Perception for Grasping and Manipulation

Arbib MA, Overton KJ, Lawton DT. 1984. Perceptual systems for robots. *Interdisciplinary Science Reviews* 9.

Early 1980s at UMass Amherst:
Laboratory for Perceptual Robotics:
Salisbury hand, visual input, tactile sensors.

Michael Arbib
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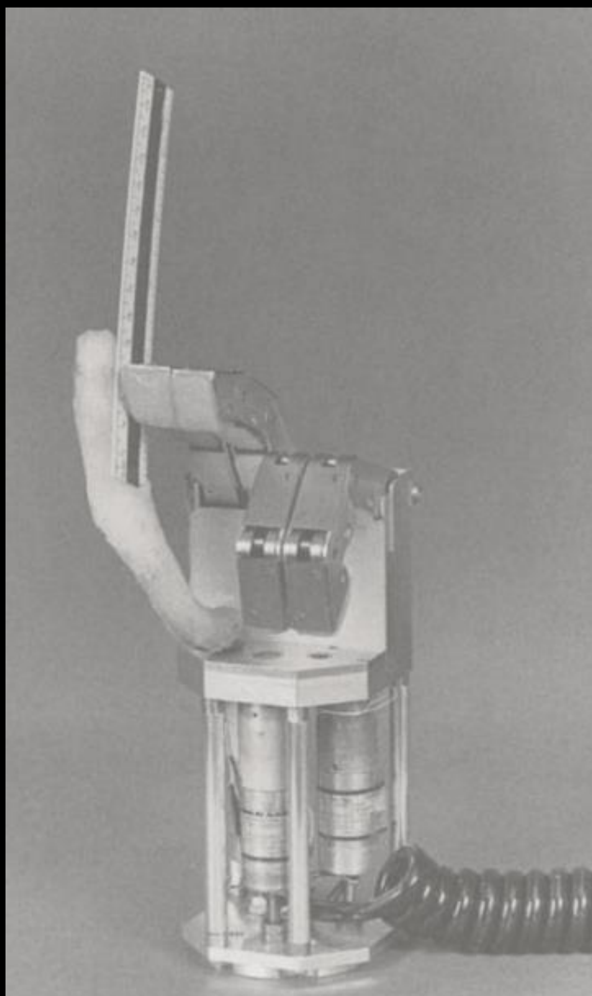
Control Architecture for the Belgrade/USC Hand

George A. Bekey[1]
Rajko Tomovic[2]
Ilija Zeljkovic[1]



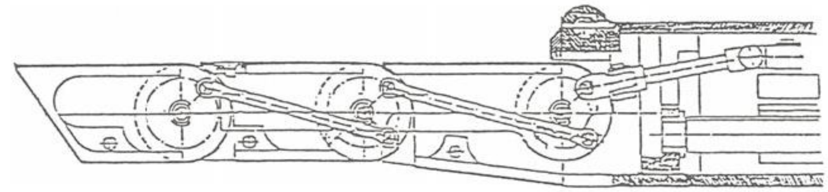


Figure 7.3: Schematic diagram of finger-side view.

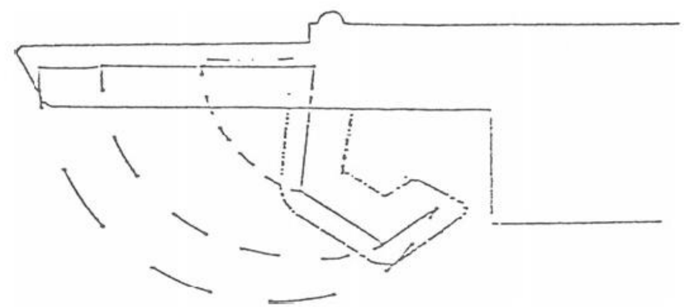
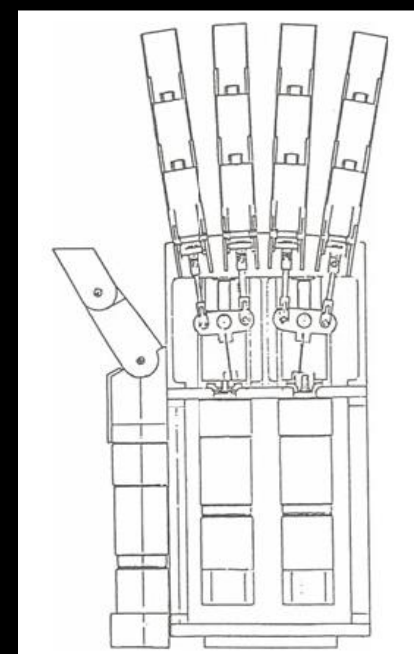


Figure 7.4: Finger motion during flexing (©IEEE, Rao *et al* 1988).



