Introduction to Cognitive Robotics

Module 6: Artificial Cognitive Systems

Lecture 4: Memory and prospection

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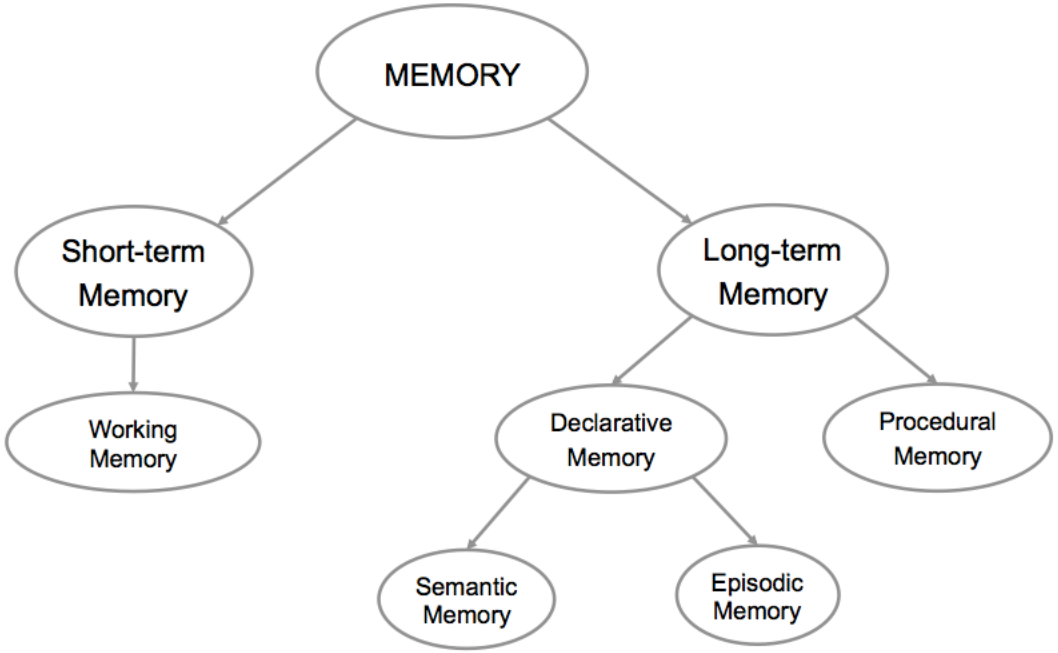
Memory

- Memory plays a crucial and sometimes unexpected role in cognition
- Strong parallel between **memory** and **knowledge**
- Memory and knowledge are equivalent: **they both encapsulate the experience** that arises from interaction with the world
- Memory is **not** just as a **passive** mechanism for storing knowledge about the past

Types of Memory

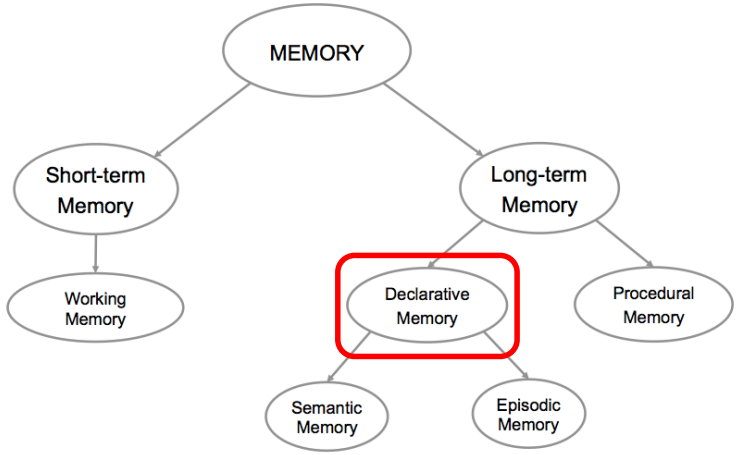
- Declarative
- Procedural
- Semantic
- Episodic
- Long-term
- Short-term
- Working
- Modal
- Amodal
- Symbolic
- Sub-symbolic
- Hetero-associative
- Auto-associative



Types of Memory

Declarative memory

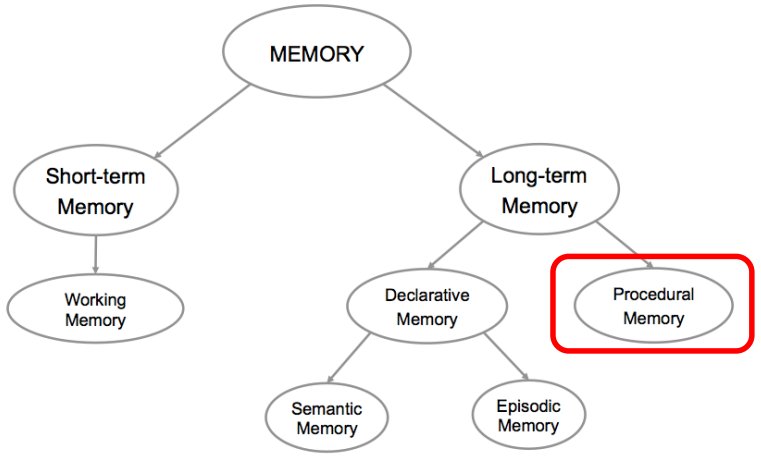
- **Knowledge of things / facts**
- "Knowing that"
- **Propositional memory** (true or false)
- Can be communicated from one agent to another through language
- Can be acquired in a single act of perception or cognition
- Accessible to conscious recall
- **Explicit memory**



