Introduction to Cognitive Robotics

Module 6: Artificial Cognitive Systems

Lecture 5: Internal simulation; the symbol grounding problem

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Self-Projection, Prospection, & Internal Simulation

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

Self-Projection, Prospection, & Internal Simulation

- When humans imagine the future
  - They anticipate an event
  - They anticipate how they feel about that event
- Knowing how you feel about something is a very good way of telling whether or not that event is safe or dangerous
- We call these the **hedonic** consequences of the event
- Pre-experience of prospection also involves **pre-feeling**

Internal Simulation and Action

- So far, internal simulation considered entirely in terms of memory-based self-projection

  Using re-assembled combinations of episodic memory to

  - Pre-experience possible futures
  - Re-experience (and possibly adjust past experiences)
  - Project ourselves into the experiences of others

- However, action plays a significant role in our perceptions so does action play a role in internal simulation?

- YES

Internal Simulation and Action

- Internal simulation
  - extends beyond episodic memory
  - includes simulated interaction, particularly embodied interaction

- Terms
  - Simulation
  - Internal simulation
  - Mental simulation
  - Emulation
    - approach tries to model the mechanism by which the simulation is produced

Internal Simulation and Action

- Several simulation theories, but perhaps the most influential is known as the **Simulation Hypothesis** [Hesslow 2002, Hesslow 2012]

- Three core assumptions

1. The regions in the brain that are responsible for motor control can be activated ***without*** causing bodily movement

   Covert action / covert behaviour

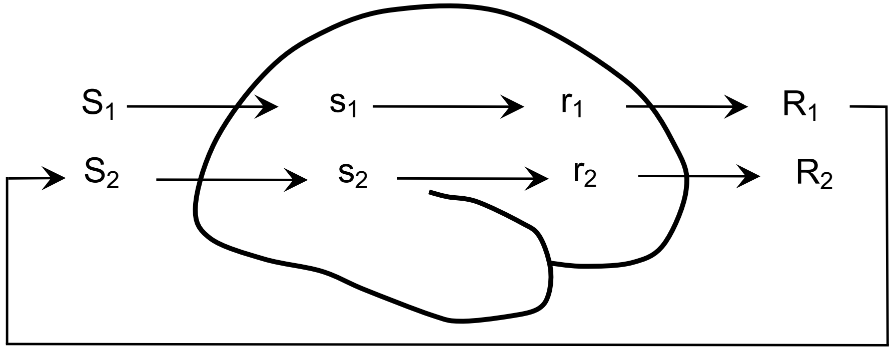
2. Perceptions can be caused by internal brain activity and not just by external stimuli

   Simulation of perceptions

3. The brain has associative mechanisms that allow motor behaviour or perceptual activity to evoke other perceptual activity

   Simulated actions elicit perceptions

Internal Simulation and Action

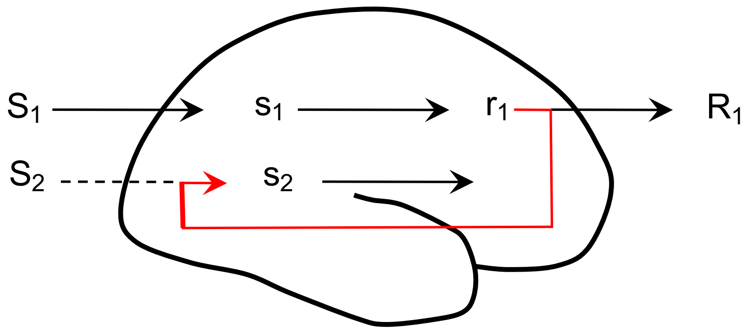


No internal simulation

Internal Simulation Hypothesis

[Hesslow 2002, 2012]

