Artificial Cognitive Systems

Module 7: Memory and Prospection

Lecture 3: Internal simulation and action; forgetting

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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

Covert action / covert behaviour

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

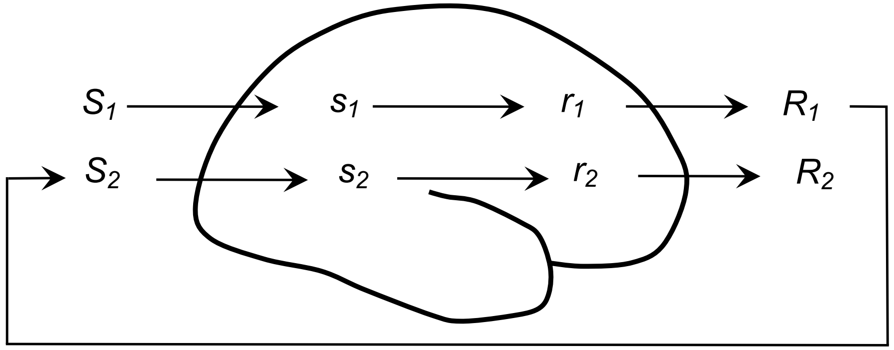
Simulation of perceptions

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

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

Simulated action elicit perceptions

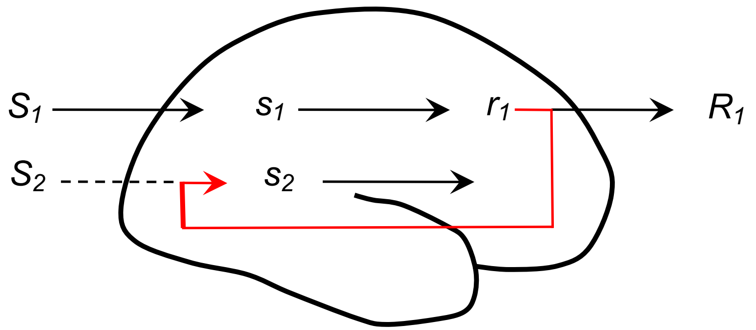
Internal Simulation and Action



No internal simulation

Internal Simulation Hypothesis
(Hesslow 2002, 2012)

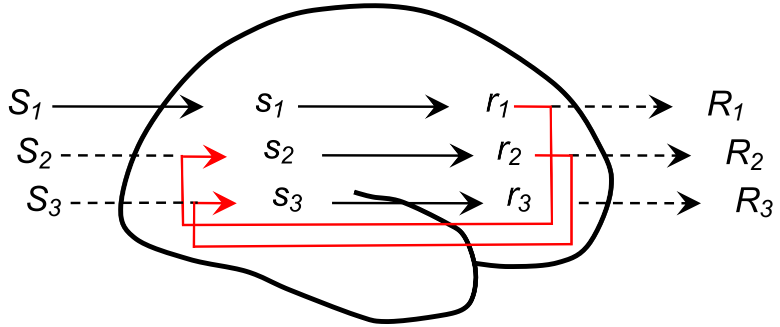
Internal Simulation and Action



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

There is an increasing amount of neurophysiological evidence in support of all three assumptions

For example, see:

H. Svensson, S. Thill, and T. Ziemke. Dreaming of electric sheep? Exploring the functions of dream-like mechanisms in the development of mental imagery simulations. *Adaptive Behavior*, 21:222–238, 2013.

Internal Simulation and Action

Action-directed internal simulation involves three different types of anticipation:

- **Implicit anticipation**
  - Prediction of motor commands from (possibly simulated) perceptions
- **Internal anticipation**
  - Prediction of the proprioceptive consequences of carrying out an action, i.e. the effect of an action on the agent's own body
- **External anticipation**
  - Prediction of the consequences for external objects and other agents of carrying out an action

Internal Simulation and Action

- Implicit anticipation selects some motor activity (possibly covert, i.e. simulated) to be carried out based on an association between stimulus and actions
- Internal and external anticipation then **predict** the consequences of that action
- Collectively, they simulate actions and the effects of actions
- Covert action involves motor imagery
- Simulation of perception is referred to as visual imagery (perceptual imagery)