Types of Memory

Procedural memory

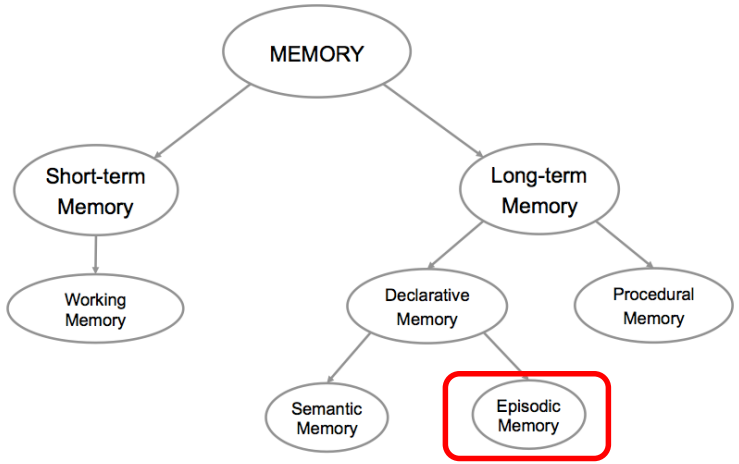
- **Skill-oriented memory of actions**
- “Knowing how”
- Can only be demonstrated
- Acquired progressively and may require an element of practice
- Not accessible to conscious recall
- **Implicit memory**
- **Non-declarative memory**



Types of Memory

Episodic memory

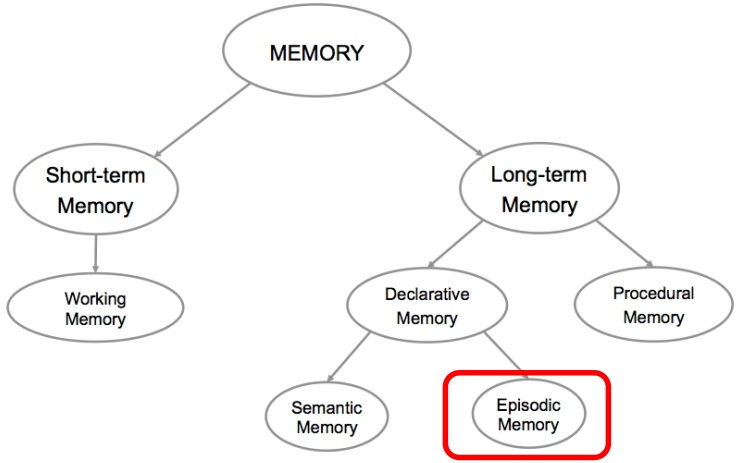
- Specific instances in the agent's experience: **autobiographical**
- **Explicit spatial and temporal context**
  - what happened, where it happened, and when it happened
  - This temporal sequencing is the only element of structure in episodic memory
- Sub-symbolic



Types of Memory

Episodic memory

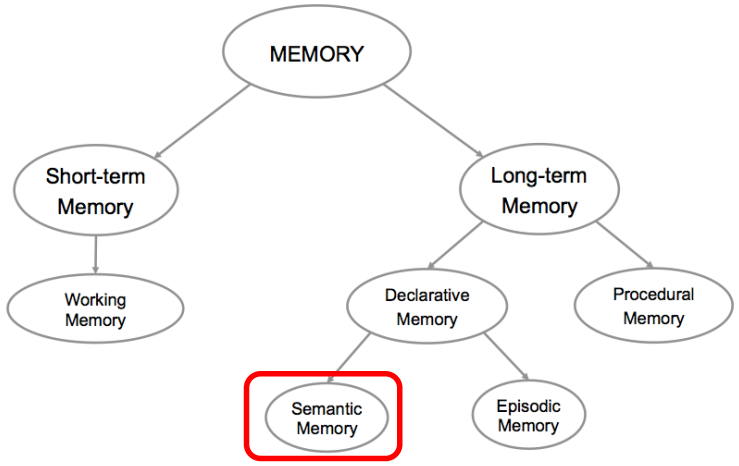
- Episodic memory is a **constructive process**
  - Each time an event is assimilated into episodic memory, past episodes are re- constructed a little differently each time
  - Related to the role that episodic memory plays in the process of internal simulation that forms the basis of prospection



Types of Memory

Semantic memory

- 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

Modal memory

- Tied directly to a particular sensory modality such as vision, audition, or touch
- Episodic memory though is more likely to be modal since it is closely tied to an agents's specific experiences

