Introduction to Cognitive Robotics

Module 1: Overview of Cognitive Robotics

Lecture 1: Component disciplines; the nature of cognition; definition of cognitive robotics

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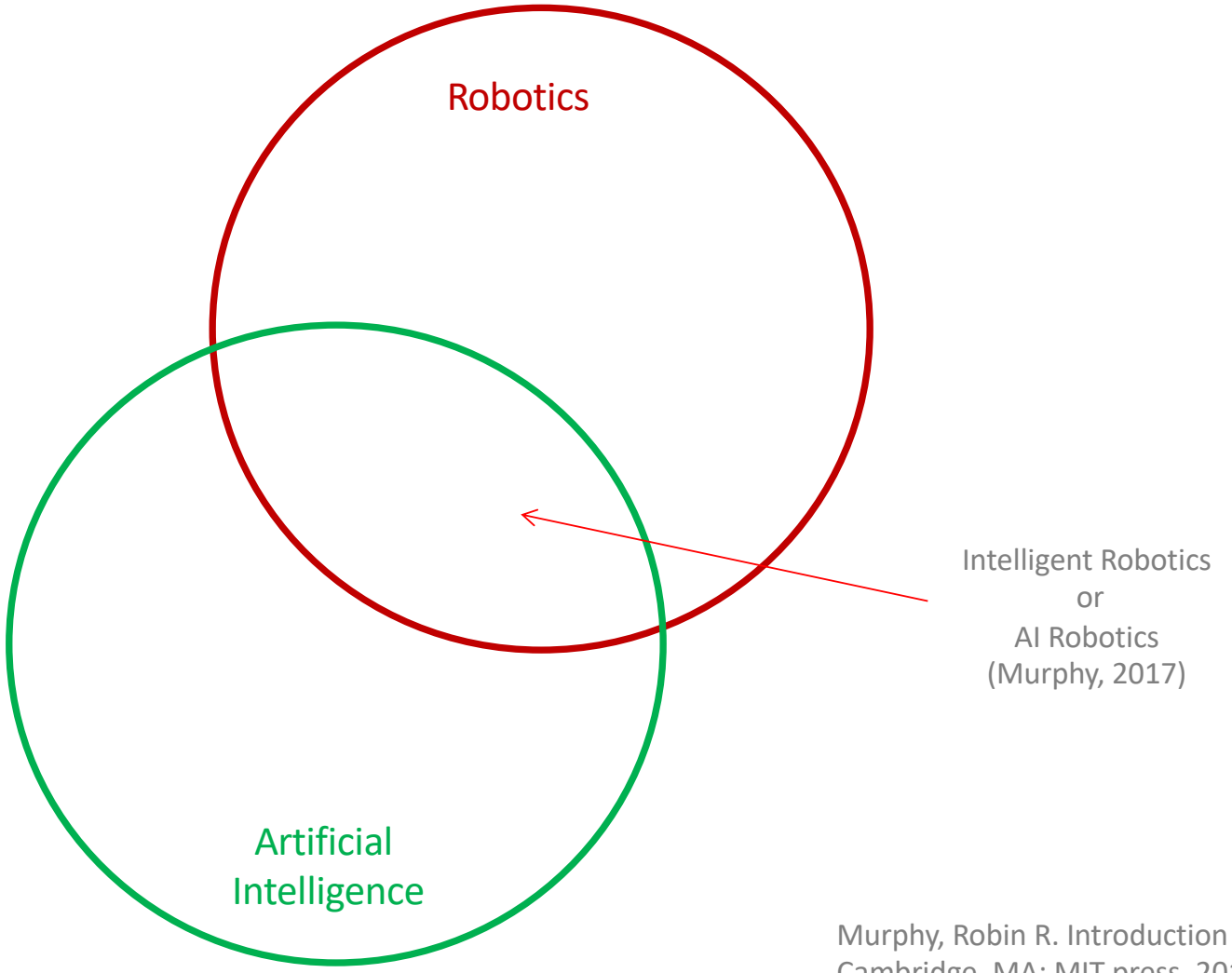
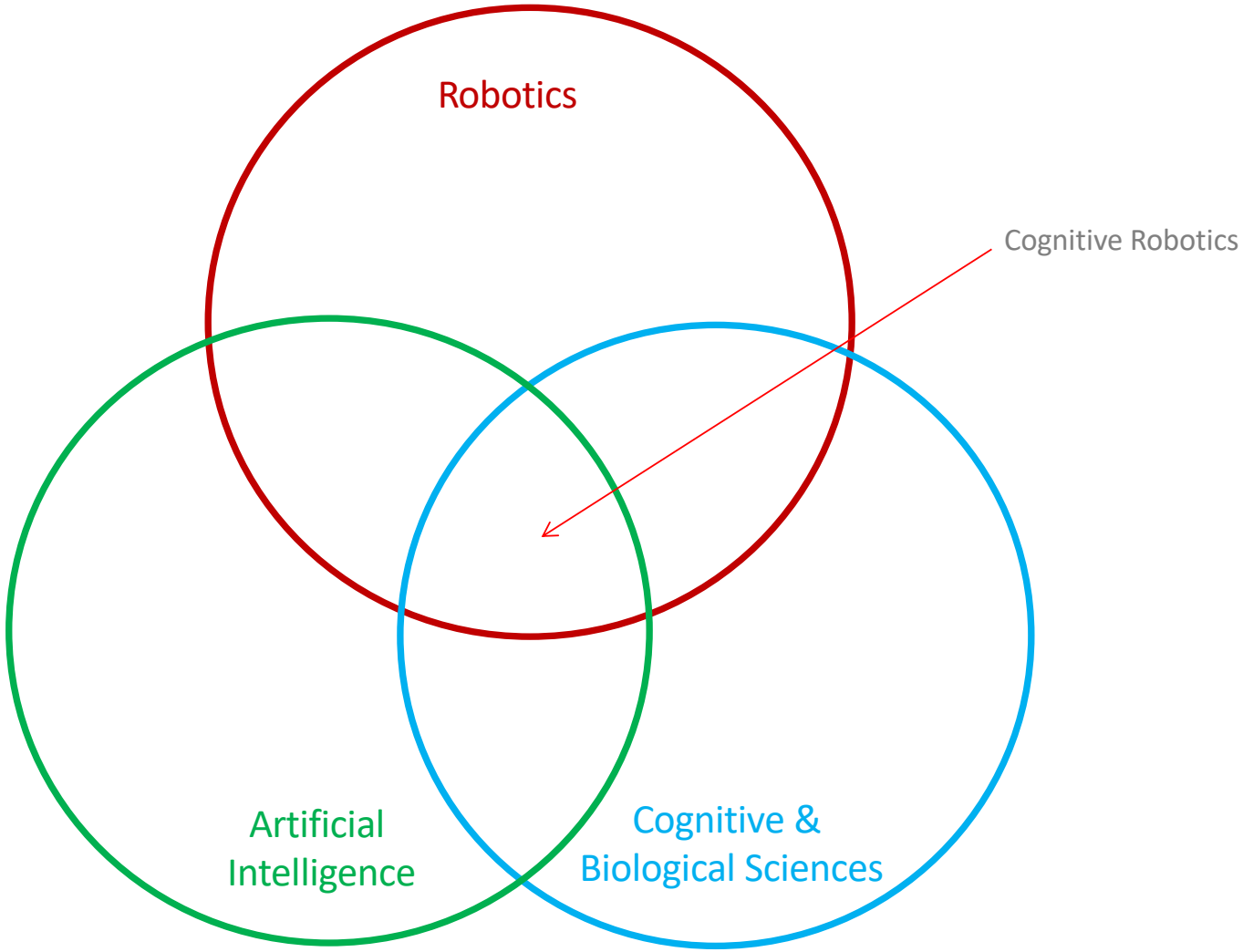
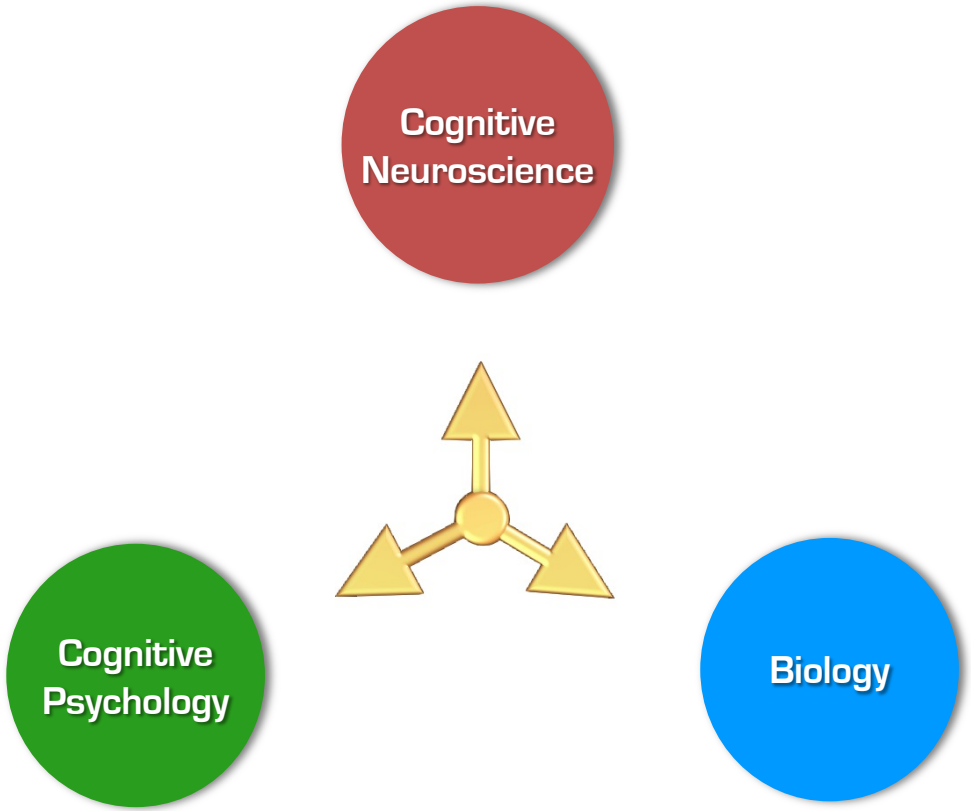