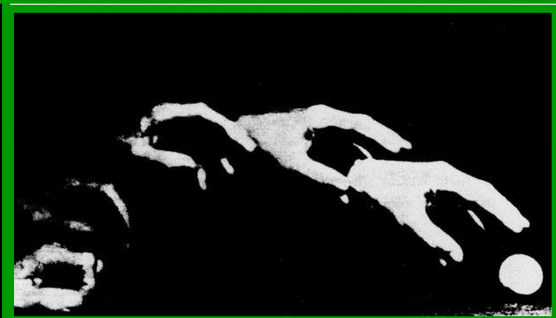
Part I

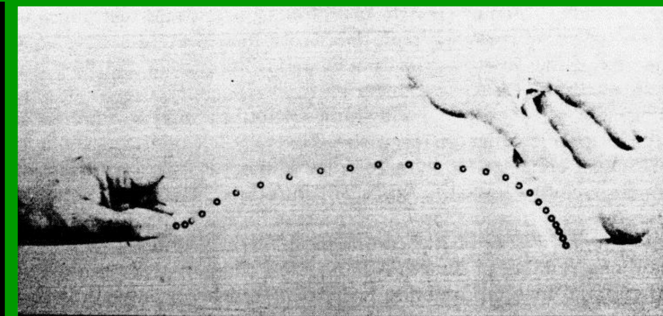
Perceptual and Motor Schemas

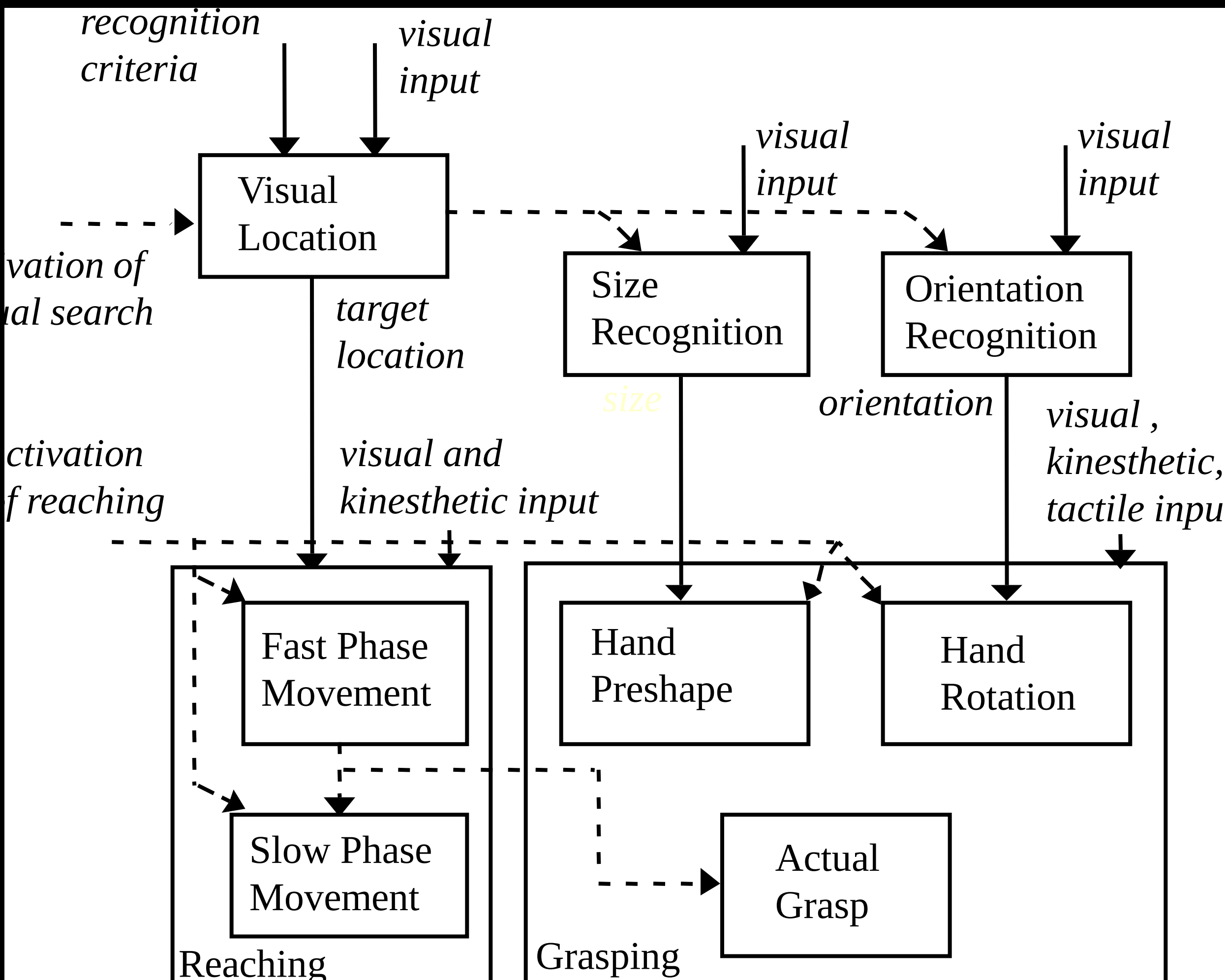
Affordances and Effectivities

Coordinated control program for reaching and grasping

Jeannerod and Biguer 1979







Perceptual schemas

Arbib 1981

Motor schemas

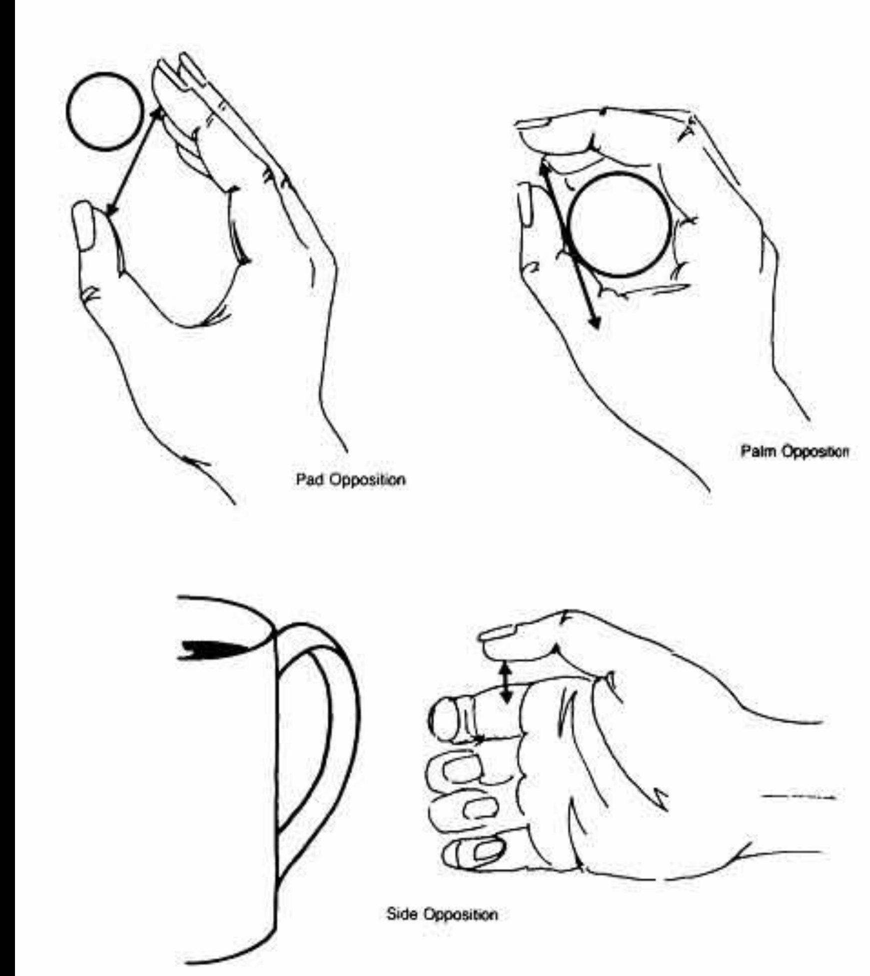
Grasping & Opposition Spaces

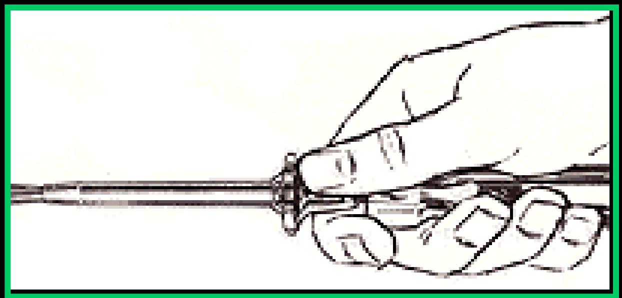
Iberall, Bingham and Arbib 1986:

An object may have different representations for different tasks

Opposition axes may be set for

- different parts of the object
- setting goals for preshaping and moving the hand
- *.... and for manipulation*



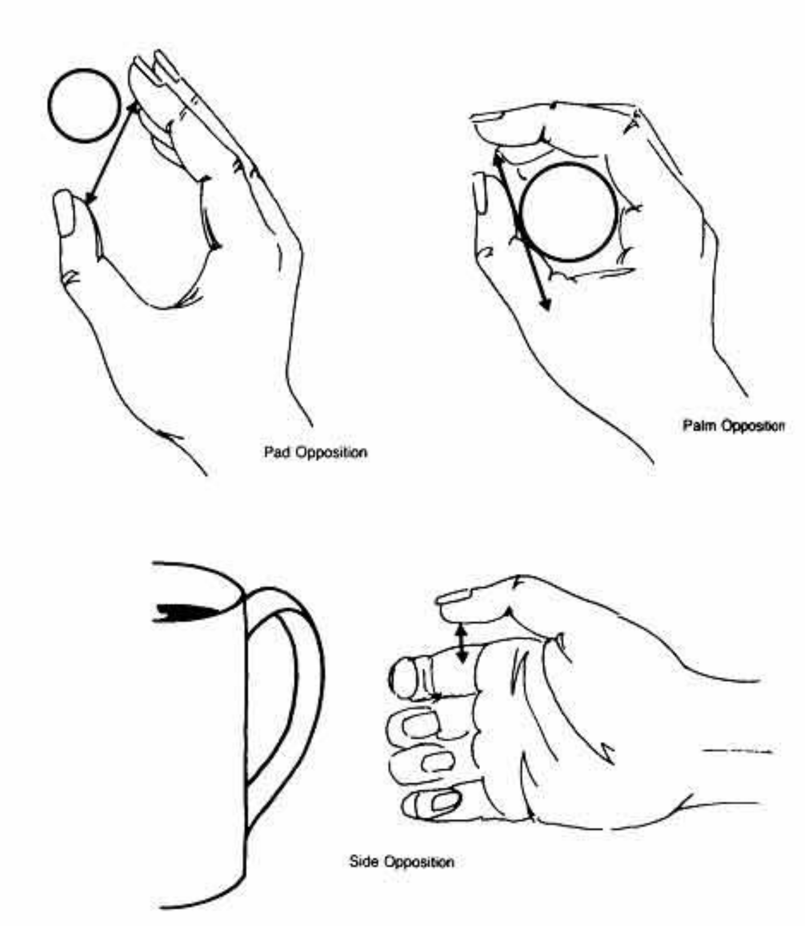


A Compound Grasp

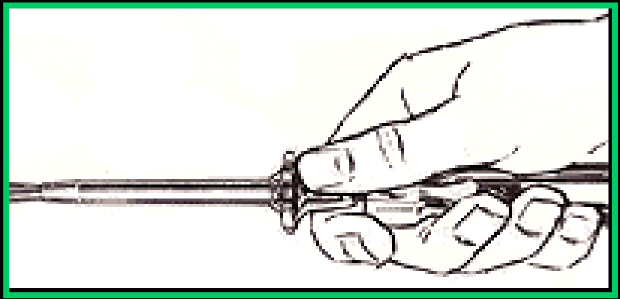
Another Vocabulary

Deploying the terminology of J.J. Gibson and his followers:

- Perceptual schemas identify **affordances** relevant to the current task
- Motor schemas deploy **effectivities** to exploit affordances



A coordinated control program integrates and schedules these but not only these schemas



A Compound Grasp

280 IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION, VOL. 5, NO. 3, JUNE 1989

A Formal Model of Computation for Sensory-Based Robotics

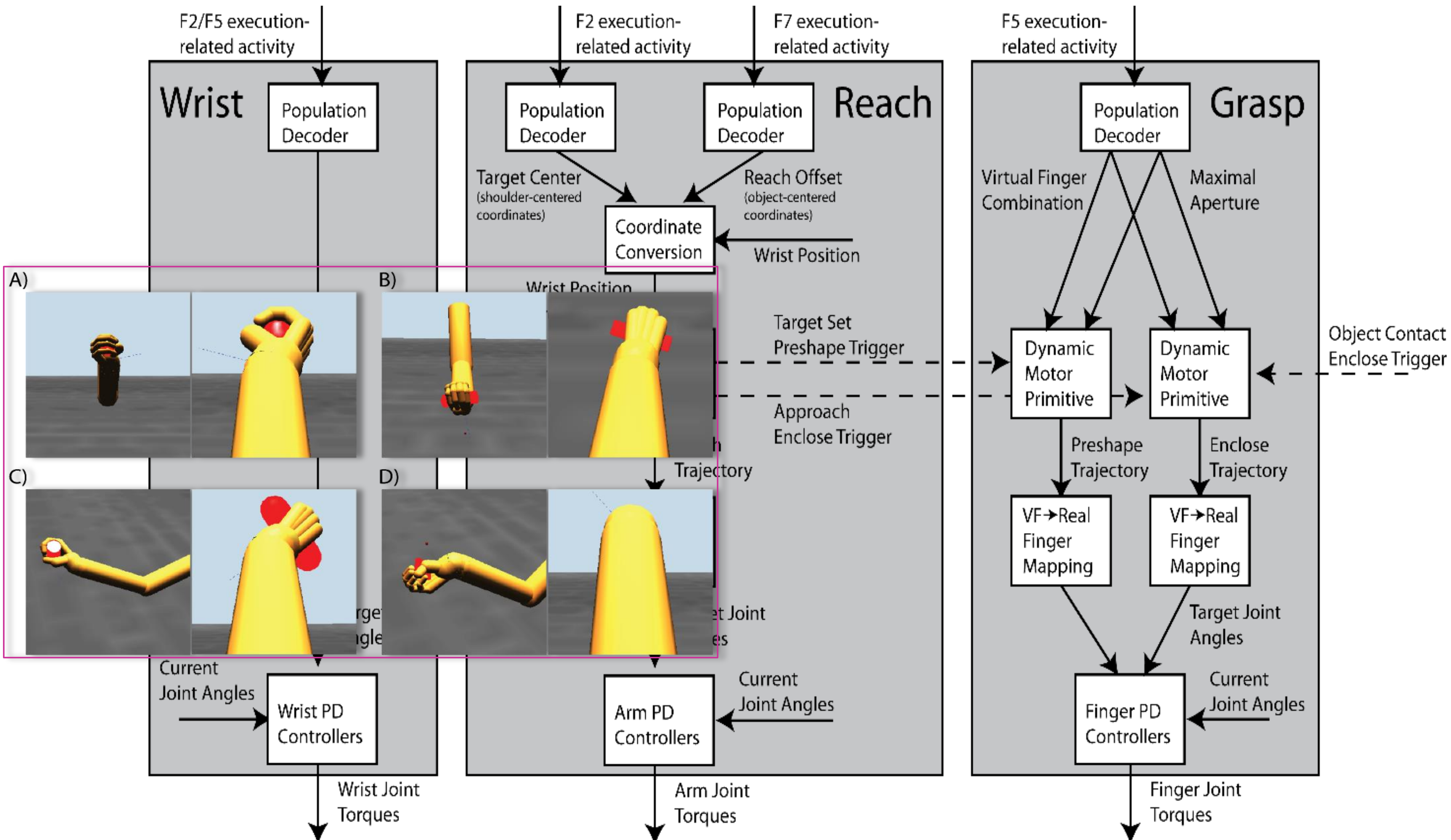
DAMIAN M. LYONS, MEMBER, IEEE, AND MICHAEL A. ARBIB

1989

RS (Robot Schemas) is a model of distributed computation embodying our nested network approach to robot programming. This paper introduces the *RS* model and shows how it can be used to represent robot programs in an efficient and concise manner.

