

Models of Imitation and Mirror Neuron Activity

COGS171

FALL Quarter 2011

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Basis for Models

- Since a majority of mirror neurons have been found in motor areas (IFG and IPL), it is reasonable to envision a role for mirror neurons in motor control .
- One possibility is that these neurons implement an internal model for control.
- The CNS uses internal models for movement planning, control, and learning
 - A Forward model is one that predicts the sensory consequences of a motor command; while
 - An Inverse model transforms a desired sensory state into a motor command that can achieve it.
 - Hurley and others propose that mirror neurons are involved in inverse modeling

The Shared Circuits Mode (Hurley)

- An abstract/conceptual explanation of how behaviors like imitation and mindreading can be enabled by subpersonal mechanisms of control, mirroring, and simulation.
- It is aimed at a middle, functional level of description, that is, between the level of neural implementation and the level of conscious perceptions and intentional actions.
- It avoids the common conception of perception and action as separate and peripheral to central cognition (the sandwich model).

Assumptions

1. Perception is an active process and cognition is embodied and situated.
 - Embodied – basis for cognition are representations rooted in sensorimotor representations
 - Situated - knowing is inseparable from doing in that all knowledge is situated in activity bound to social, cultural and physical contexts.
2. Perception-action mechanisms connect with the dynamics of self-other.
3. Perception-action mechanisms are multifunctional and reusable (i.e., they are layered)

Layer 1: Basic Adaptive Feedback Control

- SCM begins with specific comparator (error correction or supervised learning network; STS?) feedback control system. A comparator system generates outputs that are means to a target, by establishing an association between outputs and their results.
- Enables dynamic online motor control via sensorimotor feedback (embodied actions)

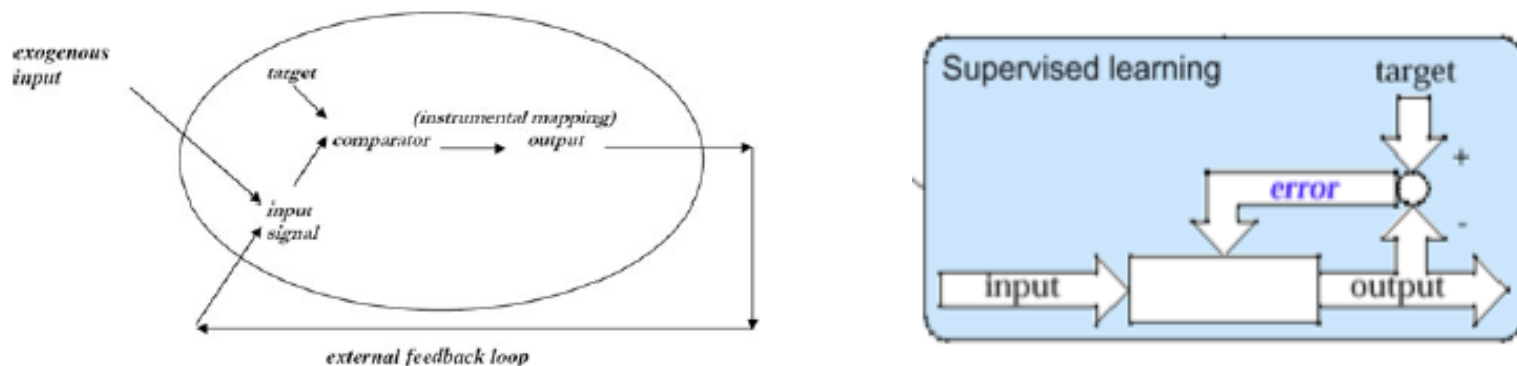


Figure 1. Layer 1: Basic adaptive feedback control.

Layer 2: Simulative prediction of effects for improved control

- Real-time feedback can be slow and produce overshooting. Control functions can be speeded and smoothed by adding online predictions of sensory feedback from ongoing motor output (Forward model)

