
# JAST Opening Conference

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# Neural Circuits Underlying Action Understanding

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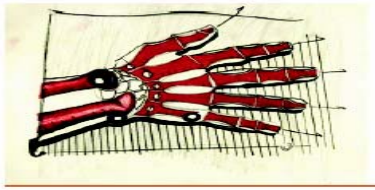


# *Artefact Structural Learning Through Imitation*

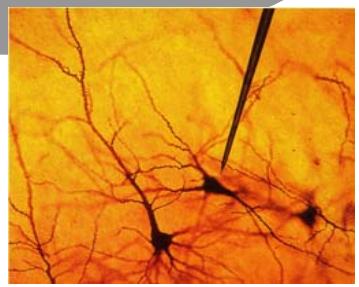
## Cognitive Psychology

Reaction Time

H. Bekkering et al
Uni Nijmegen

## Electrophysiology

Single Unit Activity, EEG, etc.



G. Rizzolatti et al, Uni Parma
P. Thier et al, Uni Tübingen

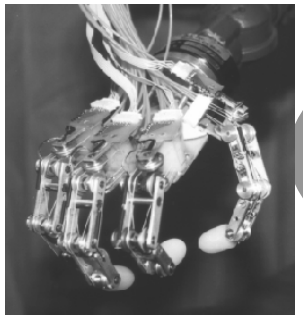
## Modeling/Theory

Uni Minho

Dynamic Field Theory, Optimization

## Robotics

Control of Arm and Hand Movement,
Goal-directed Imitation
Action Understanding

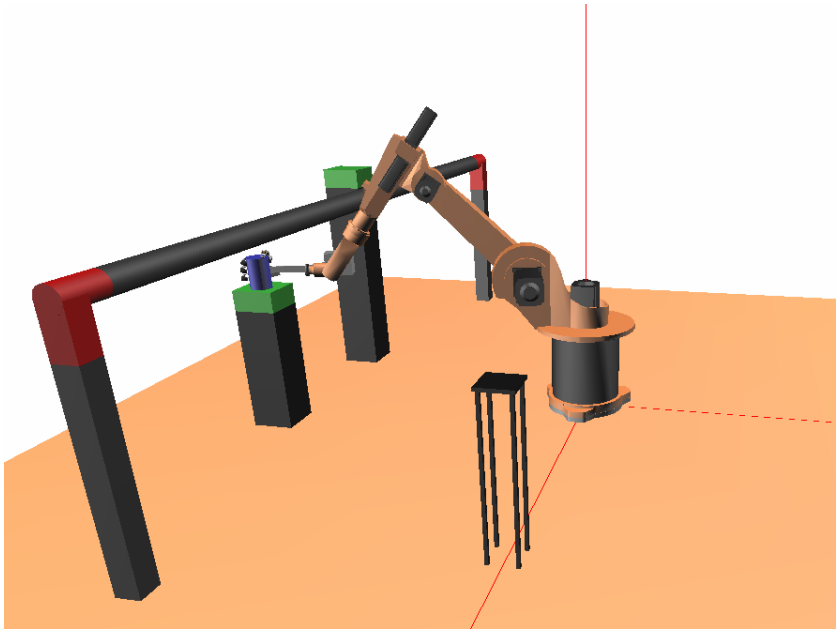


A. Knoll et al,TU München
E. Bicho et al, UMinho

# Dutch Bridge Paradigm

- Motor action composed of two motor acts:
  1) grasping an object (*proximate goal*),
  2) placing the object at one of two possible target positions (*ultimate goal*) thereby avoiding an obstacle.

- Trajectory above (AT) or below (BT) the bridge
- Grasping from the side (FG) or from above (PG)



# Main hypotheses which guided our work

- Imitation is fundamentally goal-directed,
  as opposed to trajectory-oriented „replay“ over via points.
  (Bekkering and colleagues)

- Action understanding based on “motor simulation”,
  existence of an action observation/execution matching system
  (Rizzolatti and colleagues)

**However……**

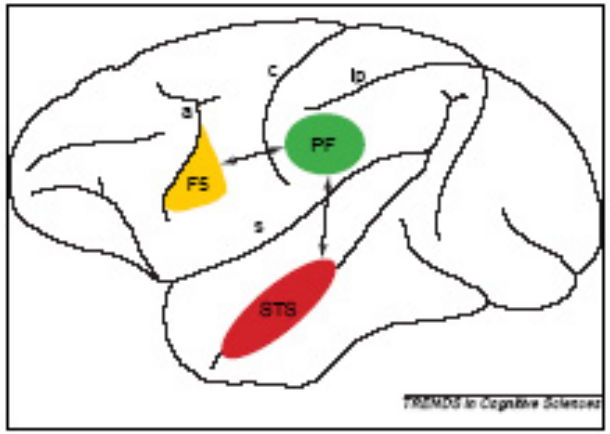
very often, the matching cannot be automatic and direct
due to differences

- in embodiment (child-adult, robot-human)
- environmental constraints (obstacles), and/or
- motor skills.

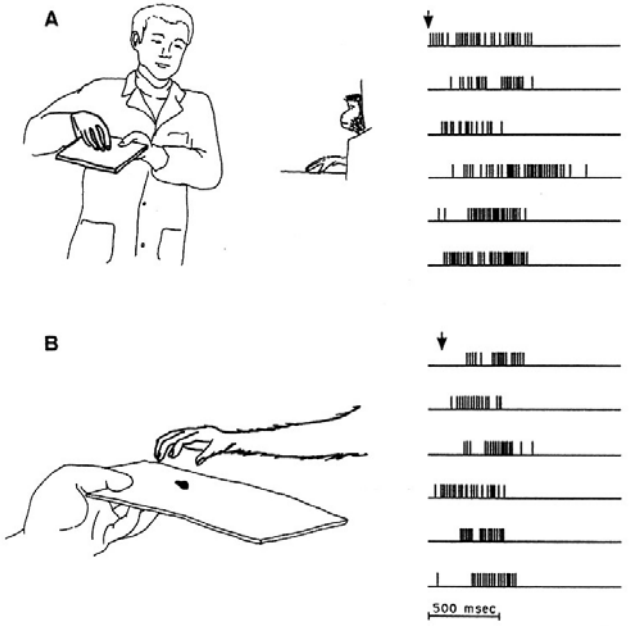
# Structure of the talk

- Neural circuits underlying goal inference and imitation
- The dynamic model
- Simulation examples (bridge paradigm)
- The real artifact in action