Integrated Learning of Grasps and Affordances: The ILGA Model

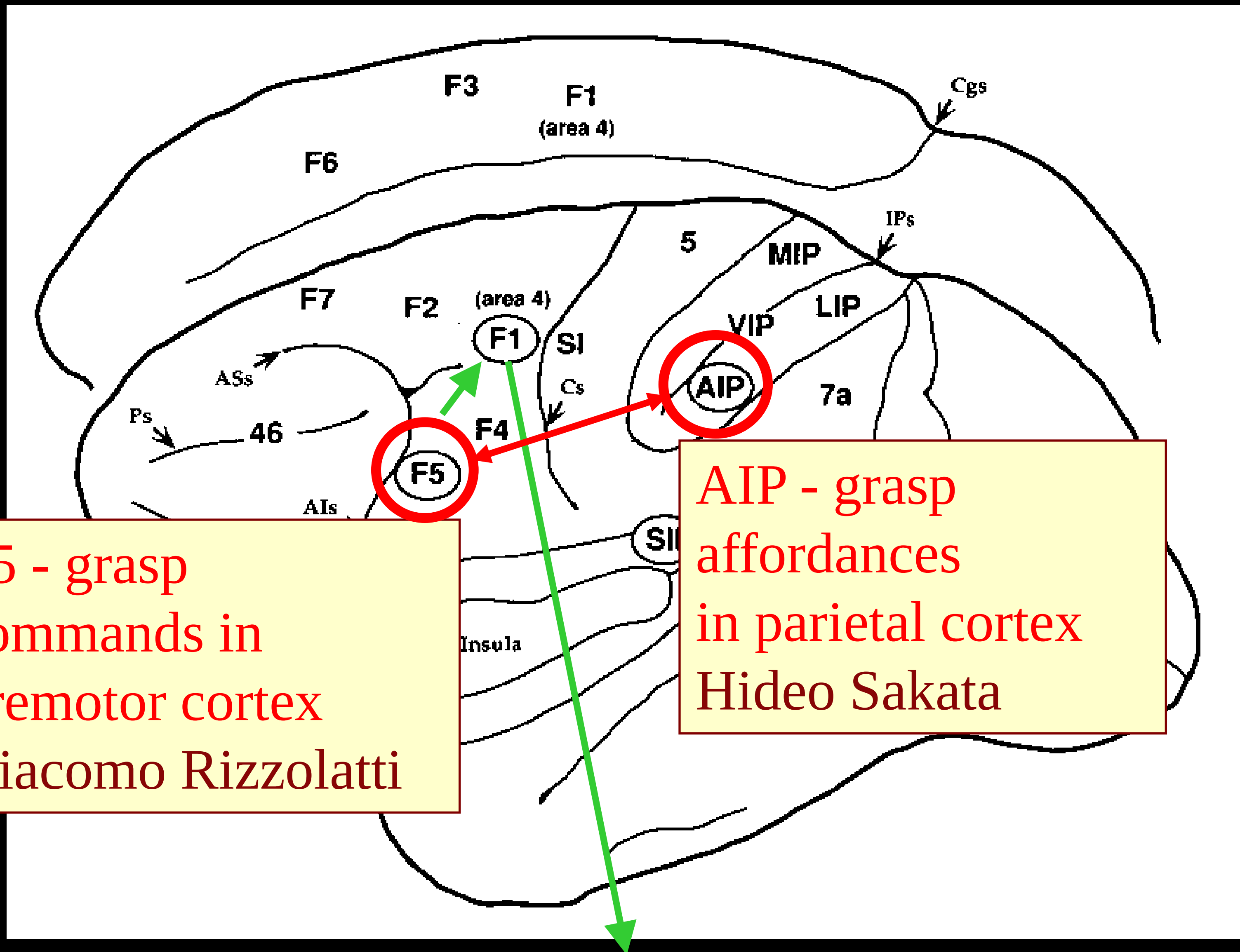
James Bonaiuto, Michael A. Arbib



Part II

Basic Parieto-Frontal Interactions for Visually Directed Hand Movements

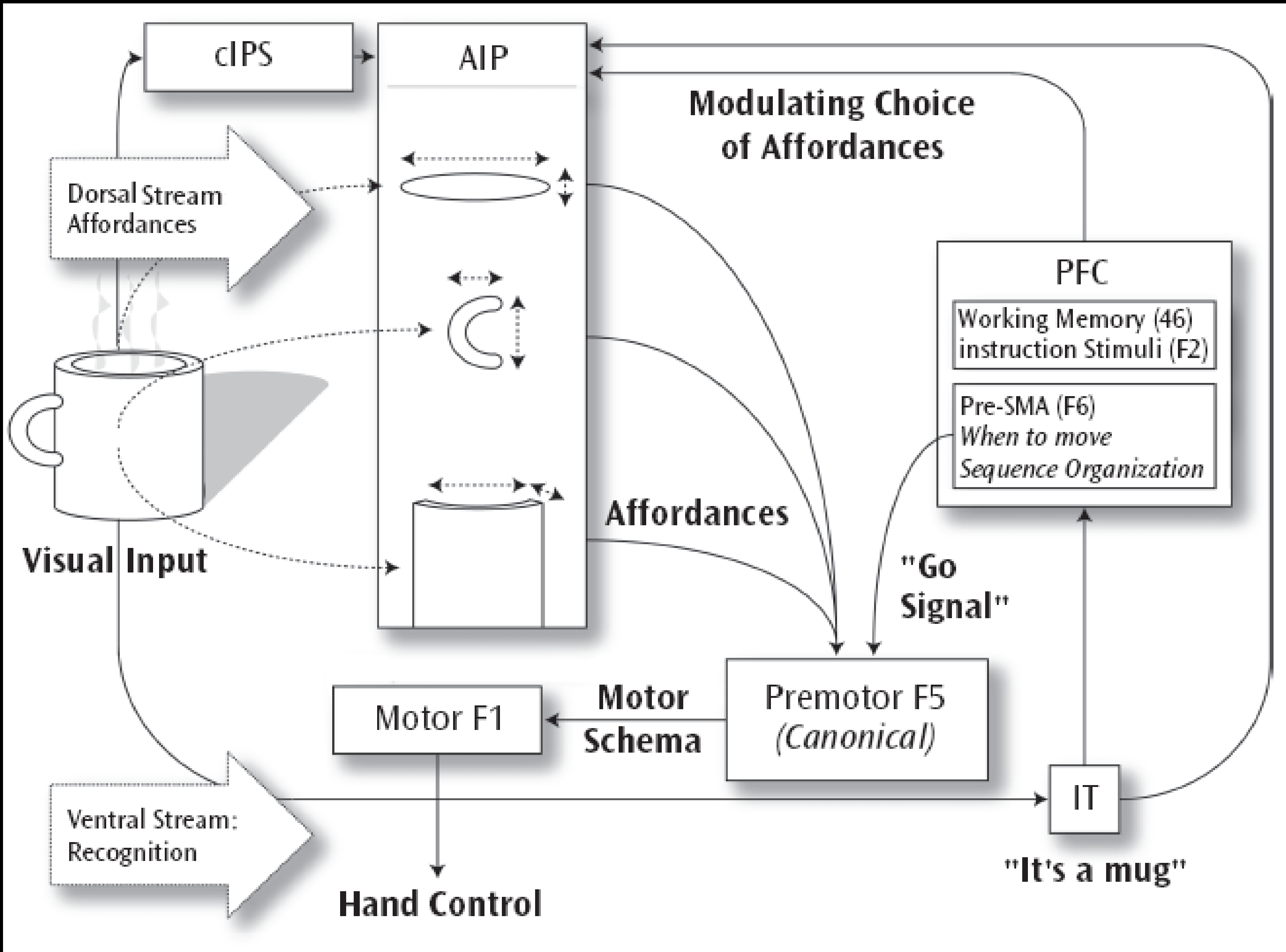
Introducing AIP and F5 (Grasping) in Monkey



F5 - grasp commands in premotor cortex
Giacomo Rizzolatti

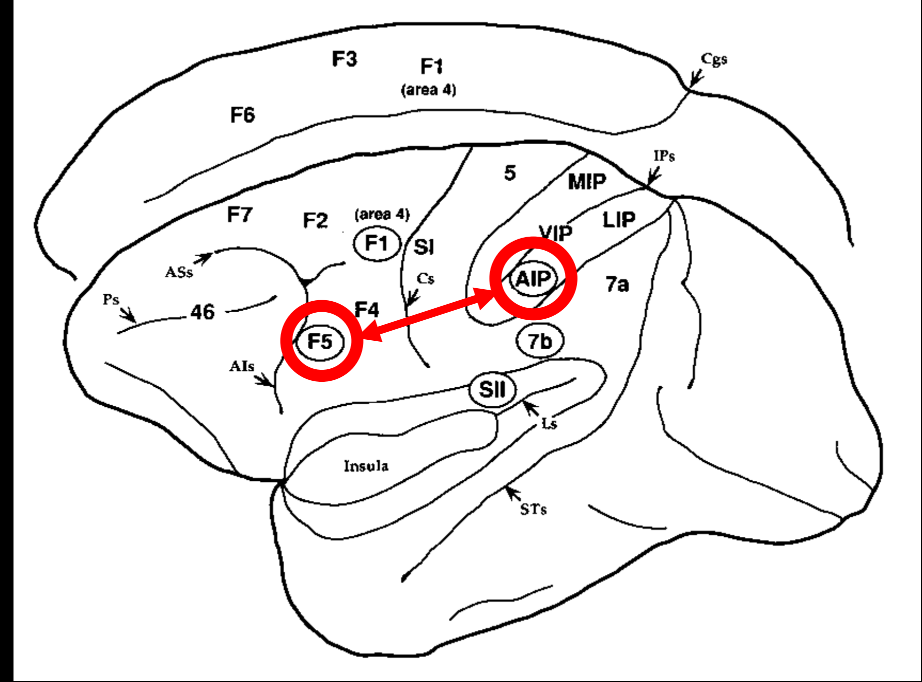
AIP - grasp affordances in parietal cortex
Hideo Sakata