Intelligent Robotics
or
AI Robotics
(Murphy, 2017)

Murphy, Robin R. Introduction to AI Robotics. Cambridge, MA: MIT press, 2019.


Robotics
Cognitive Robotics
Artificial Intelligence
Cognitive & Biological Sciences

Cognitive & Biological Sciences



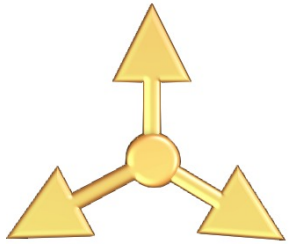
A Definition of Cognitive Robotics

"Cognitive Robotics is the field that combines insights and methods from robotics, AI and cognitive and biological sciences to design an integrated cognitive system combining the sensorimotor behavior and higher-level functions and social capabilities of an intelligent robot"

A. Cangelosi and M. Asada, Cognitive Robotics, Chapter 1, MIT Press, in press.

Cognitive Robotics Emphasizes ...

Bio-inspired
human-like and animal-like
behaviour and intelligence



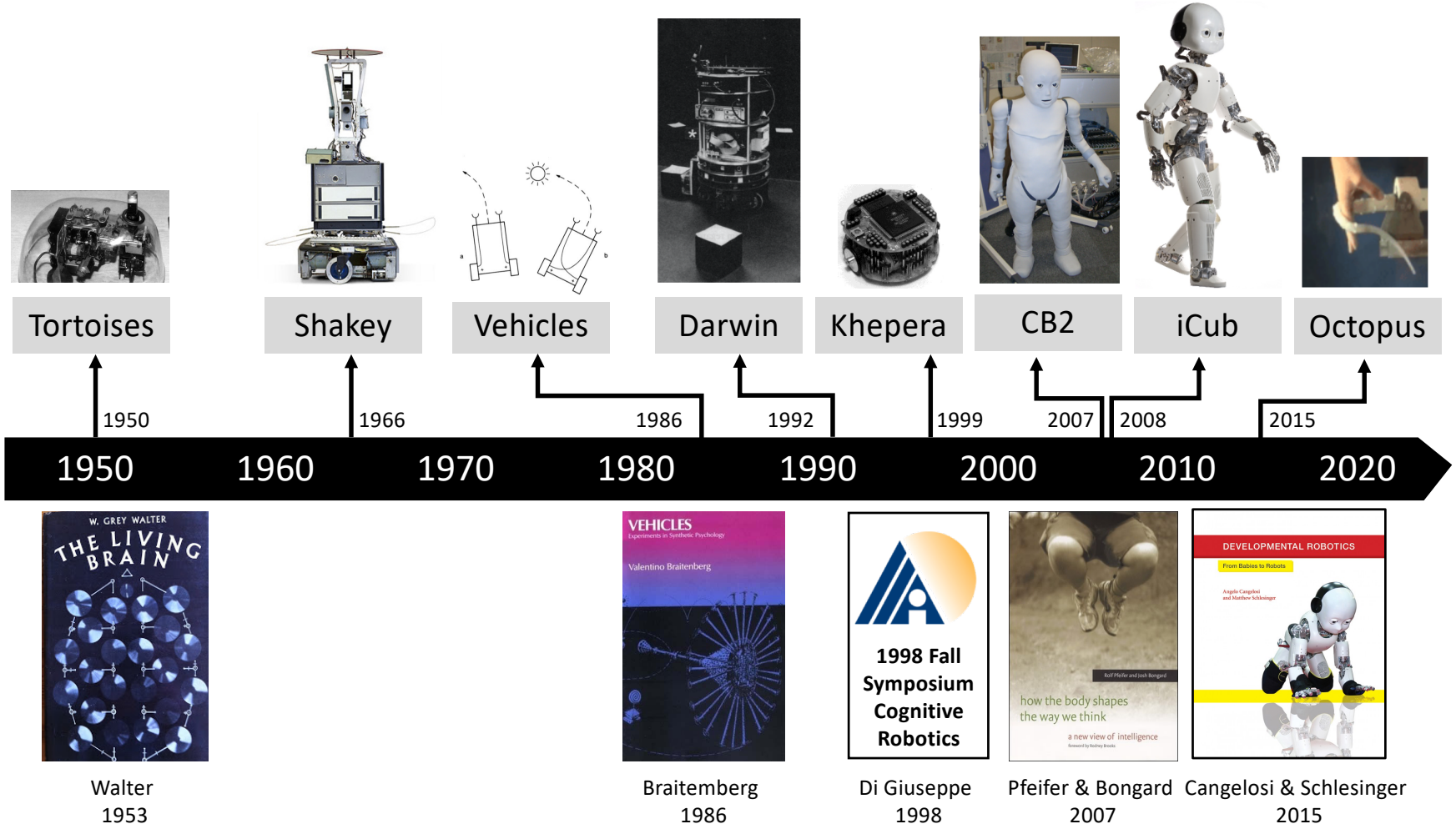
System-level integration
of a range of cognitive abilities:

- Sensorimotor skills
- Knowledge representation & reasoning
- Social interaction

Interdisciplinary approach,
including cognitive (neuro)science,
cognitive psychology, and biology

Related Fields

1. Developmental robotics
2. Neurorobotics
3. Evolutionary robotics
4. Soft robotics



A. Cangelosi and M. Asada, Cognitive Robotics, Chapter 1, MIT Press, in press.

What is cognition?

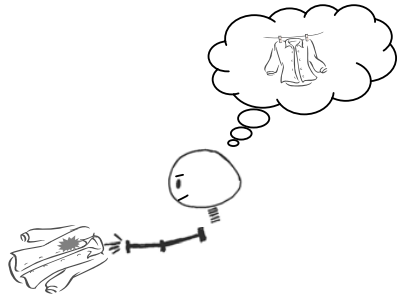
Why is cognition useful in robotics?

