Do Robots Need Cognition?

Does Cognition need Robots?

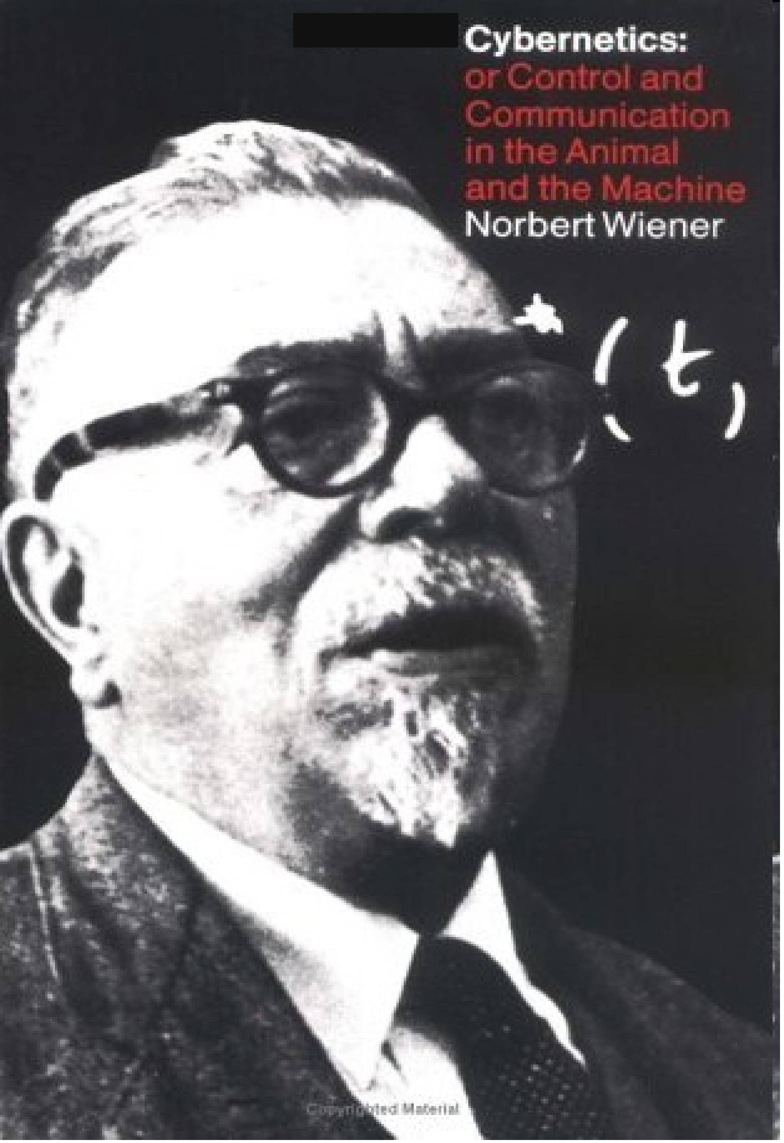
Animals, Humans, Robots and Buildings: A perspective from Cognitive Neuroscience

Michael A. Arbib

Autonomous Robot Based on Inspiration from Biology

Do **Animals** ***Need Cognition?***

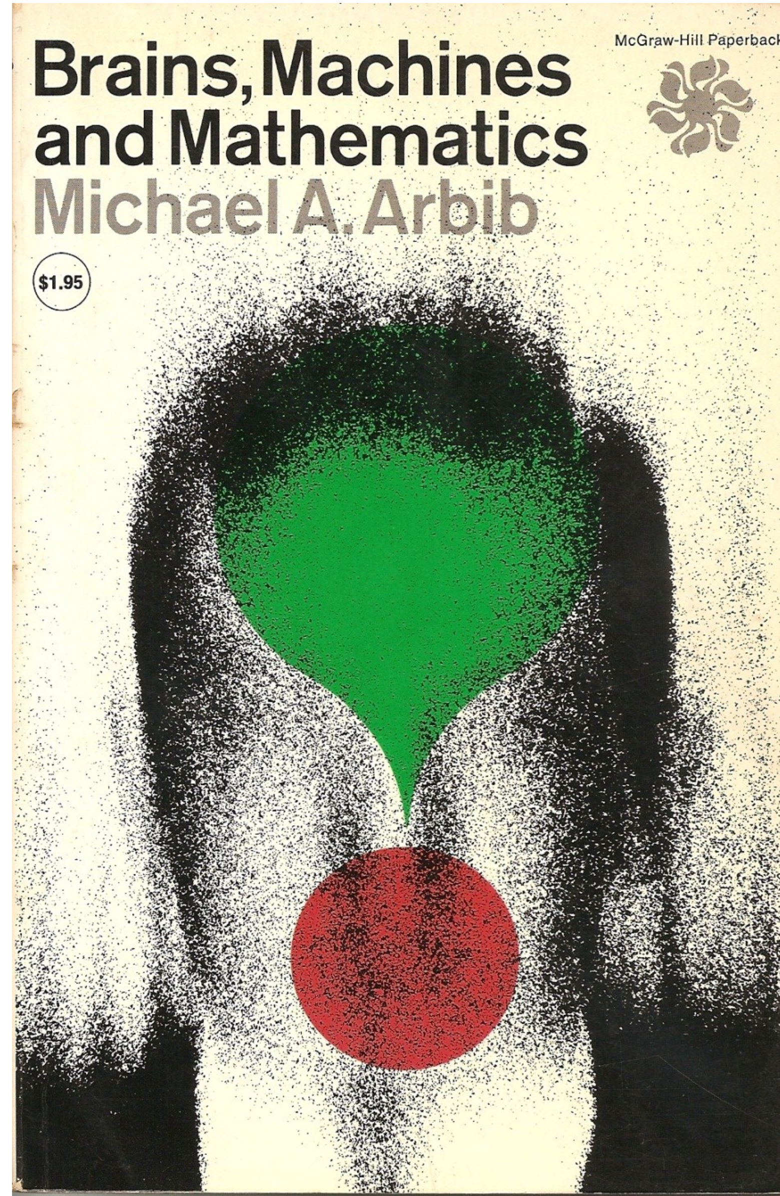
Does Cognition need **Animals** ***?***



Brain as Machine

......

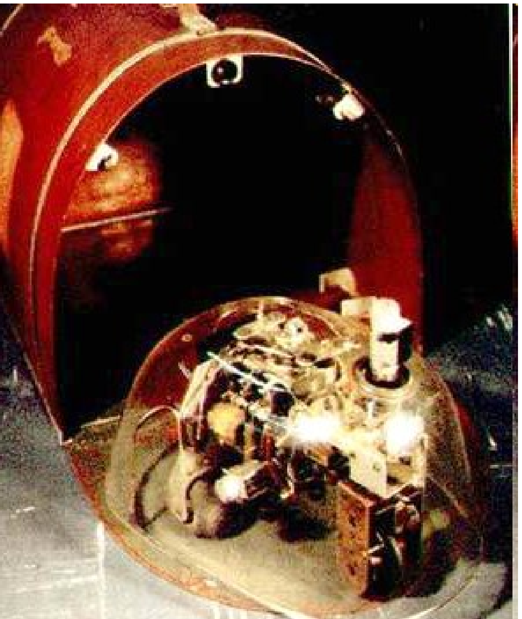
Machine as Brain

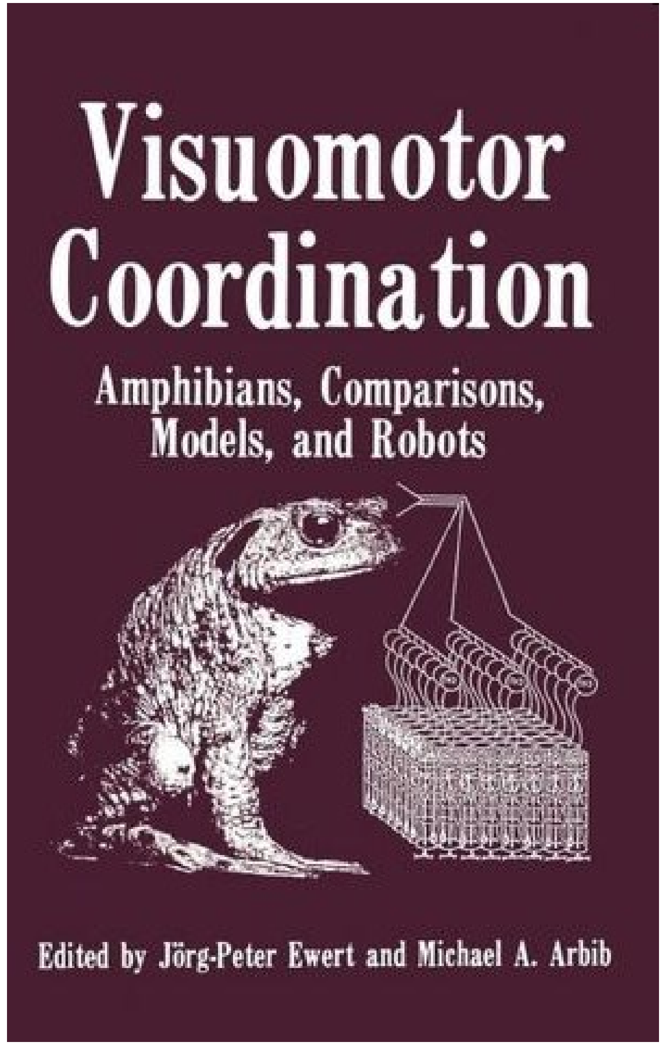


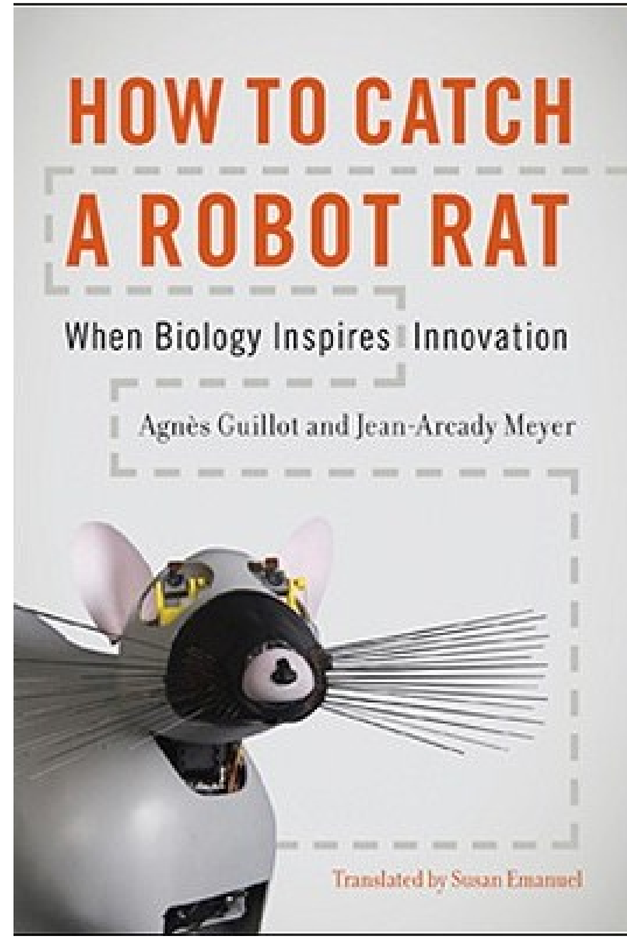
Cybernetics

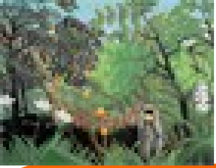
Computational/Robotic Neuroethology

From *Machina Speculatrix* to *Rana computatrix* and *Psikharpax*









Vincent Müller's definitions

Robots are *examples* of

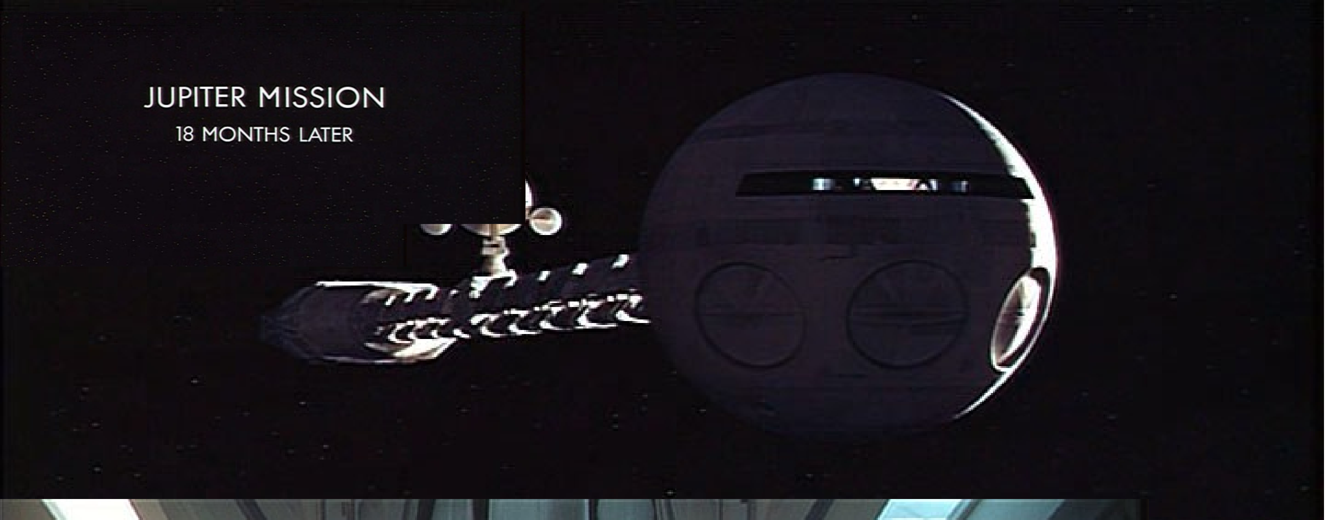
- whole **autonomous** systems that interact with a real environment
- embodied autonomous technical systems

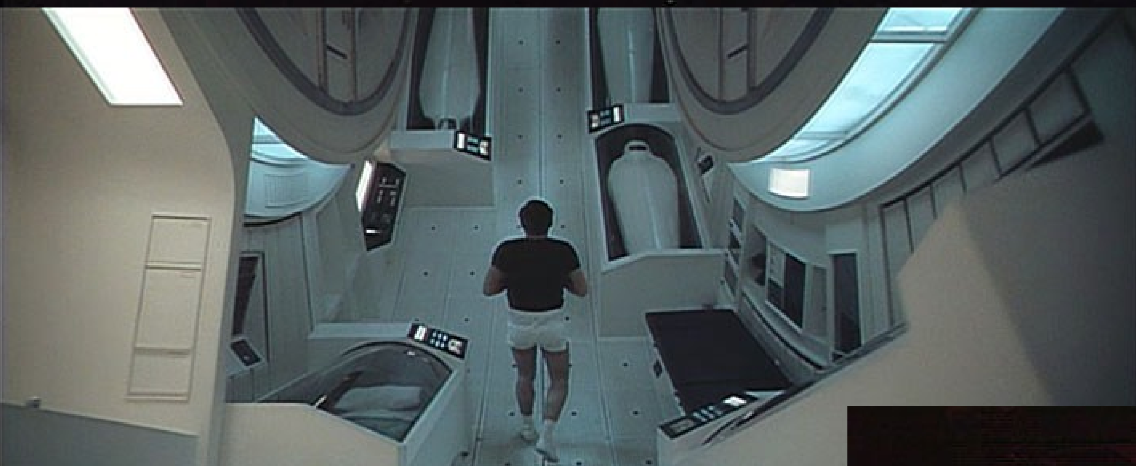
A **cognitive system** acts in flexible ways to **achieve its own goals** (this involves adaptation and learning).