The FARS (Fagg-Arbib-Rizzolatti-Sakata) Model
A Focus on "How" and "What"



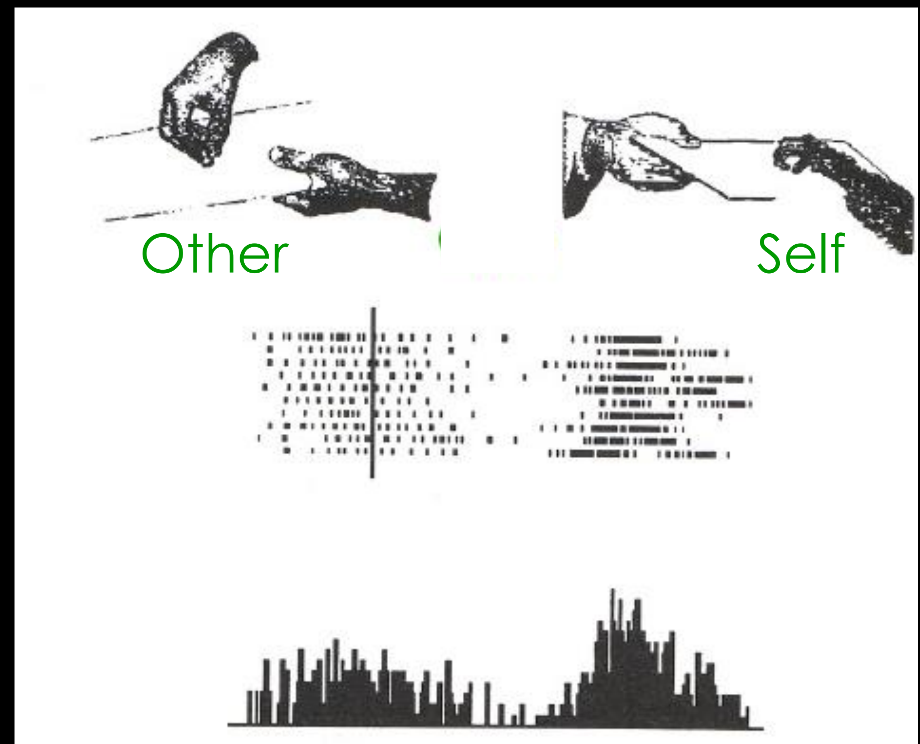
Mirror Neurons:
Learning from the Macaque

Rizzolatti, Fadiga, Gallese, and Fogassi, 1995

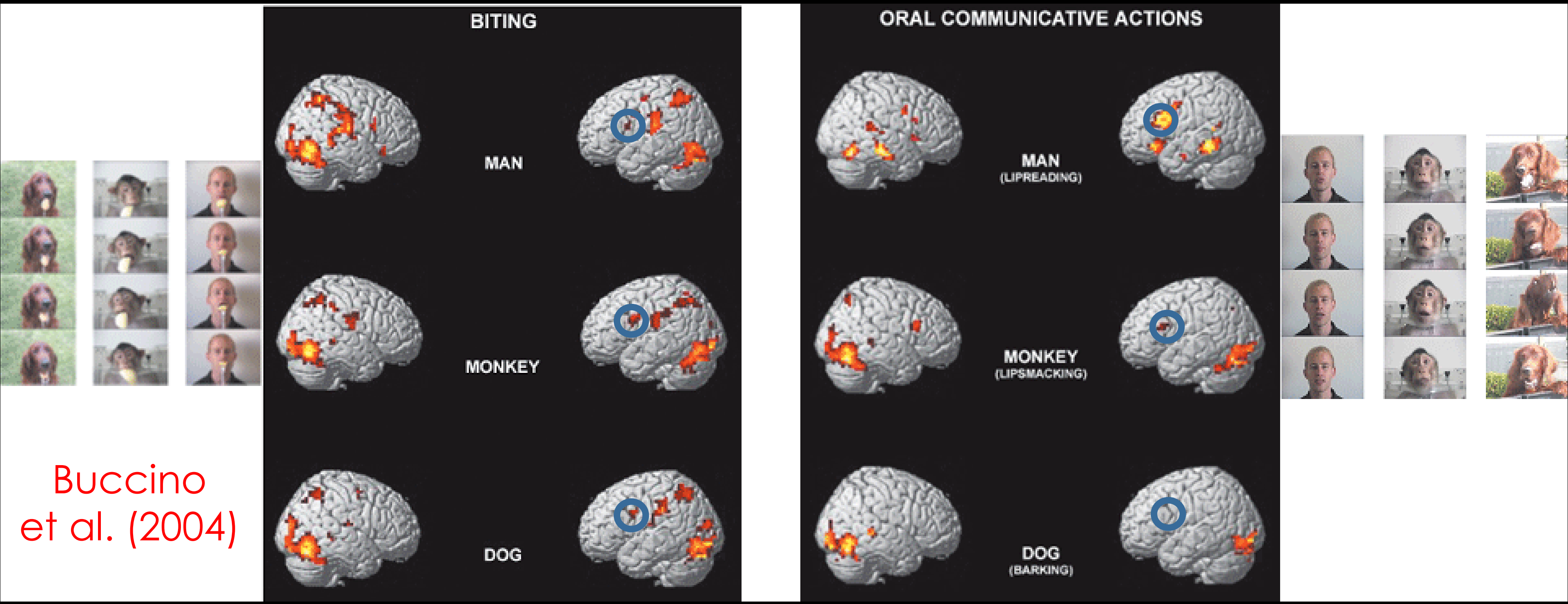


This example: a precision pinch

A **mirror neuron** is active for ***execution*** of a limited set of actions & ***observation*** of a congruent set of actions



Recognition of oro-facial actions by humans



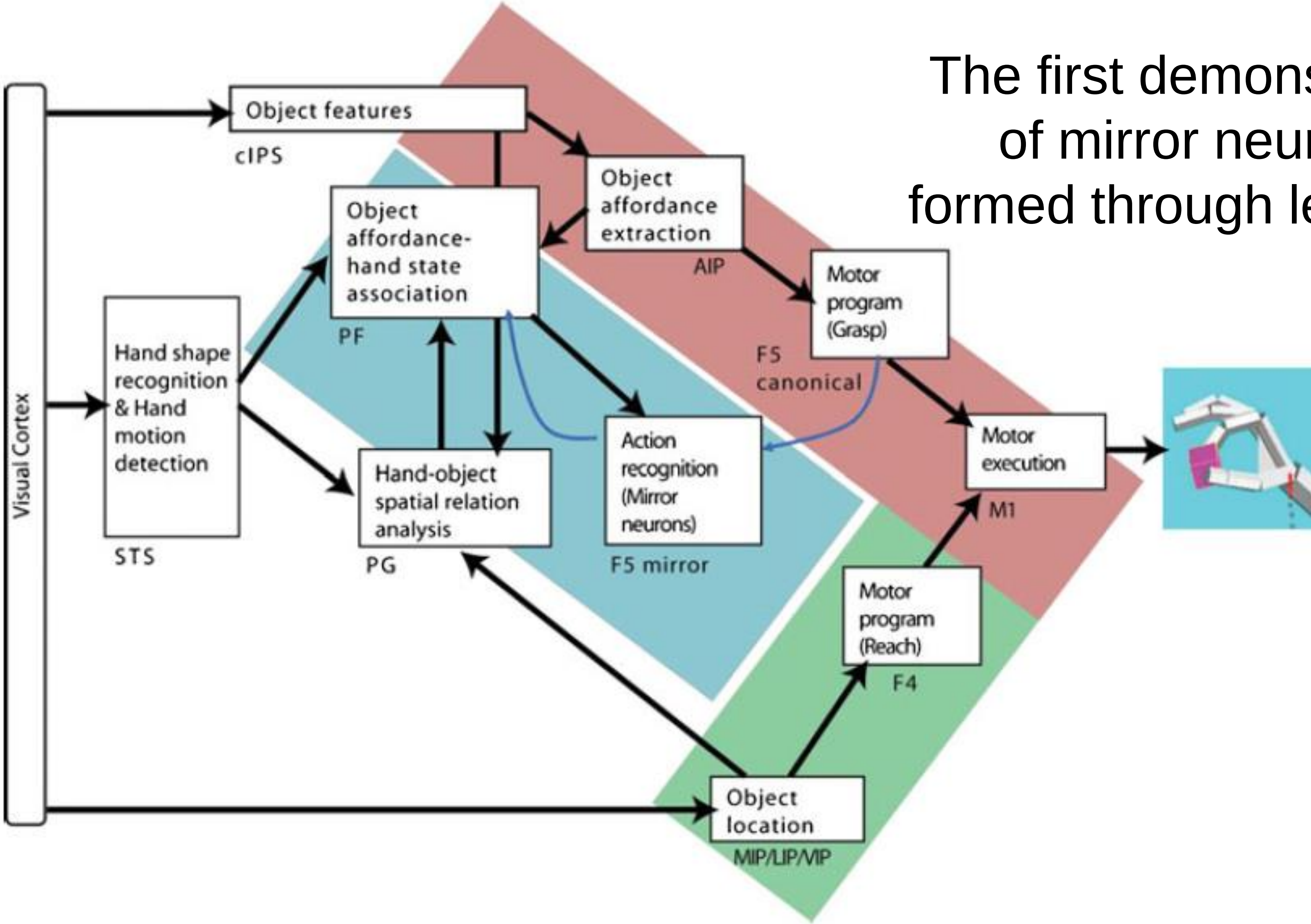
Buccino et al. (2004)

Actions belonging to the observer's motor repertoire are mapped on the observer's motor system.