Internal Simulation and Action

- Motor imagery is also a form of perceptual imagery
  - It involves the proprioceptive and kinesthetic sensations associated with bodily movement
- Covert action often has elements of both motor and visual imagery
- *Vice versa*, the simulation of perception often has elements of motor imagery

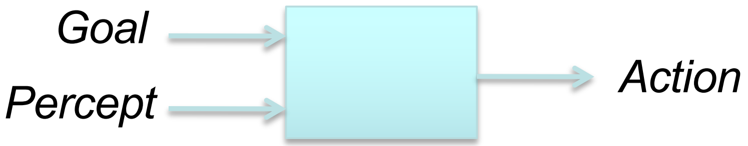
Internal Simulation and Action

- Visual and motor imagery are sometimes referred to collectively as mental imagery
- Mental imagery can be viewed as a synonym for internal simulation

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)

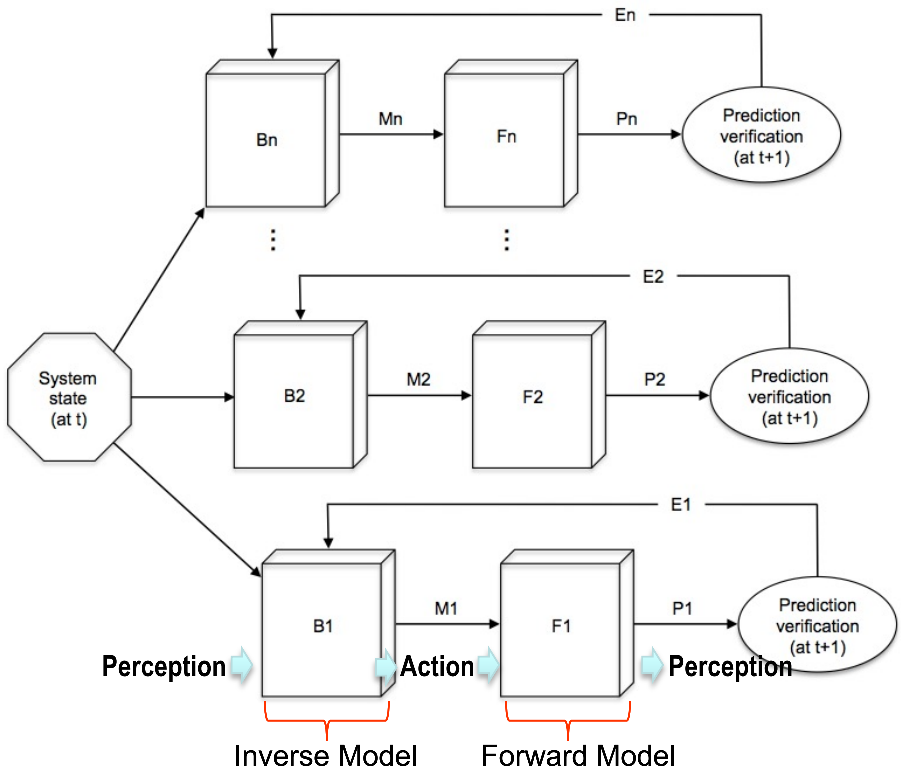
Internal Simulation and Action

HAMMER accomplishes internal simulation using forward and inverse models (Demiris and Khadhouri 2006)

