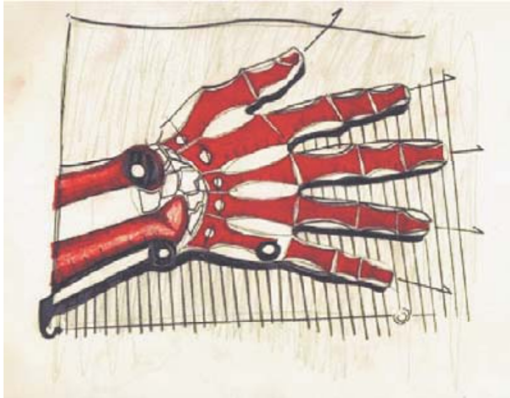
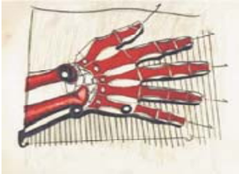


ArteSImit: Artefact Structural Learning through Imitation

(TU München, U Parma, U Tübingen, U Minho, KU Nijmegen)

Goals – Methodology – Intermediate goals achieved so far

Motivation



- "Living" artefacts will critically depend on mechanisms of action and task-level *goal-directed* learning for:
  - Developing skills based on "early primitives"
  - Adapting to the environment
  - Understanding and achieving missions
  - Cooperating with humans
- Teaching artefacts *complex sequences of actions* by demonstration has been a dream for a long time, but has hardly been explored on the basis of a systemic study of the brain functions and their interdependencies
- Our knowledge about the *mapping between action perception and action execution* in man at a neurophysiological level is still fragmentary (cognitively adequate computer-operational formal models are not available)
- *Imitation* holds the potential to become a powerful means for learning complex sensorimotor/cognitive skills because it drastically reduces the state-action space to be searched for motion generation

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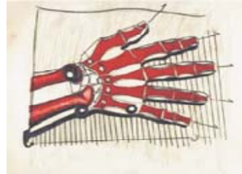
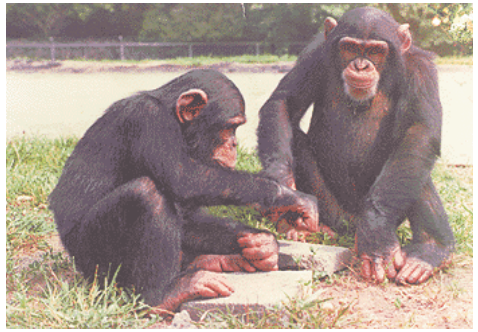
Abstract Scenario



- There is quite a lot of different task classes that may demonstrate the power of imitation (e.g. food search, navigation in mazes, etc.) and require a higher or lesser degree of abstraction for applying the learnt skills

- We chose a very complex scenario: a **“living hand“,** which
  - **first** learns action sequences through imitation *from a human instructor* based on a minimal set of initial conditions and basic knowledge and which
  - **then** learns to apply them to simple *cooperative tasks* (which may, however, involve complex motion sequences).

➢ *Seamless interaction* involves not only the permanent learning of individual skills but also their autonomous use (triggering, blending, …) for manipulation, exploration (“recursive ascent”)



Sherman and Austin use a rock on a concrete block to crack open nuts. This activity was **demonstrated** on one occasion but **never trained**.

In response for Sherman's request for juice, Austin **selects** a can of juice which he then **takes** to Sherman who is in another room.

(Georgia State University)

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Concrete Initial Scenario: the "Dutch Bridge"

- First objective: understanding the neuropsychological and neurophysiological basis of goal directed imitation learning in man and monkey
- First important two milestones:
  - development of a paradigm of goal-directed imitation (as opposed to trajectory-oriented „replay")
  - design of an experimental setup for grasping tasks. Dutch bridge, to be used by all the consortium, later also by the artefact: transport an object from one side of the bridge to a specific goal location at the other side of the bridge

Object: precision grip at the top of the object, or with a full grip at the bottom of the object

Either the goal position or the grip to be **selected** is **cued** (colored LEDs)

Measuring brain activity (EEG)
Cueing: goal location is on the right/left or that the grip to be used was precision or full