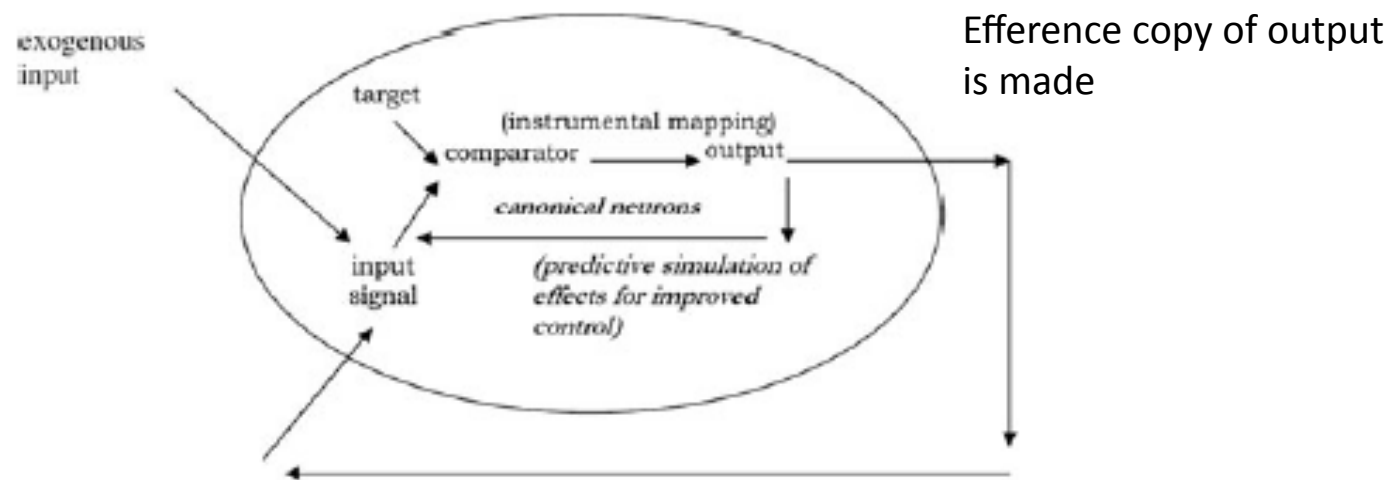


Figure 2. Layer 2: Simulative prediction of effects for improved control.

Layer 3: Mirroring for priming, emulation, and imitation (beginning of circuit sharing)

- In the next iteration of the model, not only does efference copy produce simulated input in forward models, but these input signals can now evoke mirroring efference or motor output (reverse model). This runs the predictive simulations of forward models in reverse.

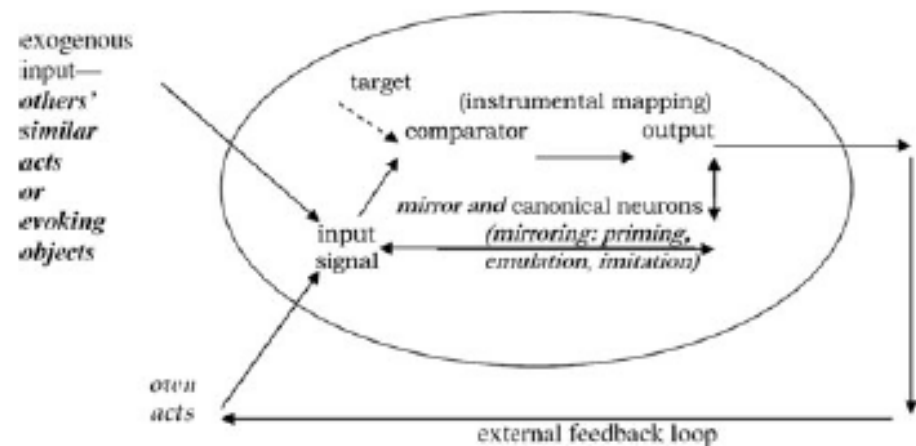


Figure 3. Layer 3: Mirroring for priming, emulation, and imitation.

observing movements generates motor signals in the observer that tend to cause similar movements enabling copying/imitation.

Layer 4: Monitored output inhibition combined with simulative prediction and/or simulative mirroring

- Layer 4 introduces the capacity to inhibit actual output and monitor this inhibition while instrumental associations are activated.
- This capacity for monitored inhibition supports **self-other distinction** and could enable **action understanding**.