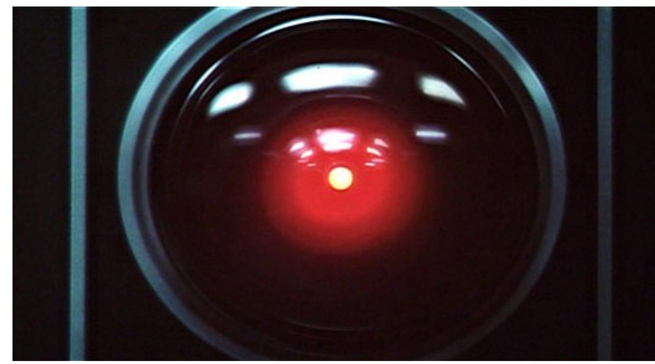
Greater cognitive ability will often be achieved by

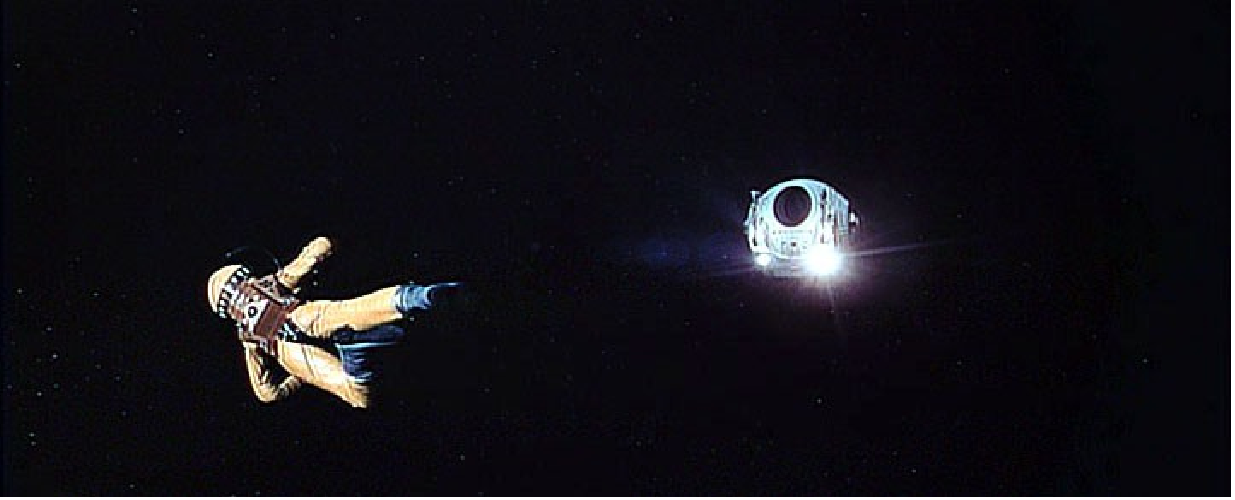
- use of 'higher' functions like anticipation and reasoning.
- **cooperation with other agents**

Claim: Systems with top-down control and full pre-specification (typically in **sense-process-act loops**) are less robust and more limited than autonomous and flexible systems.

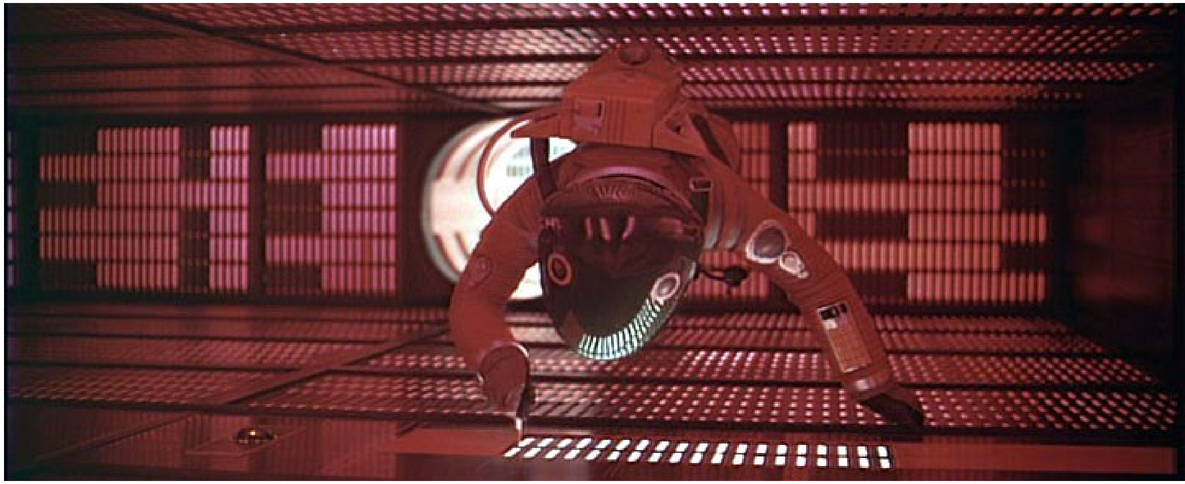

JUPITER MISSION
18 MONTHS LATER

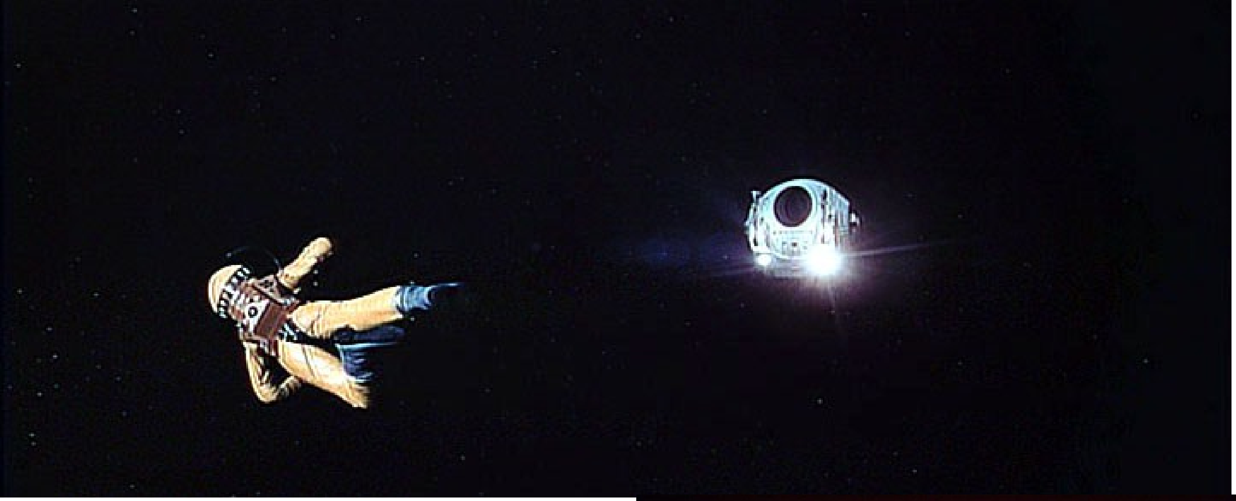


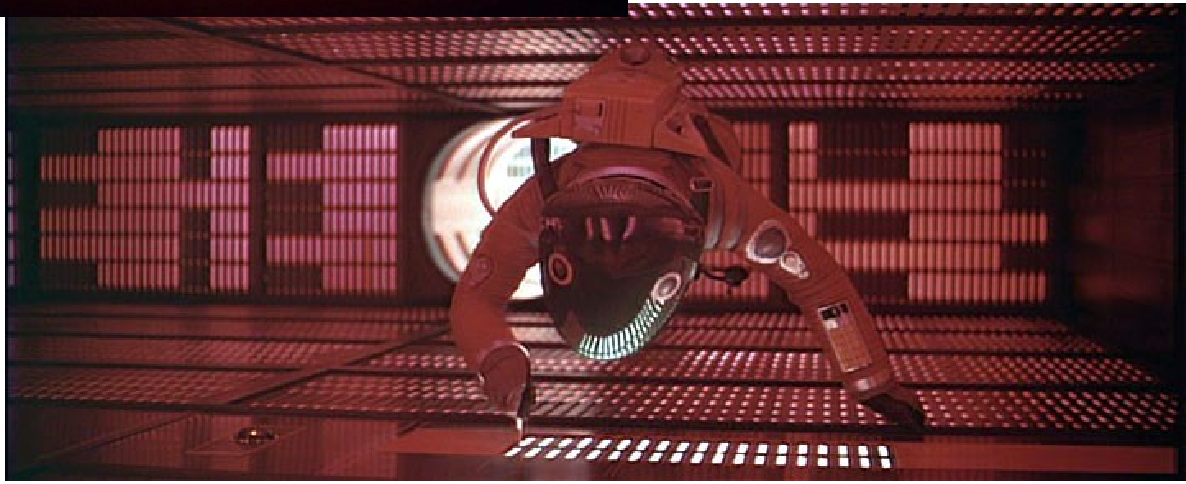




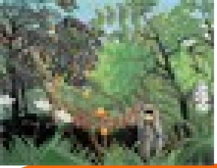

LIFE FUNCTIONS
TERMINATED







How autonomous do you want your cognitive robot to be?



Emotions and Social Intelligence

It is crucial to the plot of the movie that we be aware of HAL's dual status as both a person (the voice is male monotone) and a computer.

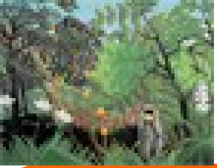
What is the nature of personhood?

Can anyone "not of woman born" be a person?

What is memorable about HAL is that

- initially he seems to have more human feelings than Dave and Frank
- eventually he sees humans merely as obstacles to the mission.

Of course, many humans exhibit ruthless behavior towards other people, but we see this as a moral flaw because most humans have the ability to appreciate and respond to the personhood of others.



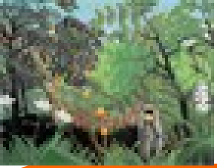
Challenges for Social Robotics

Autonomy versus social norms.

- Social constraints – even ethics and morality – for interacting agents
- The issue of "empathy" – understanding the other to the extent that their goals and intentions must be taken into account.

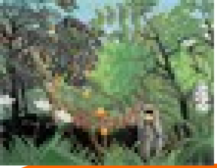
Social Interaction: a Key to Who "We" Are

Allman, ***Evolving Brains,*** Page 178



Towards a Cognitive Social Neuroscience

- Much classic work has been done on the brain mechanisms in the hypothalamus that relate to the basic drives of hunger, thirst, fear and sex.
- Emotion only enters the picture when these are linked to the cognitive level.
- Much work in neuroscience has centered on the isolated animal
- We are now paying more and more attention to the brain mechanisms underlying social behavior



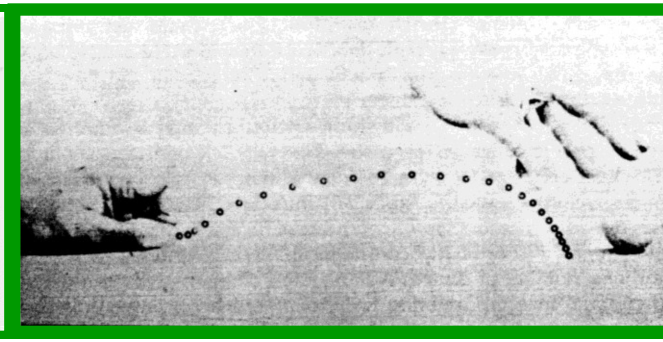
Giving Intelligence a Hand

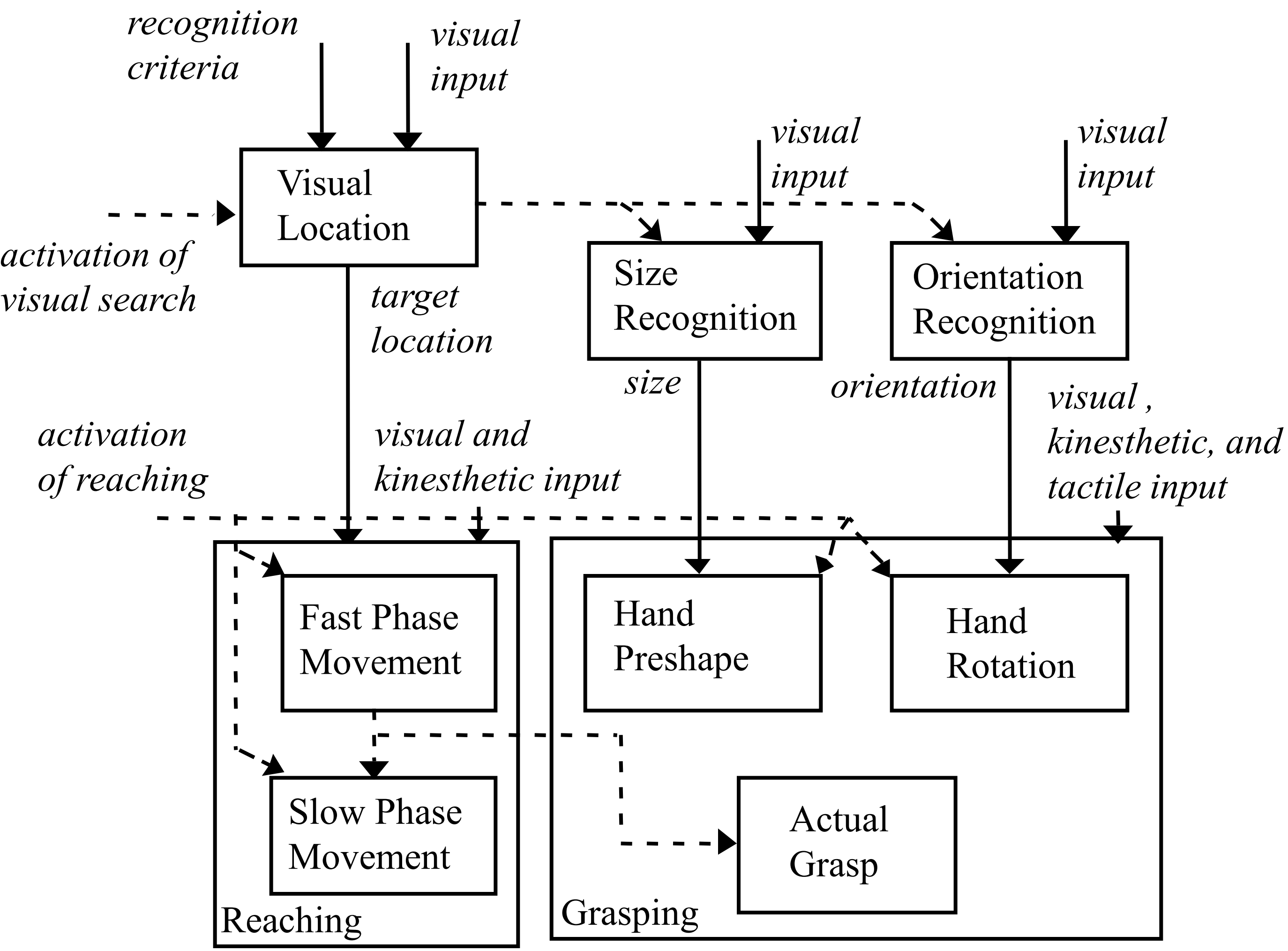
Anaxagoras indeed asserts that it is his possession of hands that makes man the most intelligent of the animals, but surely the reasonable point of view is that it is because he is the most intelligent animal that he has got hands.[124]

I'm an Anaxagorean!