Internal Simulation and Action

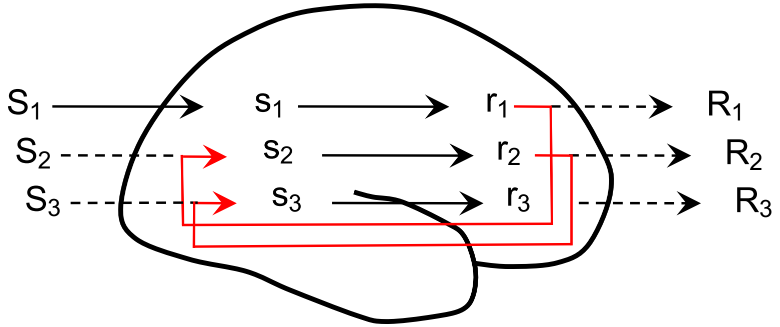


A motor response
to an input stimulus
causes the internal simulation
of an associated perception …

Internal Simulation Hypothesis

[Hesslow 2002, 2012]

Internal Simulation and Action



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

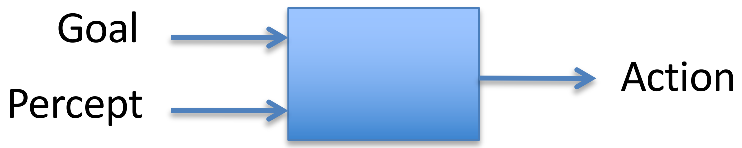
Internal Simulation Hypothesis

[Hesslow 2002, 2012]

Internal Simulation and Action

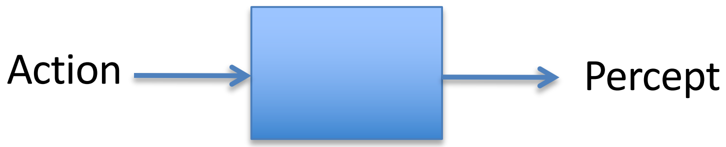
HAMMER accomplishes internal simulation using forward and inverse models

– The inverse model



- Takes as input the current state of the system and the desired goal, and it outputs the motor commands necessary to achieve that goal

– The forward model



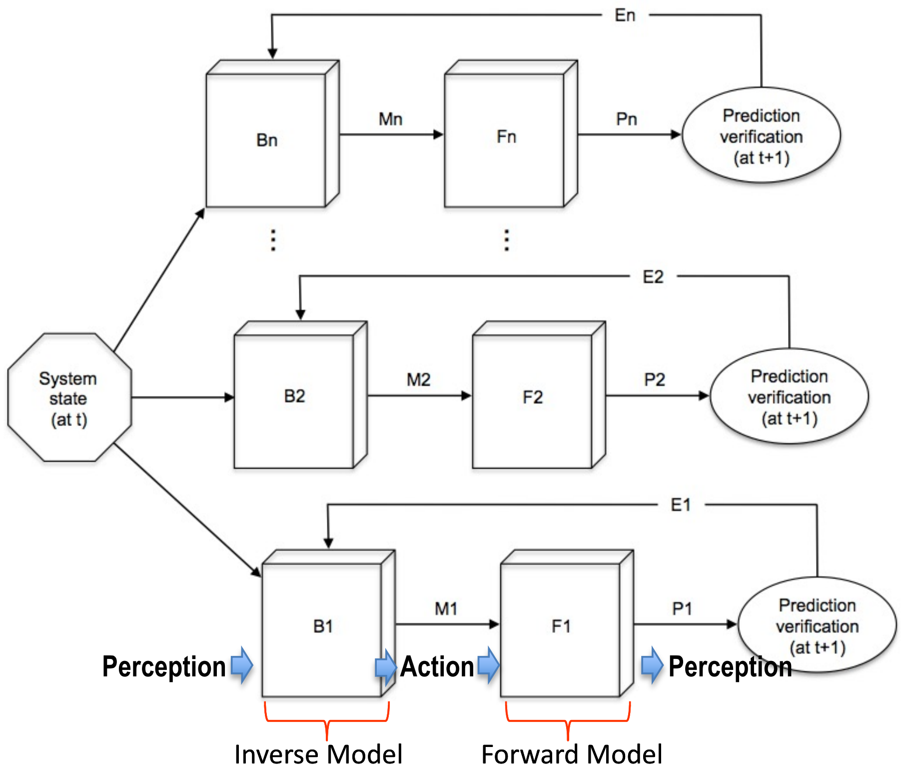
- Acts as a predictor

- Takes as input the motor commands and simulates the perception that would arise if this motor command were to be executed

