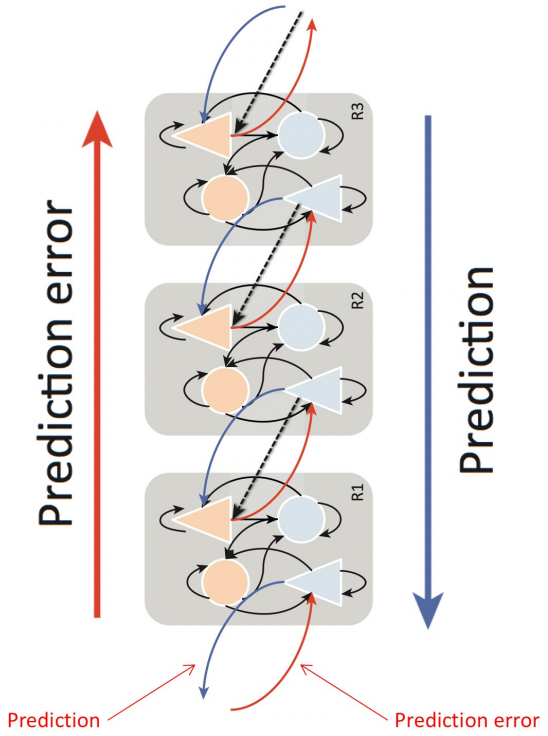
A. Seth, "The Cybernetic Bayesian Brain: From Interoceptive Inference to Sensorimotor Contingencies",
in T. Metzinger & J. M. Windt (Eds). Open MIND: 35(T). Frankfurt am Main: MIND Group,1–24, 2015.

Expanded version of Free Energy Principle

Organisms minimize an upper bound on the entropy of sensory signals

Minimize surprisal …

Minimize the long-run prediction error

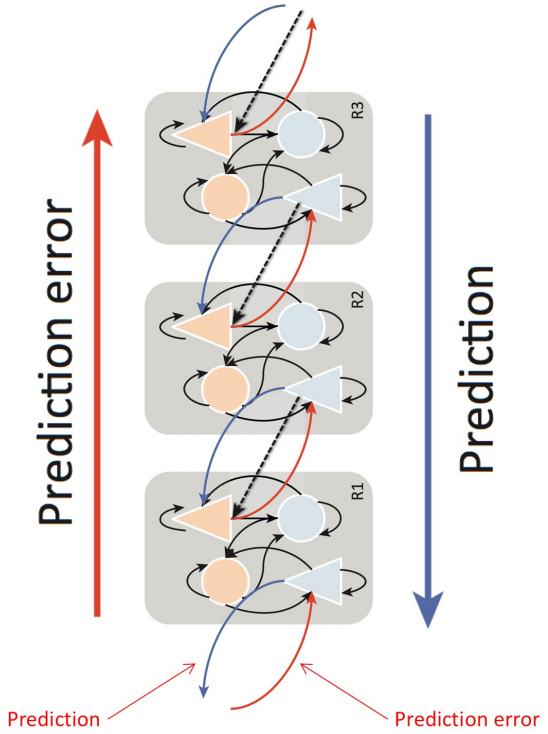


A. K. Seth. Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11):565–573, November 2013.

"Passively"

Change the model to fit the perceptual data

Predictive Processing
Perceptual Inference

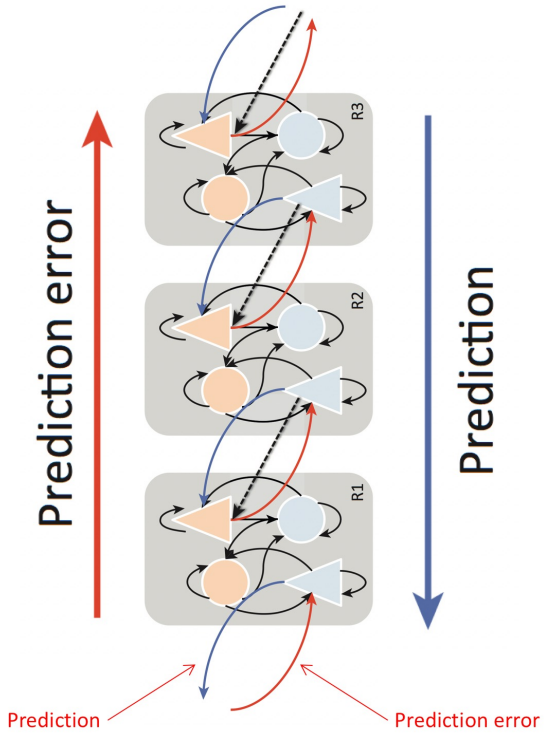


A. K. Seth. Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11):565–573, November 2013.

"Passively"

Change the model to fit the perceptual data

Predictive Processing
Perceptual Inference

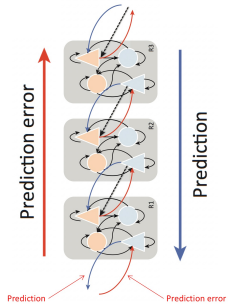


"Actively"

Change the sampling to suit the prediction

Active inference

A. K. Seth. Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11):565–573, November 2013.



Active inference:

- Confirming sensory predictions

The usual view

- Seeking "disruptive" actions that test current predictions

and/or

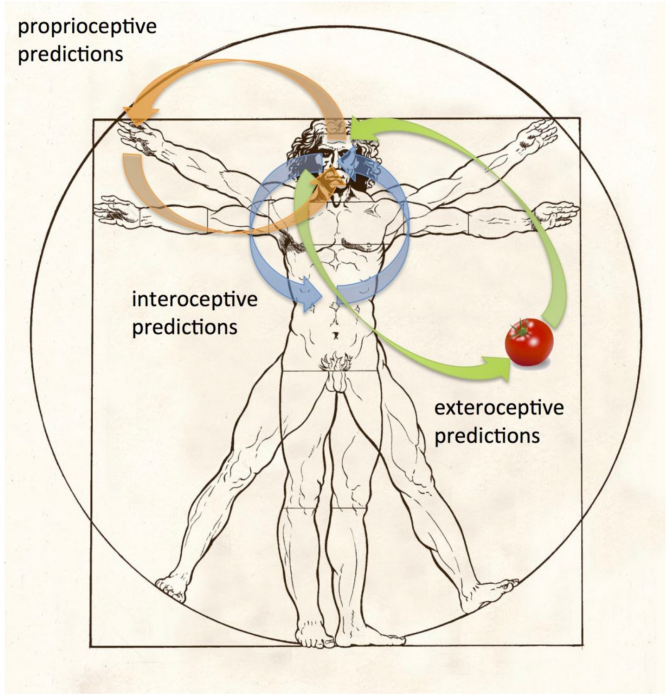
Disambiguate competing predictions

New view: counterfactually-equipped predictive models

A. Seth, "The Cybernetic Bayesian Brain: From Interoceptive Inference to Sensorimotor Contingencies", in T. Metzinger & J. M. Windt (Eds). Open MIND: 35(T). Frankfurt am Main: MIND Group,1–24, 2015.

Shift in perspective

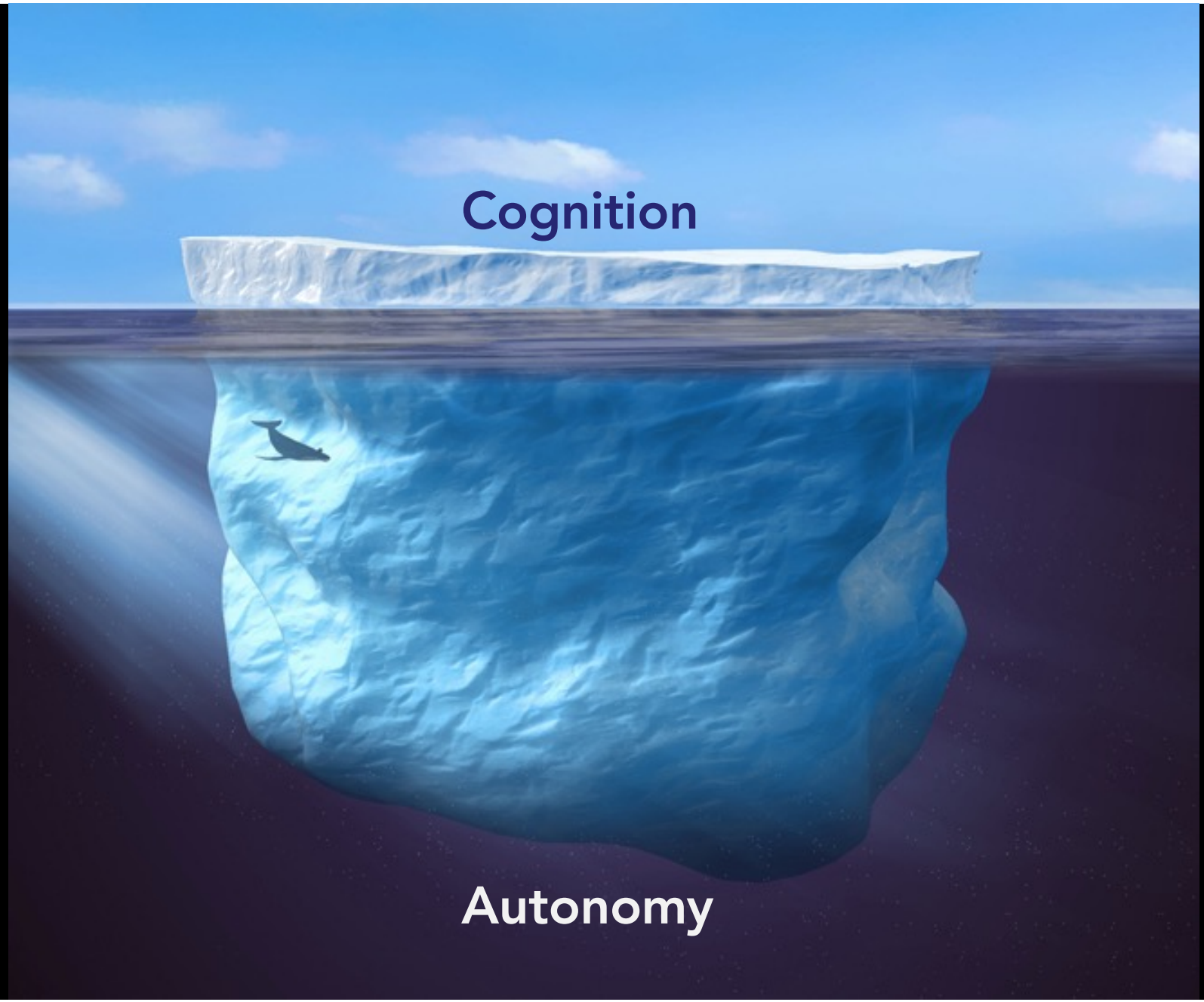
https://unsplash.com/photos/-TQUERQGUZ8?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