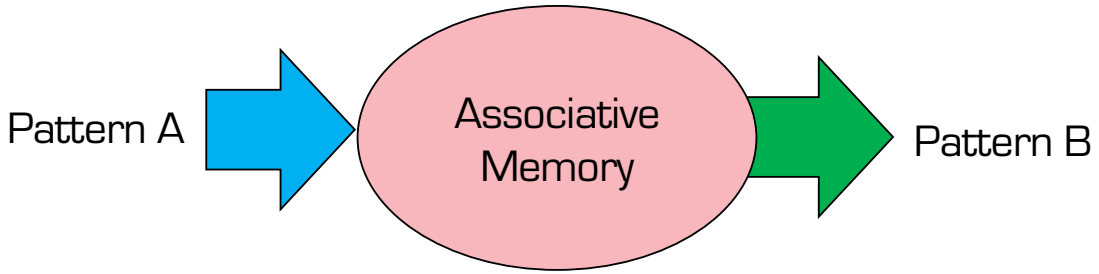
Amodal memory

- Amodal memory has no necessary association with the sensorimotor experiences
- Semantic declarative facts, represented symbolically, are typically amodal

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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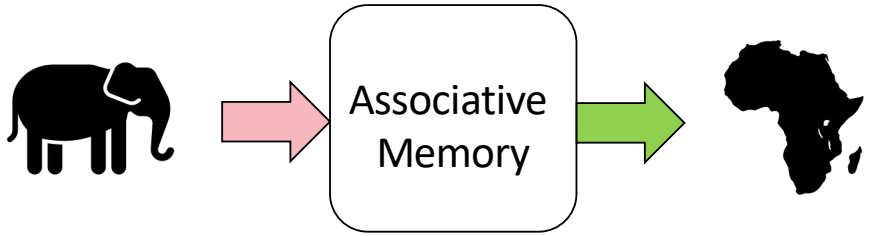

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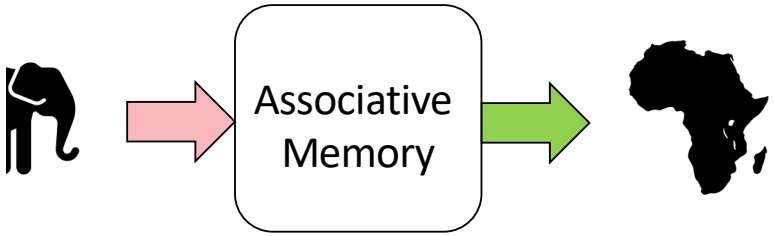

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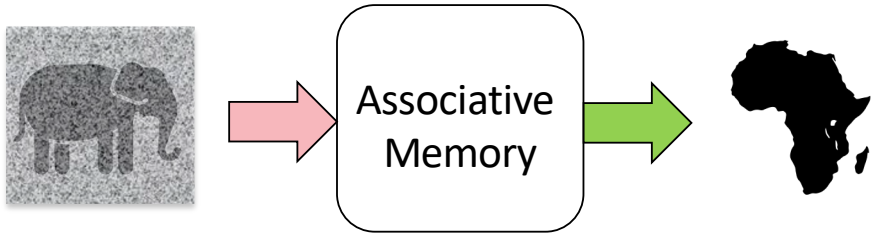
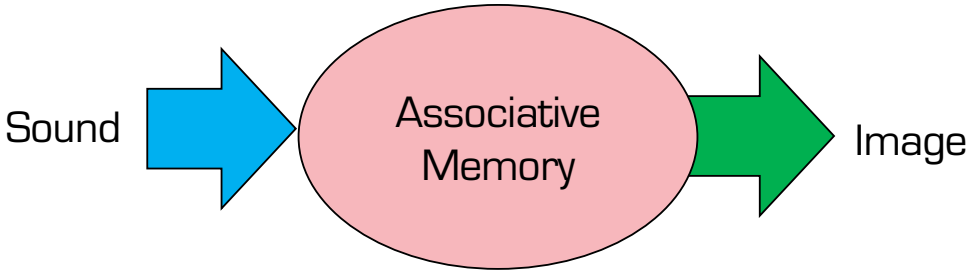


Types of Memory

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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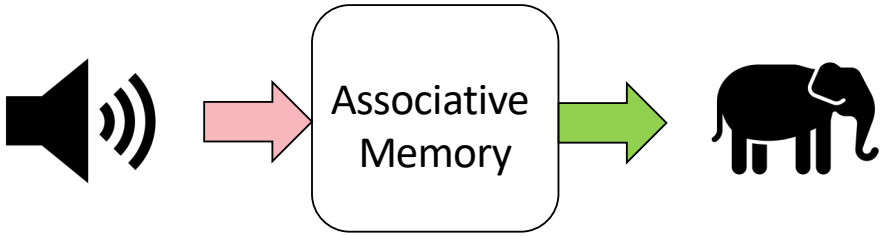