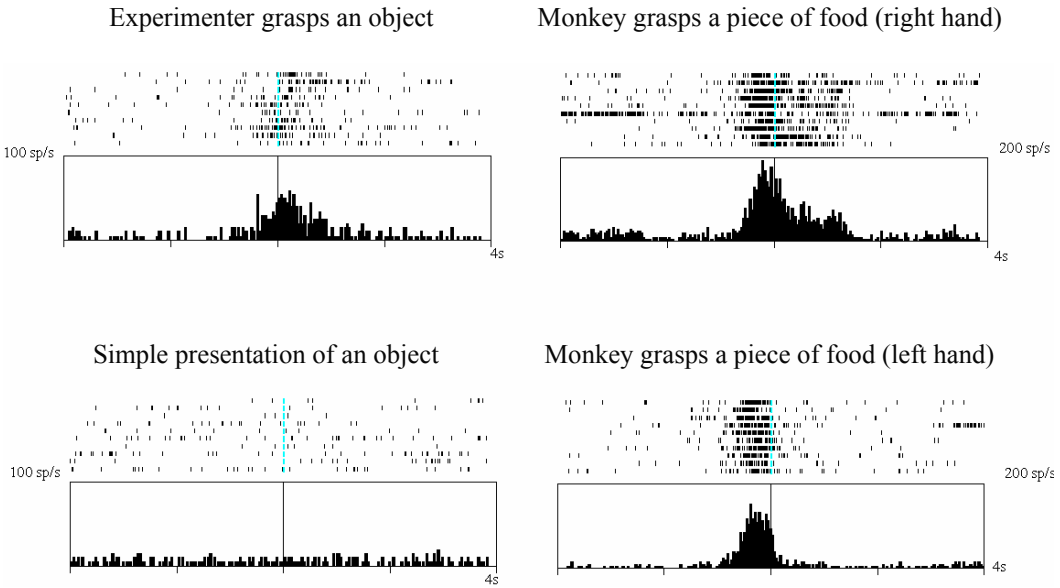
# The mirror neuron circuit




**Mirror neuron in the premotor cortex**



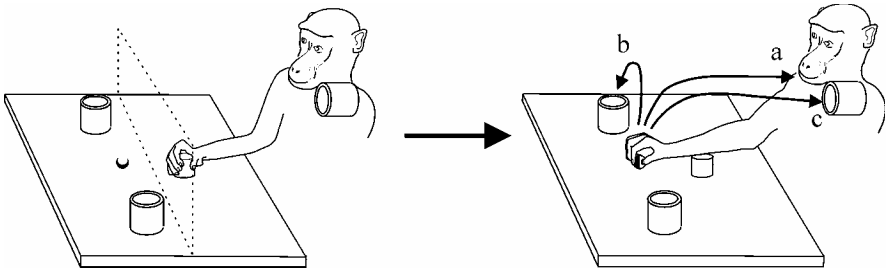

**Mirror neuron in the parietal cortex**

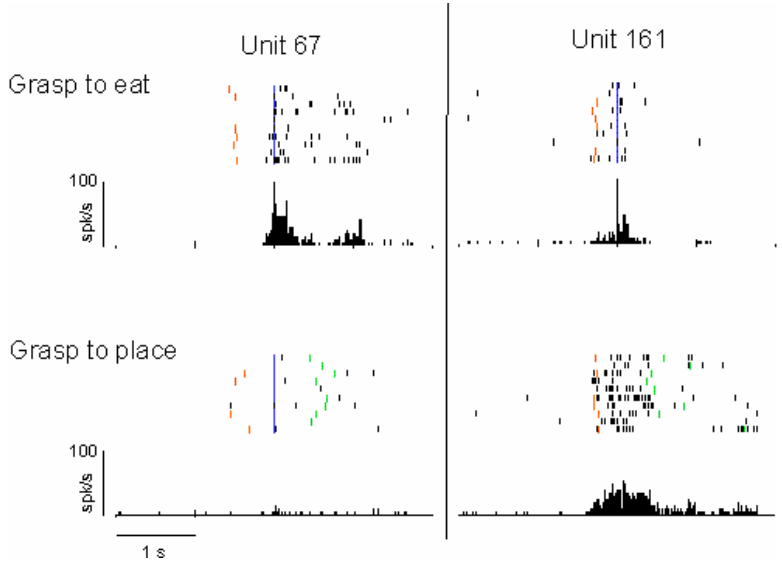



*(Rizzolatti et al, 2001)*

## Motor responses of parietal neurons

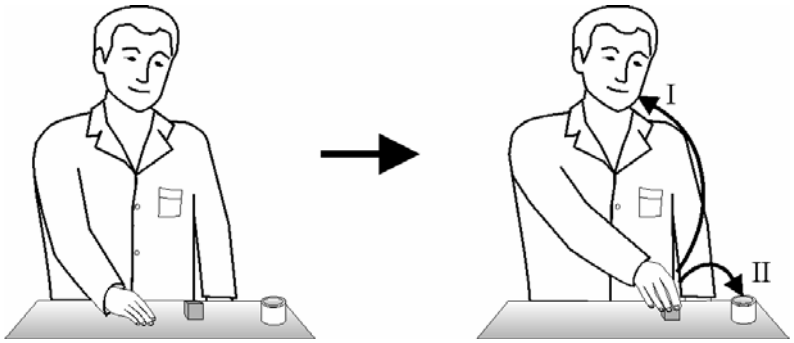
Motor task

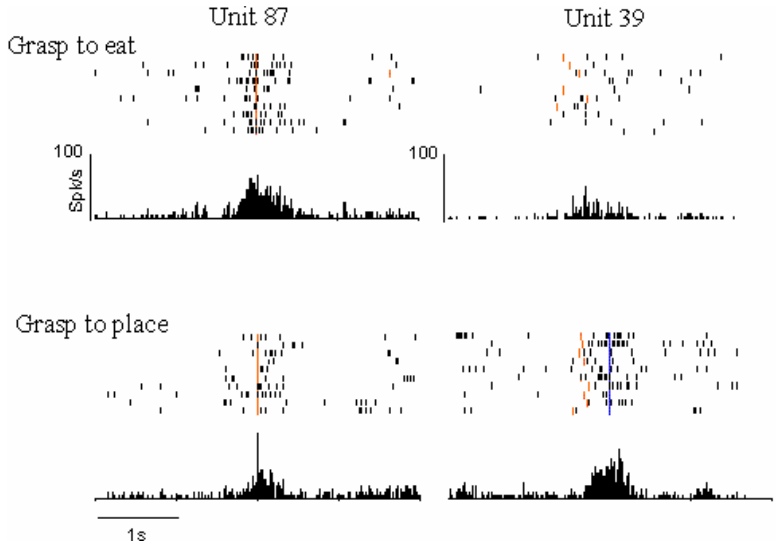



## Visual responses of parietal mirror neurons

Observation task

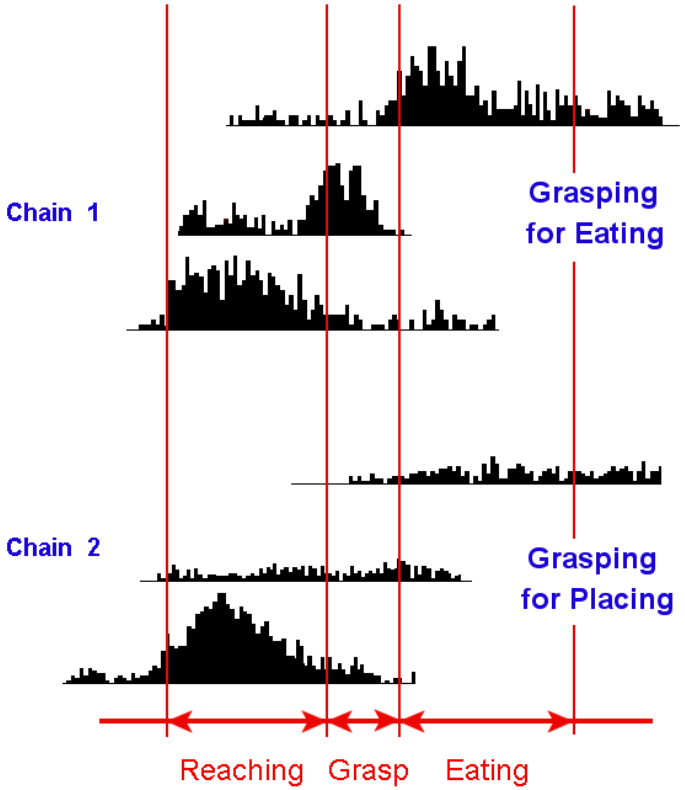



Fogassi et al, *Science*, in press

# Action organization in the parietal cortex

- Neurons of inferior parietal cortex appear to be organized in chains, each of which is aimed to a final action goal.




*(Fogassi et al, in press)*

# Beyond the mirror circuit

- Integration of contextual informtion
- Establishing a link between  means and goal (physical outcome) of an action sequence.

# Role of Prefrontal Cortex (PFC)

- Combine *sensory* and *contextual* information to organize the means represented in other brain areas to achieve an intentional goal.
  $\Rightarrow$ strong connections to IPL (areas PF/PFG)

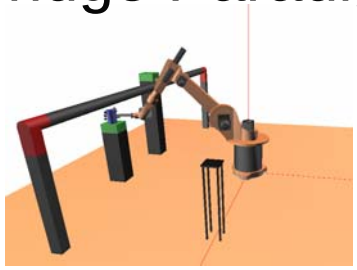
- Cognitive control, for instance, to override prepotent responses (e.g., a direct matching).

- Form associations between events separated in time ("Learning object meaning").

- Learning novel complex actions by combining existing motor primitives.