  (just as the simulation hypothesis envisages)

Internal Simulation and Action

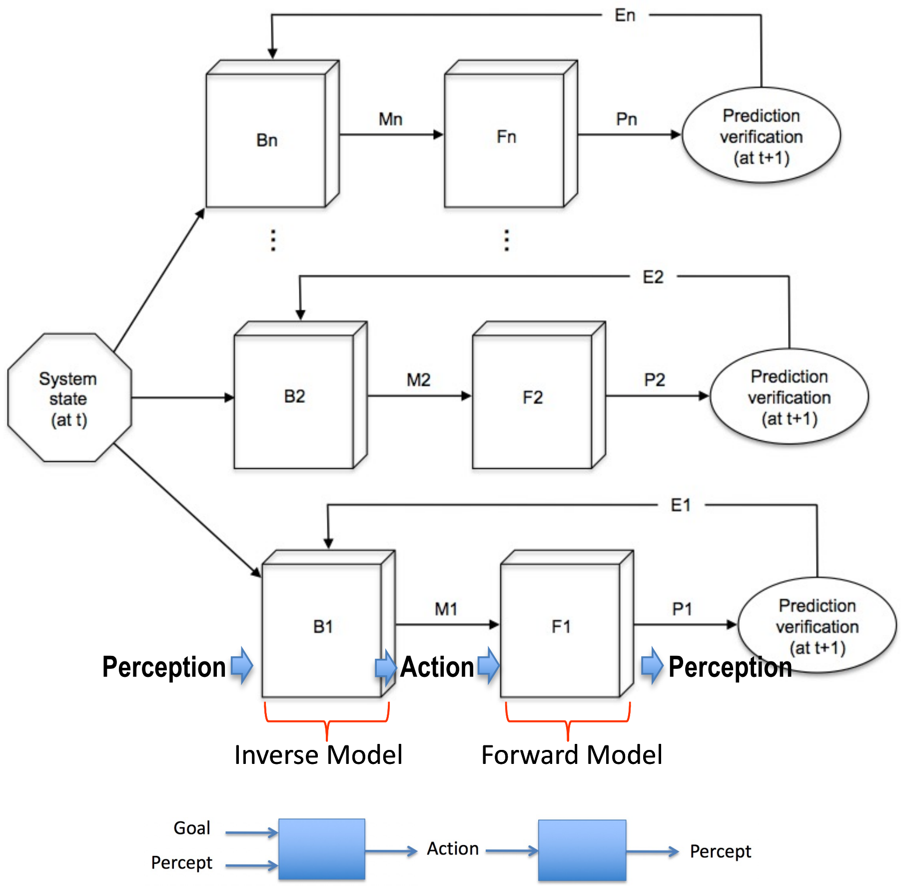
HAMMER Architecture



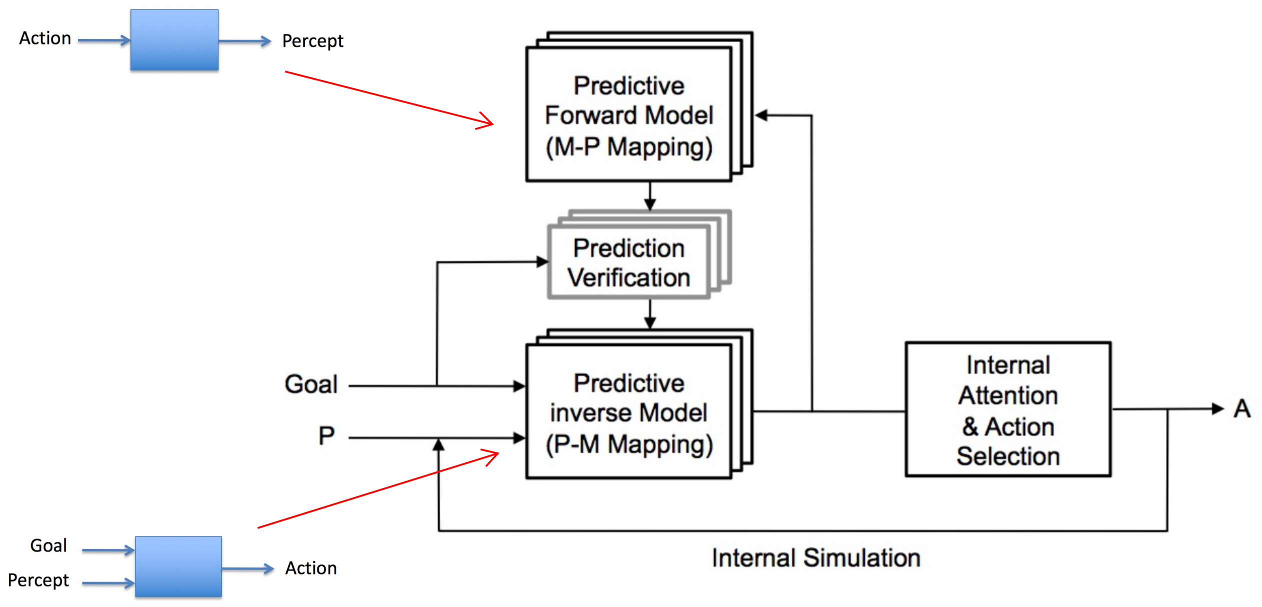
Y. Demiris and B. Khadhouri. Hierarchical attentive multiple models for execution and recognition (HAMMER). Robotics and Autonomous Systems, 54:361– 369, 2006.