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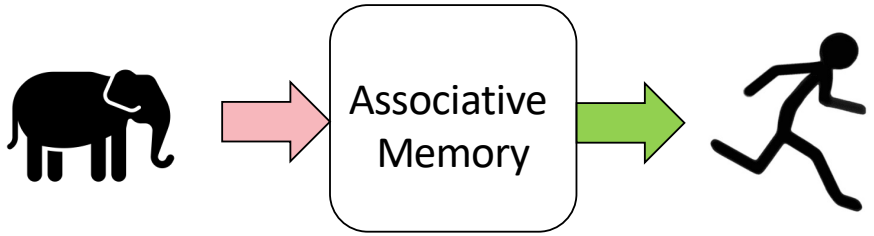
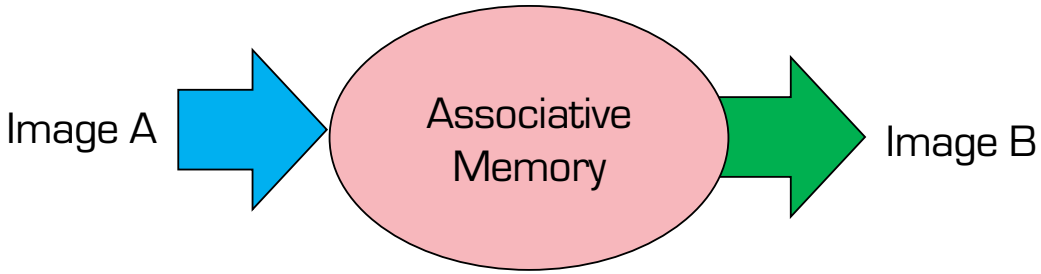


Types of Memory

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



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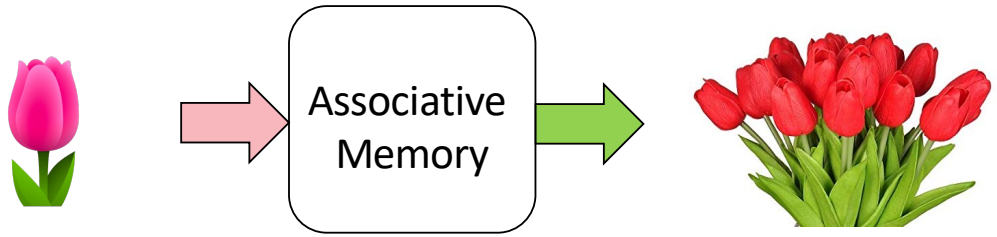


Role of Memory

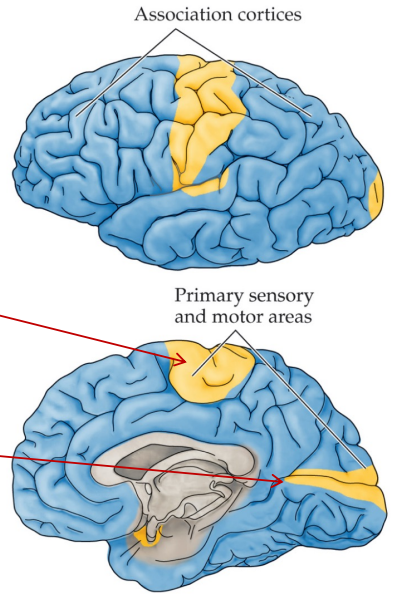
The role of memory – why do we remember things?

- To recognize objects, events, and people we've encountered before
- To act towards them in some appropriate way (attraction/avoidance)
- Memory is what makes it possible for the changes that occur as a result of learning and development to persist
- **Memory also is what makes it possible to project forwards into the future**

Types of Memory

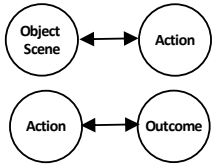
Cortical structures

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



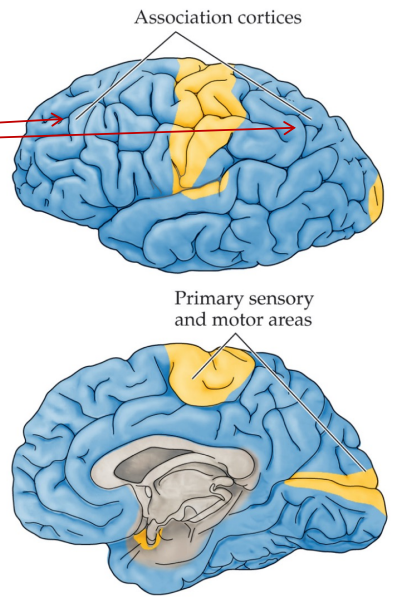
Types of Memory

Associative Processes



Cortical structures

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



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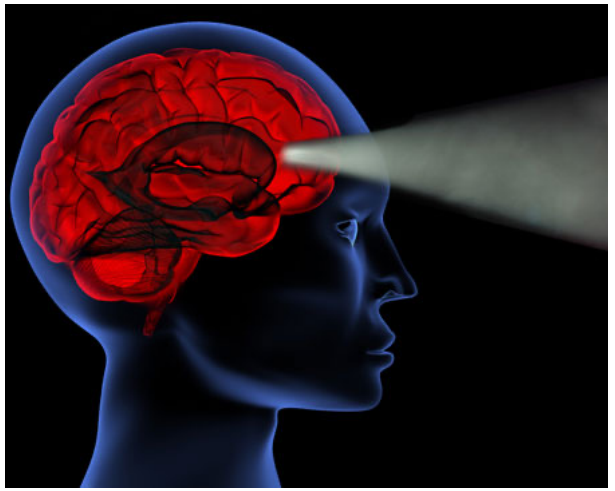