Coordinated control program for reaching and grasping

Jeannerod and Biguer 1979





Perceptual schemas

Arbib 1981

Motor schemas

Schemas

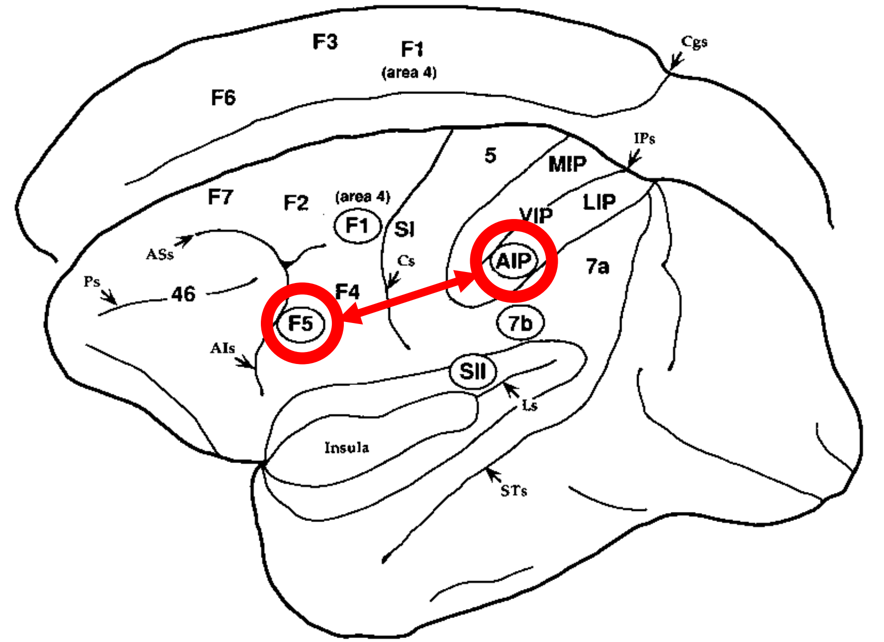
A higher-level representation of what neural networks – and networks of networks – do

Integrating

- patterns of perception (**perceptual schemas**) with
- patterns for action (**motor schemas**)

within larger schema assemblages/coordinated control programs

Mirror Neurons for grasping

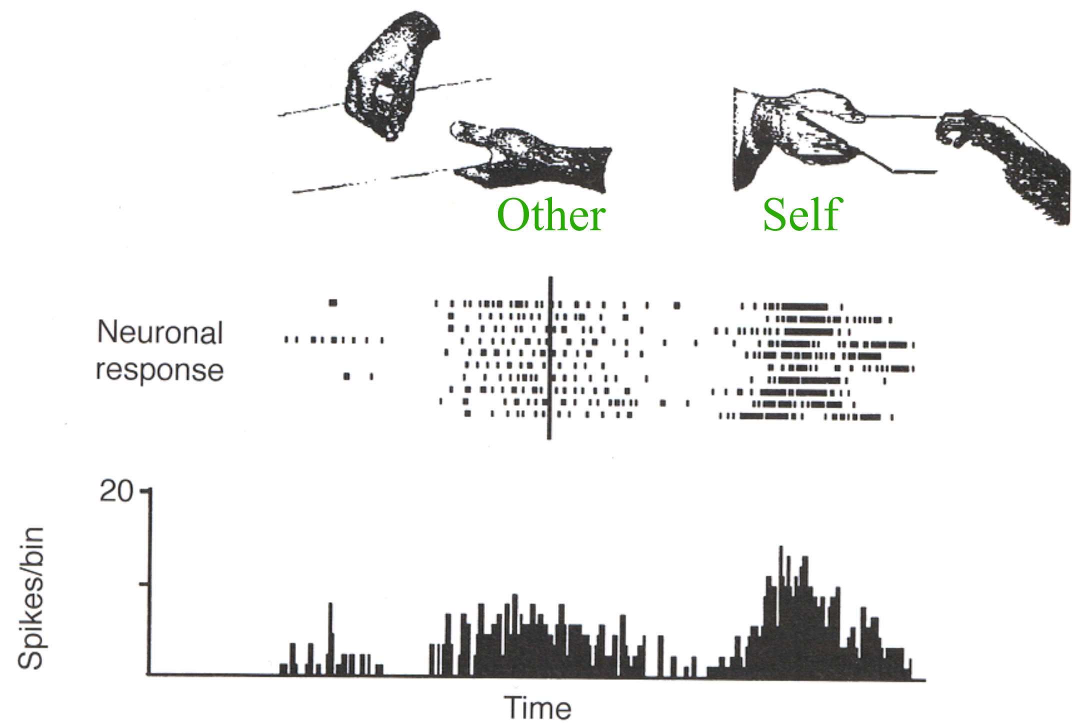


The effective observed movement

≈

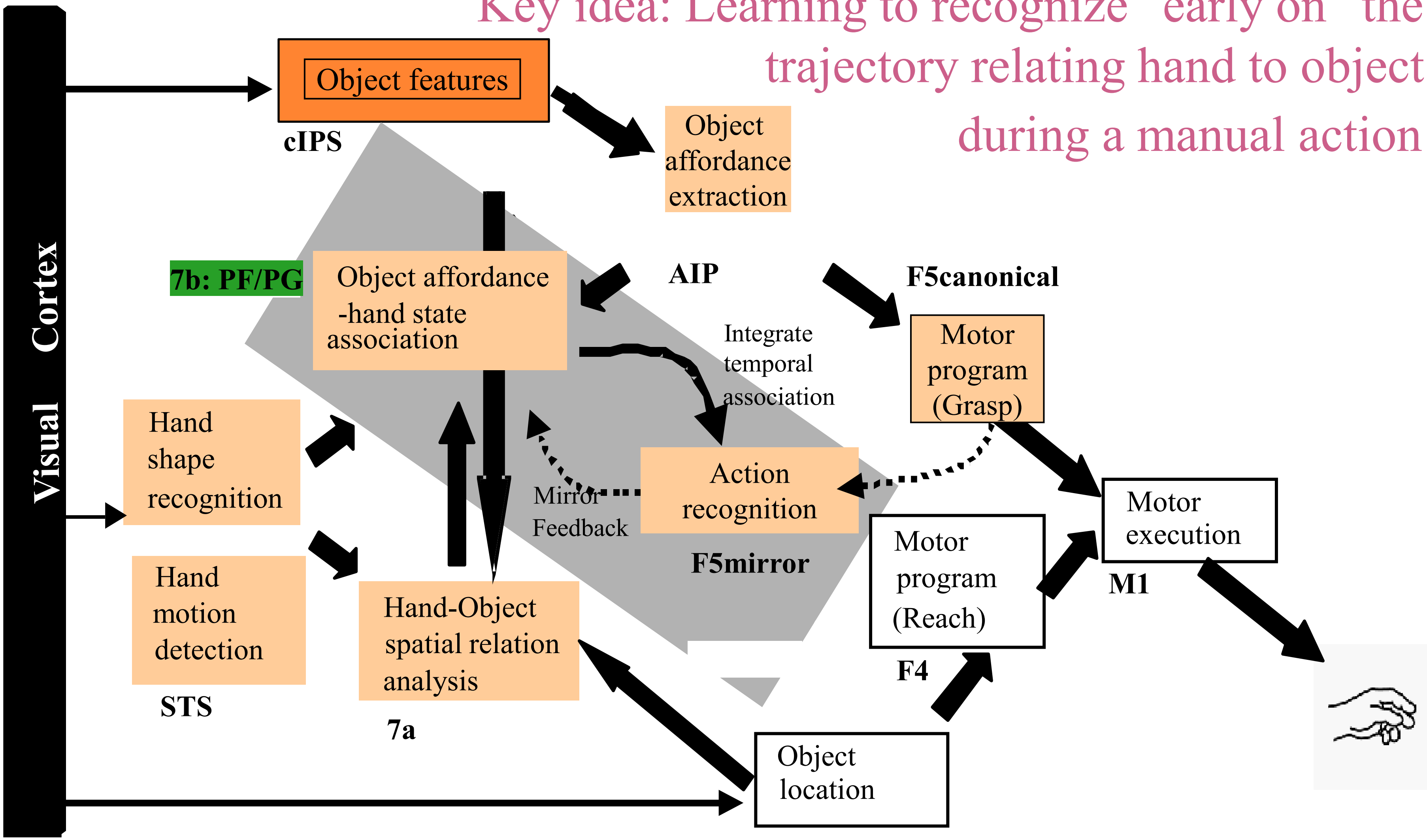
The effective executed movement

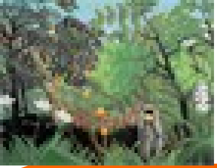
Rizzolatti, Fadiga, Gallese, and Fogassi, 1995



MNS Model of the Mirror System (Oztop & Arbib 2002)

Key idea: Learning to recognize "early on" the trajectory relating hand to object during a manual action





Hidden Grasps

Experiment:

Umiltà et al. (2001) found that grasp-related mirror neurons will respond to grasps obscured by a screen as long as an appropriate object was previously seen before being obscured by a screen.

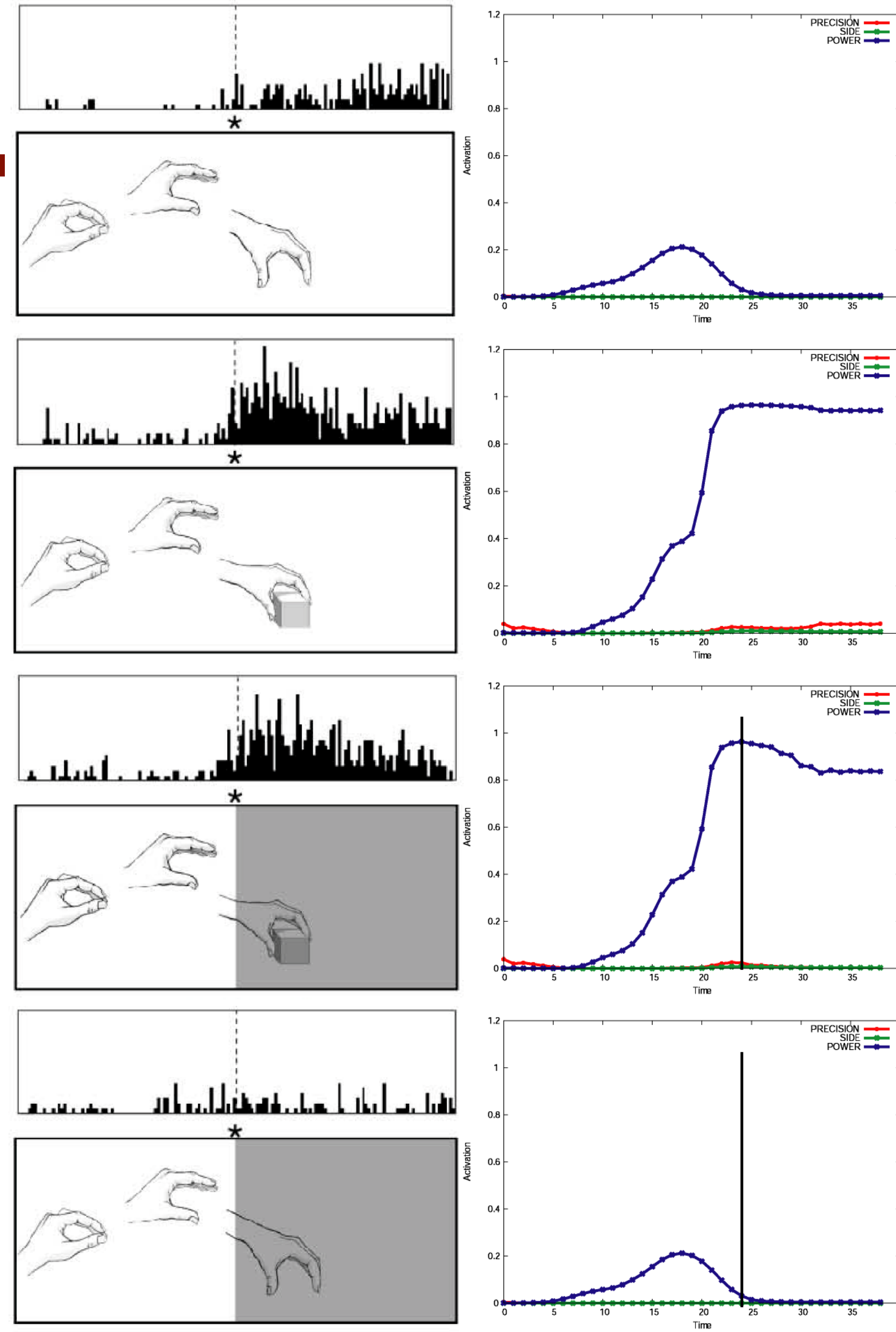
Model additions required:

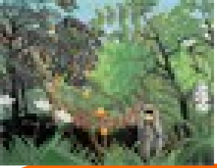
Working memory for parietal cortex

❈object and hand information

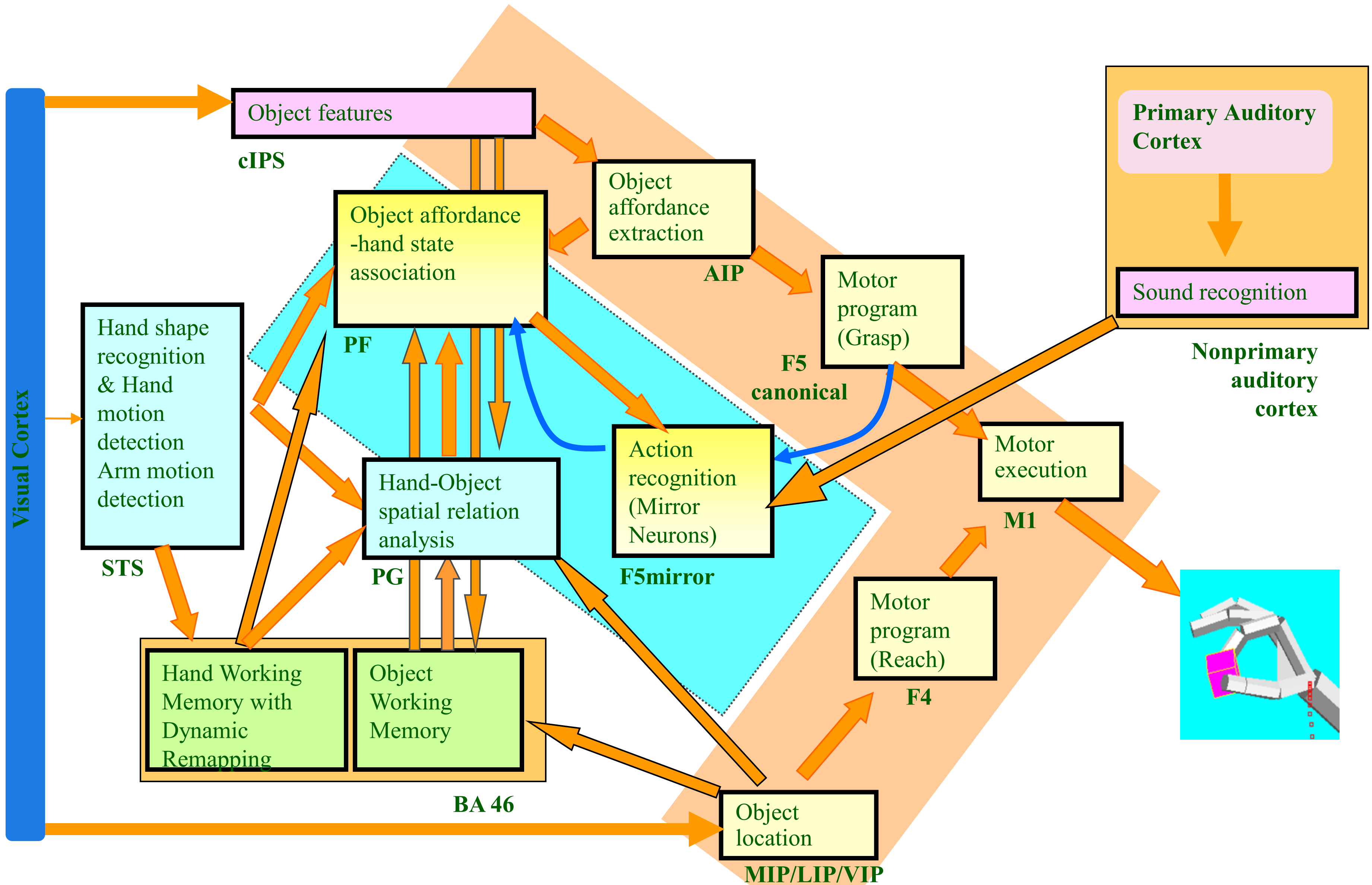
Dynamic remapping

❈ update working memory representation of hand location based on visible arm movement

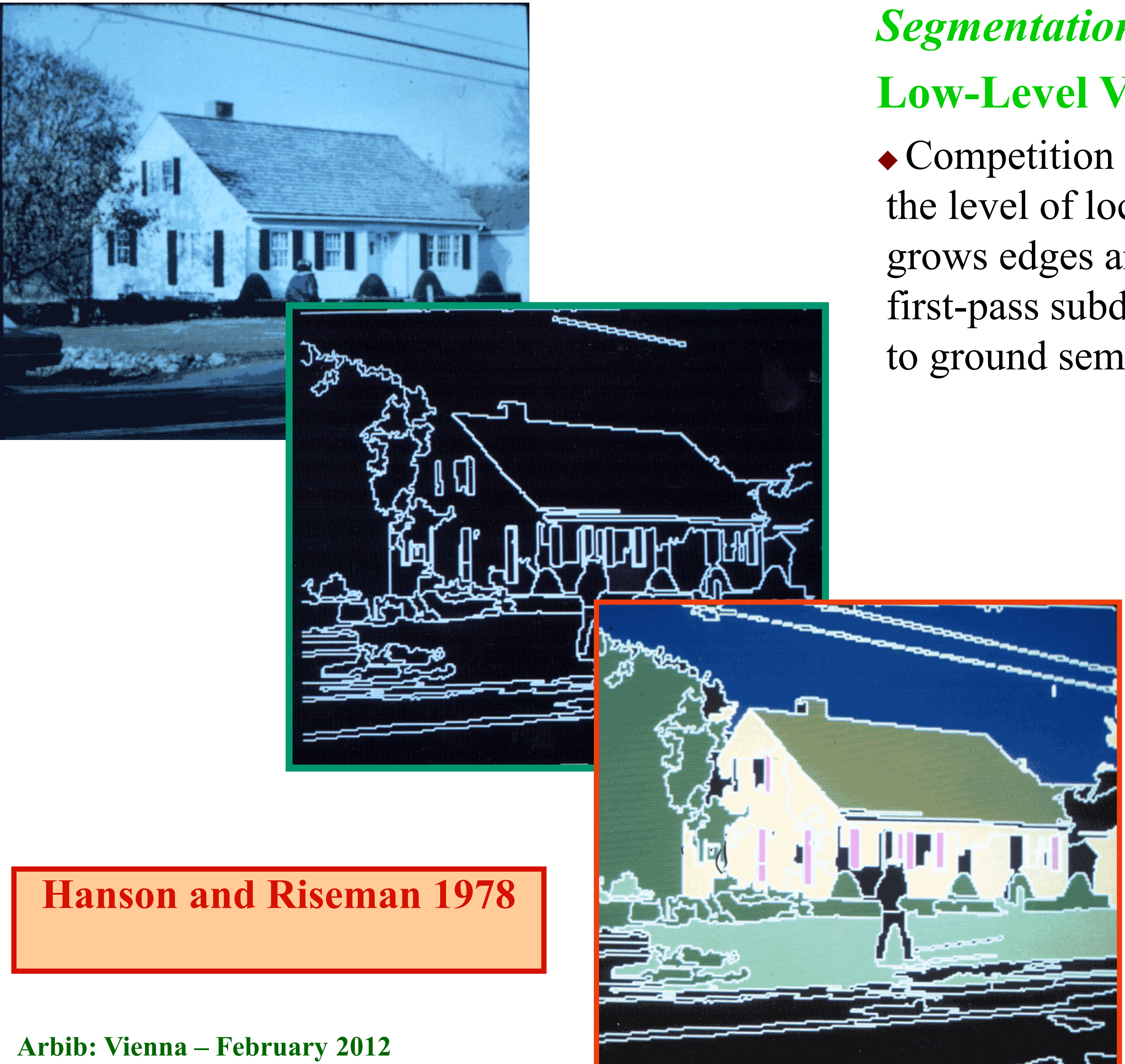




MNS2 Extends MNS



Processing an Image with VISIONS



Segmentation

Low-Level Vision

- Competition and Cooperation at the level of local image features grows edges and regions to yield a first-pass subdivision of the image to ground semantic analysis

Recognition

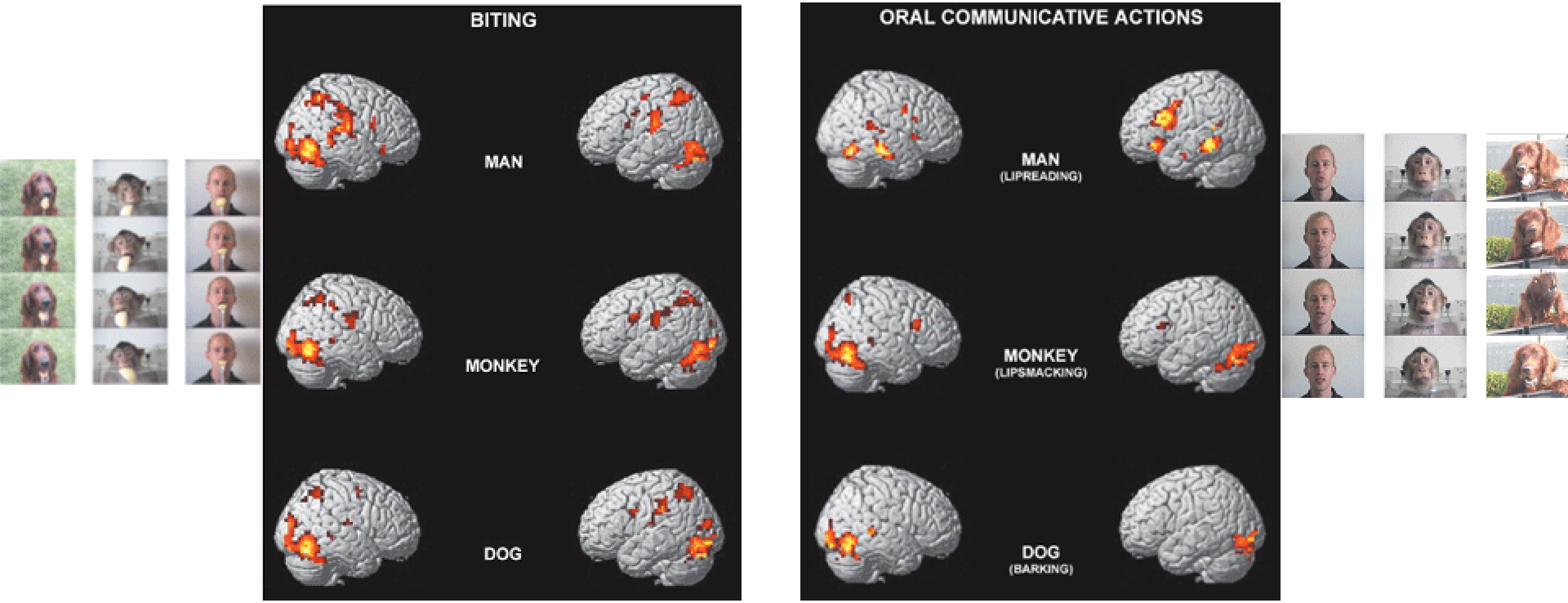
High-Level Vision

- Sky: Data driven
- Roof: Data driven (but with context)
- Wall: Hypothesis driven

Schema instances compete and cooperate to interpret different regions

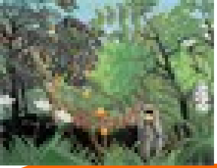
Hanson and Riseman 1978

Buccino et al. (2004) Neural circuits involved in the recognition of actions performed by nonconspecifics



Their Hypothesis: Actions belonging to the motor repertoire of the observer are mapped on the observer's motor system. Actions that do not belong to this repertoire are recognized based without such mapping.

My Hypothesis: All actions can be recognized without mirror system activity *but activation of mirror neurons when available can enrich such recognition.*