We answer this question first

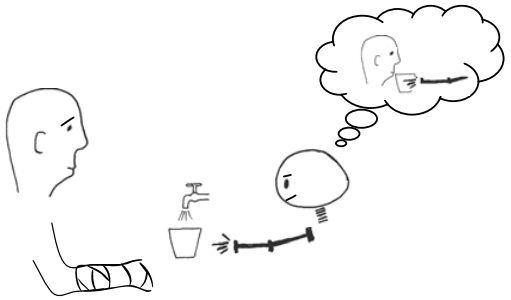
How do cognitive robots work?

Why is cognition useful in robotics?

1. It allows robots to work autonomously in everyday environments



2. It enables effective interaction with humans

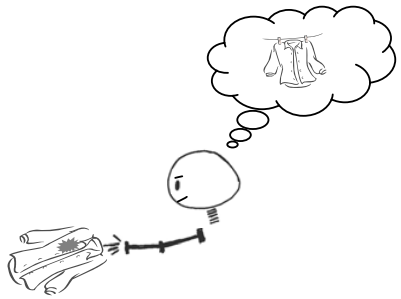


Why is cognition useful in robotics?

1. It allows robots to work autonomously in everyday environments

   a) anticipating outcomes when selecting the actions it will perform

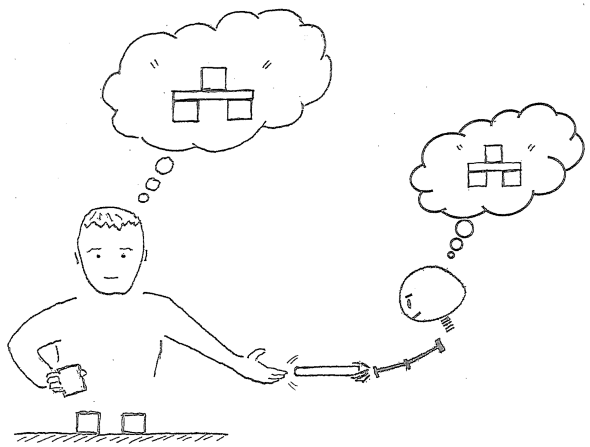
   b) adapting to changes and unforeseen situations



Why is cognition useful in robotics?

2. It enables effective interaction with humans

a) A cognitive ability can enable a robot to infer the goals and intentions of the person with whom it is interacting and thereby allows it to behave in a helpful manner.



Why is cognition useful in robotics?

2. It enables effective interaction with humans

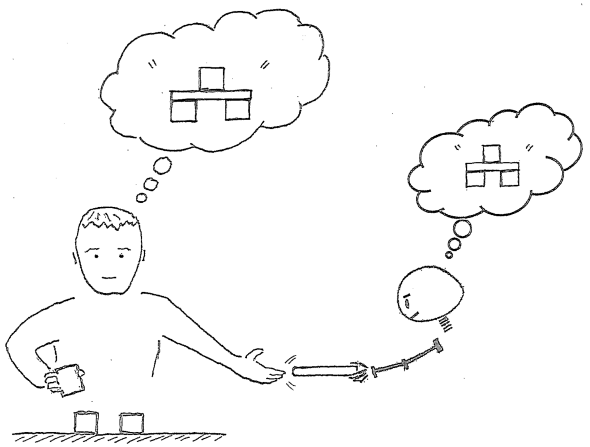
a) A cognitive ability can enable a robot to infer the goals and intentions of the person with whom it is interacting and thereby allows it to behave in a helpful manner.

b) Humans like to engage with other cognitive agents: if a robot has a capacity for cognition it fosters human robot interaction

Why is cognition useful in robotics?

- A cognitive robot is capable of flexible context-sensitive goal-directed action
- The robot anticipates
  - the need to act
  - the outcome of the action
- The action itself is guided by prospection
- It can also adapt to changing circumstances
  - Adjusting existing action policies
  - Creating new action policies when required
- It does this by dynamically recruiting several core cognitive abilities:
  perception, attention, action selection, memory, learning, reasoning, metacognition, prospection

The robot's need to act and a human's need to act



What is cognition?

Now we answer this question

Why is cognition useful in robotics?

How do cognitive robots work?

euCognition

The European Network for the Advancement of Artificial Cognitive Systems

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Definitions of Cognition & Cognitive Systems

The following definitions were contributed by members of euCognition in response to a questionnaire. If you haven't completed the questionnaire, please consider doing so.

The definitions are listed in the order in which they were submitted.

Cognition is the ability to relate perception and action in a meaningful way determined by experience,learning and memory.
Mike Denham

A cognitive system possesses the ability of self-reflection (or at least self-awareness).
Horst Bischof

Cognition is gaining knowledge through the senses.
Majid Mermehdi

Cognition is the ability to ground perceptions in concepts together with the ability to manipulate concepts in order to proceed toward goals.
Christian Bauckhage

An artificial cognitive system is a system that is able to perceive its surrounding environment with multiple sensors, merge this information, reason about it, learn from it and interact with the outside world.
Barbara Caputo