Role of Memory

One of the central pillars of cognitive capacity:

- the ability to **simulate internally the outcomes of possible actions** and select the most appropriate one for the current situation
- Memory can be seen as a mechanism that allows a cognitive agent **to prepare to act,** overcoming through anticipation the inherent “here-and-now” limitations of its perceptual capabilities
- **a cognitive system** doesn’t operate just on the basis of its current sensory data bu**t readies itself for what it expects and adjusts to the unexpected**

Role of Memory

Memory is an active & constructive process, and it is fundamentally associative

- Memories are recalled by associated triggers, possibly other memories
- If you have a network of associative memories, you can run through this network **backwards** or **forwards**
- Running through it **forwards** provides the **anticipatory predictive** element of memory suggesting possible sequence of events leading to a desired goal
- Running through it **backwards** provides a way of **explaining** how some event or other might have occurred or **imagining** ways in which it might have turned out differently

"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

"It's a poor sort of memory that only remembers what has actually happened"

Remarks by Tom Ziemke
at a talk in Linköping University

Memory is Constructive

Self-Projection, Prospection, & Internal Simulation

Memory plays at least four roles in cognition

1. Remember past events
2. Anticipate future ones
3. Imagine the viewpoint of other people
4. Navigate around our world

Self-Projection, Prospection, & Internal Simulation

All four roles involve **self-projection**

- Ability of an agent to shift perspective from itself in the here-and-now
- It does this by **internal simulation**,

  i.e. the mental construction of an imagined alternative perspective

Self-Projection, Prospection, & Internal Simulation

There are four forms of internal simulation

1. **Recalling episodic memories** (remembering the past)
2. **Navigation** (orienting yourself topographically, i.e. in relation to your **present** surroundings)
3. **Theory of mind** (taking someone else's perspective on matters)
4. **Prospection** (anticipating possible future events)

Self-Projection, Prospection, & Internal Simulation

- All four forms of simulation are **constructive**
  - They involve a form of **imagination**
- Fine for prospection, theory of mind, or navigation
- **but remembering the past? … more on this in a moment**

Self-Projection, Prospection, & Internal Simulation

- There is a difference between knowing about the future and projecting ourselves into the future
- **Projection is experiential, knowing is not**
- Episodic memory (experiences) and semantic memory (facts) facilitate different types of prospection

Self-Projection, Prospection, & Internal Simulation

- Episodic memory
  - **Re-experience** your past
  - **Pre-experience** your future
- Projecting yourself forward in time is important when you form a goal
  - Creating a mental image of yourself acting out the event
  - **Episodically pre-experiencing** the unfolding of a plan to achieve that goal
  - **Episodic Future Thinking** [Atance and O'Neill 2001]

Self-Projection, Prospection, & Internal Simulation

Episodic memory is inherently constructive

- Old episodic memories are reconstructed slightly differently every time a new episodic memory is assimilated or remembered

- The **constructive episodic simulation hypothesis** [Schacter and Addis 2007]

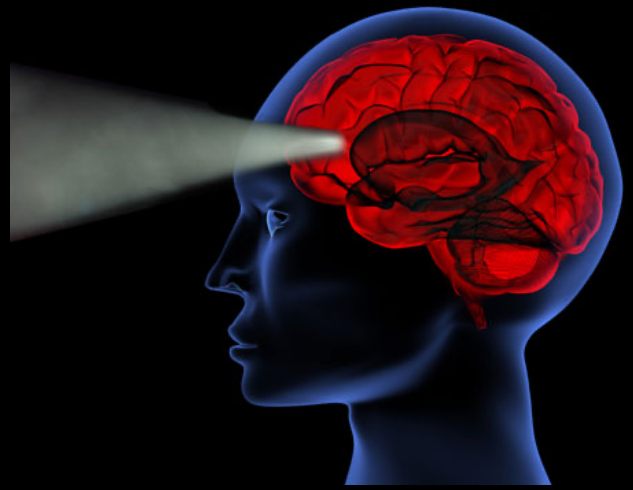
  - Episodic memory allows the **simulation of multiple possible futures**

  - This imposes an **even greater** need for a constructive capacity because of the need to extrapolate **beyond past experiences**