Internal Simulation and Action

HAMMER Architecture



Internal Simulation and Action



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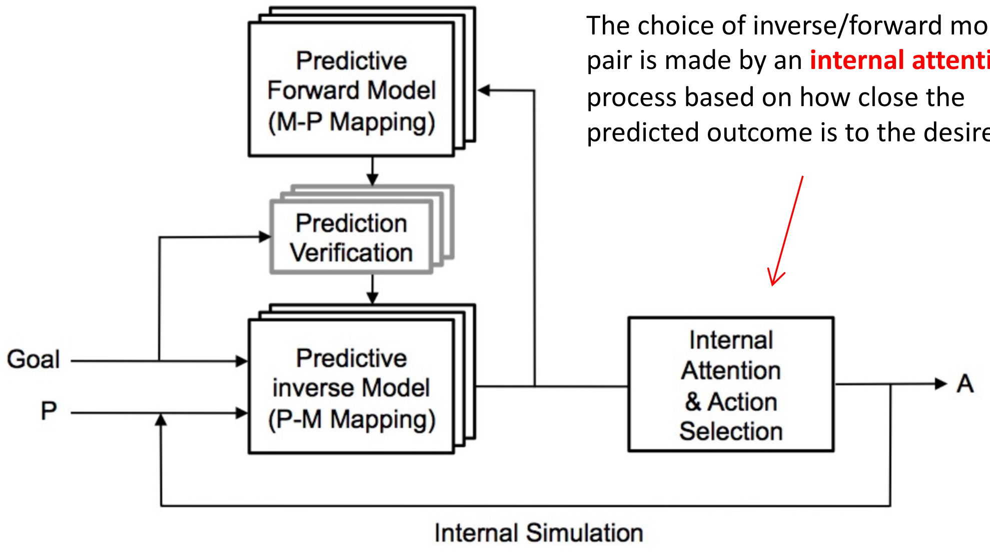
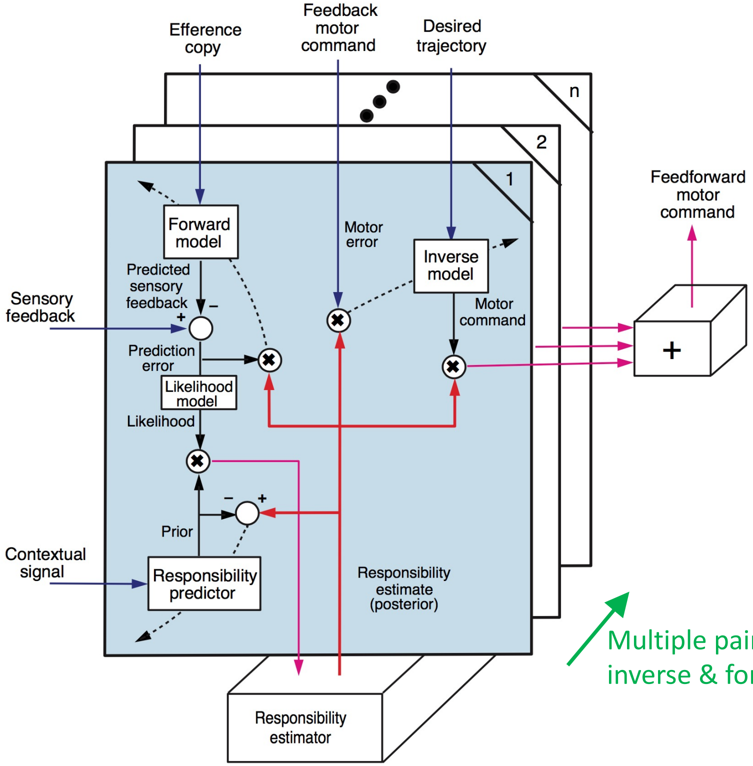
Internal Simulation and Action