42 definitions

http://www.vernon.eu/euCognition/definitions.htm

Cognition

"Cognition is the process by which an autonomous system

perceives its environment,

learns from experience,

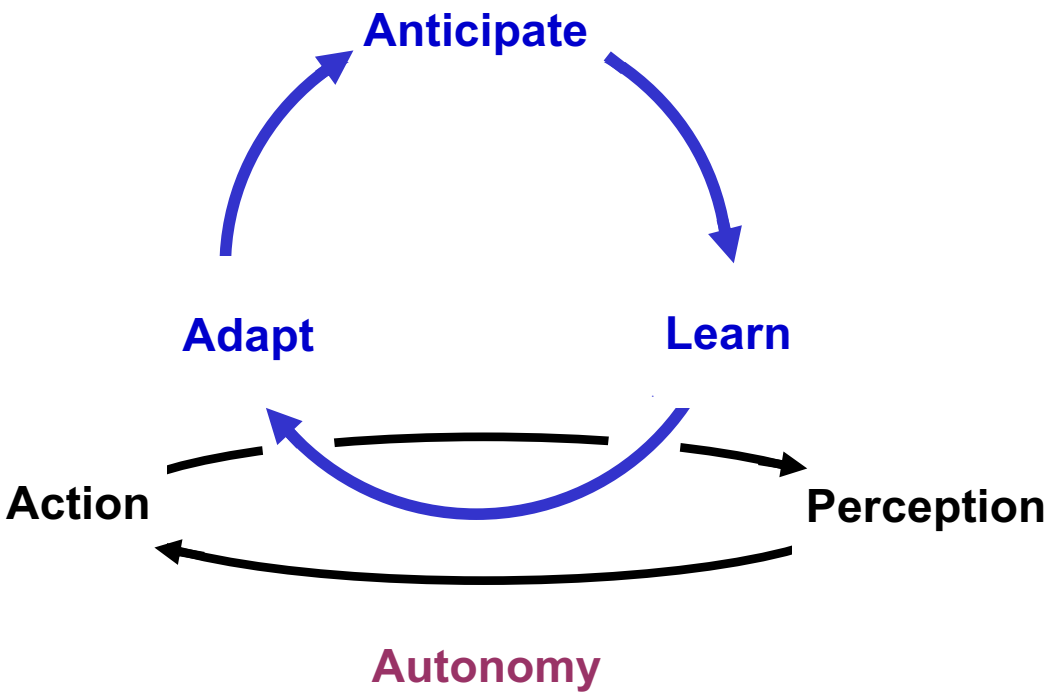
anticipates the outcome of events,

acts to pursue **goals**, and

adapts to changing circumstances."

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

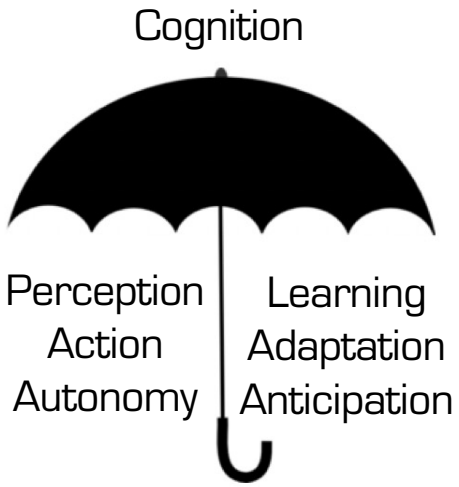
Cognition



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

The Thinker
Auguste Rodin

One view of cognition



An alternative view

"Cognitive vision is a lot about being able to assert that something is there,

given very little visual evidence,

and even perhaps despite evidence to the contrary”

Aaron Bobick

Core abilities of a cognitive system

Perception
Attention
Action selection
Memory
Learning
Reasoning
Meta-reasoning

Kotseruba, I. and J. Tsotsos. 40 years of cognitive architectures: core cognitive abilities and practical applications. Artificial Intelligence Review 53(1), 17 – 94, 2020.

... and prospection

– the capacity to anticipate the future –

is, arguably, the hallmark of cognition

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.

Cognition

"The brain constantly attempts to anticipate future events"

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

The Future

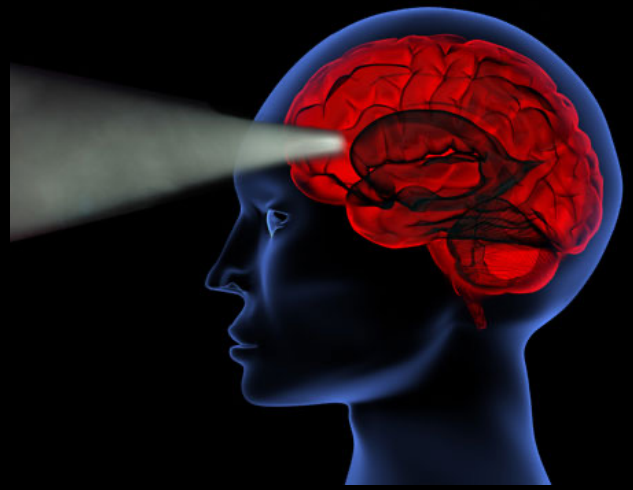
Cognition: breaking free of the present and the limitations of perception