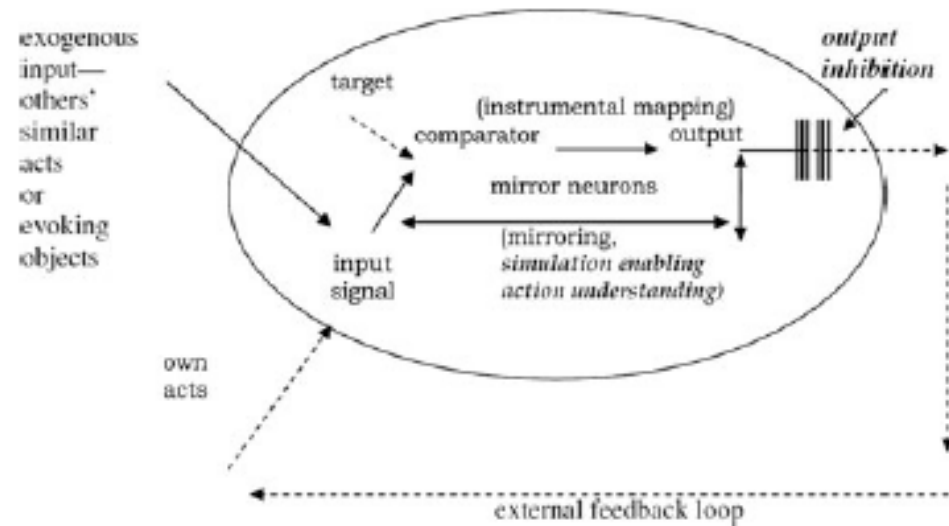


Figure 4. Layer 4: Simulative mirroring (or prediction) combined with monitored output inhibition, enabling action understanding (or instrumental deliberation).

Layer 5: Counterfactual input simulation

- Finally, the system can be taken offline for input as well as output.
- Adds the function of **monitored simulation of input** specifying possible observed actions, which allows for counterfactual reasoning.
- Counterfactual inputs can simulate different possible acts by others and their results.

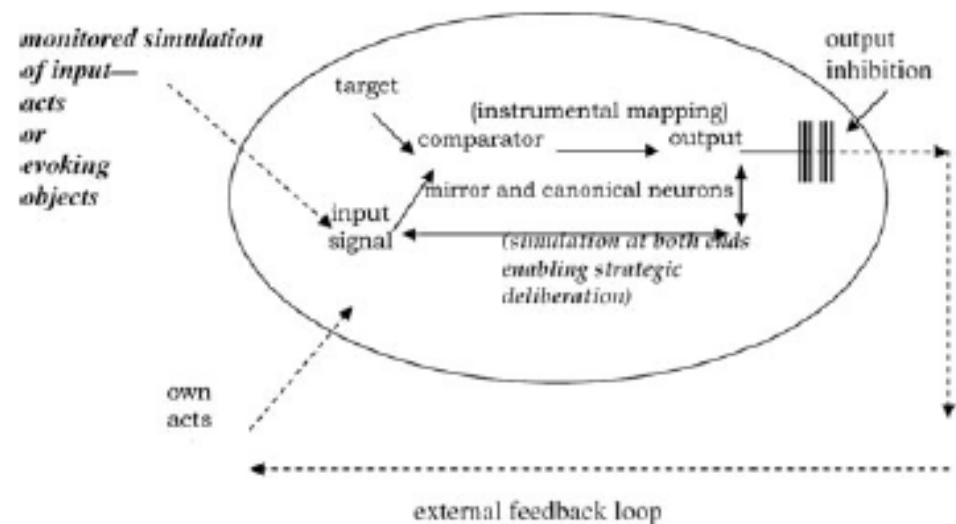


Figure 5. Fifth layer: Counterfactual input simulation enabling strategic deliberation.

Advantages of SCM

- Explains the possibility of imitation, mindreading and intelligent social interaction
- Built entirely on the foundation of sensorimotor circuits (embodied) that are adaptive and responsive to world events (situated)
- Does not require the inheritance of semantic content from one level to another, but rather it's built around the inheritance of 'function'