Episodic Memory

Specific instances of
the agents experience

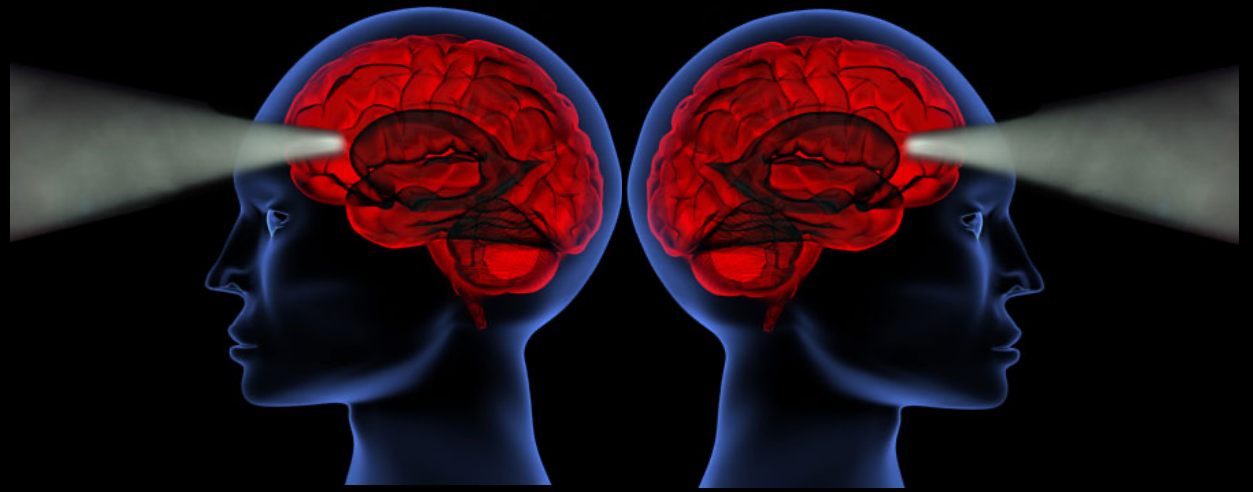
The Past



Past events are
reconstructed ...

Episodic Memory

The Past



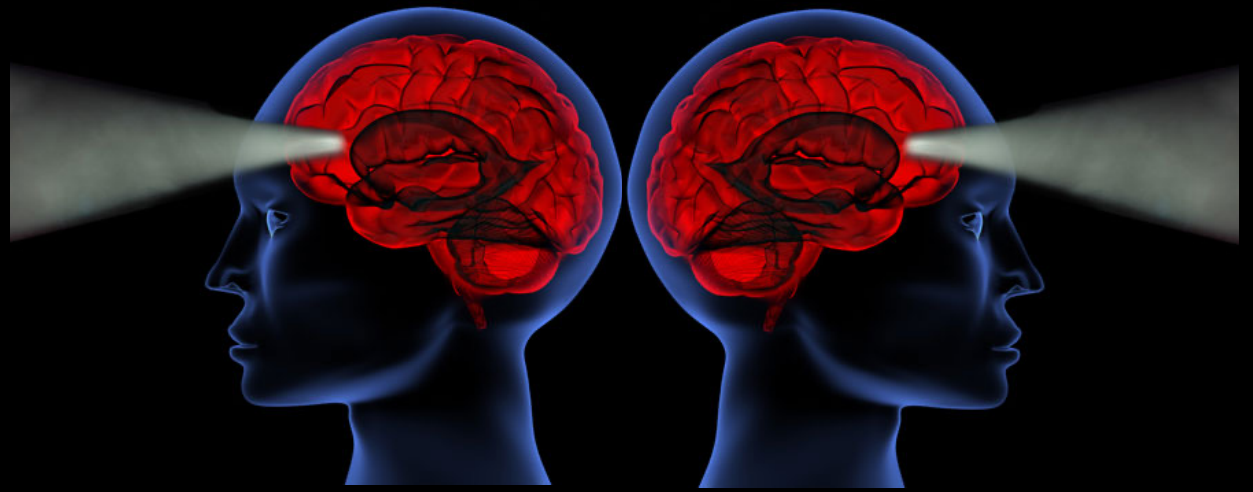
The Future

Past events are
reconstructed ...

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

Episodic Future Thinking

The Past



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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

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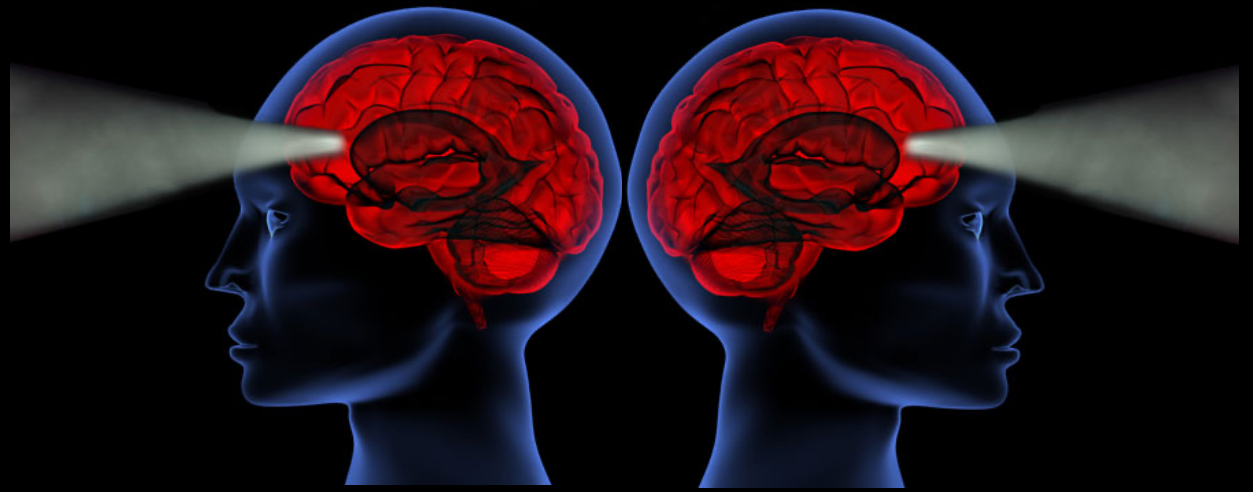

Future A
Future B
Future C
...