My Addendum: ***All*** actions can be recognized by other routes, whether or not in cooperation with mirror systems

MNS Model of Learning in the Mirror Neuron System

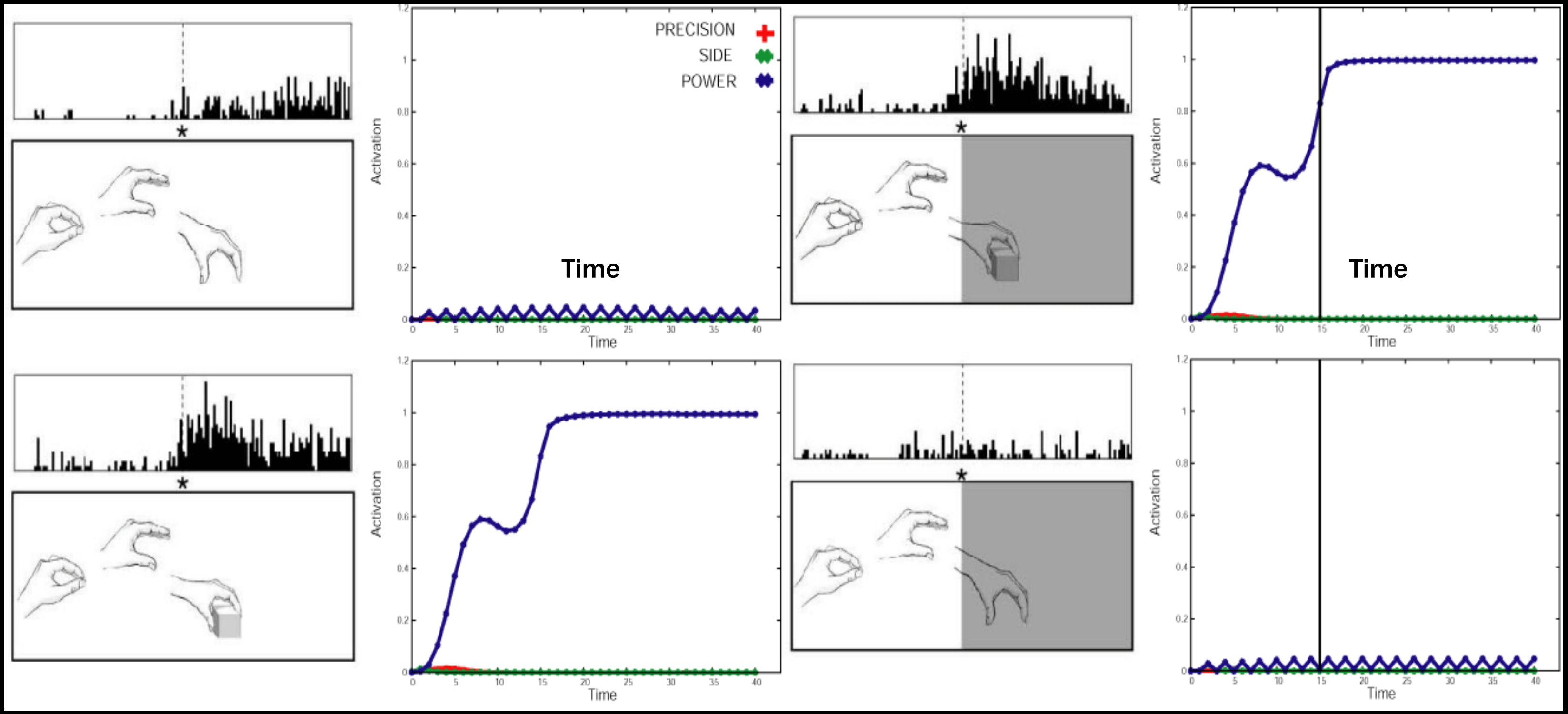
The first demonstration of mirror neurons as formed through learning



Original Model: Oztop & Arbib, *Biological Cybernetics*, 2002

MNS2 extends MNS: Again, much more than just Mirror Neurons

Examples: (1) Bringing in audition
(2) Partially Hidden Grasps: Data from Umiltà et al., 2001



Fully Visible **Partially Hidden**

Working memory and dynamic remapping of hand working memory allows hidden grasps to be recognized

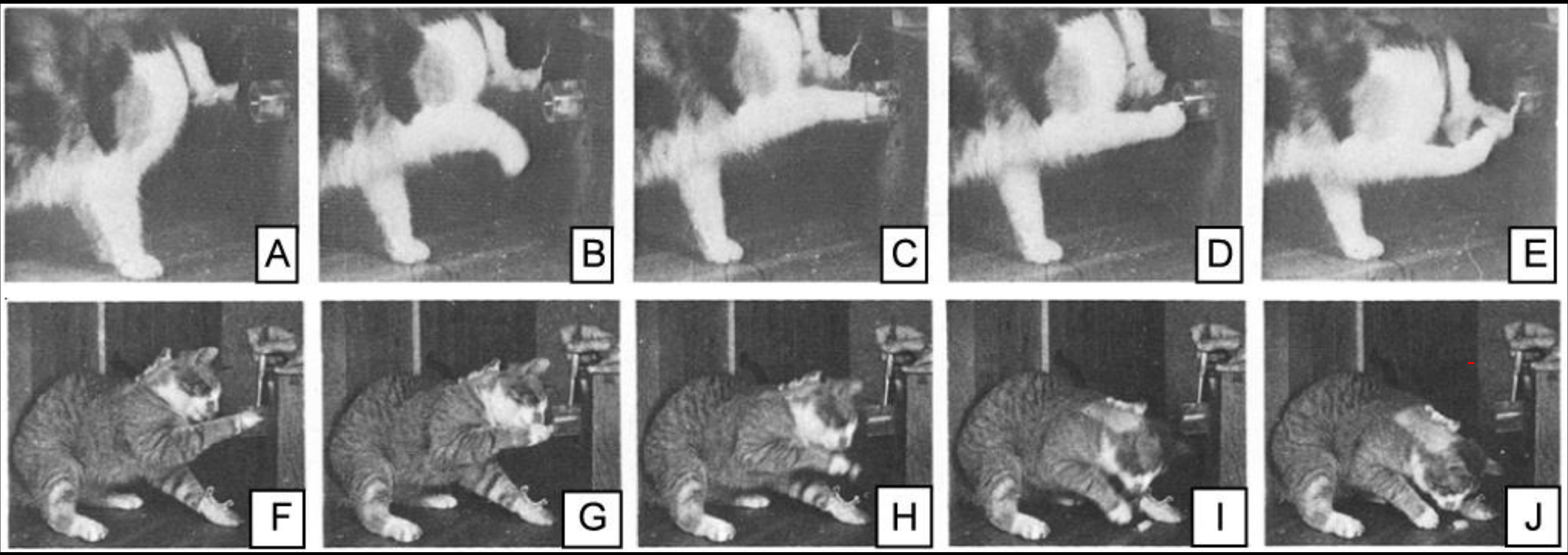
No response if object is not visible and not in working memory

What are Mirror Neurons For?: New Dimensions of Perception

The usual story: Recognizing the actions of others supports
1) cooperation and competition between individuals
2) Imitation
   - Caveat: Monkeys have little if any capacity for imitation as compared to apes. So imitation involves further mechanisms than mirror neurons *simpliciter*

A complementary (and perhaps evolutionarily prior) function implicates mirror neurons in observing one’s own actions

Alstermark's Cat – Flexible Action Patterns and their Rapid Reorganization



From Alstermark et al. (1981)

Three Key Ideas

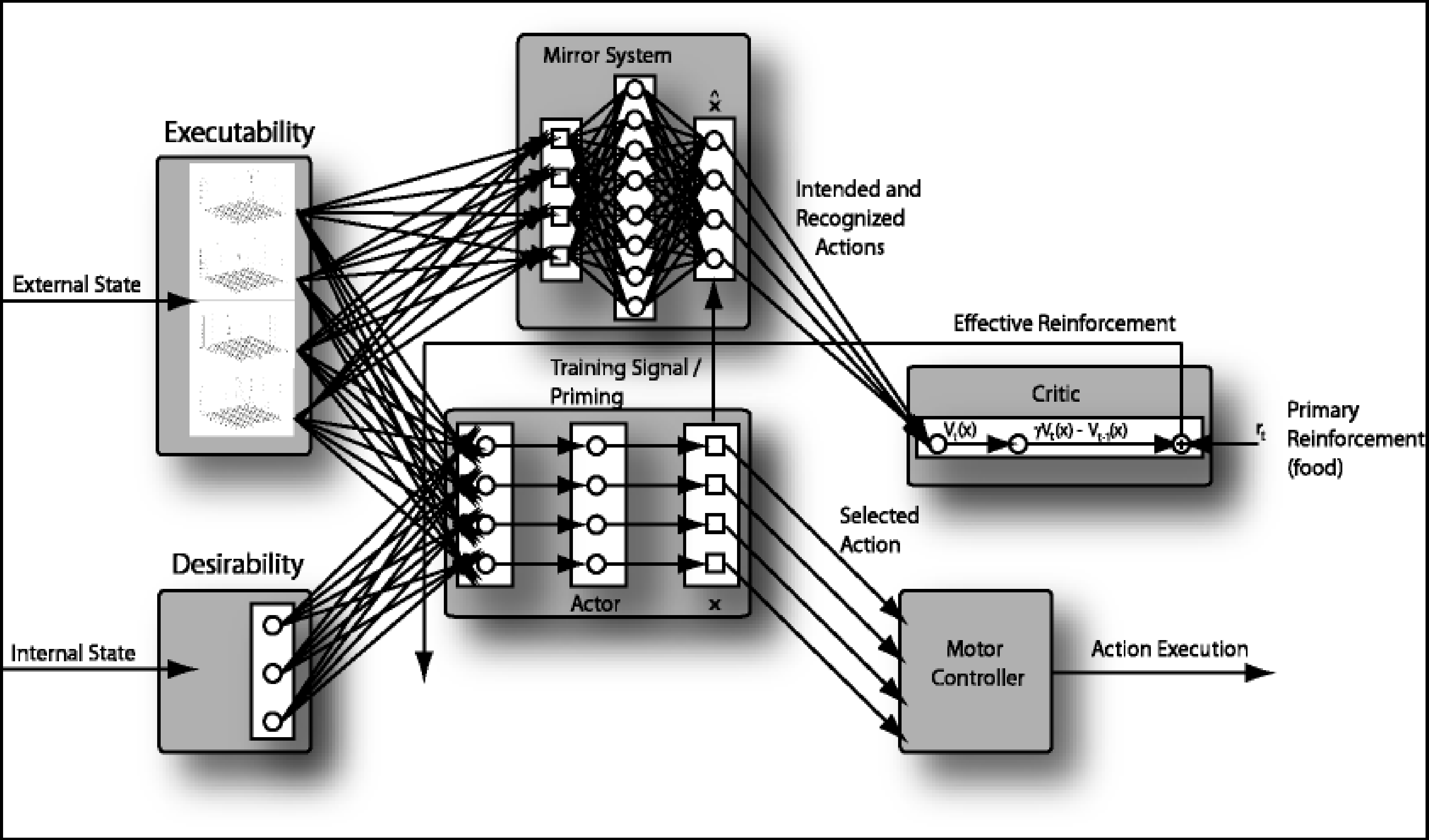
Motor schema activation determined by

- Desirability – Dynamically updated via reinforcement learning
- Executability – Determined by affordances and probability of action's success

A New Role for Mirror Neurons: What Did I Just Do?