# Model architecture

Bridge Paradigm



**PFC:**

Goal representations
Task input
Object properties (e.g. colour)

**STS:**

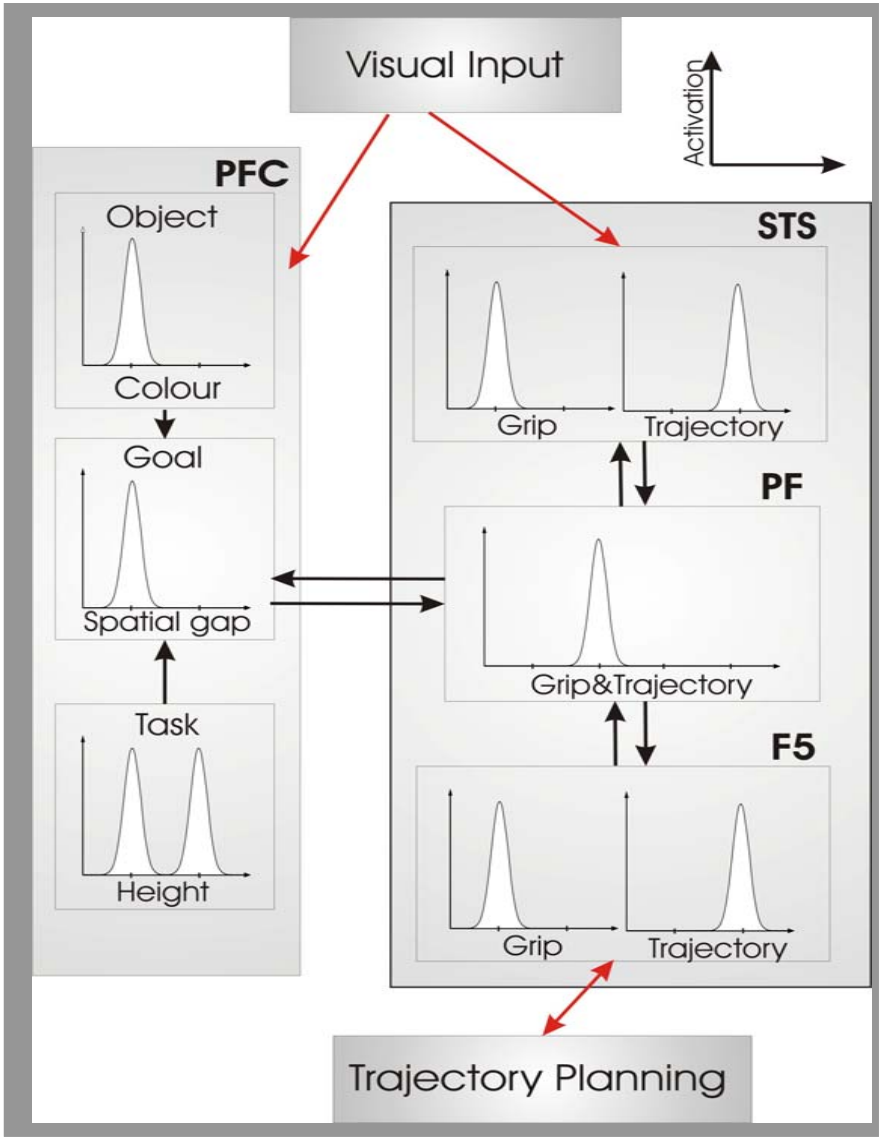
Visual desciption of grip and trajectory

**PF:**

Sequence of means

**F5:**

Movement primitives

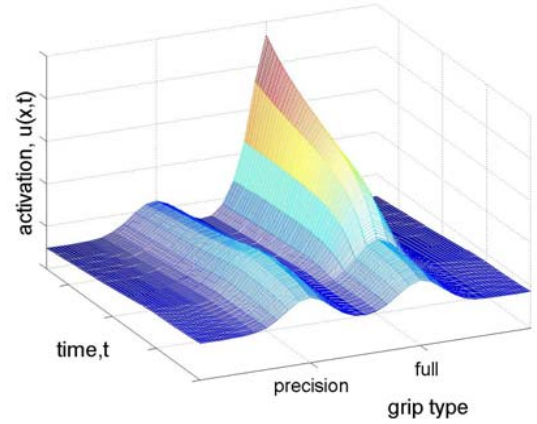


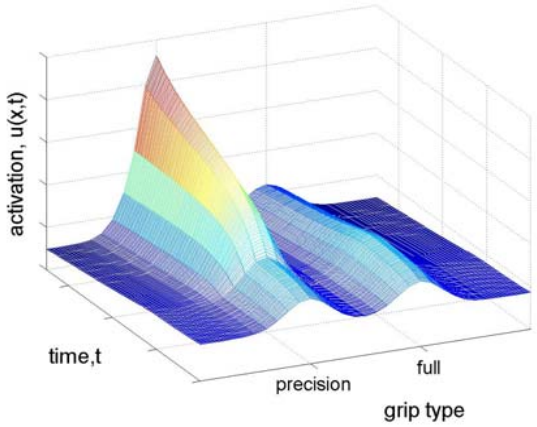

*(Erlhagen et al., 2005)*

# Basic Concepts of the Dynamic Model

- in each layer, neuronal activation patterns encode task relevant information

Type of grasping behaviour




Mean-Field Rate Model

$$\frac{du(x,t)}{dt} = -u(x,t) + G\big(u(x,t)\big)\int W_u(x-x')F\big(u(x',t)\big)dx' + h + S(x,t) - v(x,t)$$

$$\frac{dv(x,t)}{dt} = -v(x,t) + \int W_v(x-x')F\big(u(x',t)\big)dx'$$

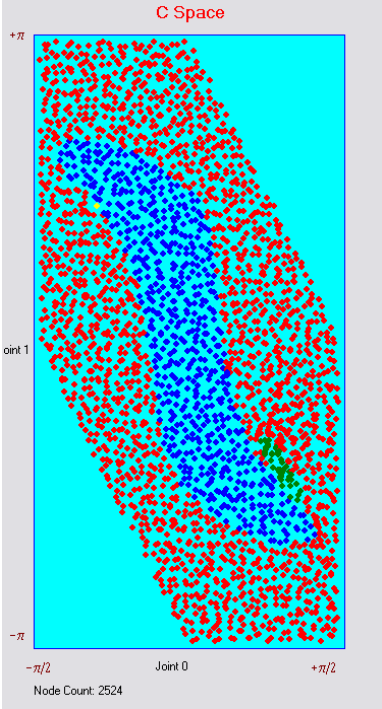
- Integration: representations evolve under the influence of multiple information sources *S(x,t)* (visual input, input from other layers...)

- Decision making in ambigious situations through recurrent inhibition

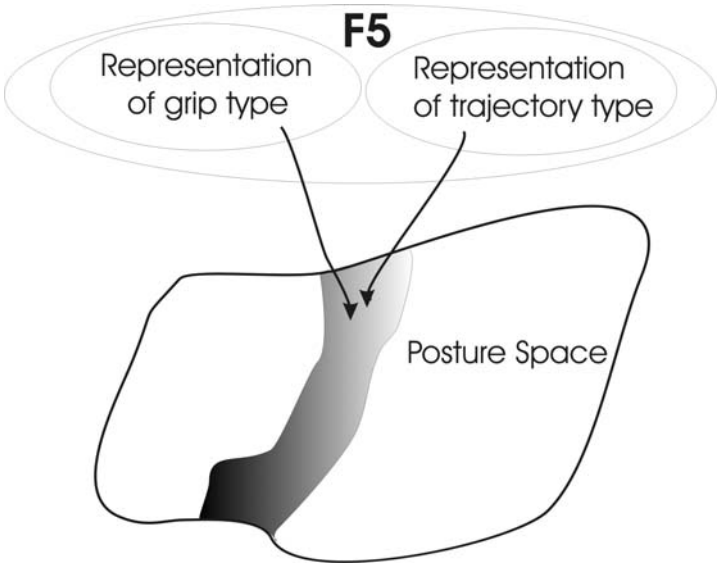
*(e.g., Erlhagen & Schöner, 2002)*

# Path planning in posture space

- Planning provides a posture sequence linking the initial posture to the desired end-posture.
- Movement primitives in F5 serve to pre-select relevant parts of the posture space.
- Obstacles are mapped into posture space.