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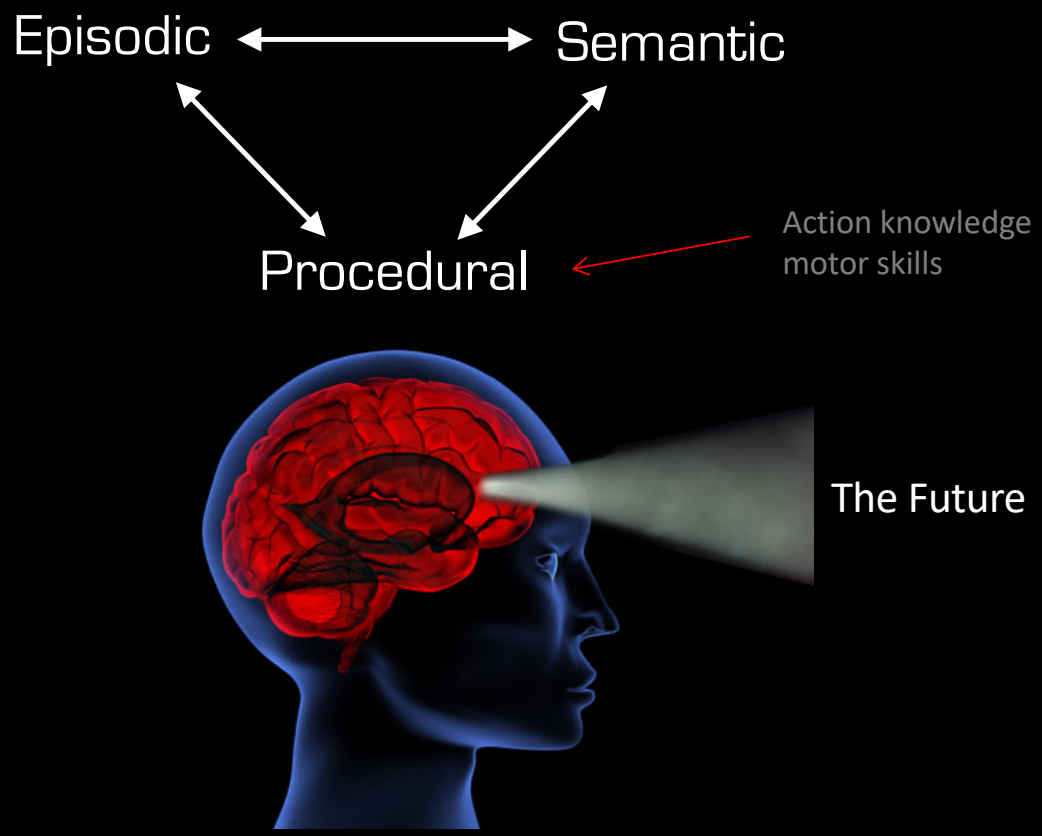
D. L. Schacter and D. R. Addis, "The cognitive neuroscience of constructive memory: Remembering the past and imagining the future," Philosophical Transactions of the Royal Society B, vol. 362, pp. 773–786, 2007.

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.



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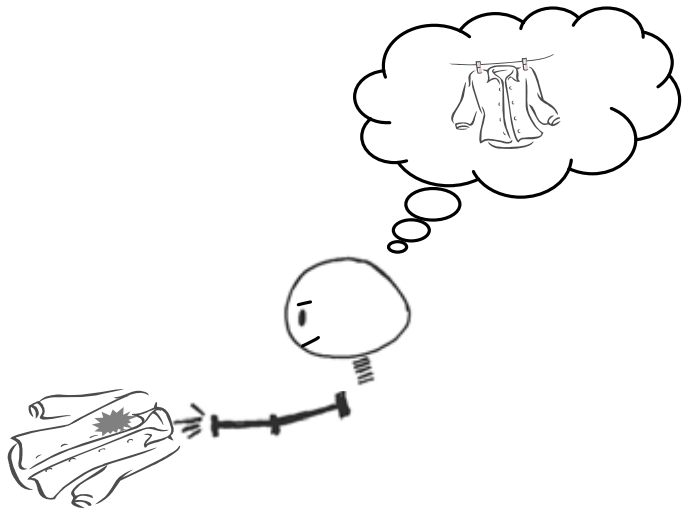