- An observation/execution matching (mirror) system may contribute to rapid reorganization of motor programs in the face of disruption when a known schema can be recognized as "filling the gap" for disrupted schemas
  by updating executability and observability estimates

The Augmented Competitive Queuing (ACQ) system



Bonaiuto & Arbib, *Biological Cybernetics*, 2010

Part III

Evolution, All too Briefly

Oxford University Press, 2012

Several steps beyond

Arbib (2002, 2005)

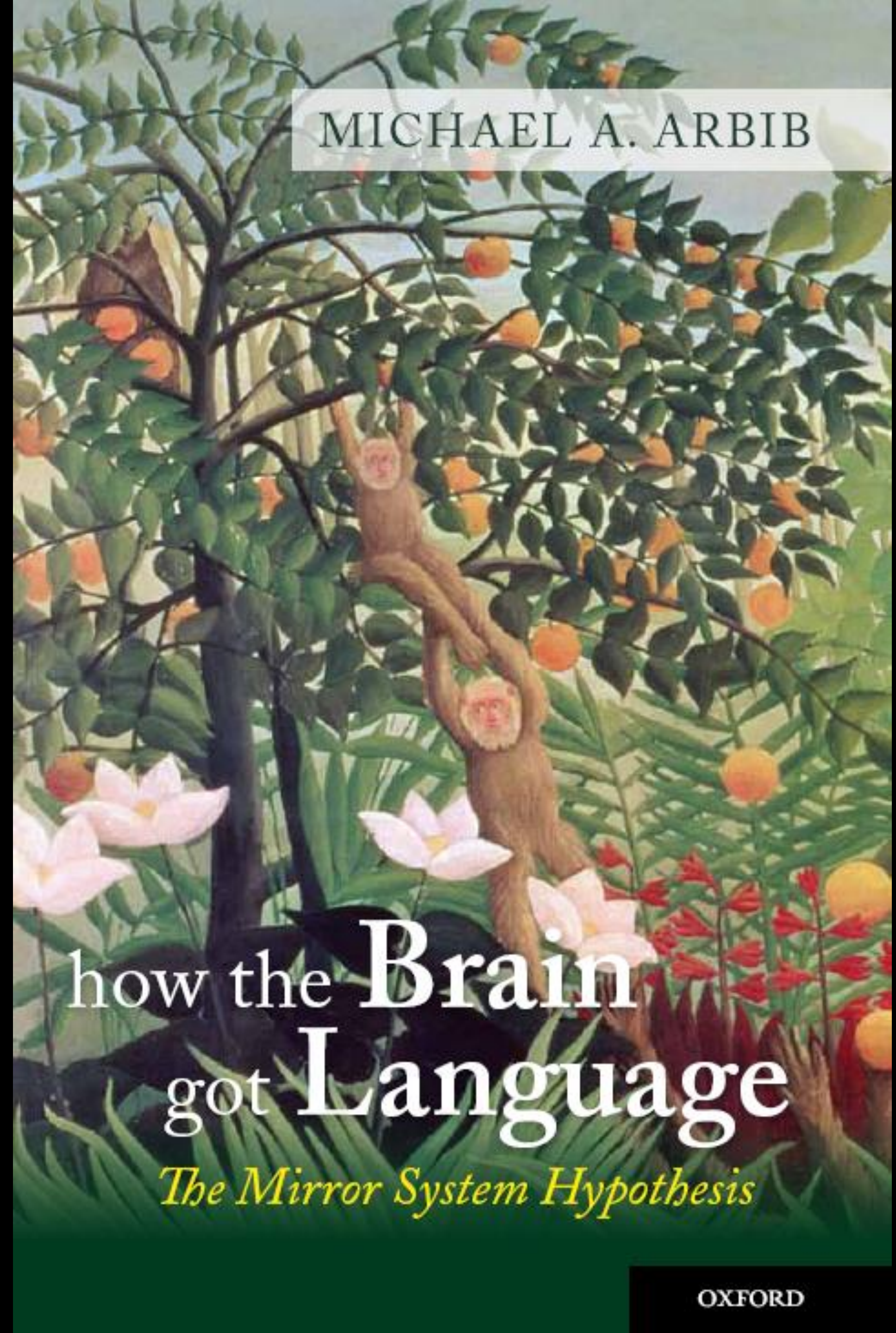
For 12 critiques and a Response

Language and Cognition

2013 5(2/3)

Edited by David Kemmerer

This work was supported in part by National Science Foundation Grants No. 0924674 & BCS-1343544



A Key Hypothesis: Bringing in Complex Imitation

i) Monkeys (and LCA-m): Little capacity for imitation

ii) Apes (and LCA-c): A capacity for simple imitation based more on attention to subgoals than to how movements are shaped to achieve them

ii) Hominid Evolution yields a complex imitation system:
The abilities to

- recognize another's performance as a set of familiar movements
- use this recognition to repeat the performance, and

More generally: the ability to

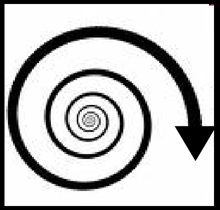
- recognize that another's performance combines variants
- approximate the performance on this basis, with increasing practice yielding increasing skill.

Note utility for language learning and use once this can be applied to words and word streams – **but it evolved** (we claim) **to support praxis**

The Mirror System Hypothesis (2012):
A) Evolving the Language-Ready Brain and Protolanguage

Pre-Hominid:
Grasping
A mirror system for grasping: LCA-m
A simple imitation system for grasping: LCA-c

Hominid Evolution
A complex imitation system
"Naïve" Pantomime: Adapting the action repertoire to **open** up communication



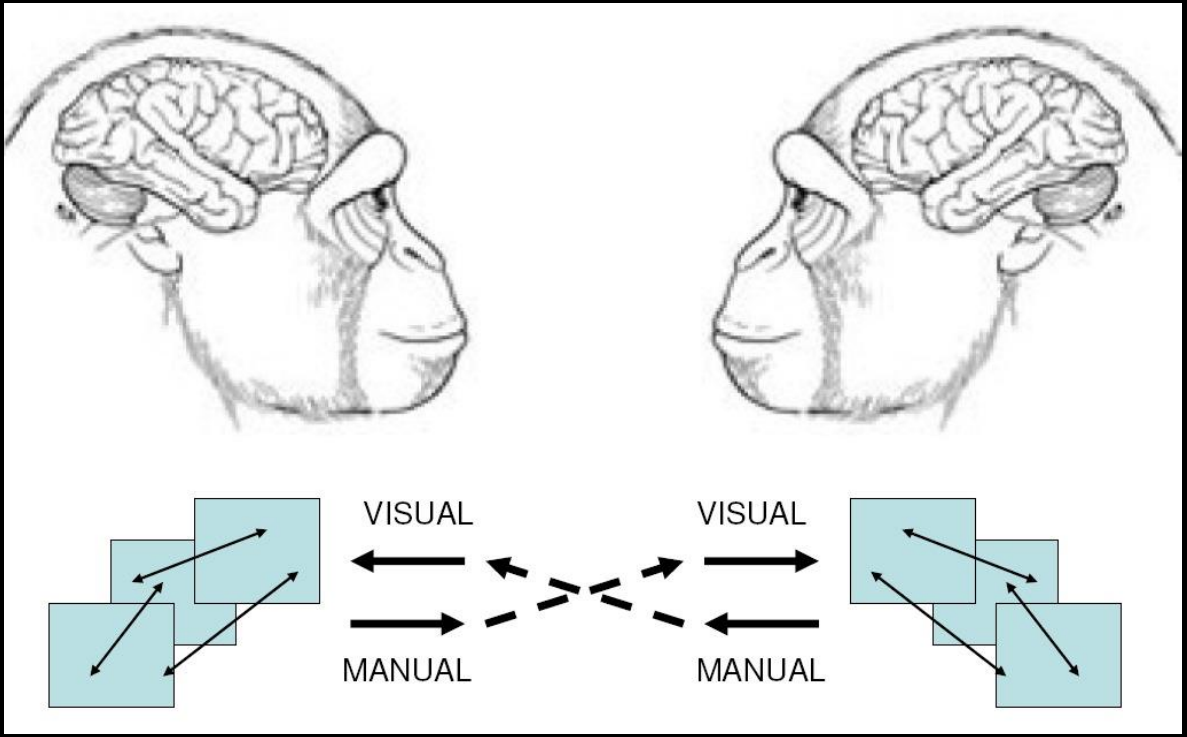
- **Protosign:** a manual-based communication system, breaking through the fixed repertoire of primate vocalizations to yield an **open** repertoire for semantic expression
- **Protospeech and multi-modal protolanguage:** resting on the invasion of the vocal apparatus by collaterals from the protosign system

The Mirror System Hypothesis (2012):
B) From Protolanguage to Language

How the Brain Got Language, Chapter 10: Once early *Homo sapiens* emerges, cultural evolution dominated biological change:

From protolanguage to language; Emergence of grammar:
Complex imitation supports co-emergence of
- Phonology
- Lexicon
- Constructions

Dyadic Brain Modeling



A Hypothetical Example: Beckoning

Child has distal goal: Social bonding – getting mother to hug him:

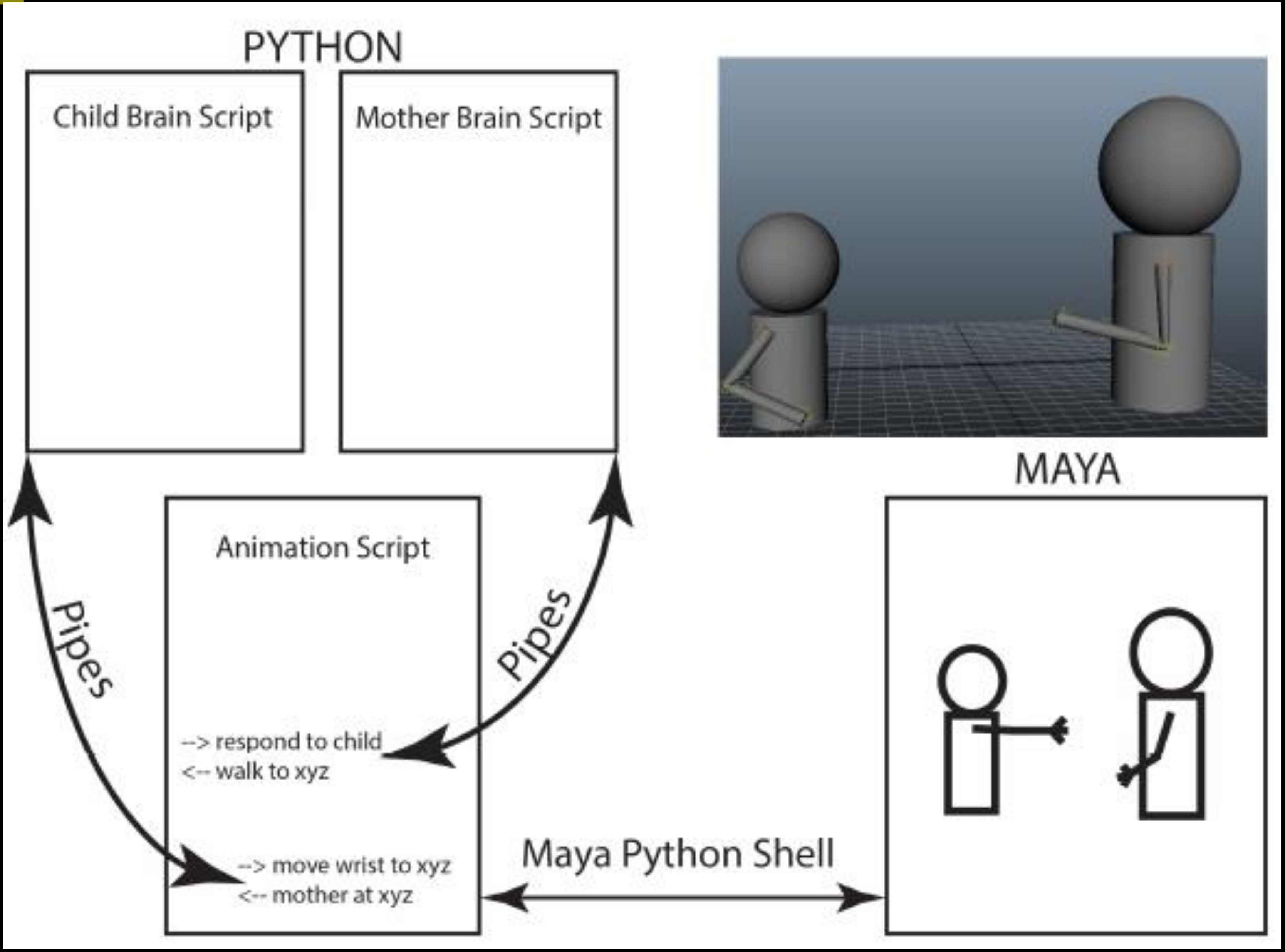
1) **Child reaches out, grabs, and tugs on Mother**, leading Mother to move towards Child as a response.

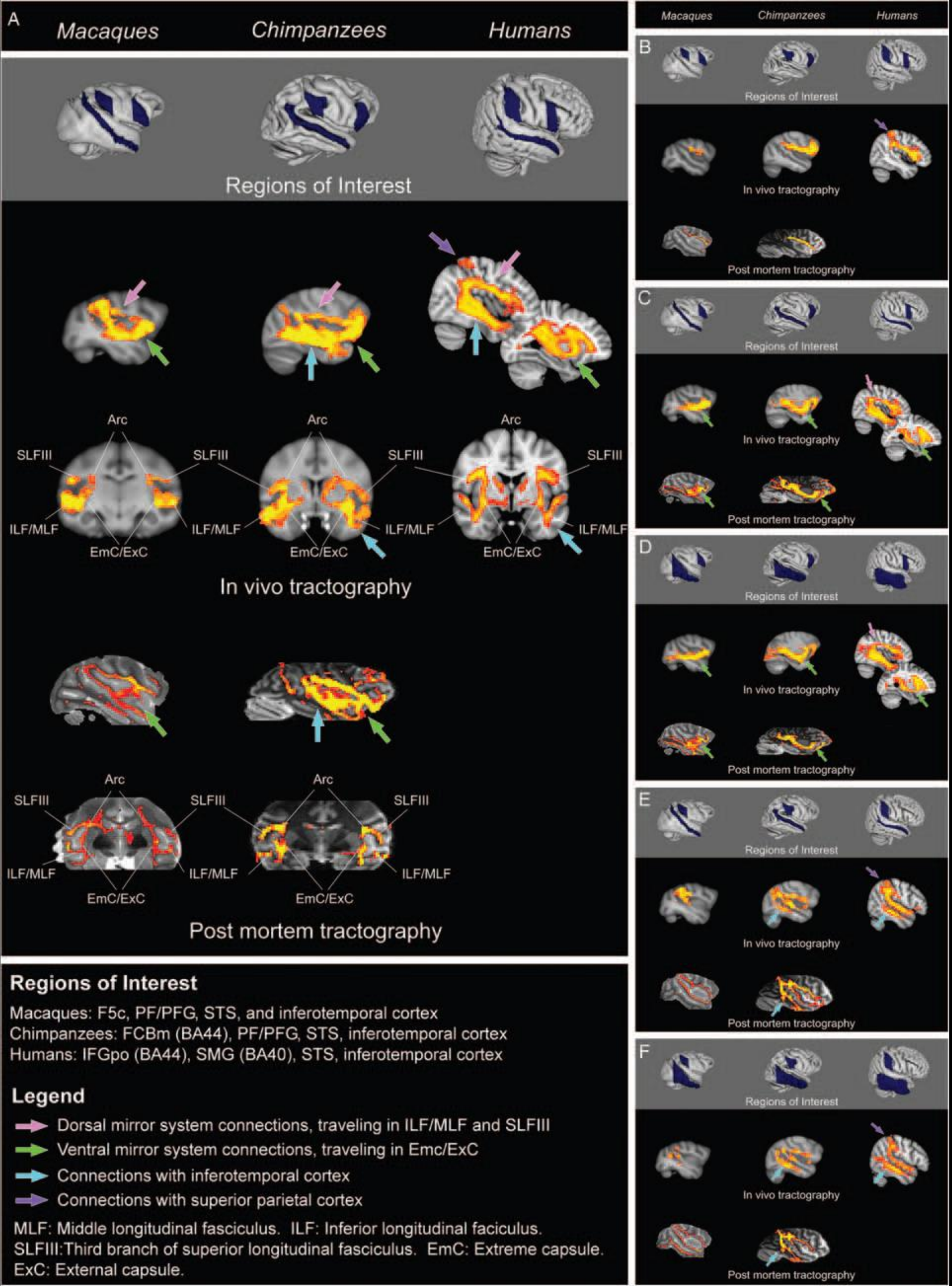
↓

6) **Child beckons Mother** to move towards her.

A Model: Arbib, M. A., Ghanesh, V., & Gasser, B. (2014). Dyadic Brain Modeling, Ontogenetic Ritualization of Gesture in Apes, and the Contributions of Primate Mirror Neuron Systems. *Phil Trans Roy Soc B*

Computational Comparative Neuroprimatology: Each Brain Script Extends the ACQ Model *in the same way*





Not only do hands evolve, but so too do the pathways that open up new possibilities for perception and control

Process Versus Product in Social Learning:
Comparative Diffusion Tensor Imaging of Neural Systems for Action Execution–Observation Matching in Macaques, Chimpanzees, and Humans.

Hecht, Gutman, Preuss, Sanchez, Parr, Rilling. Cereb Cortex. 2013;23:1014-24.