"The purpose of cognition (including perception and action) is to maintain the homeostasis of essential variables and of internal organization (ultrastability)"

A. Seth, "The Cybernetic Bayesian Brain: From Interoceptive Inference to Sensorimotor Contingencies", in T. Metzinger & J. M. Windt (Eds). Open MIND: 35(T). Frankfurt am Main: MIND Group,1–24, 2015.


Cognition

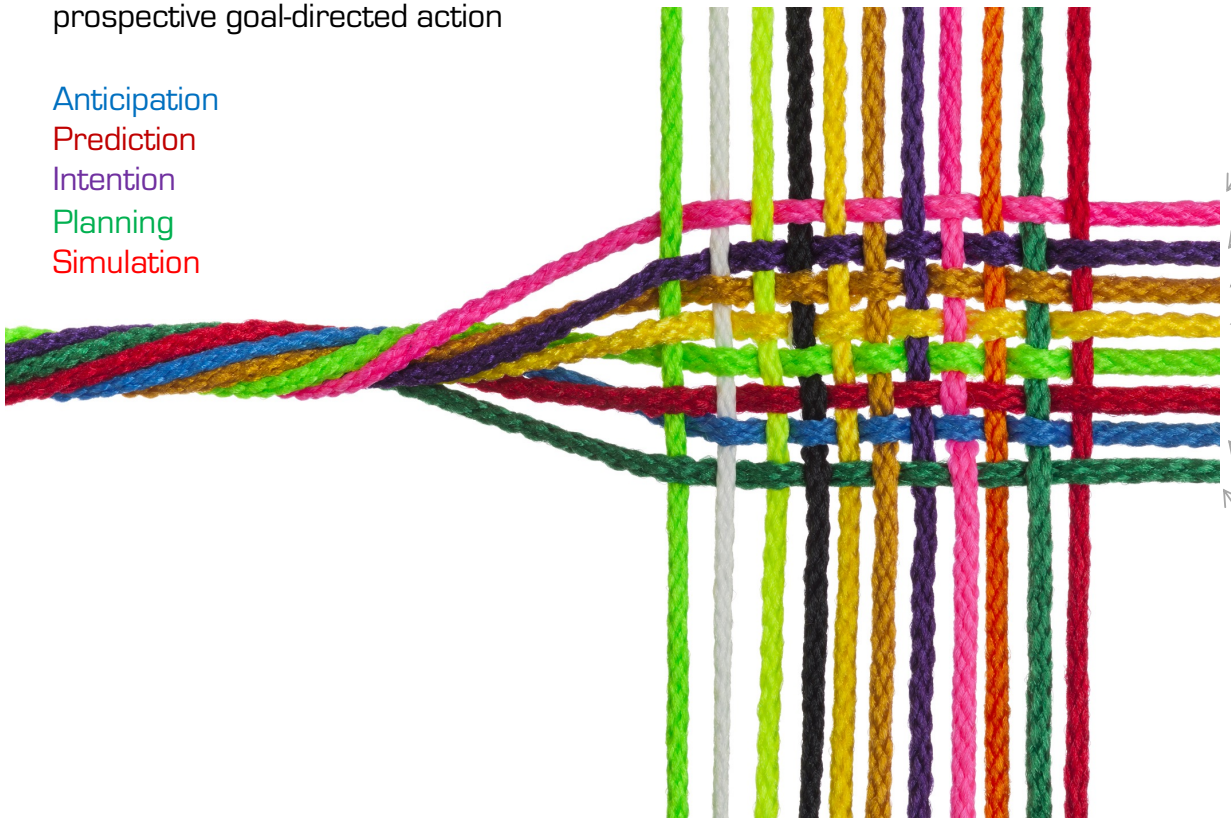

Cognition
Autonomy

The Research Challenge

A unified account of
prospective goal-directed action

Anticipation
Prediction
Intention
Planning
Simulation

Generative Internal Models



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

Ontological organization

Symbolic reasoning

Associative recall

Adaptive composition

Hierarchical self-organization

Few-shot learning

Counterfactual predictive processing and active inference

Autonomous self-maintenance & development

Prospection

David Vernon
Institute for Artificial Intelligence
University of Bremen

International Foundation of Robotics Research Robotics Global Colloquia

Robotics Colloquia

IFRR

Thank you for watching