Timescale increases through cognitive development

Episodic Memory

Specific instances of
the agents experience

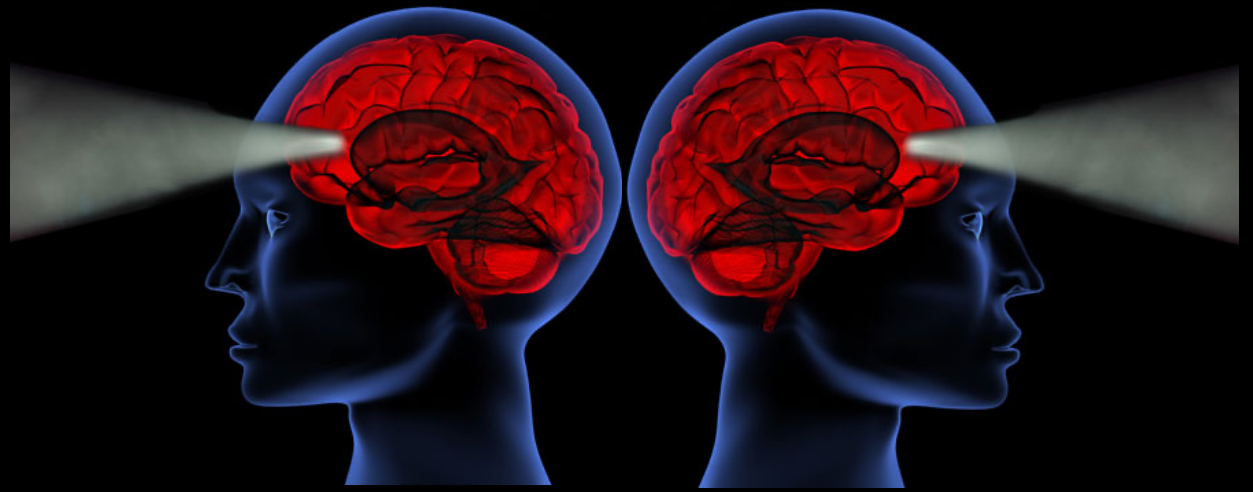
The Past



Past events are
reconstructed ...

Episodic Memory

The Past



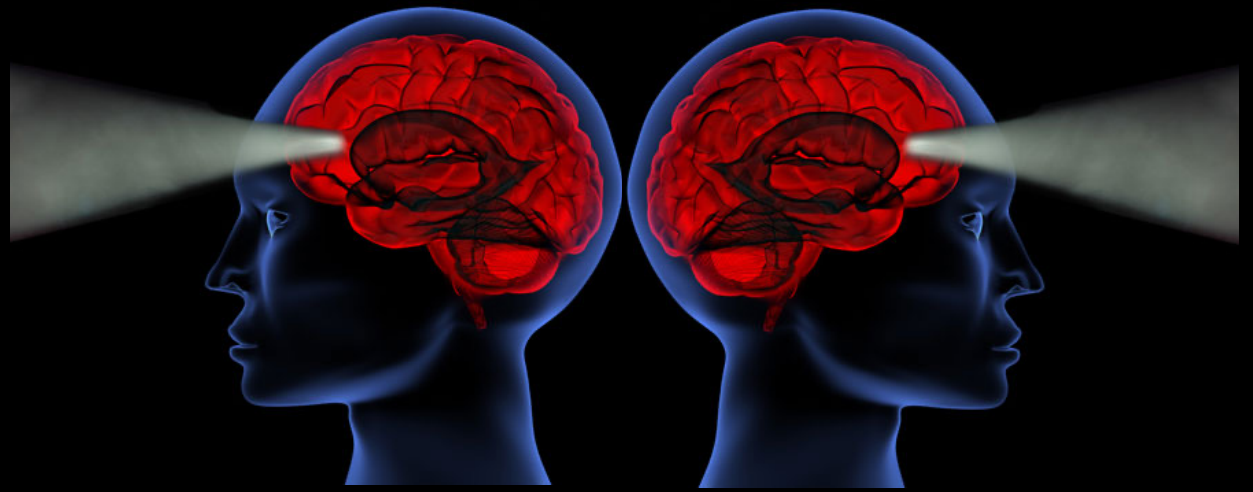
The Future

Past events are
reconstructed ...

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

Episodic Future Thinking

The Past



The Future

Past events are
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.

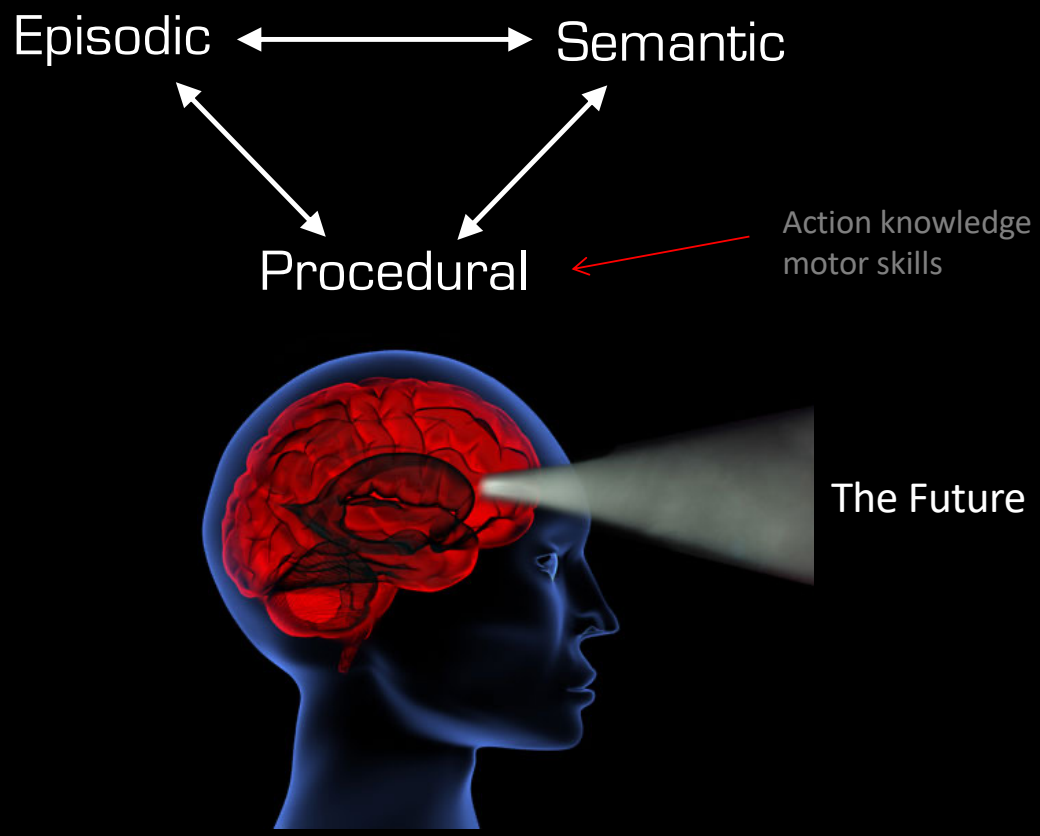
D. L. Schacter and D. R. Addis, "The cognitive neuroscience of constructive memory: Remembering the past and imagining the future," Philosophical Transactions of the Royal Society B, vol. 362, pp. 773–786, 2007.