- Active Node
- Inhibited Node
- Target Node

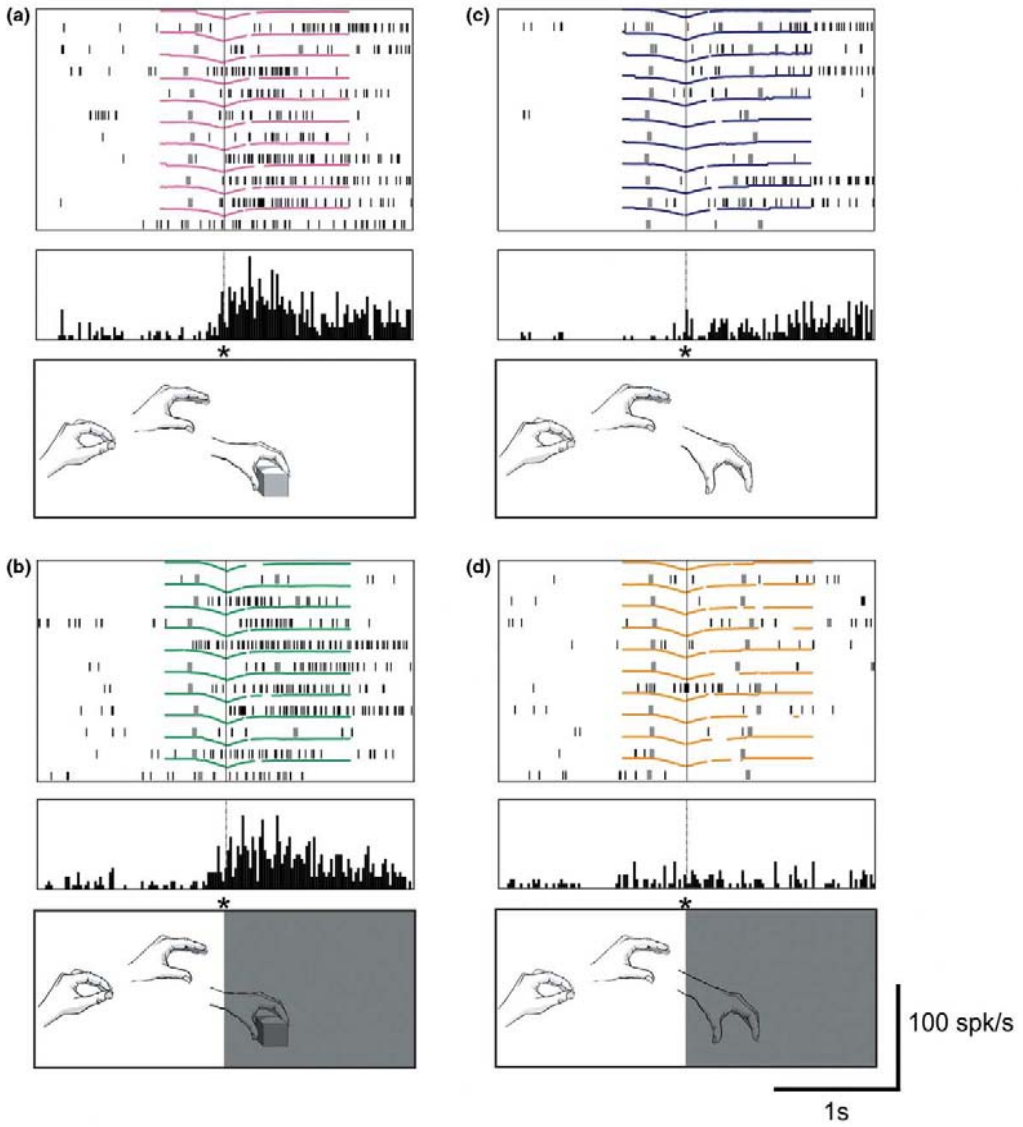


# Model Simulations

- Goal inference and choice of means
- Growth of cognitive skills through learning

# “I know what you are doing”

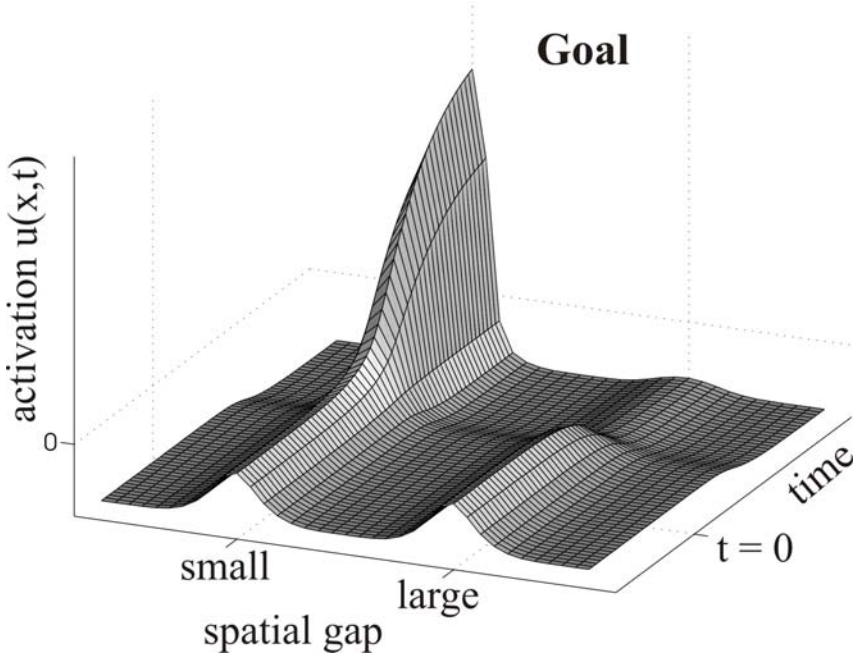
(Umiltà et al, 2001)