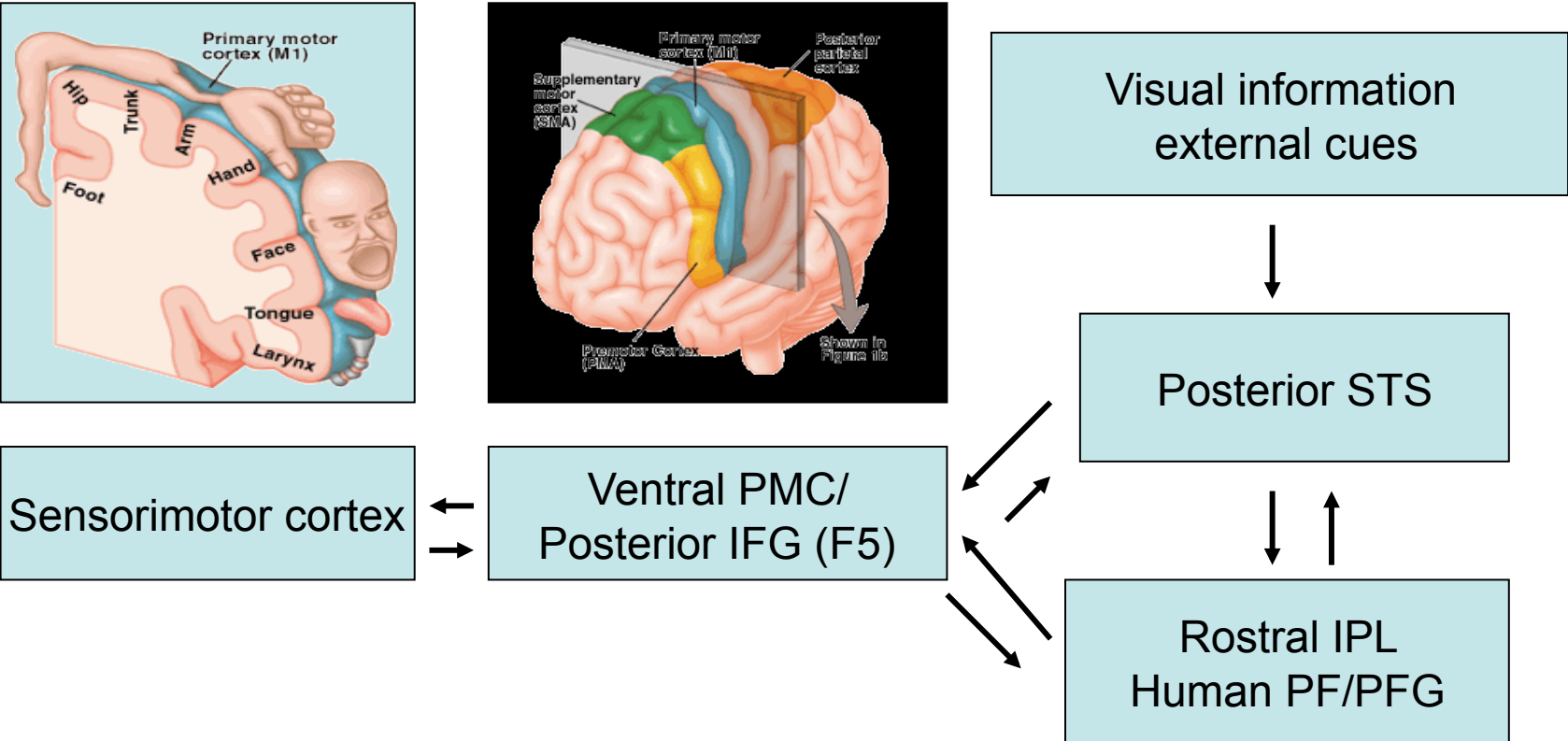
Many Questions To Be Answered

- How is a precise visual description of one's own body mentally produced given a motor command (forward problem)
- What are the cortical mechanisms that support the processing stages that transform retinal input caused by an action observation into mirror neuron responses?
 - how is the retinal image transformed to motor commands in a precise way (inverse problem)
- What is encoded by the mirror neuron activity?
 - Is it the motor command, the meaning or the intention of the observed action?

Models

1. STS acts as a comparator for the mirror neuron-projected action code that matches the observed action code best. This can be used for subsequent imitation.
2. Furthermore, the STS-F5 circuit can be run in the reverse direction (inverse modeling) to map the observed action into motor codes (mirror activity) so that a rough motor representation of the observed act becomes available for imitation. According to this hypothesis, the F5- STS circuitry must be capable of producing detailed visual representation of the self-actions.