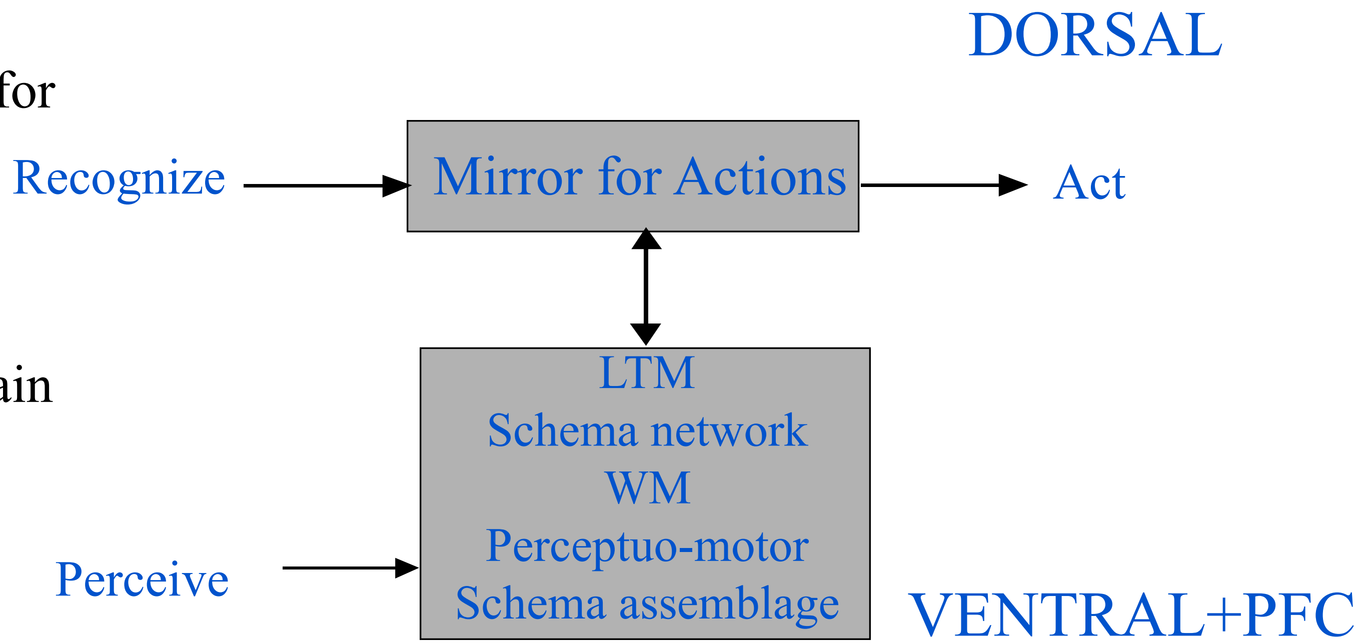


A Basis for Evolution

- a mirror system for actions

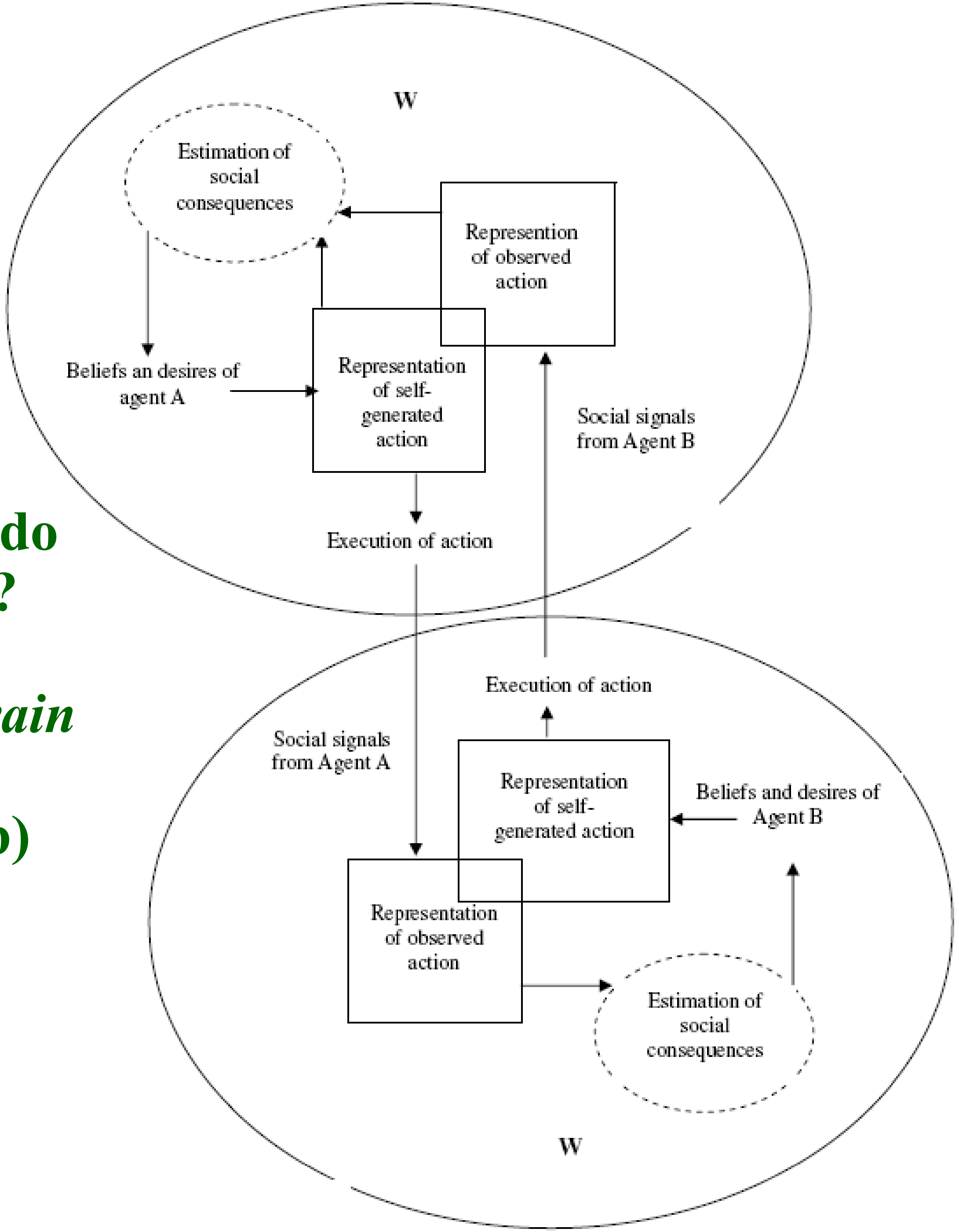
links to:

- schemas and brain mechanisms for perception and planning: diverse actions, objects, attributes and abstractions



Cooperation with other agents

Two embodied brains interacting

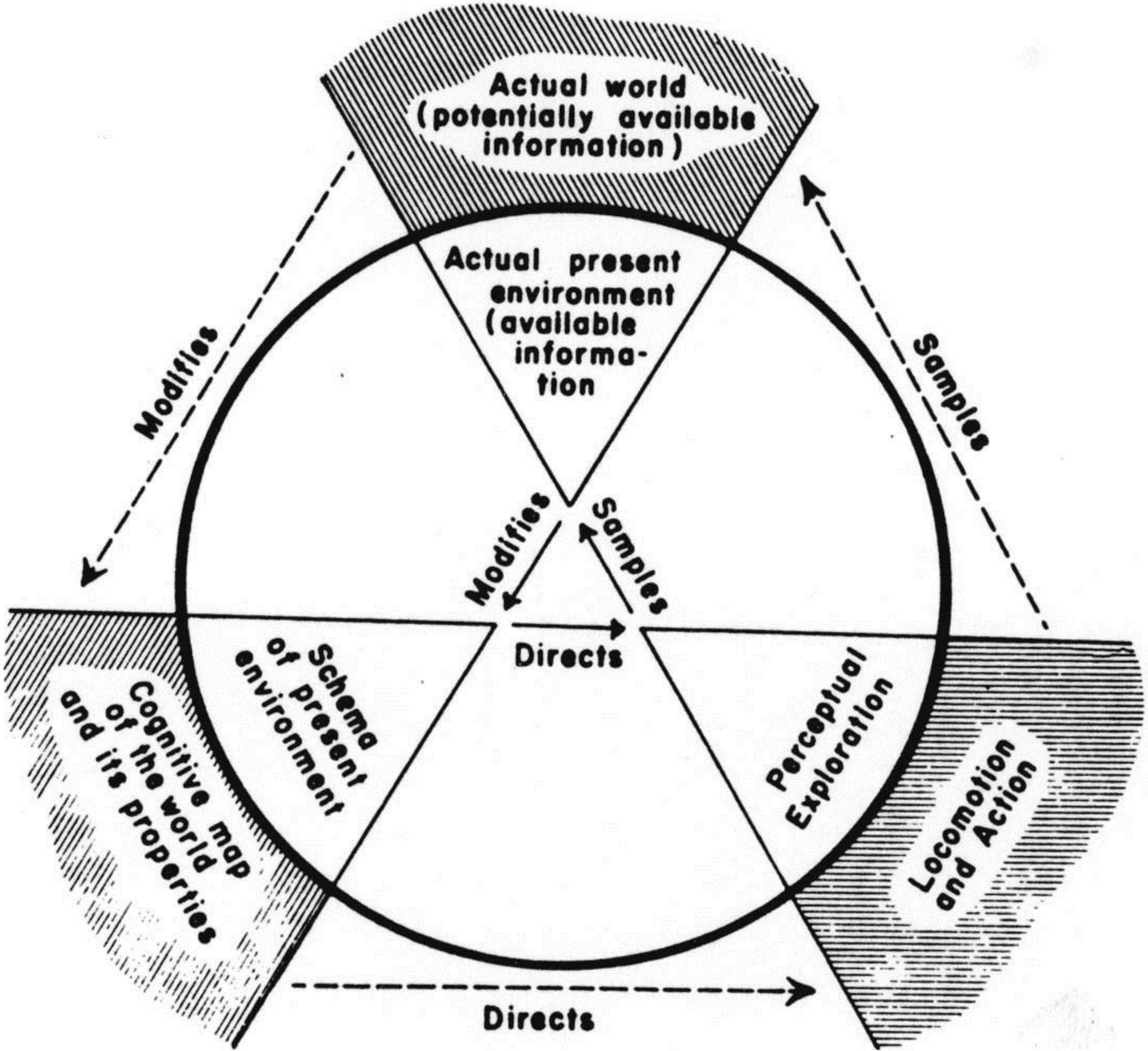


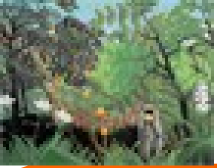
Marc Jeannerod 2005. How do we decipher others' minds? in *Who Needs Emotions: The Brain Meets the Robot*, (ed. J-M Fellous, MA Arbib) Oxford University Press

Beyond the sense-process-act loop

Action-Oriented Perception (Arbib, 1972)

The Action-Perception Cycle (Neisser, 1976)





Before "The Great Move"

A fixed repertoire of schemas:

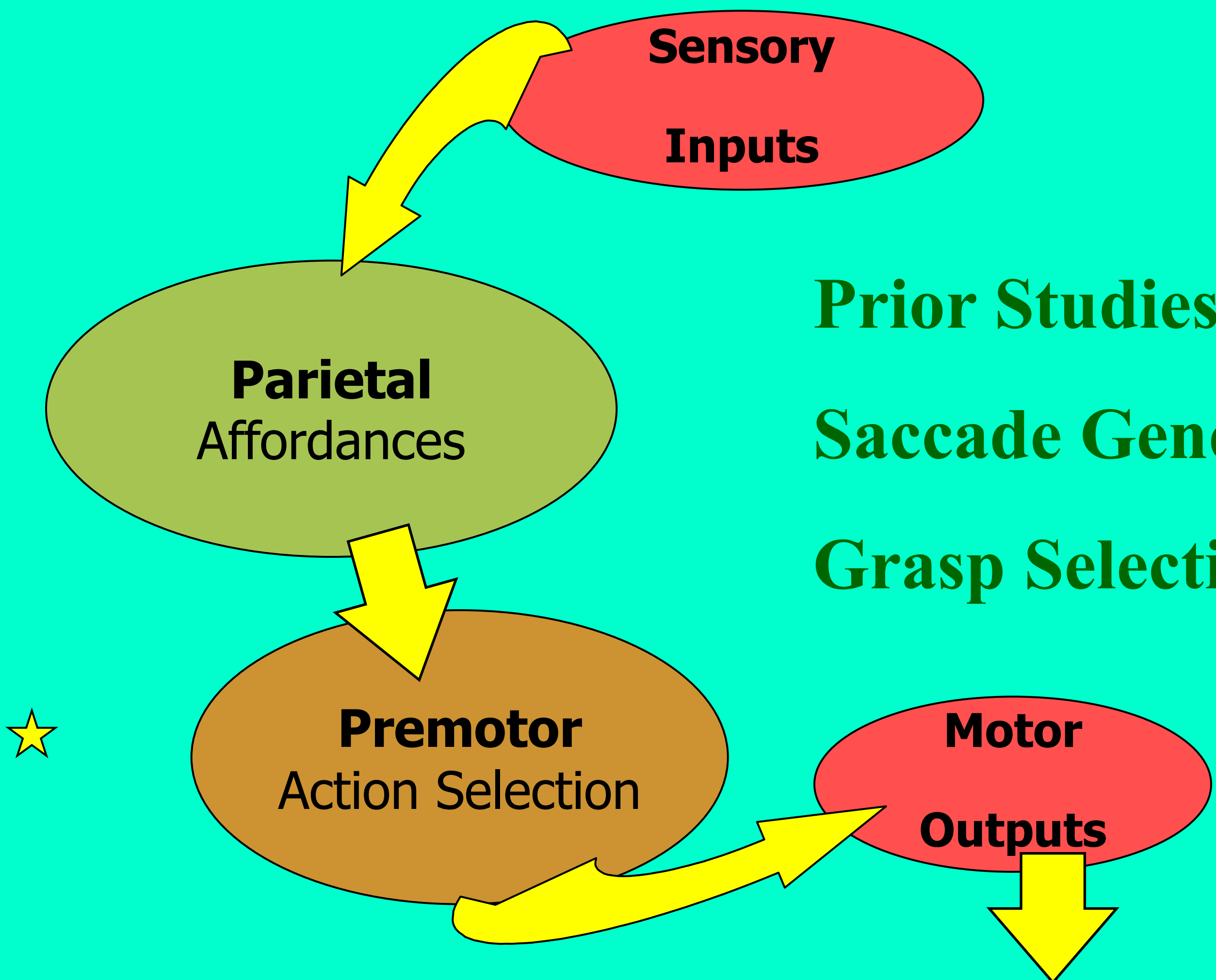
Ethologists study the adaptive character of lower organisms

- moving toward more and more specialized networks with specialized dynamics to support a great variety of representational demands
- e.g. in Frog: orient, approach, snap, escape, …
  - schemas are strongly linked to basic motivational systems related to hunger, escape from danger, sex, ...

A Conundrum

Why is the human brain so complicated?

A General Paradigm:
Parietal Affordances - Premotor Action Selection

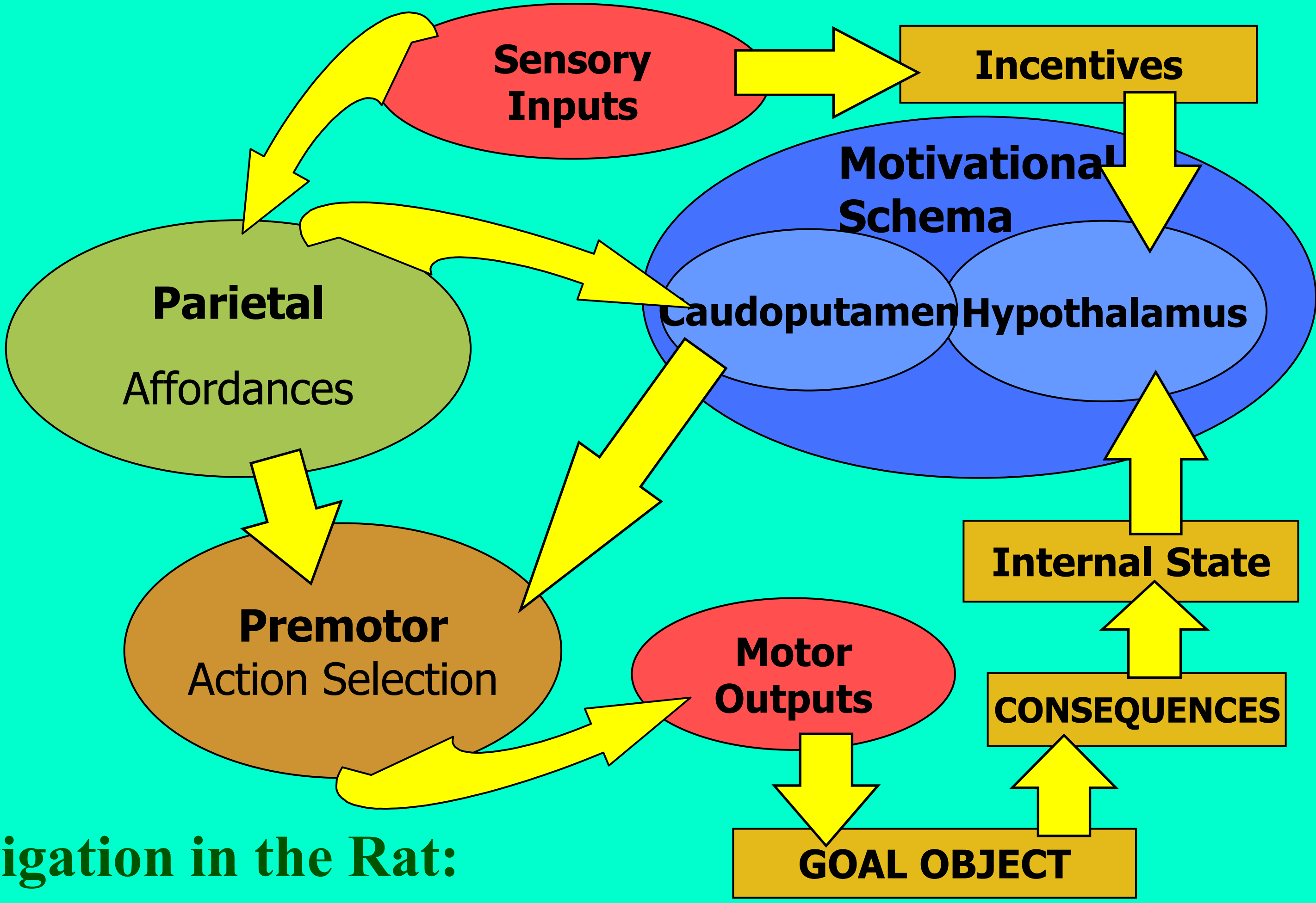


Prior Studies in Monkey

Saccade Generation (LIP-FEF)