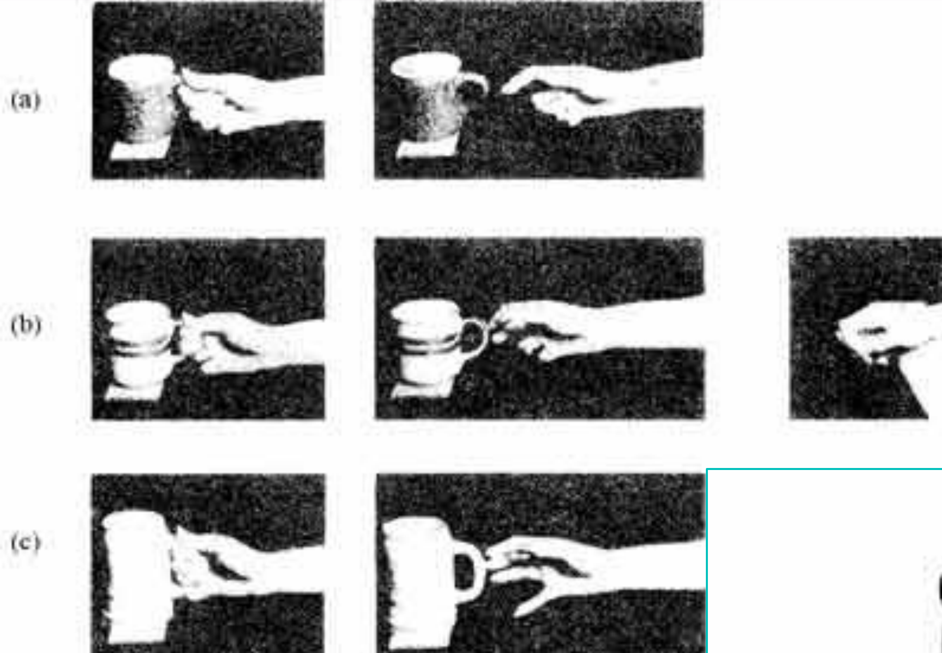
Part IV

Distalization of the End Effector

Distalizing the End-Effector

Grasping: the hand as end-effector

Manipulation: First hand then object as end-effector

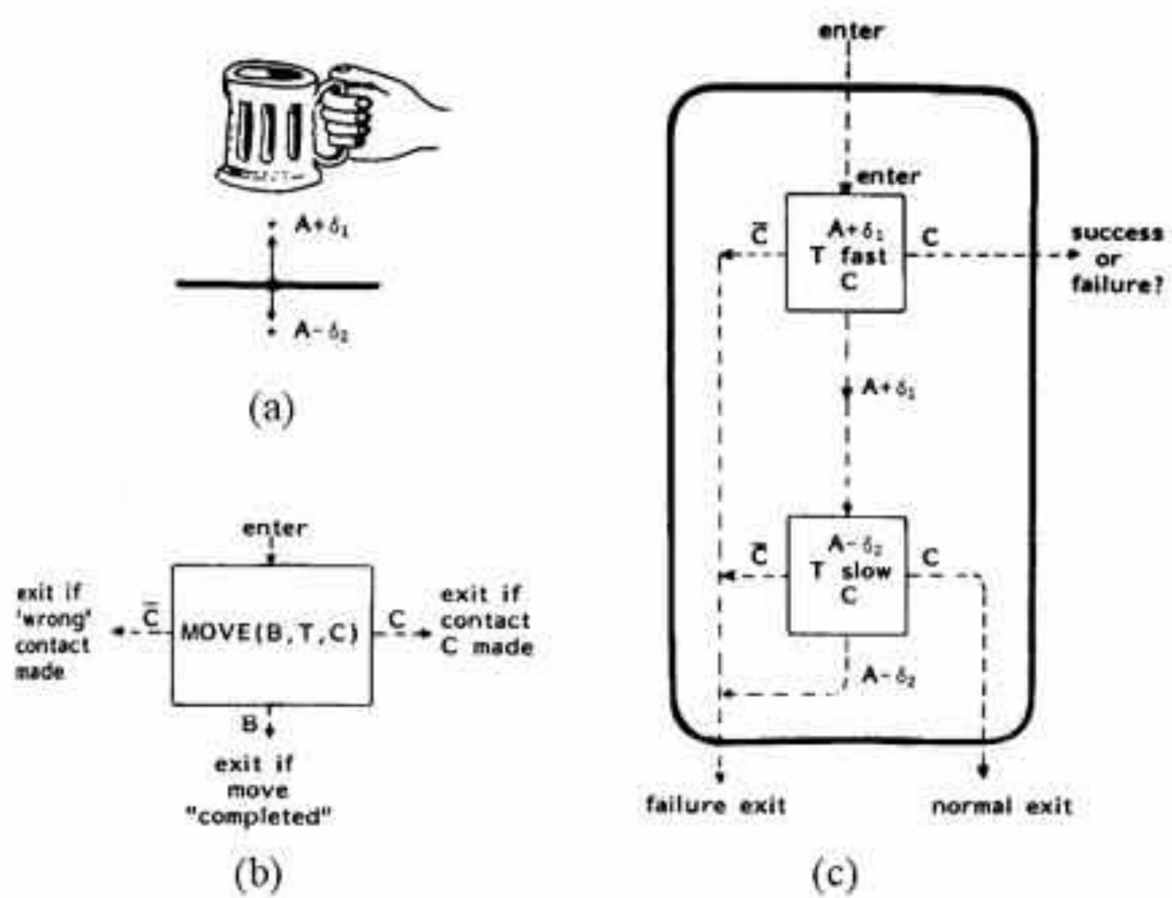


Virtual Fingers

Another two-stage action

Contrast doing this with vision and in the dark

- Feedback &/vs feedforward
- Bringing in hapsis and proprioception



Arbib: Perception for Grasping and Manipulation

Tool Use

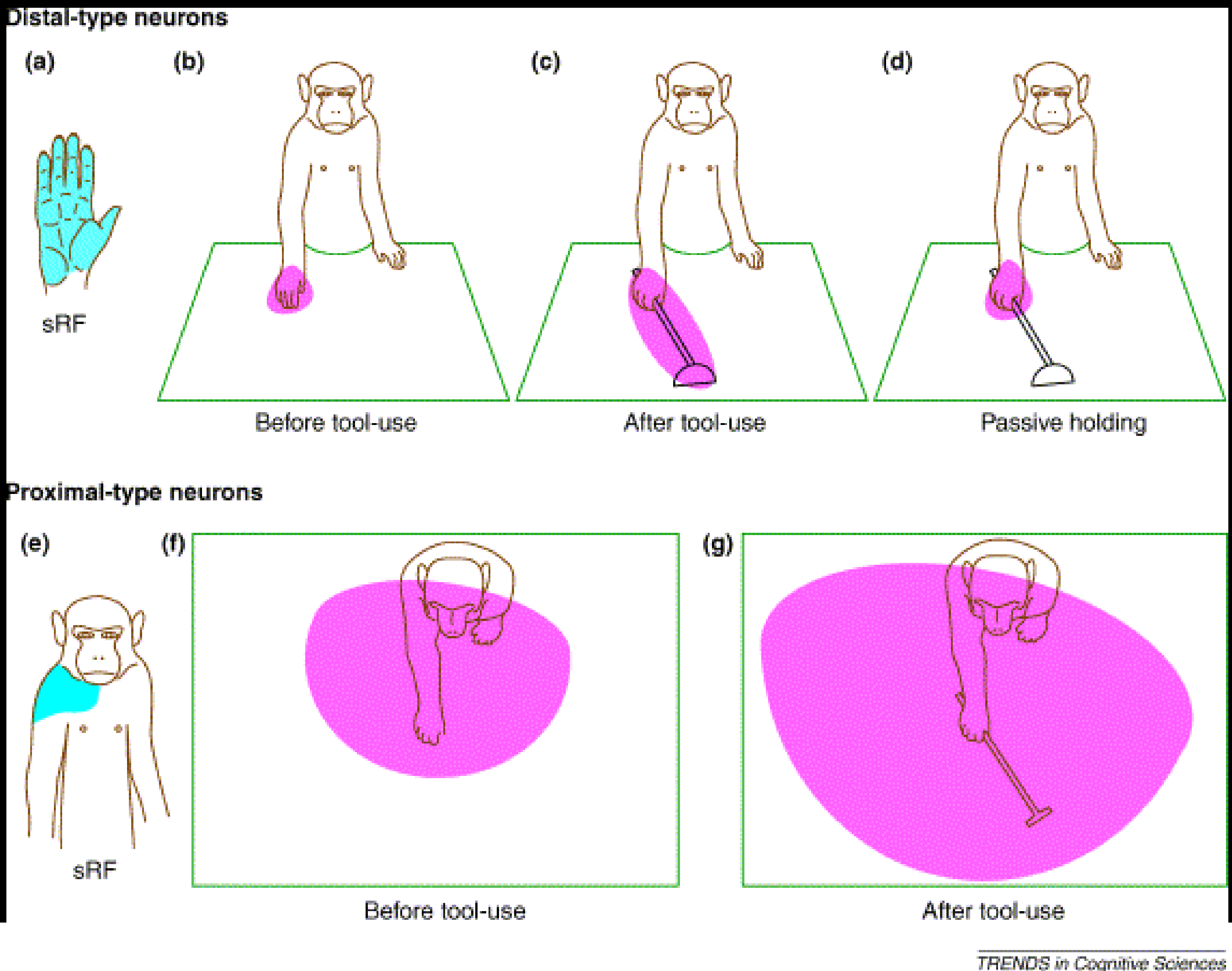
Phase 1: Grasping the Tool: The hand is the end effector: attention to the relation of hand and tool guides the action

Subsequent Phases: Using the Tool: The tool becomes the end effector: attention to the relation of the "business end" of the tool and object guides the action

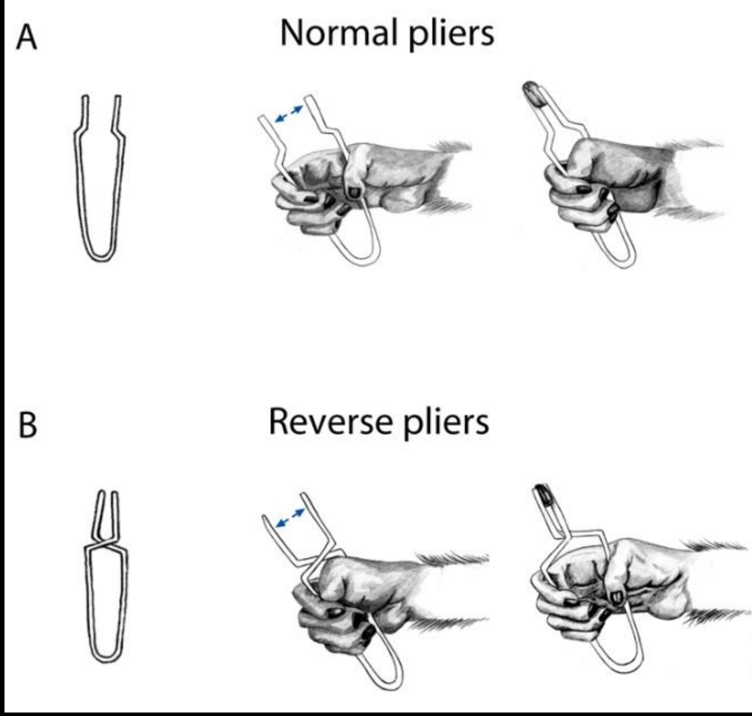
Another issue: Bimanual coordination

Case Study 1: Macaque postcentral neurons coding a body schema modified by tool use

Atsushi Iriki, Tools for the body (schema), *Trends in Cognitive Sciences*, 8:79-86.



Case Study 2: Neurons coding for pliers and for fingers in the monkey motor system

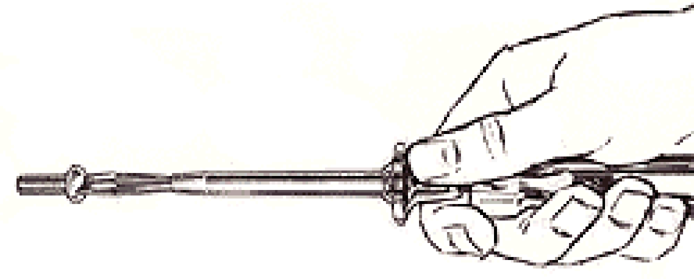


Umiltà et al. (2008) recorded F5 and F1 neuron activity in monkeys trained to grasp objects using "normal pliers" and "reverse pliers"

For the F5 neurons studied: ***activity correlated with the movements of the end effector, the jaws of the pliers.***

For M1/F1 neurons: some discharged in relation to hand movements, others in relation to end effector motion

Tool Use and the extension of perception



The end effector migrates distally from the hand.

- Yet it is still the hand that has to be controlled
  - Visual attention is directed to the tip of the tool rather than to the hand itself
  - Haptic feedback is still provided via the hand but its meaning (the deployed perceptual schema) depends strongly on the phase of the current task

Tool Use and the extension of perception

When Justus plays the cello:

- Visual attention?
- Haptic feedback
- Other senses …