Bridging Visual and Motor Representations



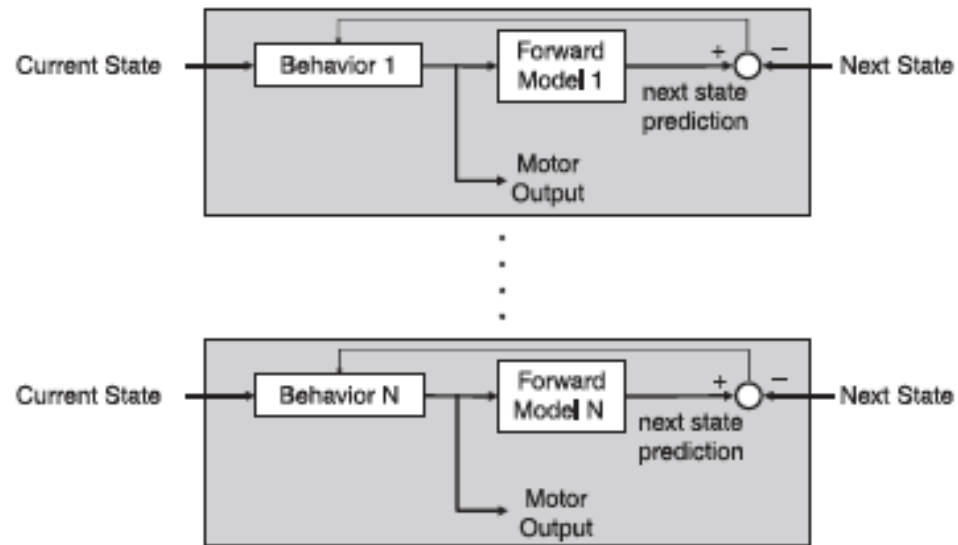
Models (cont)

- Others have proposed that the forward and inverse computations required can be carried out by the cerebellum and PPC (posterior parietal cortex), respectively.
- Models of imitation generally make a couple of wrong assumptions:
 1. that mirror neurons are responsible for generating actions and
 2. that area F5 is composed only of mirror neurons.

A Modular Architecture for Imitation

(Demiris and Johnson, 2003)

- The key structure is formed by a battery of behaviors (modules) paired with forward models, where each behavior module receives information about the current state (and possibly the target goal), and outputs the motor commands that is necessary to achieve the associated behavior



A Modular Architecture for Imitation

(Demiris and Johnson, 2003)

- Assumes that the demonstrator's current state is available to it.
 - When the demonstrator executes a behavior, the perceived states are fed into the imitator's available behavior modules in parallel which generate motor commands that are sent to the forward models.
- The forward models predict the next state based on the incoming motor commands, which are then compared with the actual demonstrator's state at the next time step.
 - The error signal resulting from this comparison is used to derive a confidence value for each behavior (module). The behavior with the highest confidence value (i.e. the one that best matches the demonstrator's behavior) is selected for imitation.

A Modular Architecture for Imitation (cont.)

(Demiris and Johnson, 2003)

- If an observed behavior is not in the existing repertoire, none of the existing behaviors reach a high confidence value, indicating that a new behavior should be added to the existing behavior set.
- This is achieved by extracting representative postures while the unknown behavior is demonstrated, and constructing a behavior module to go through the representative postures extracted.

An Evolutionary Model

- Borenstein and Ruppin (2005) used evolutionary algorithms to explain MNs and imitation
- An evolutionary algorithm maintains a population of structures ('individuals') that evolves according to rules of selection, recombination, mutation and survival.
- After many generations one expects to find a set of high performing individuals which represent close-to optimal solutions to the original problem.
- Using a 1-hidden layer feedforward neural net, Borenstein and Ruppin (2005) defined individuals as simple agents that could sense the state of the world and the action of a teaching agent (inputs) and generate actions (outputs).

An Evolutionary Model (cont)

- A population of 200 individuals evolving over 2000 generations developed those who could learn to imitate the teacher
- The hidden units revealed those which were active both when observing the teacher and when executing the correct action (although not all actions were mirrored!)

Hebbian Learning: Associative or Content-Addressable Memory Models

- Key feature: a partial representation of a stored pattern is sufficient to reconstruct the whole.
- When the organism generates motor commands the representation of this command and the sensed effects of the command (in somatosensory, visual and auditory areas) are associated within the mirror neuron system.
- Then, later when the system is presented with a stimulus that partially matches one of the stored patterns (i.e. vision or audition of an action alone) the associated motor command representation is retrieved automatically.
- This representation can be used (with additional circuitry) to mimic the observed movement.