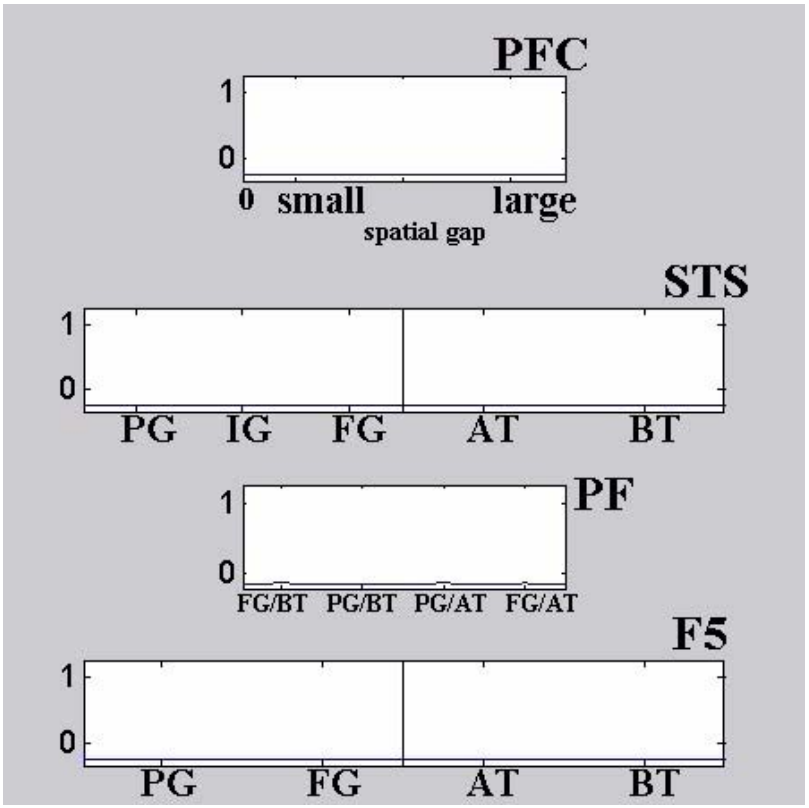
# Goal Inference: Bridge Paradigm

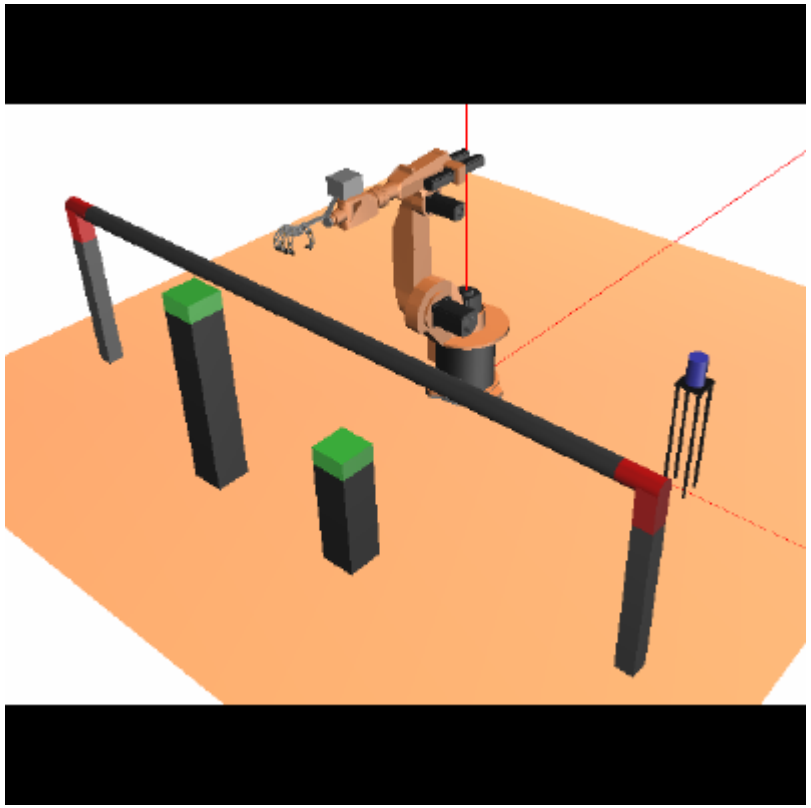
- Combination of partial visual information (grasping) with prior task information.

- Constant task input results in a "preshaping" of neural populations representing goals (in PFC) and associated sequences of means (in PF).

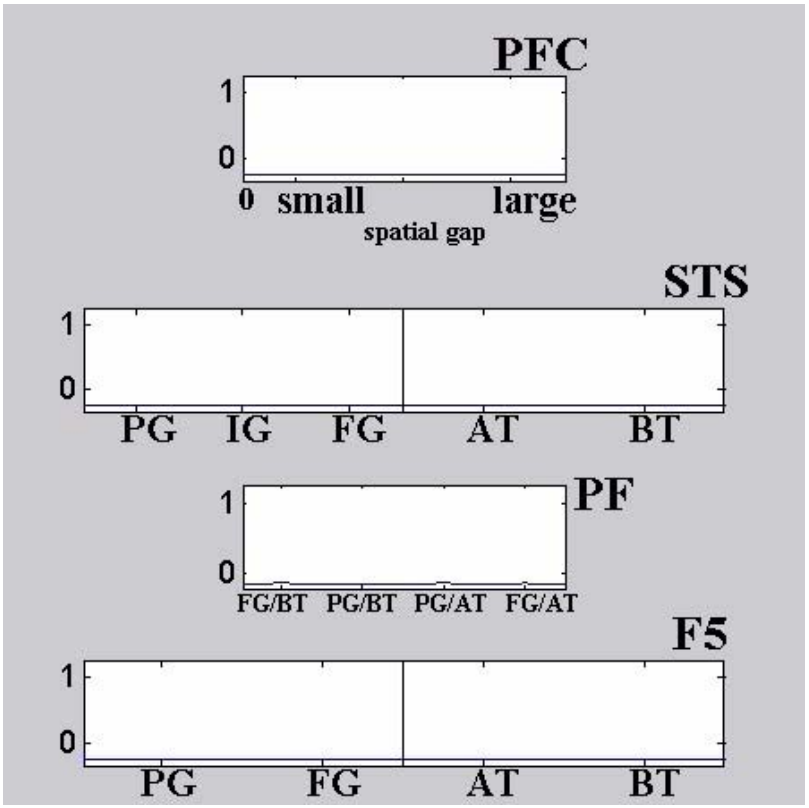


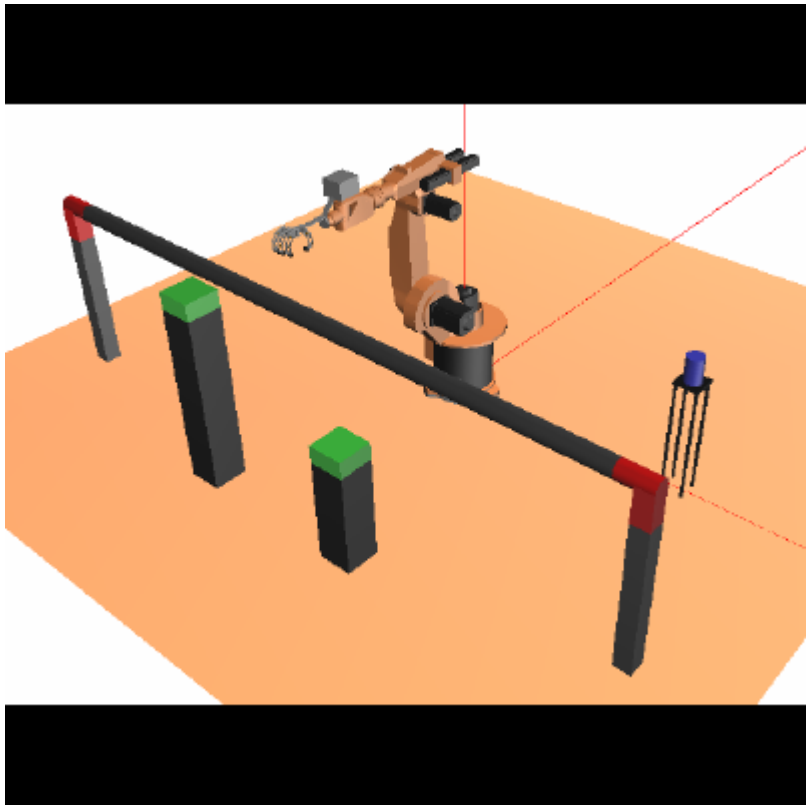
# Goal Inference Task



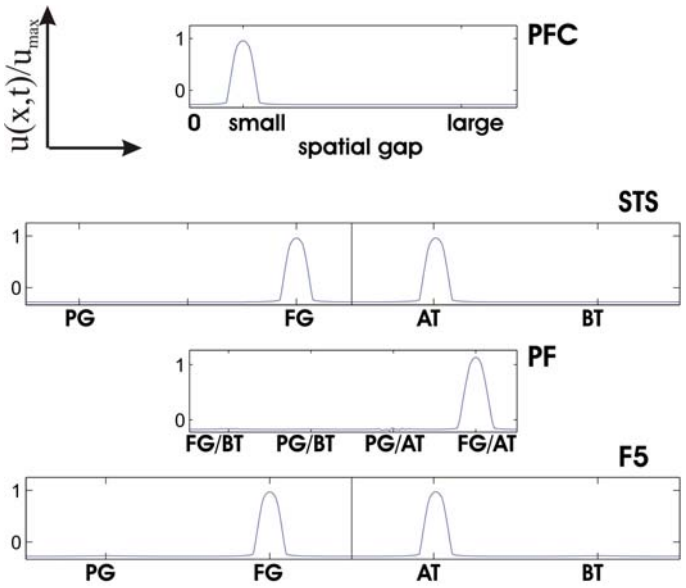



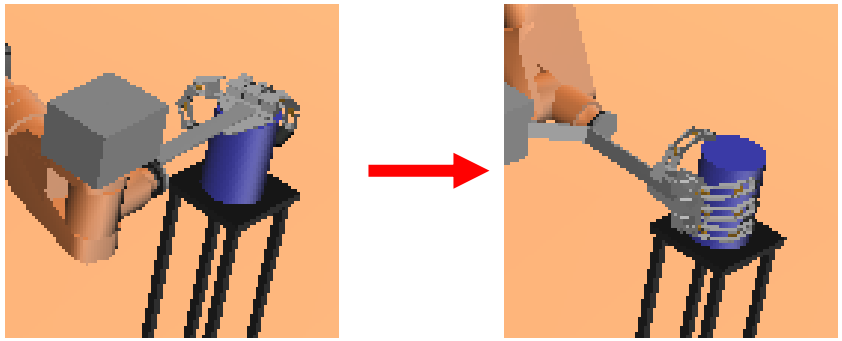
# Goal-directed imitation: Conflict in the grip type