Episodic ⟷ Semantic

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.

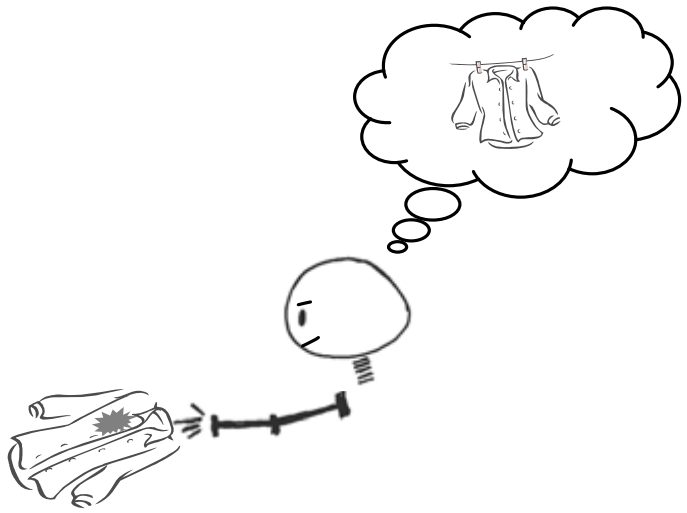


K. K. Szpunar, R. N. Spreng, and D. L. Schacter, A taxonomy of prospection: introducing an organizational framework for future-oriented cognition, PNAS 111(52), 18414–18421, 2014.

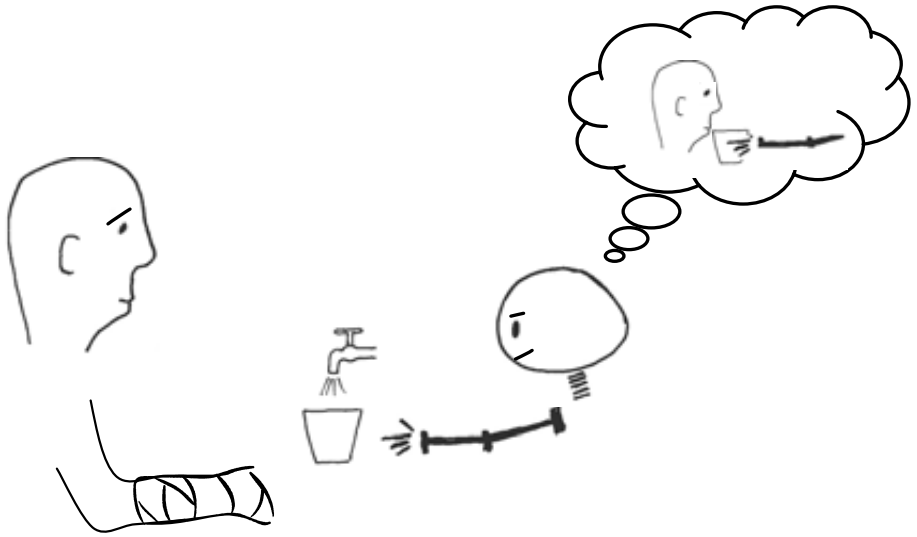
Cognitive systems continually predict

The need for action
(self and others)