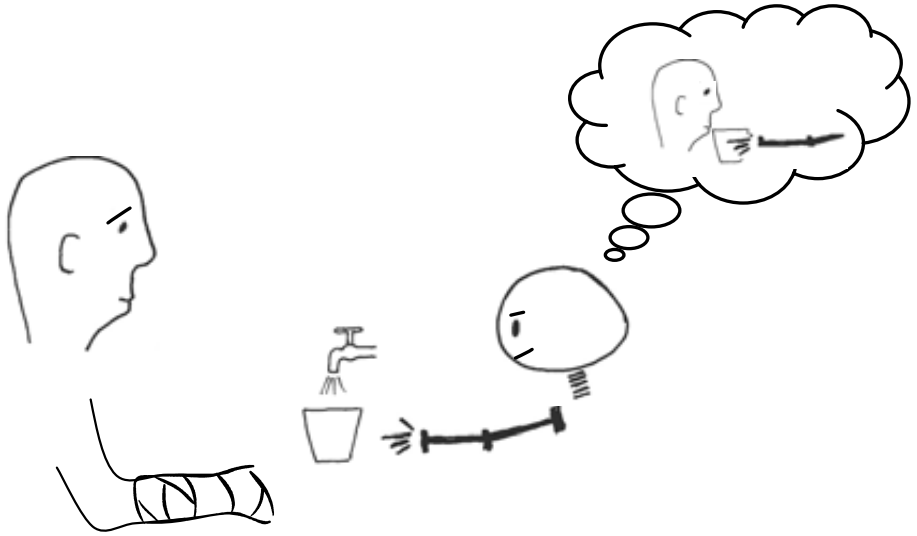

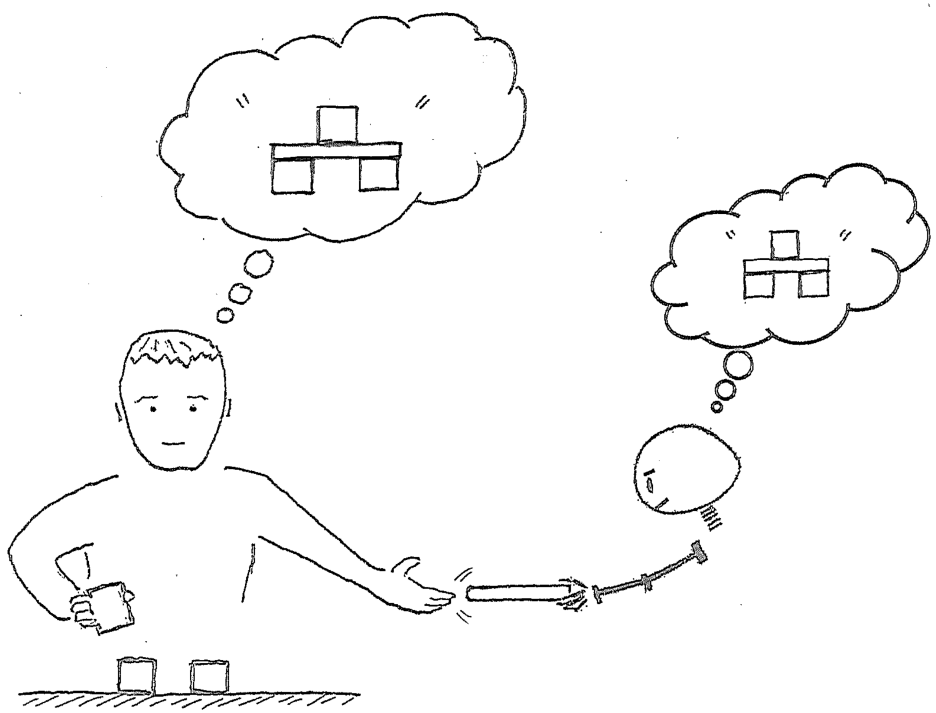

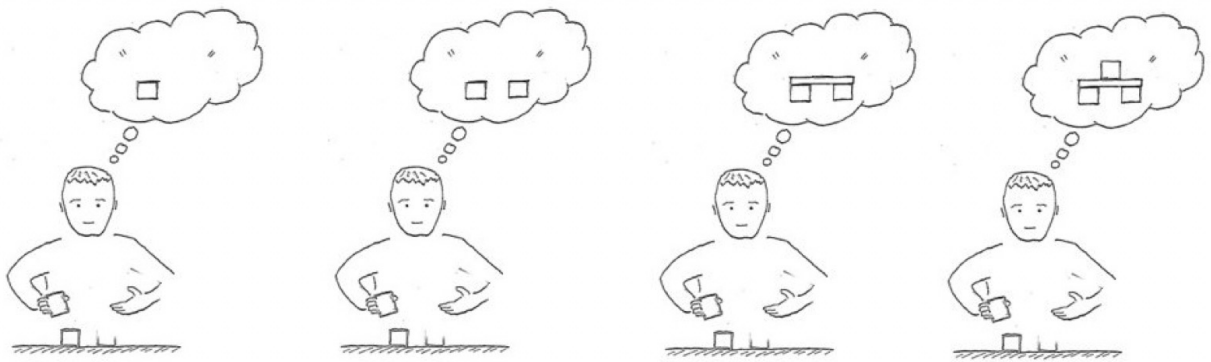

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