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.

Internal Simulation and Action



Multiple pairs of
inverse & forward models

D. Wolpert, R. C. Miall, and M. Kawato. Internal models in the cerebellum. Trends in Cognitive Sciences, 2(9):338–347, 1998.

Internal Simulation and Action

- HAMMER provides for the hierarchical composition of primitive actions into more complex sequences

- It has been implemented both in robot simulations and on physical robotic platforms

Internal Simulation and Action

- HAMMER goes beyond the scope of episodic memory in effecting internal simulation by invoking actions and behaviours

- The sensorimotor associations involved in internal simulations, for forward and inverse models, requires both **episodic memory** and **procedural memory**

- **Episodic memory** is needed for **visual imagery**, including proprioceptive imagery

- **Procedural memory** is needed **for motor imagery**

The Symbol Grounding Problem

- Assuming a cognitive system has some form of symbolic representation of the world around it
  - i.e. some set of tokens that denote objects in the agent's world
- **How does the representation, i.e. the symbols, acquire meaning?**

  How do purely symbolic representations acquire semantic content?
- These apparently innocent questions are made difficult by the fact that (physical) symbol systems are governed by purely syntactic processes

The Symbol Grounding Problem

- Physical symbol systems
  - Atomic symbols
  - Strings of symbols
  - Symbol-based rules that define the manipulation and recombination of symbols and strings of symbols
- Defined in terms that make no reference to what these symbols mean

The Symbol Grounding Problem

- But they are all "semantically interpretable"

  – the syntax can be assigned a semantic meaning so that symbols and strings of symbols can represent objects, events, or concepts, and describe them or stand in for them

- The problem is how to assign this meaning

- This is the **symbol grounding problem** [Harnad 1990]

The Symbol Grounding Problem

- Symbolic representations have to be grounded bottom-up in non-symbolic representations of two kinds:

- **Iconic** representations
  - Derived directly from sensory data (e.g. visual imagery, motor imagery)
  - Allow you to discriminate between different objects

- **Categorical** representations
  - Based on the output of both learned and innate processes that detect invariant features of object & event categories from these sensory data
    (e.g. object affordances, repeated behaviours … food is nice; dogs bite)

The Symbol Grounding Problem

- Higher-order symbolic representations can then be derived from these elementary symbols
- Both types of representation are non-symbolic
- **A non-symbolic process is required to learn the invariances and thereby form the categories**

The Symbol Grounding Problem

- Usually, we use some form of connectionist approach
  - Create the mapping
  - Form the categorical representation
- As a consequence, according to this argument, a grounded symbol system is a **hybrid system**: a combination of symbolic and emergent approaches (h not H)

The Symbol Grounding Problem

- A restricted form is the **symbol anchoring problem** [Coradeschi and Saffiotti 2003]

- Concerned only with artificial systems

The Symbol Grounding Problem

- Establish a relationship between a symbolic label denoting some object and the sensory perception of that object

- Maintaining that relationship over extended periods of time, even when that object cannot be seen

- Only concerned only with grounding physical objects

  – Doesn’t address the grounding of abstract concepts (war or peace)