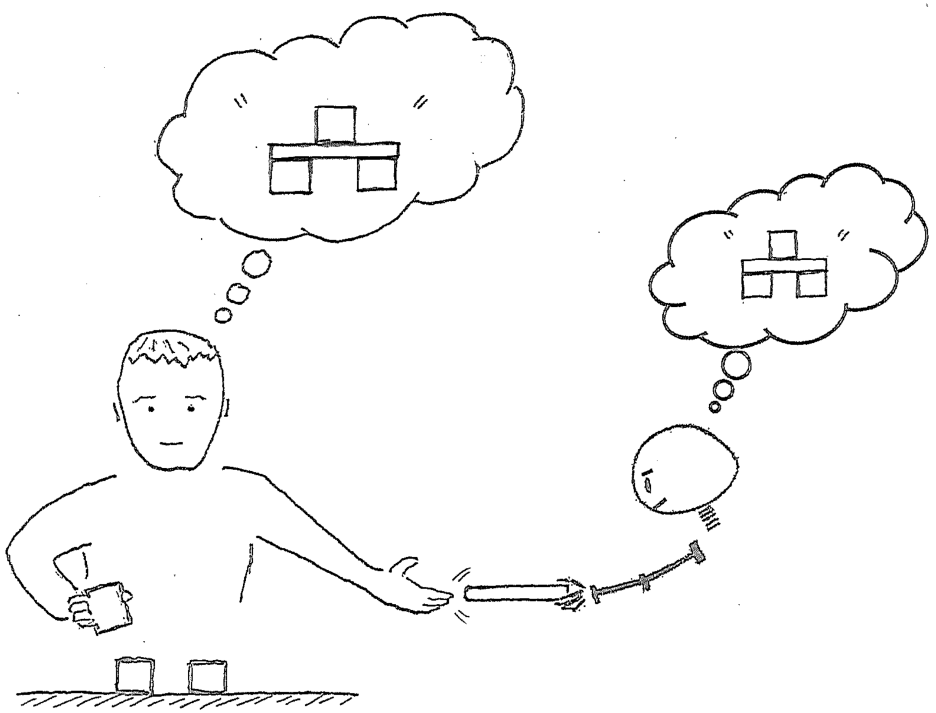
The outcome of those actions



Everyday activities: apparently routine but often complex and demanding



Anticipate the needs of others

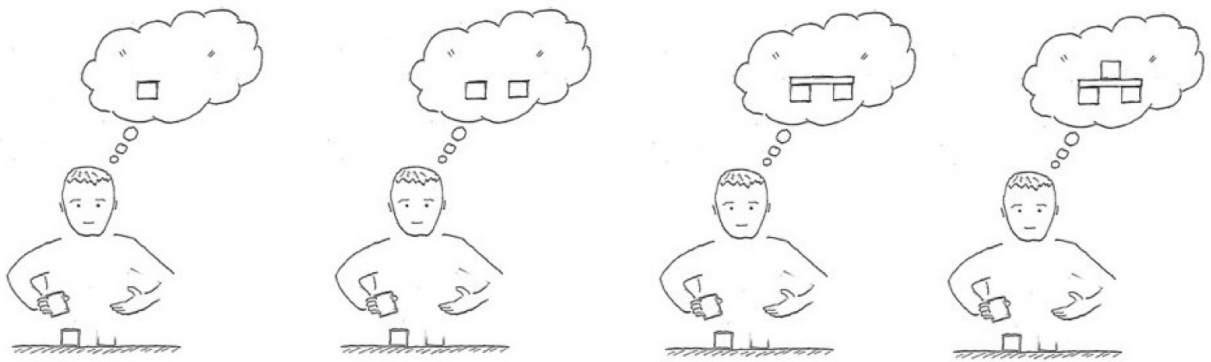


Interact, assist, and collaborate with others

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

Claes von Hofsten

D. Vernon, C. von Hofsten, and L. Fadiga, A Roadmap for Cognitive Development in Humanoid Robots, vol. 11 of Cognitive Systems Monographs (COSMOS). Berlin: Springer, 2010



The Future

A More Detailed Definition of 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., A. Sciutti, and D. Vernon. Cognitive Robotics. In M. Ang, O. Khatib, and B. Siciliano (Eds.), Encyclopedia of Robotics. Springer, 2021.

Recommended Reading

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

A. Cangelosi and M. Asada, Cognitive Robotics Handbook, MIT Press, 2022; Chapter 1.

Acknowledgements

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This course was developed over a four-year period leading up to, during, and directly after the time I spent working at Carnegie Mellon University Africa in Rwanda. My thanks go to the students I taught there, several of whom have contributed directly or indirectly to the material. Their deep interest and searching questions made all the difference. Special thanks go to Vinny Adjibe, Abrham Gebreselasie, Innocent Mukoki, Ribeus Munezero, and Timothy Odonga for their work developing material and software tools for the course during their Summer 2020 CMU-Africa internships, and to Derrick Odonkor, who validated the material and developed the Pepper tutorial for CRAM during his internship at the Institute for Artificial Intelligence, University of Bremen, in the Spring of 2020.

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The module on mobile robots benefitted greatly from a course developed by Alessandro Saffiotti, Örebro University, Sweden, on Artificial Intelligence Techniques for Mobile Robots. I borrowed heavily from this material, whilst creating my own illustrations and diagrams.

The module on robot vision is a very short version of my course on applied computer vision which, in turn, drew inspiration from several sources, including courses given by Markus Vincze at Technische Universitat Wien, by Kenneth Dawson-Howe, Trinity College Dublin, and Francesca Odone, University of Genova. Many of the OpenCV examples are taken from Kenneth Dawson-Howe's book A Practical Introduction to Computer Vision with OpenCV and the code samples.

The material on CRAM (Cognitive Robot Abstract Machine) was derived from tutorials on the CRAM website. I am greatly indebted to Michael Beetz and Gayane Kazhoyan for the time and effort they invested explaining CRAM and teaching me how to write CRAM Plan Language programs during my summer visits to the Institute for Artificial Intelligence, University of Bremen, and during the time I was a member of Prof. Beetz's team from August 2020 to September 2021.

All images and diagrams are either original or have their source credited. My apologies in advance for any unintended omissions. Technical drawings were produced in LaTeX using TikZ and the 3D Plot package.

David Vernon, Carnegie Mellon University Africa, Rwanda

December 2021