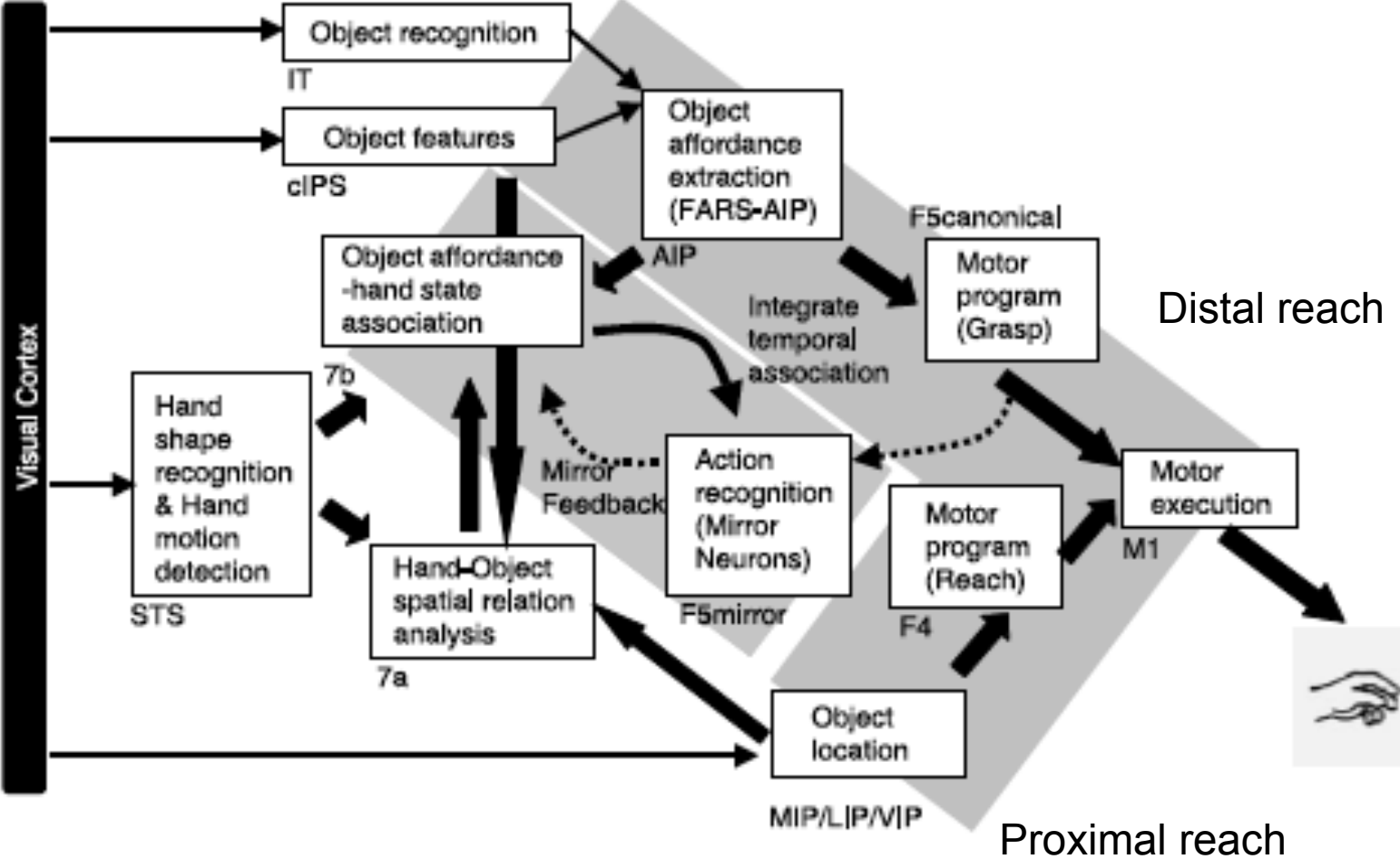
Hebbian Learning: Associative or Content-Addressable Memory Models

- The learned association enabled neurons of the hidden layer of the network to behave as mirror neurons
- The hidden units could become active with one of motor, vision or language inputs

MNS Model (Oztop and Arbib, 2002)

- A systems level model that takes a developmental point of view and explains how the mirror neurons are developed during infancy
- Proposes that MNs are initially evolved to support motor control
- The temporal profile of the features an infant experiences during self-executed grasps provides the training stimuli for the mirror neuron system to develop
- Its focus is how mirror neurons may learn to recognize the hand-state trajectories (hand-object relationships) for an action already within the repertoire and not for a novel action.

Model



Definitions

- F4 – controls proximal movements
- F5 – controls distal movements
- Inferotemporal (IT)/caudal Intraparietal sulcus (cIPS) - Provide visual input (what/where information) to anterior intraparietal area (AIP)
- AIP - extracts the affordances the object offers for grasping