Grasp Selection (AIP-F5)

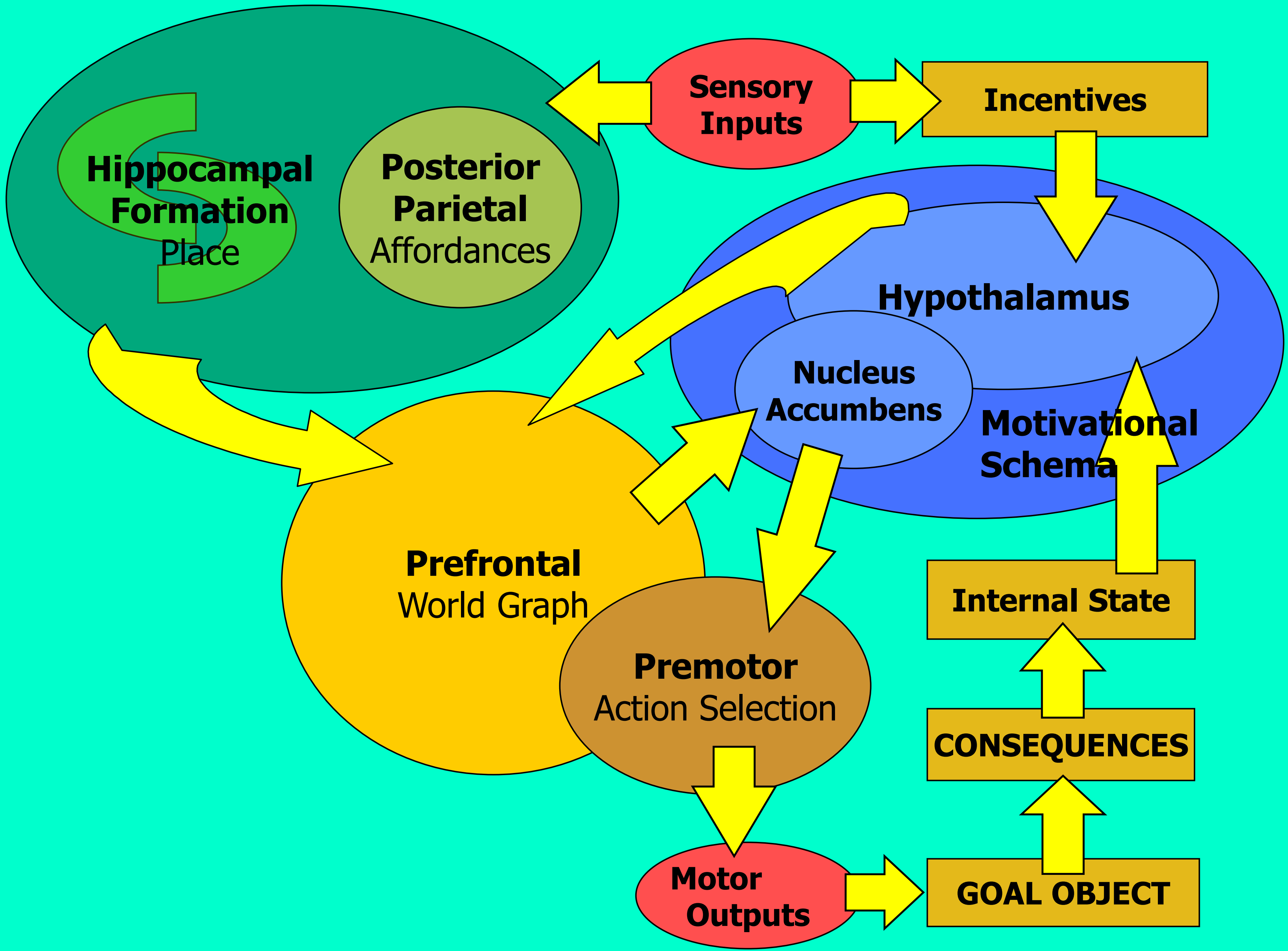
The Taxon-Affordances Model (TAM): Neural Correlates



Taxon-Based Navigation in the Rat:

Bringing in Reinforcement Learning and the Role of Motivation for Goal-Selection

The World Graph (WG) Model: Neural Correlates



The Great Move

Allen Newell (*Unified Theories of Cognition*, 1990) argued that, rather than being dependent on specialized networks with specialized dynamics, the range of human cognition is the result of

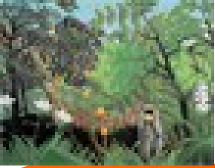
The Great Move:

- to using a neutral, stable medium that is capable of registering variety and then *composing* whatever transformations are needed to satisfy the requisite representation law. This opens up the whole world of indefinitely rich representations.
- Yielding the richness of each human's ***schema encyclopedia***
  - humans acquire a multitude of schemas which can be deployed in an endless variety of role- and context-dependent groupings

And It's **not** *a Great Move to a Single General Purpose Computer (GOFAI)*

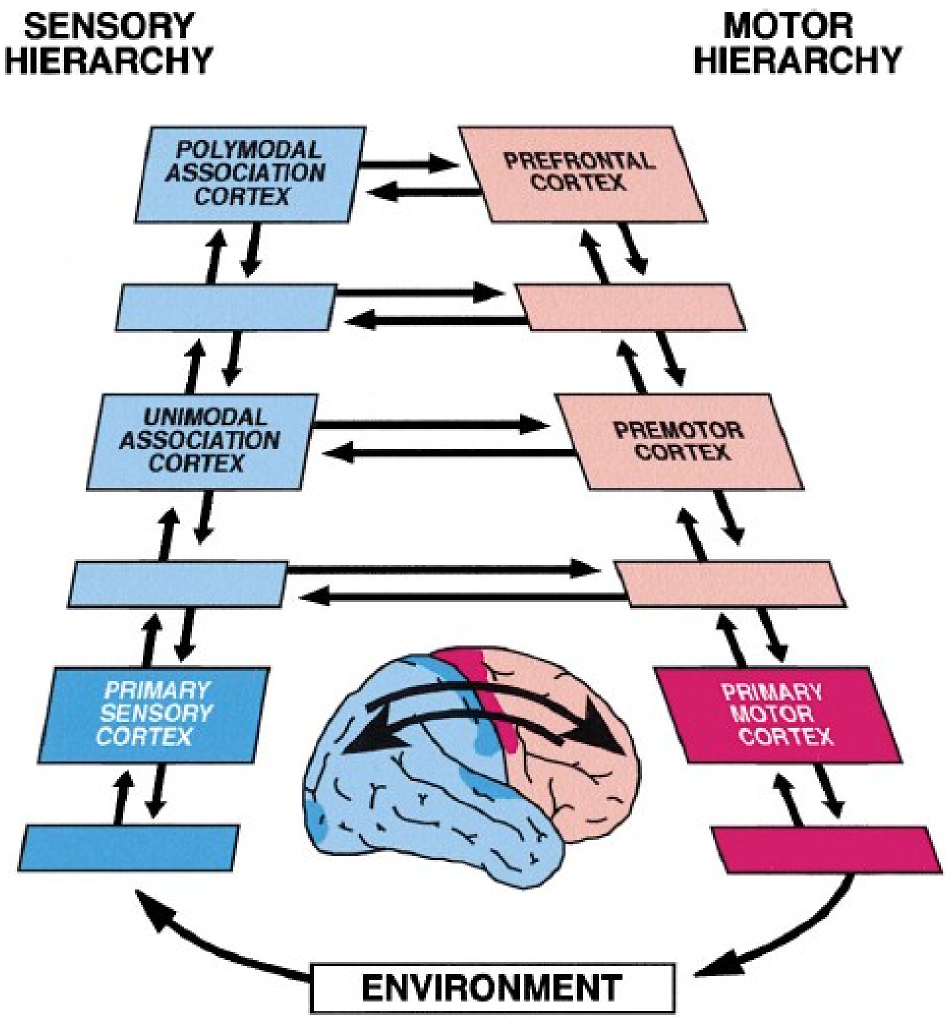
Our counterpoint:

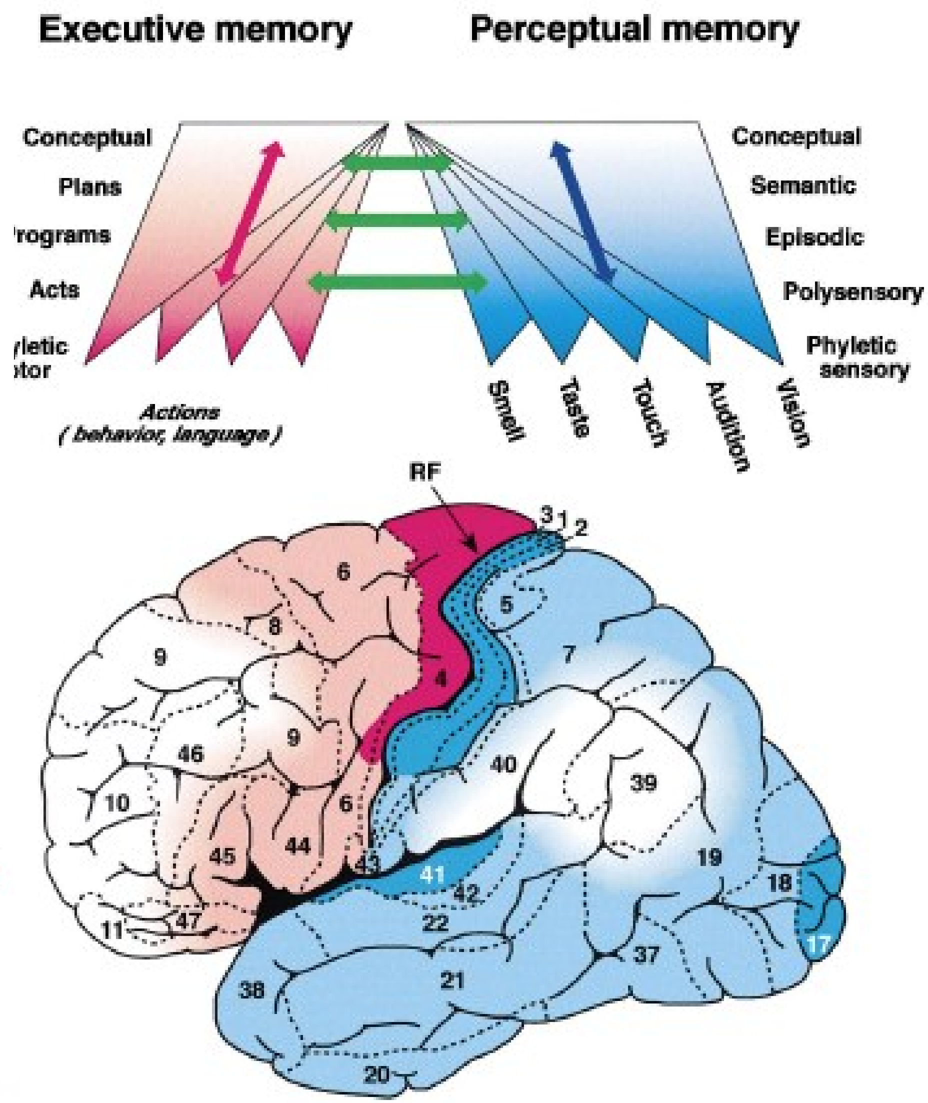
- Many specialized networks with specialized dynamics endure even as circuits supporting cognitive systems evolve atop them.
- Enlargement of the pre-frontal lobe extends the number, sophistication and coordination of parieto-frontal perceptuo-motor systems to extend the reach in space and time
  - Using motivation to evaluate future courses of action linked to sophisticated memory and planning structures
  - As prefrontal circuitry expands, refinements of the basal ganglia and cerebellum keeping pace



The Action-Perception Cycle and the Human Brain

Fuster JM. 2001. The Prefrontal Cortex—An Update: Time Is of the Essence.