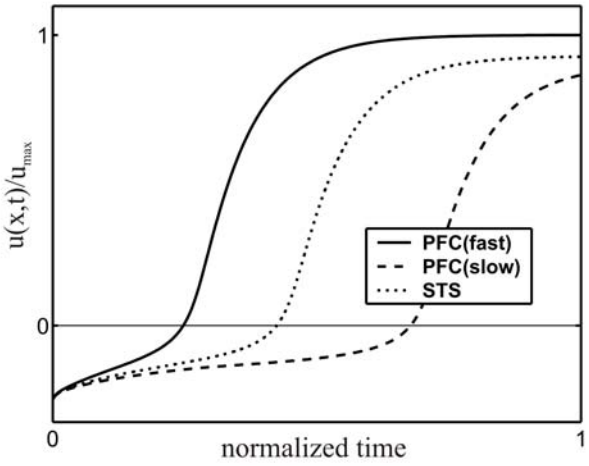



# Constraints allow to copy the means



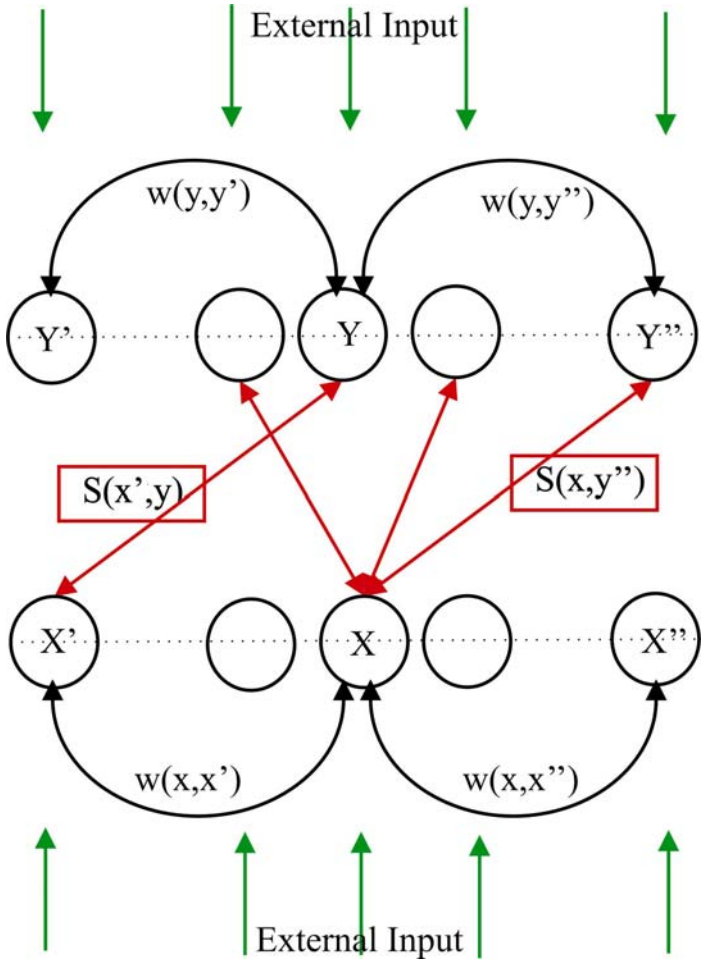
Time course in PFC




<u>Purely</u> <u>temporal mechanism:</u>
Change in baseline firing rate
affects time course
(e.g., *Asaad, Rainer & Miller, 2000*)

# Learning the synaptic links between Dynamic Fields

- Learning results from modifying synaptic connections between neurons (Hebb 1949).
- The modification of synapses is slow compared with the caracteristic time scale of neuronal dynamics.
- Internally generated reinforcement signal representing a successful planning defines epoches of learning (goal-directed).



# Mathematical formalization

- Learning the connections between *Field* [1] and *Field* [2]

$$\frac{\partial s(x,y,\tau)}{\partial \tau} = -s(x,y,\tau) + \alpha \int g(\tilde{u}_1(y-y'))\, f(\tilde{u}_2(x-y'))dy'$$

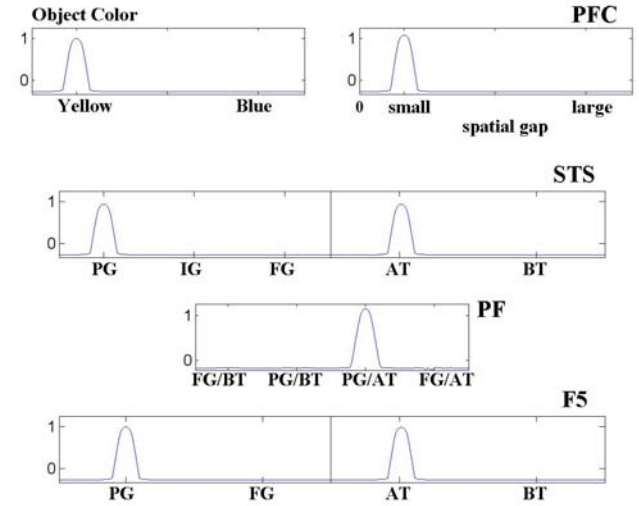
with $\alpha = const.$ and $\tilde{u}_1, \tilde{u}_2$ equilibrium solutions of the relaxation phase.

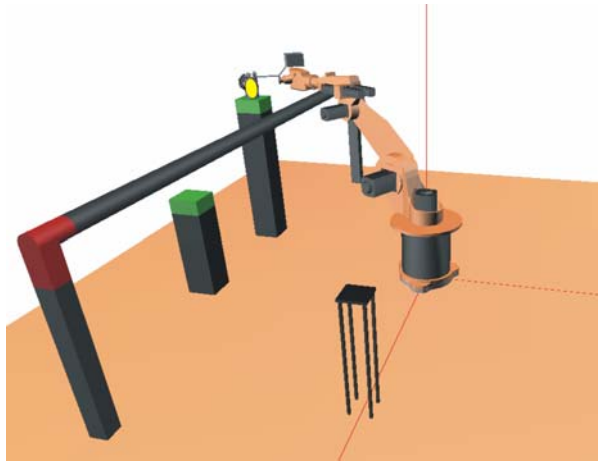
- Total input to *Field* [2] after learning (equivalent for *Field* [1]):

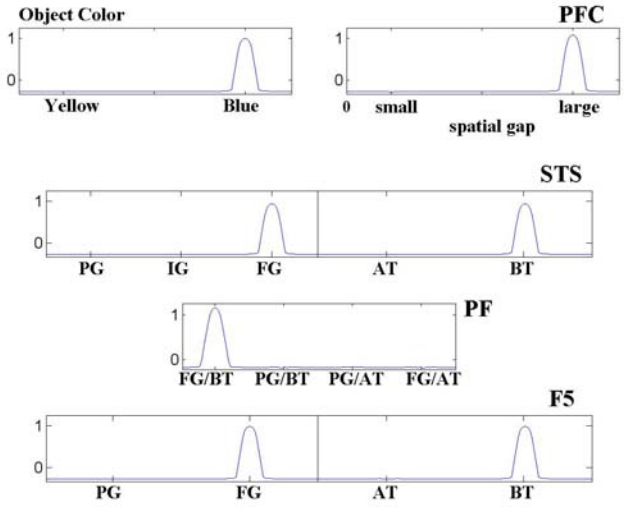
$$\bar{S}(x,y) = \int g(\tilde{u}_1(y-y'))s(x,y')dy'$$

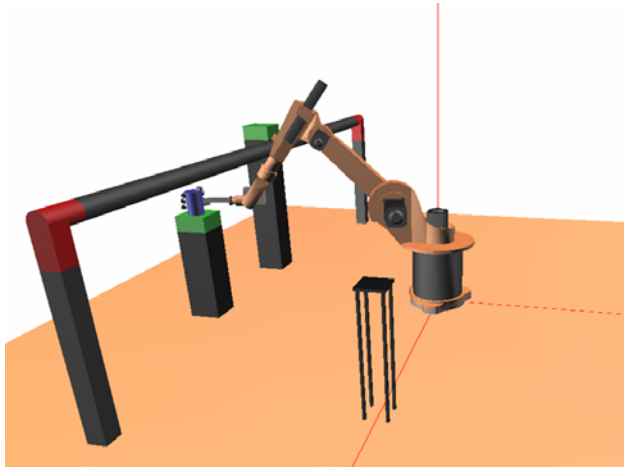
# Learning object meaning

## Example: color ↔ goal





# A Hebbian perspective on how mirror properties evolve

- First learning phase (correct alignment):
  Pay attention to your own arm/hand,
  motor system provides stimulus for the visual system.