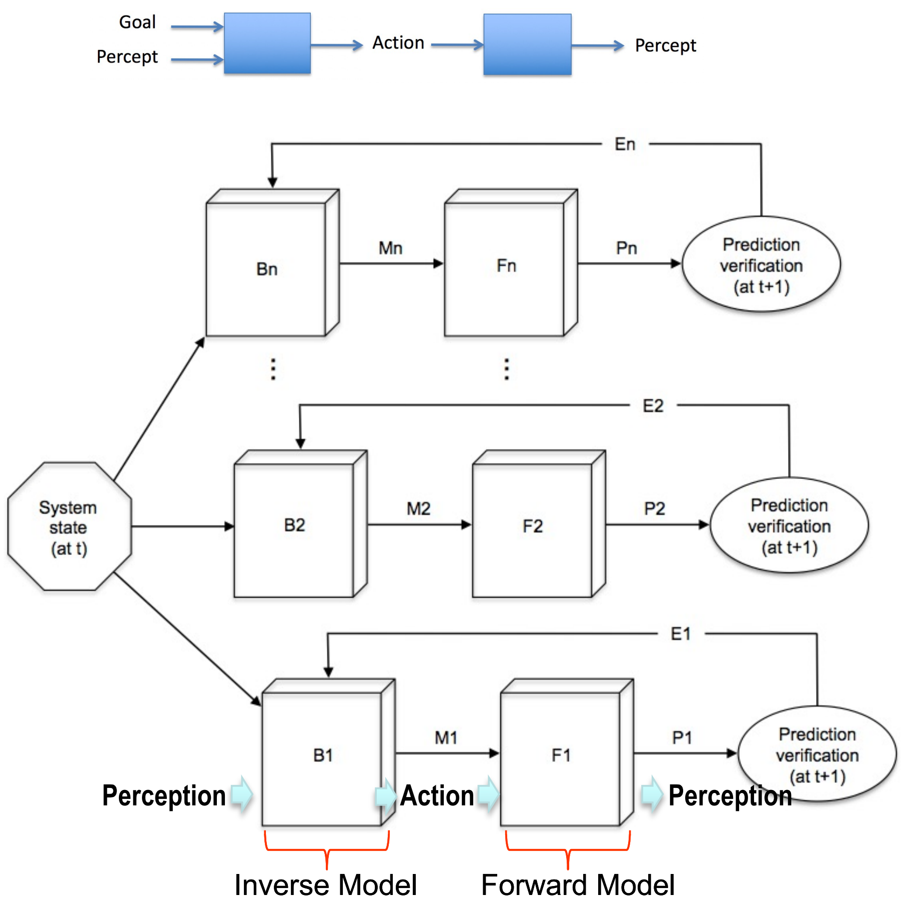
Takes internal simulation one step further:

- Provides the output of the inverse model as the input to the forward model

HAMMER



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



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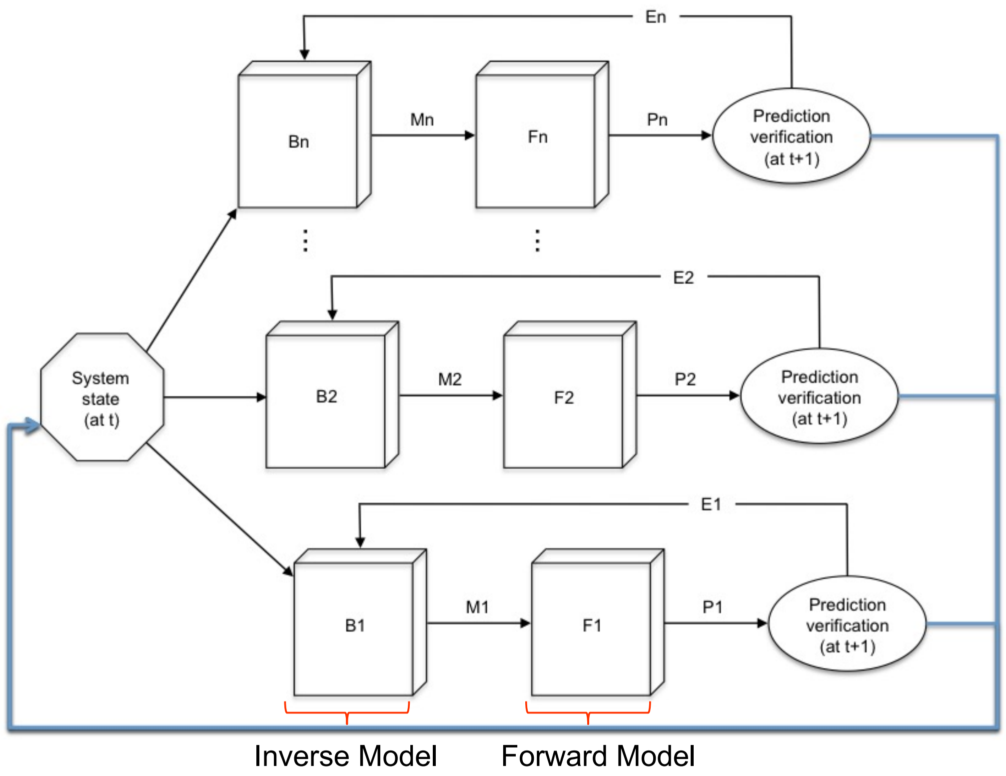
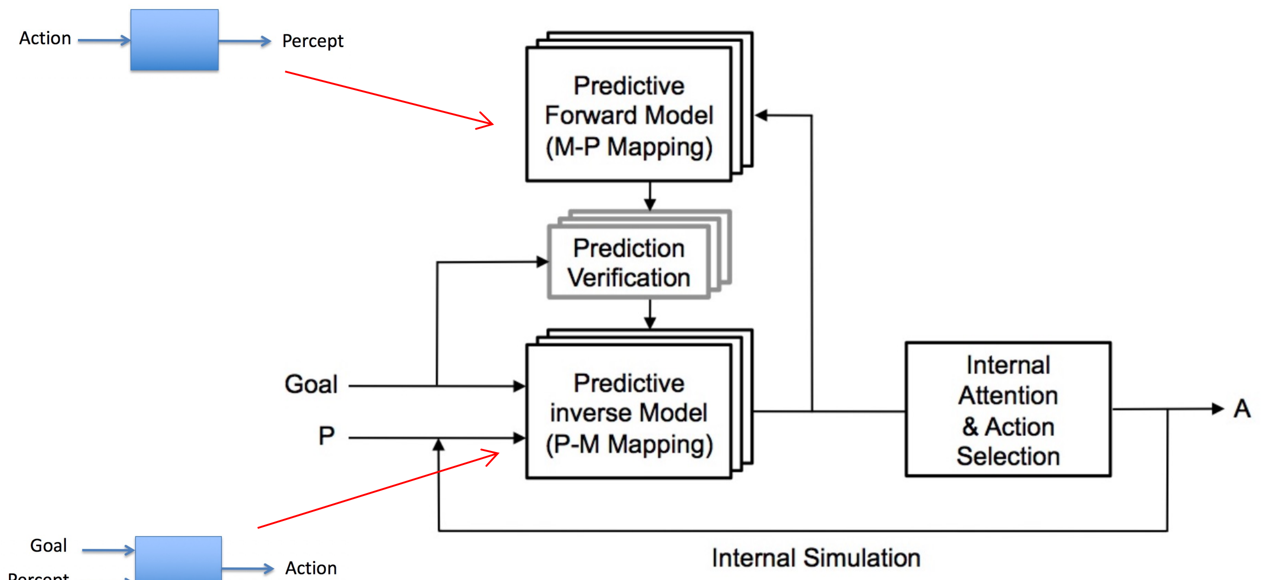


The choice of inverse/forward model pair is made by **an internal attention process** based on how close the predicted outcome is to the desired one