Brains Differ from Region to Region not just Overall Size

Allman,
Evolving Brains
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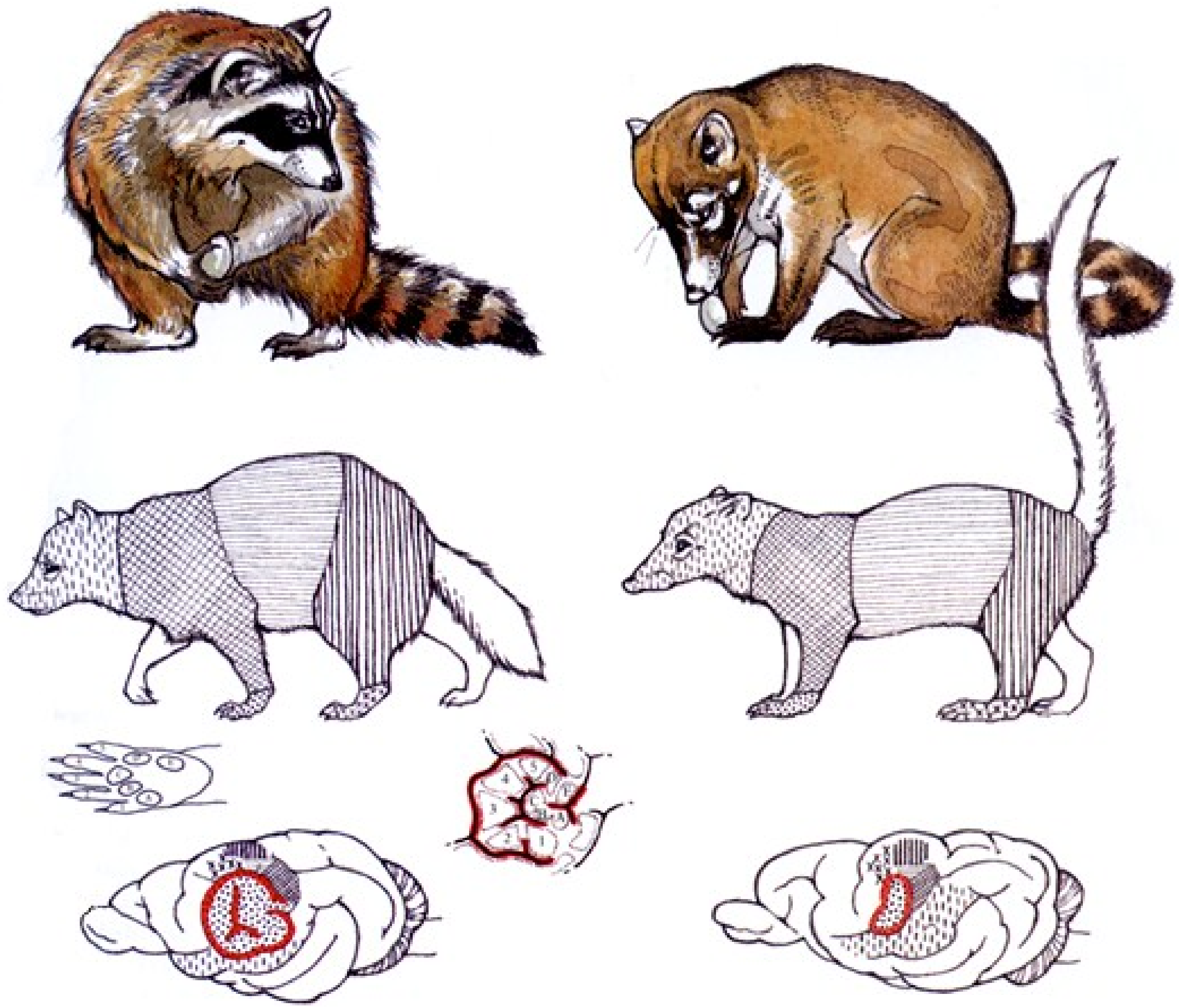
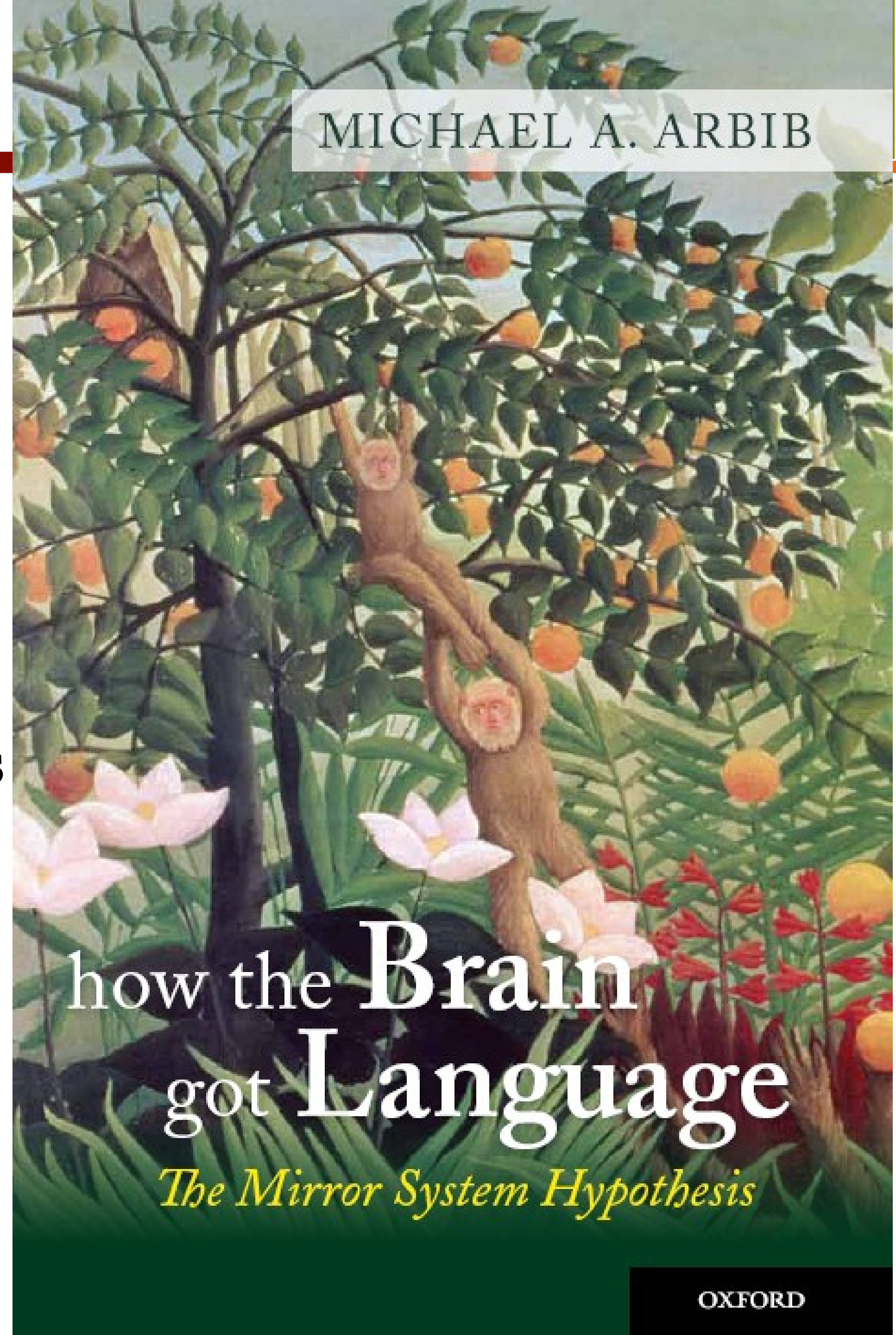
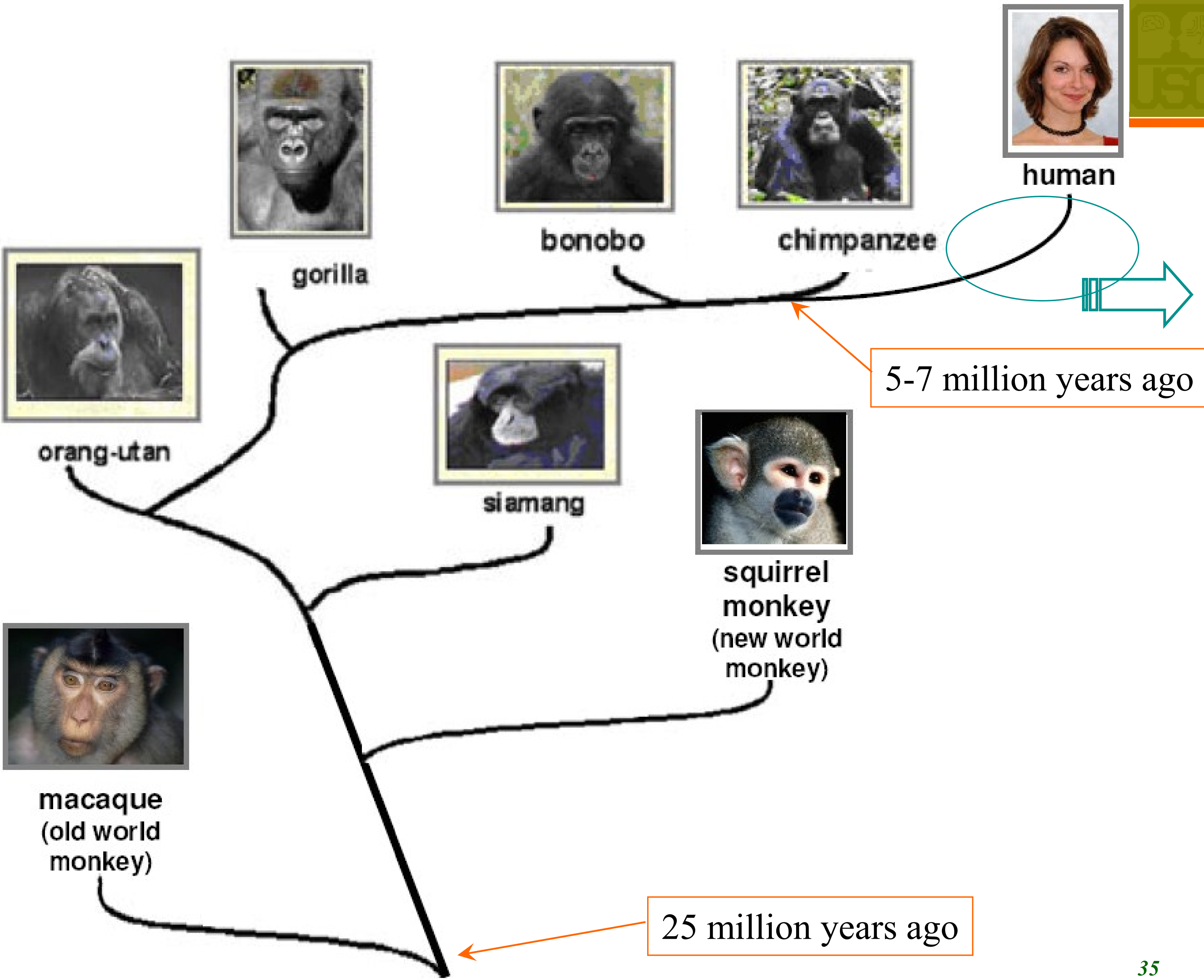
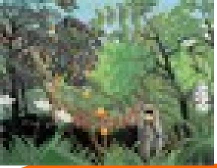


Raccoon   Coatimundi

An evolutionary framework for understanding cognition in terms of multiple interacting brain systems




human
bonobo
chimpanzee
gorilla
orang-utan
siamang
squirrel monkey (new world monkey)
macaque (old world monkey)
5-7 million years ago
25 million years ago



Chimpanzees and Humans

Similar Body Size

but very different brains!

Allman,
Evolving Brains
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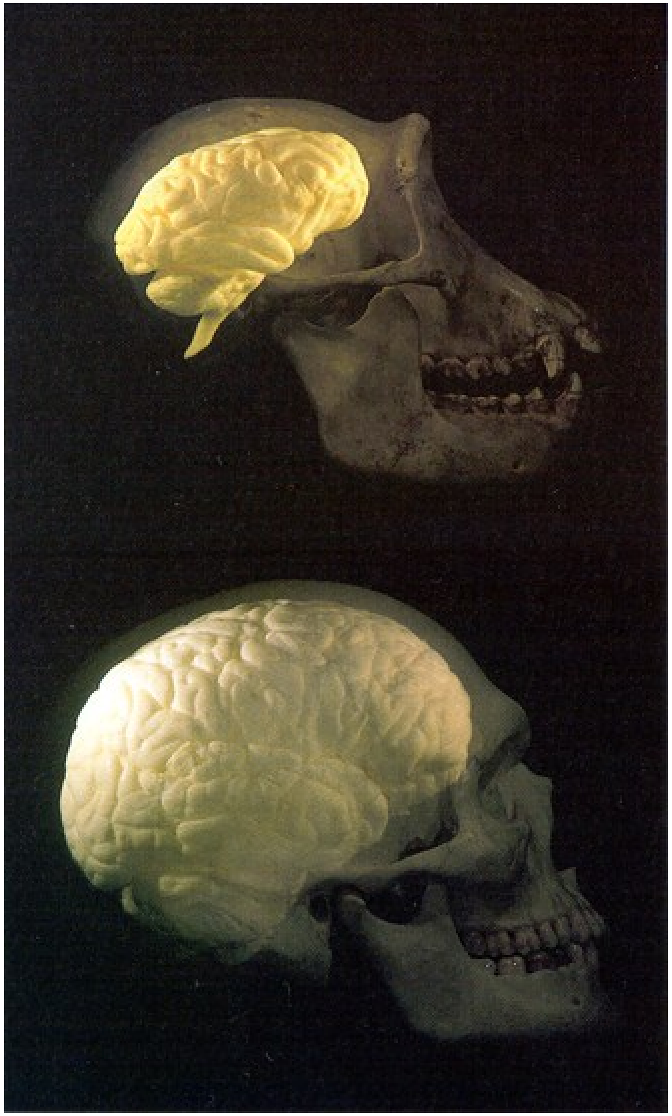


From Grasp to Language 1
Extending the Mirror System Hypothesis (Arbib, 2012)

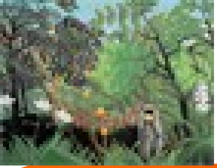
- a mirror system for grasping
  Shared with common ancestor of human and monkey
- a simple imitation system for grasping
  Shared with common ancestor of human and great apes.

–***Pre-Hominid***

http://www.lpzoo.org/Understanding_Chimpanzees/

Simple imitation:

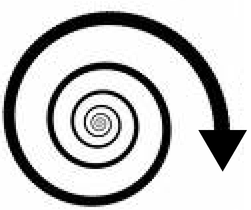
Masako Myowa-Yamakoshi:
The "imitation" employed by chimpanzees focuses on moving objects to objects rather than on the structure of movements per se.



From Grasp to Language 2

↓ *Hominid Evolution*

- a complex imitation system: *complex imitation* combines
  - the ability to recognize another's performance as a set of familiar movements with
  - the ability to use this recognition to repeat the performance, and
  - complex action recognition (more generally): the ability to recognize that another's performance combines actions which can be more or less crudely be imitated by variants of actions *and/or movements* already in the repertoire and attempt to approximate the performance on this basis, with increasing practice yielding increasing skill.
- pantomime: exapting complex action recognition for communicative actions



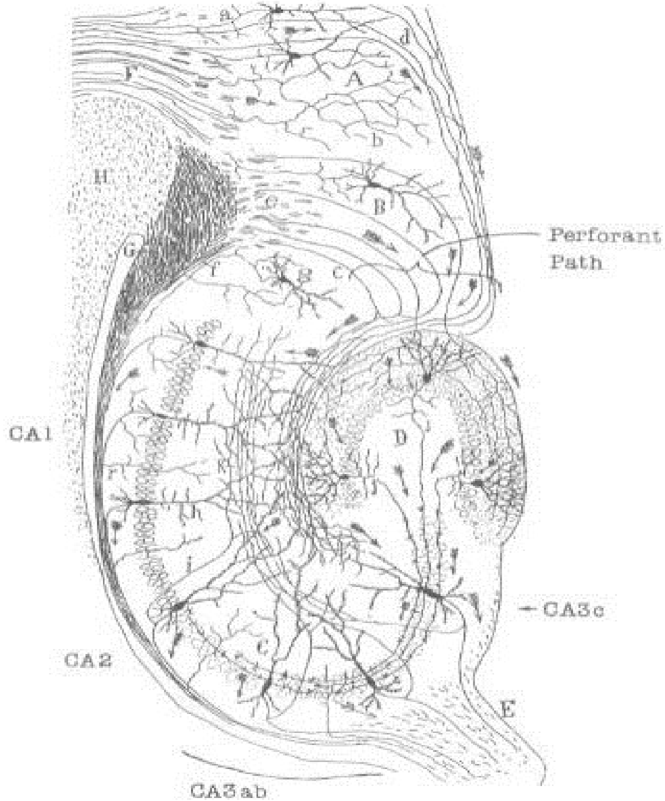
  - protosign: a manual-based communication system, based in part on conventionalization of pantomimes to yield an open-ended semantics
  - protospeech: resting on the "invasion" of the vocal apparatus by collaterals from the communication system based on the adaptive pressure to emulate and expand upon protosign semantics