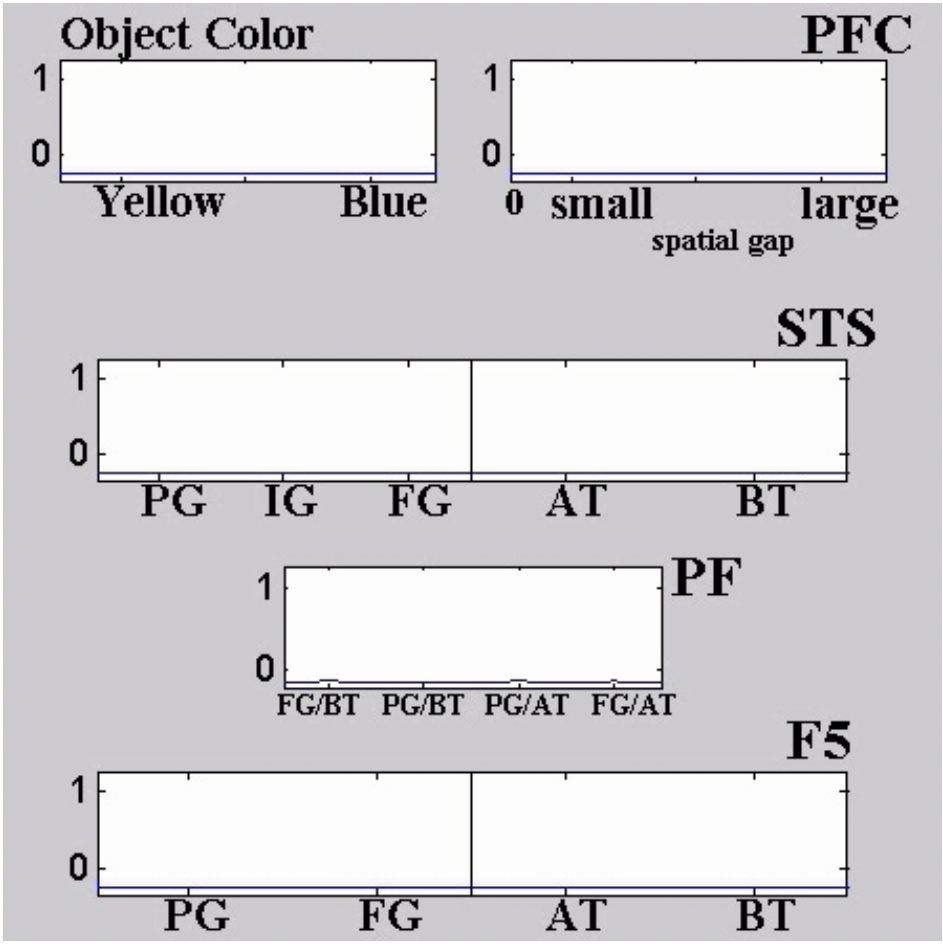
- Second learning phase (mirror properties):
  Generalization to goal-directed actions of others.

⇒Action understanding requires high level of abstraction
⇒Learning a goal-directed matching

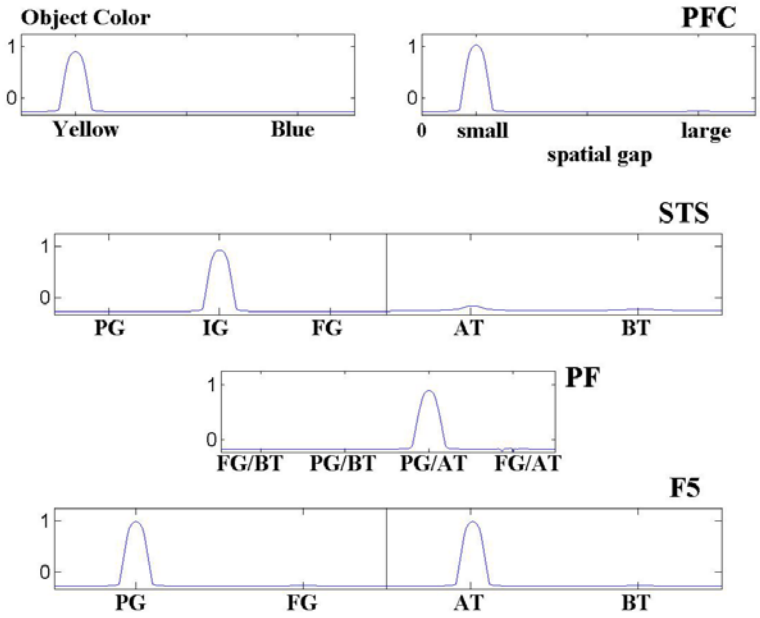
# Understanding actions made with tools

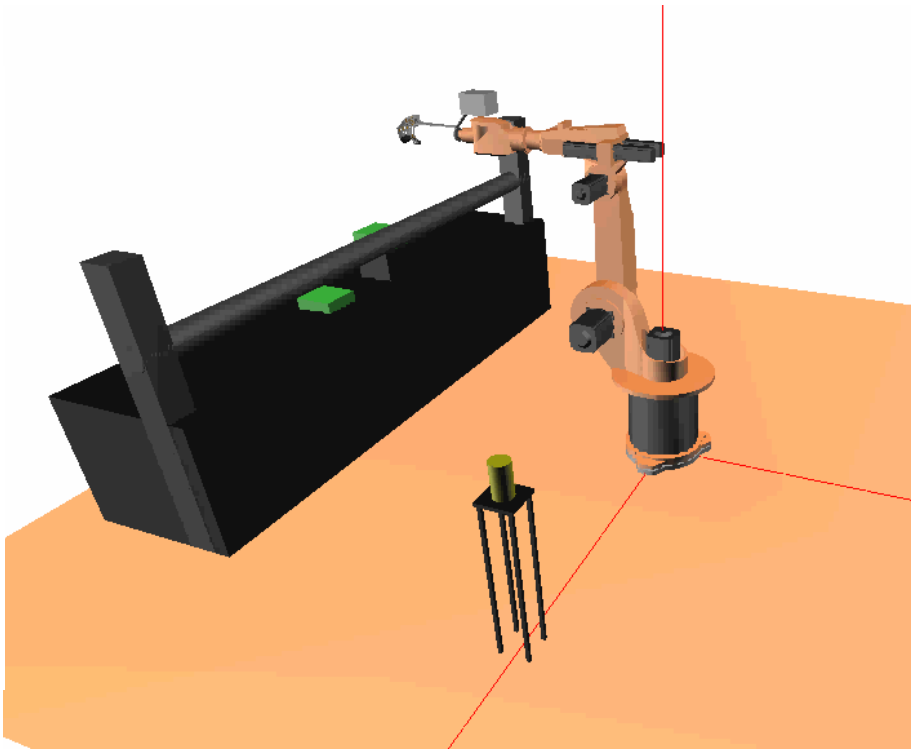
- Tool-use not in the repertoire of the observer
- Long visual exposure to represent the hand-tool motion in STS
- End-state/goal should be observable

Inference task:
Only the tool-grip “IG” is observable,
color information is ambigious.