HAMMER



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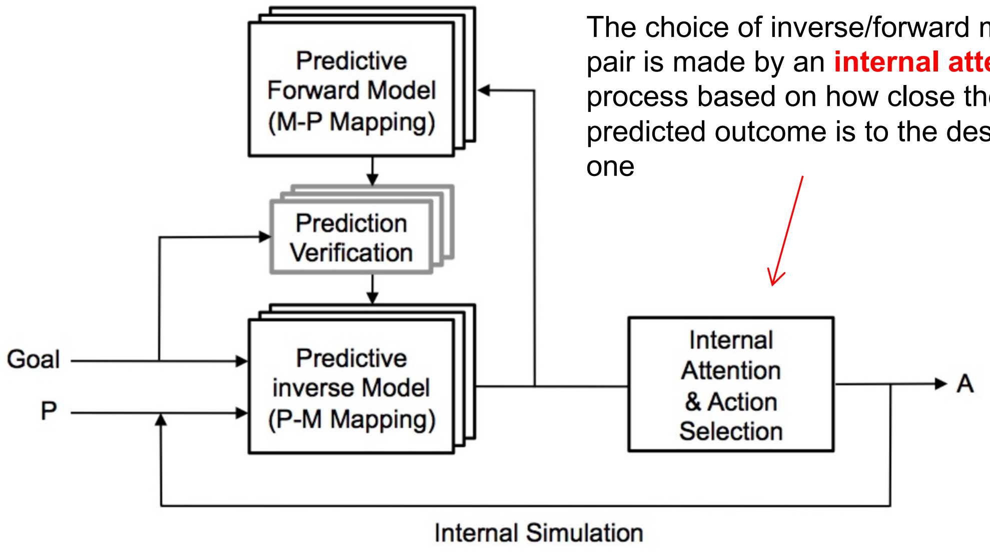

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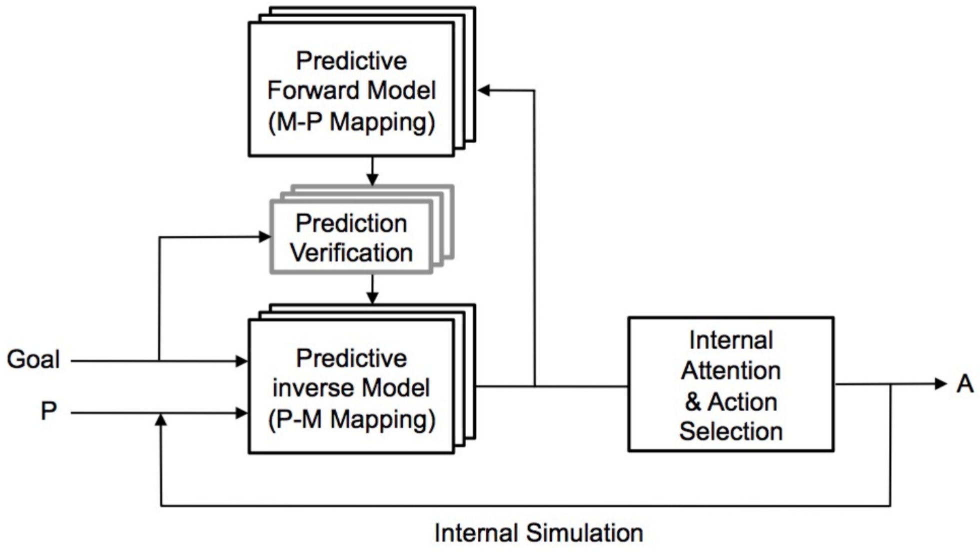
HAMMER

Provides for hierarchical composition of primitive actions
into more complex sequences



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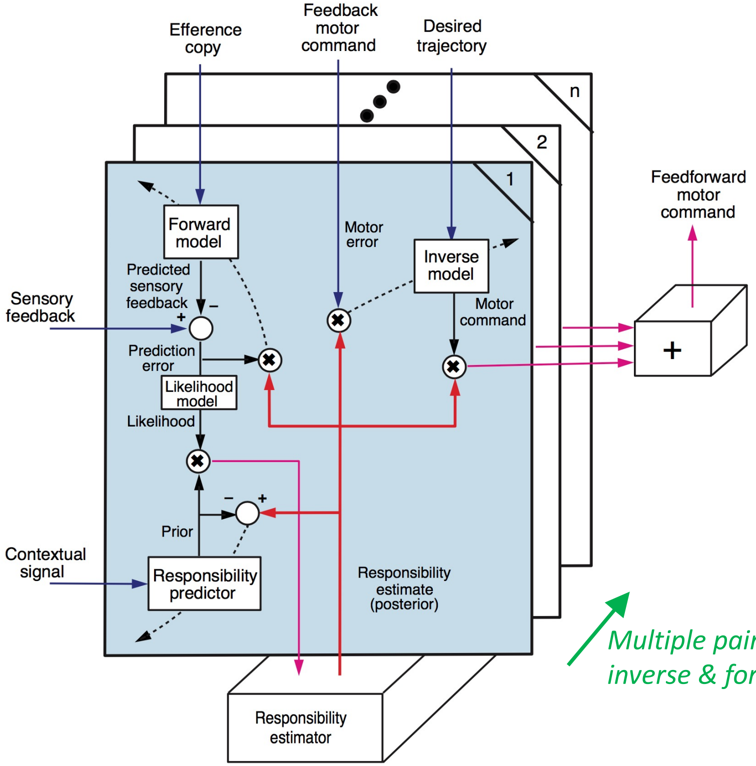
Internal Simulation and Action