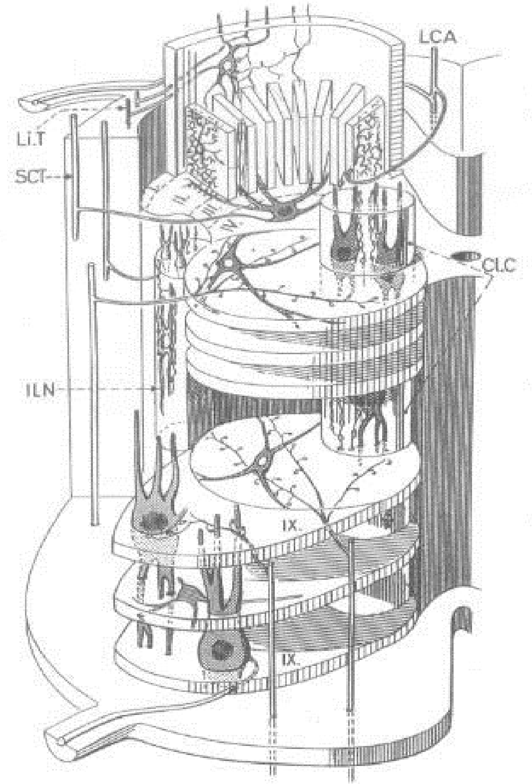
↓ *Cultural Evolution in Homo Sapiens*

- language: from protowords linked to action-object frames via fractionation to words and constructions building on verb-argument structures to yield syntax with a compositional semantics: co-evolution of cognitive & linguistic complexity

Different Parts of the Brain Have Dazzlingly Different Architectures

Hippocampus
(Ramon y Cajal)

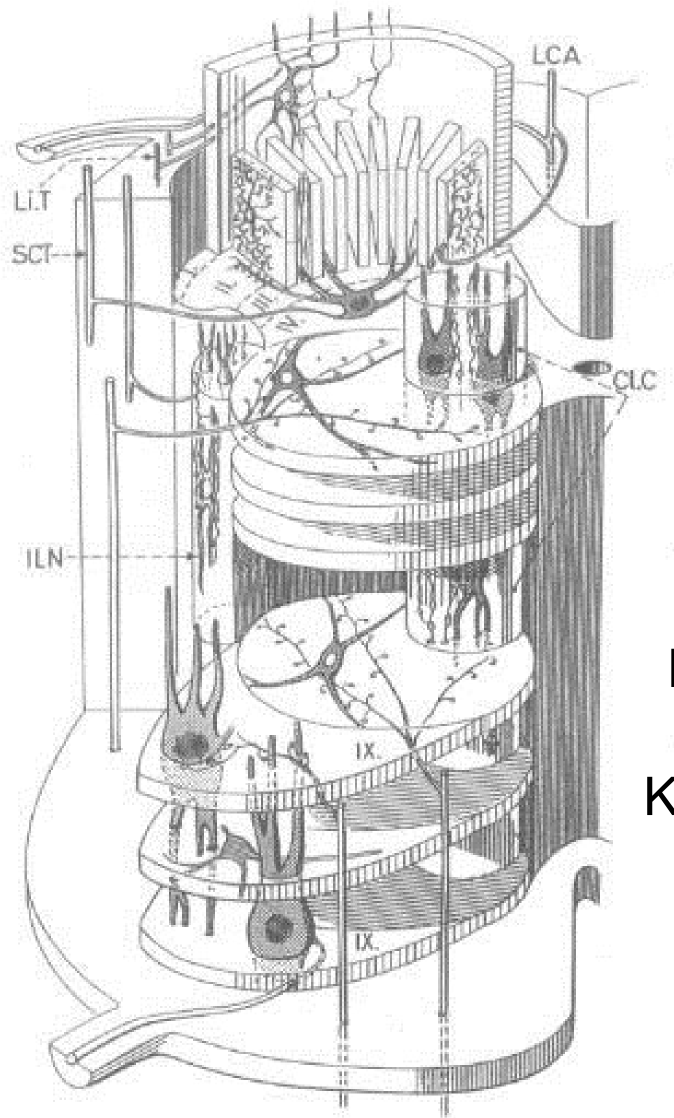




Spinal Cord
(Szentágothai)

The enduring challenge: to relate this diversity of form to function

– noting the immense plasticity that “over-rides” it
to create “virtual machines”



Ken Yeang:
Menara Mesiniaga/
IBM Tower,
Kuala Lumpur (1992)

A visual pun – but I'm serious about
Neuromorphic Architecture
as a new approach to "smart architecture for the built environment

The Neuromorphic Design & Functionality of the Interactive Space 'Ada'

Rodney Douglas, Paul Verschure & Colleagues

A pavilion at the Swiss National Exhibition of May - October, 2002

Over 550,000 guests visited Ada

Ada, the Intelligence Space

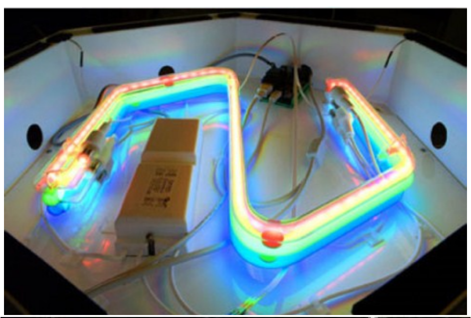
Not designed with a static functionality to which users must adapt
But constructed as a perceiving, acting and adapting entity

Ada had a “brain” based (in part) on artificial neural networks

She had “emotions” and “wanted” to play with her visitors

Ada's sense of touch
in addition to cameras and microphones

- Ada had a “skin” of pressure-sensitive floor tiles
- Can determine where a visitor is standing
  - and in which direction a visitor is moving
- The floor plates function like an (artificial) *neural network* that simulates synaptic interactivity.
- Ada's “skin” (floor) also serves as a communications organ whose play with light allows Ada to "communicate."



A natural progression in visitor interaction:

Sleep	One tile color for all visitors
Wake	Visitors given different-colored floor tiles
Explore	Probe for “interesting” visitors; deploy light fingers and gazers
Group	Try to direct visitors to a certain location in space
Play	Play game selected on basis of number of visitors in space
Leave	Tile effects show path to exit of space for each visitor

Emotions in a Neuromorphic Architecture

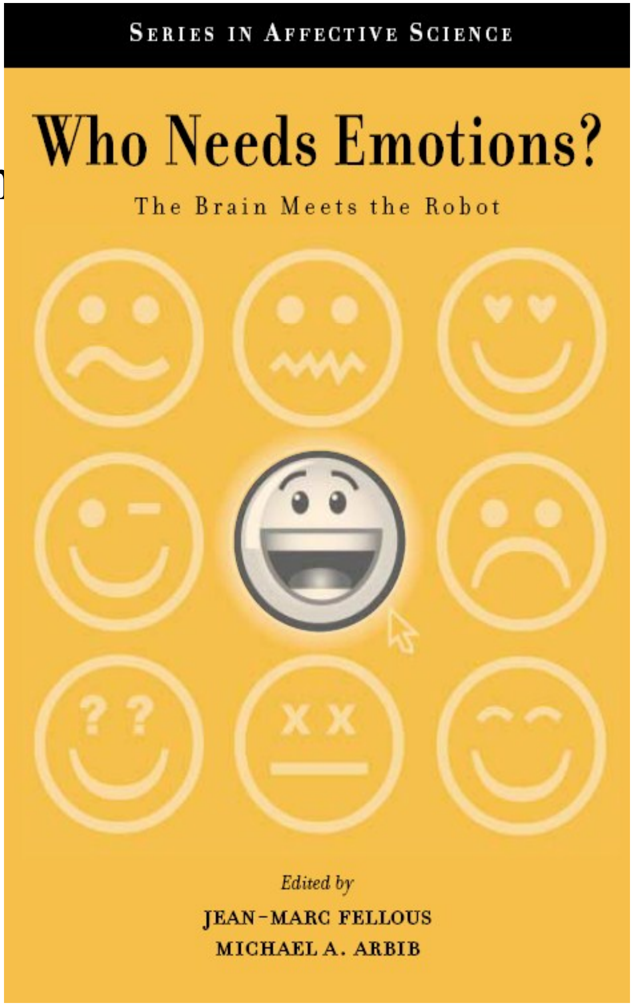
Ada continually evaluates the results of her actions and expresses emotional states accordingly, and tries to regulate the distribution and flow of visitors

- Ada's level of overall happiness is translated into the soundscape and the visual environment in which the visitor is immersed, establishing a closed loop between environment and visitor

Ada “wants” to interact with people

When people participate, she is happy

When they do not, she is frustrated



Happiness (H)

Happiness increases with survival, recognition & interaction

Survival: how well Ada maintains the flow of visitors over time

Recognition: how well Ada has been able to track and collect data about people, as a precondition for more advanced interactions

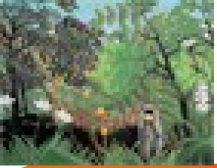
Interaction: the extent of successful human interactions in which Ada has been involved, with more complex interactions weighted more highly

Ada's goal: to maximize the value of H

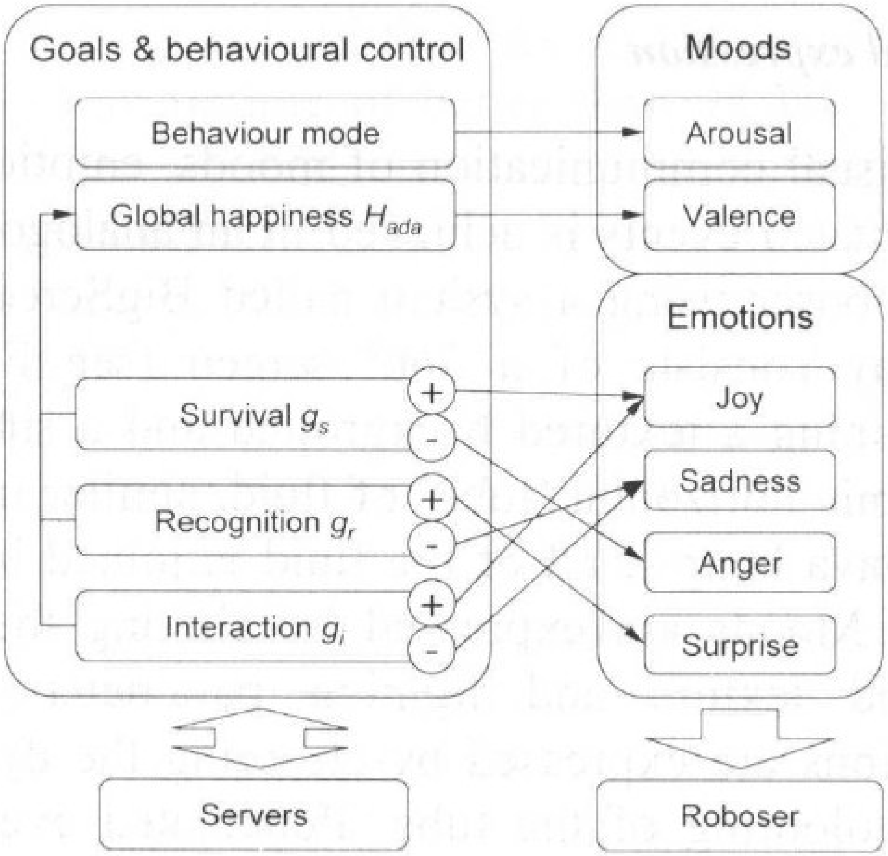
Ada could encourage high visitor throughput, or

Ada could achieve a high value of H with only a few visitors, but with high recognition and interaction with each visitor

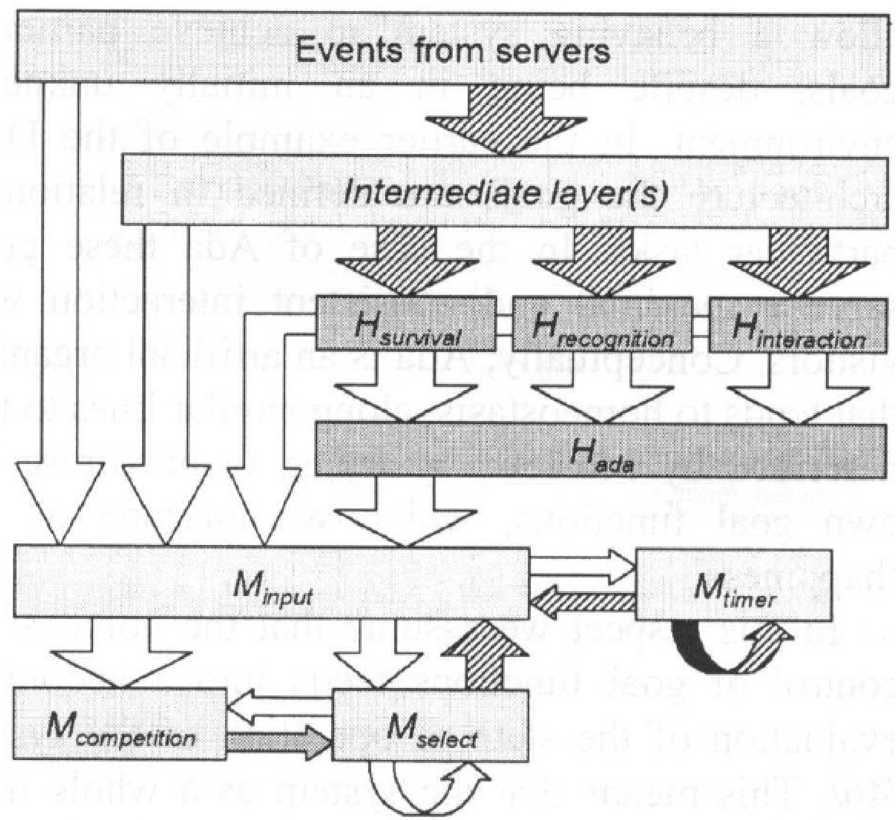
The actual computation of H occurs in multiple ways



Ada's moods and emotions drive behavior and are driven by its outcomes



The emotions are Joy, Sadness, Anger & Surprise



Adapted from Wassermann, K. C., Eng, K., Verschure, P. F. M. J. & Manzolli, J. Live soundscape composition based on synthetic emotions. *Multimedia, IEEE* (2003)

<u>Do Animals Need Cognition?</u>

Humans, Yes. Frogs, No.

Different niches demand different brains

<u>Do Robots Need Cognition?</u>

Some will (and so will some buildings = "Inside-Out Robots")
and many will not

♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎ ♎

<u>Does Cognitive Science need Animals?</u>

Yes. Invaluable data for Comparative Neuroscience of where
"cognitive subsystems" are and are not needed
and how diverse systems work together

<u>Does Cognitive Science need Robots?</u>

Yes, as "embodied testbeds" for new models of cognition and its neural
underpinnings – understanding animals, designing robots