# Tool-use task: Overt behavior

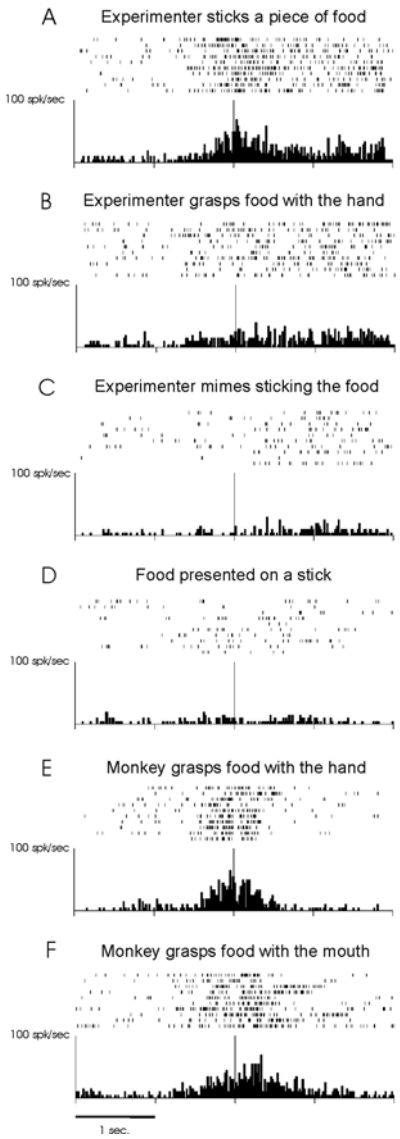


# Tool-responding mirror neurons

UNIT 088 **F5**

*(Ferrari et al., 2005)*



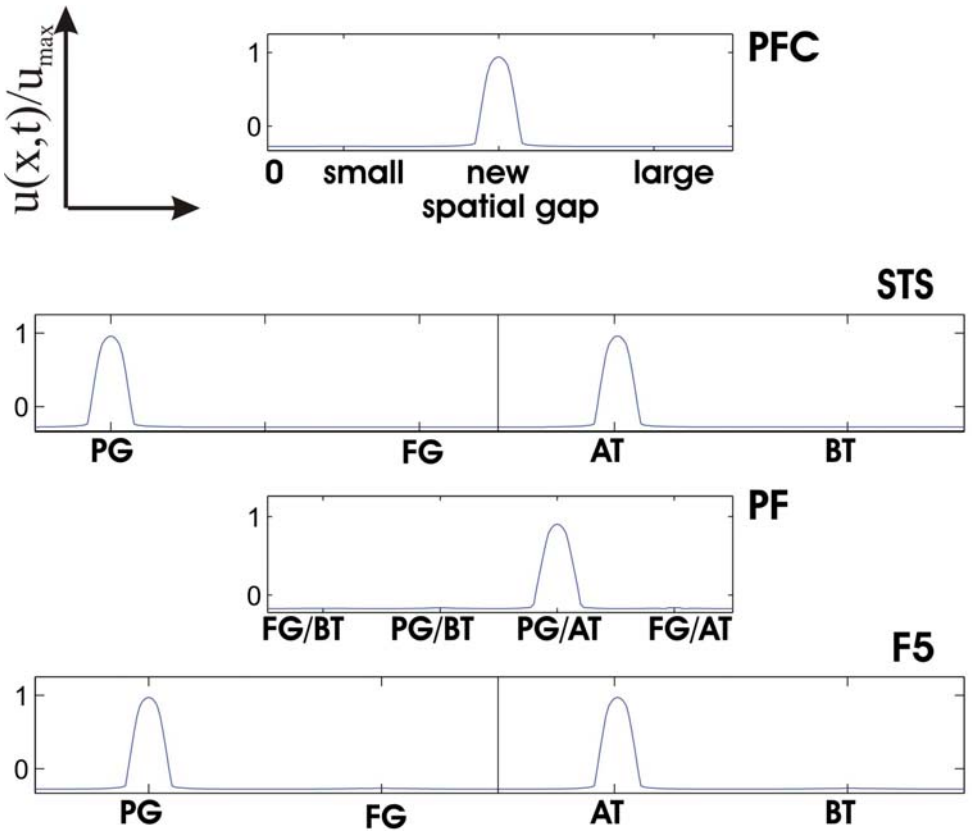

Experimental conditions:

- Long exposure to actions made with tools.
- Tool can be associated by the monkey to the possibility to receive food.

# Learning the link between goal and means
(PFC-PF)

**Copying the organizational structure of actions**

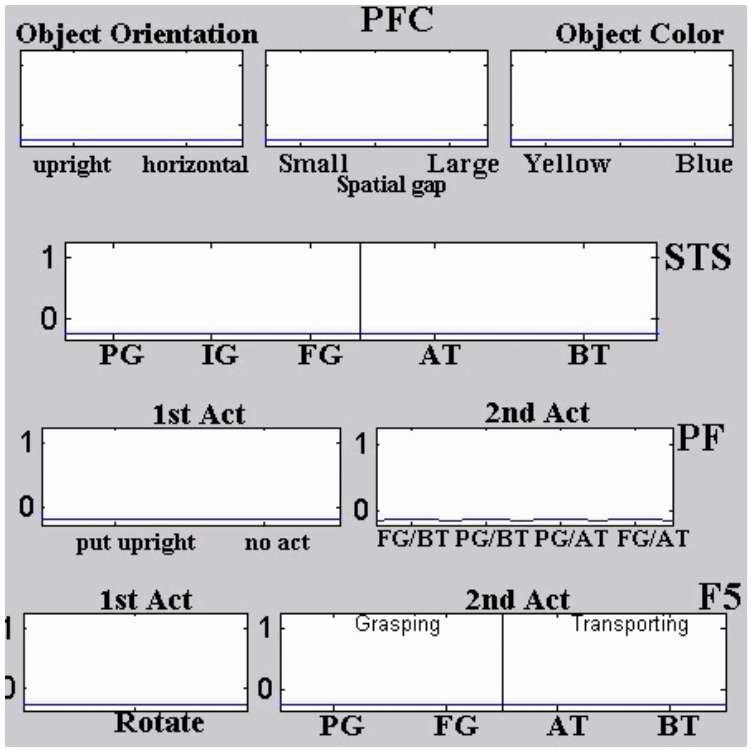
- New goal parametrized by an intermediate gap.
- Trying to copy the demonstrator's means (covert planning).
- If sucessful, association is learned between PFC and PF.

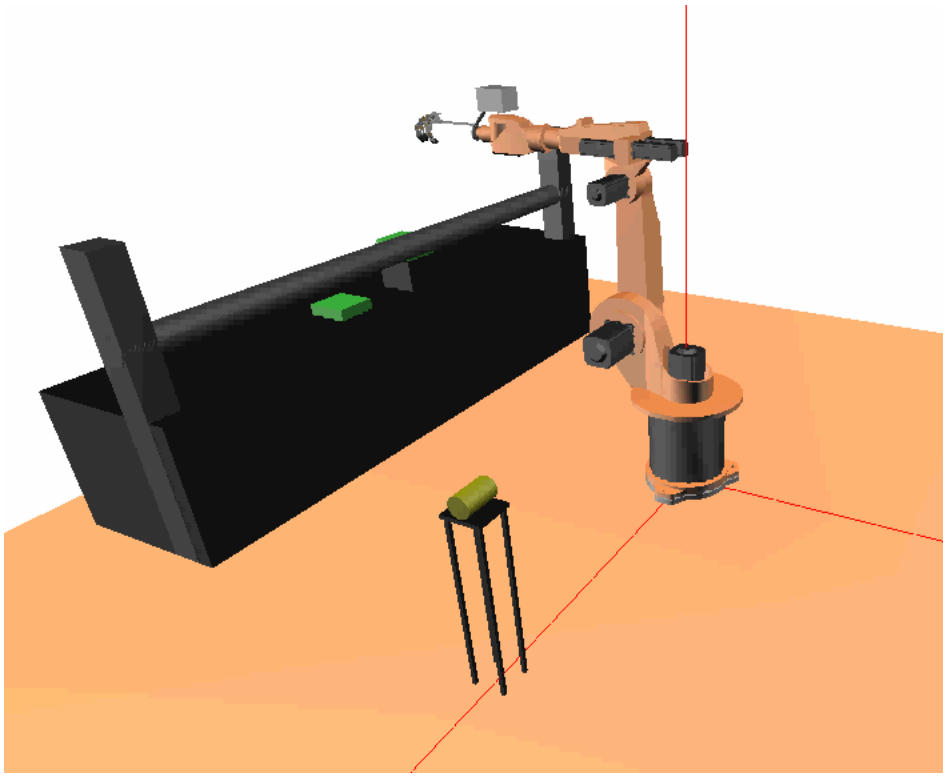


# Learning of a new action sequence

## Example: object not in upright position

After learning (no teacher)



# Conclusions

Experimental and modelling results suggest that

- *action understanding* is a continuous process which combines sensory evidence, prior task knowledge and a goal-directed matching,

- a *goal-directed matching* between action observation and action execution may develop during practice using a *biologically plausible learning rule*.

The model architecture may be extended to allow also for inferring higher intentional goals.

# References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