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**

Internal Simulation and Action

Classical treatments of memory (above) usually maintain a clear distinction between

- Declarative memory and procedural memory, in general,

- Episodic memory and procedural memory, in particular

Internal Simulation and Action

Contemporary research takes a slightly different perspective

- **Joint perceptuo-motor representations**
- E.g. Marco Iacoboni's instantiation of Ideo-motor Theory
- Theory of Event Coding by Bernhard Hommel and colleagues

Internal Simulation and Action

Imagination

- A cognitive activity that operates without direct recourse to an agent's sensory system

- Same as internal simulation

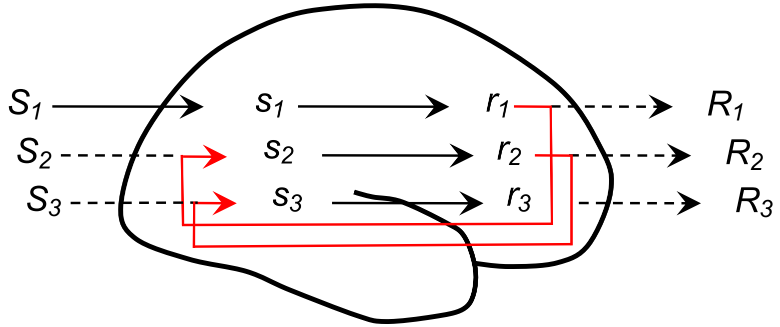
Internal Simulation and Action

- What is the origin of the internal model that the simulation is based on?
- How does the simulation process get started and how does it develop?

Internal Simulation and Action

- Two terms that are used frequently are afference and efference
  - **Afference** refers to sensory input
  - **Efference** refers to motor output
- Afferent & efferent signals to refer sensory stimuli and motor commands respectively
- The term efference copy means that the motor commands are sometimes directed to other sub-systems, not just the actuators
  - By literal copy, stored temporarily in memory
  - By direct connection via a feedback loop

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

- Prospection and internal simulation so far has focussed on anticipation over long periods of time: seconds, minutes, or more

- Internal simulation and internal models are also involved in short-term prospection less than one second

  - Motor control and trajectory planning

  - The delays in acquiring and processing feedback (i.e. information that captures the error between a desired and an actual state) in biological system are in the region of 150–250 ms

  - This is far too long to be effective in controlling the agent’s movement

Internal Simulation and Action

Both forward models and inverse models are involved

- The forward internal models predict the future state of the body part being controlled
    - e.g. the hand when reaching for some object, on the basis of efference copies of the motor commands that are being issued.
- The inverse models determine the motor commands that are required to achieve some desired state.

Internal Simulation and Action

- The predicted or desired state in question might be position, velocity, acceleration of the body part being controlled (and related forces) or it might be some set of associated sensory features.

- These are referred to as

  – **a dynamic model** (because they model the system's dynamics) and

  – a **sensory output model** (providing, e.g., the predicted afferent consequences of a movement)

- Again, multiple models are thought to be involved, all operating simultaneously, just as with prospection and internal simulation over longer periods as discussed above

Reading

Vernon, D. Artificial Cognitive Systems – A Primer, MIT Press, 2014; Chapter 7.