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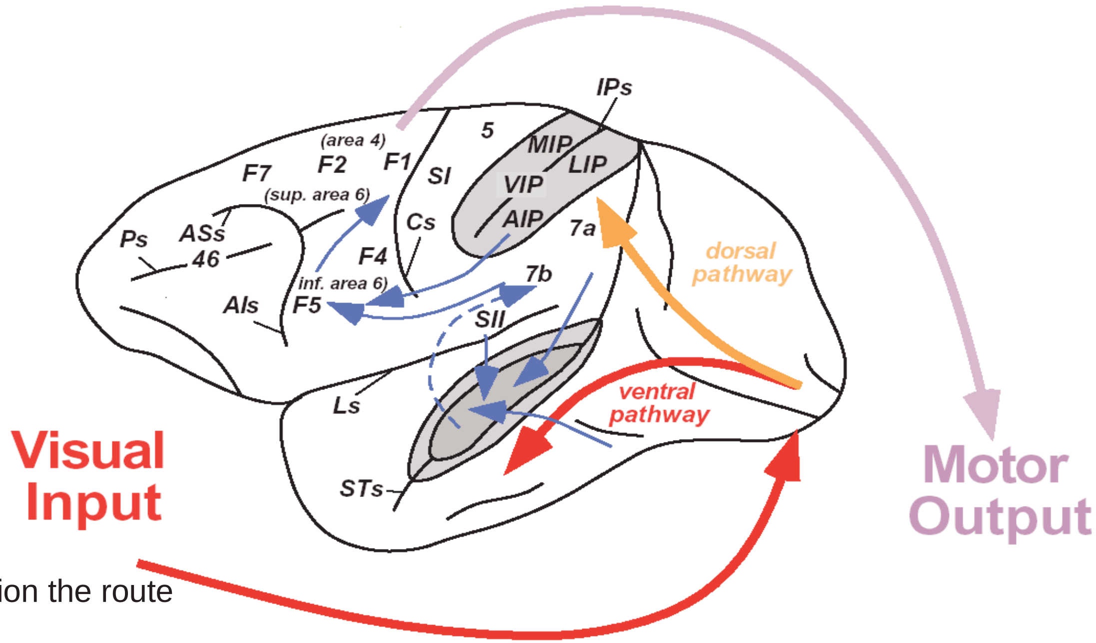
Concrete initial neurophysiological contributions

- Out of many highly interesting *phenomena* and brain areas that may be involved in *imitation*, we chose to begin our study with three particularly interesting:
  - The mirror neuron system
  - The cerebellum and its role in motion generation
  - Balance between Broca's and the premotor vs. visual-parietal areas in grasping through recording of ERPs: event-related brain potentials



From S. Schaal: Is imitation the route to humanoid robots?

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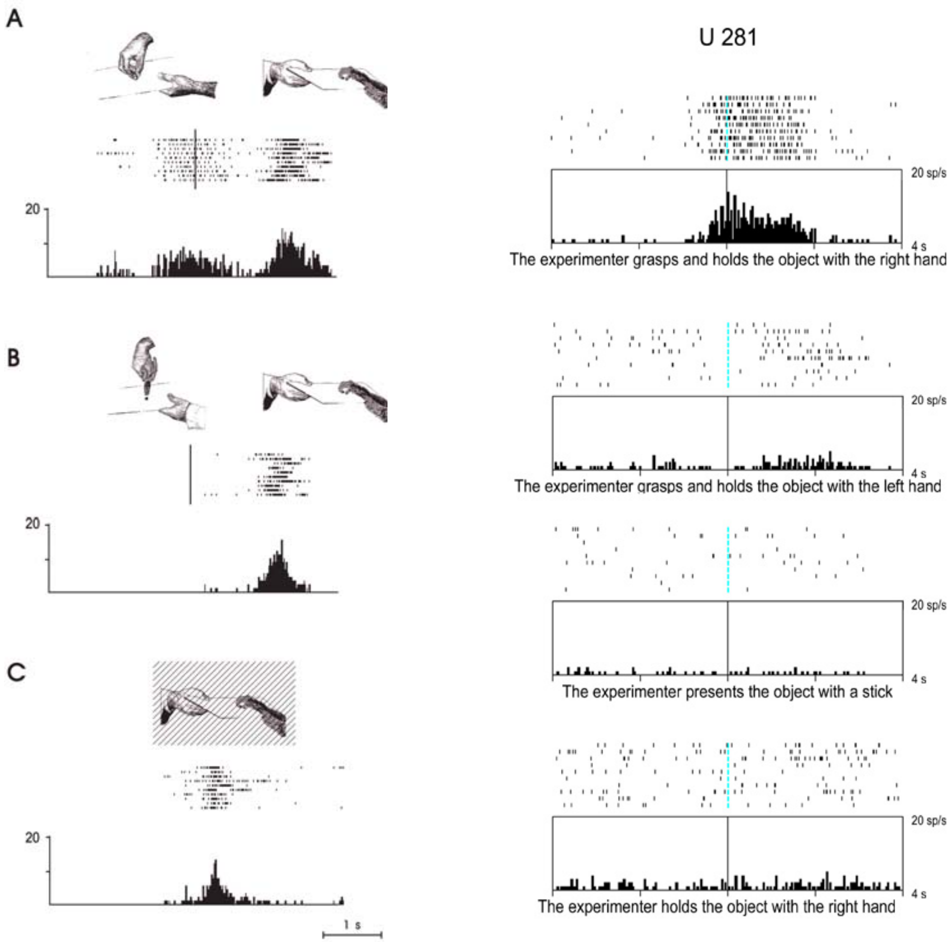
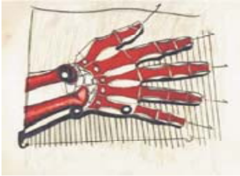
Ia: The mirror neuron system

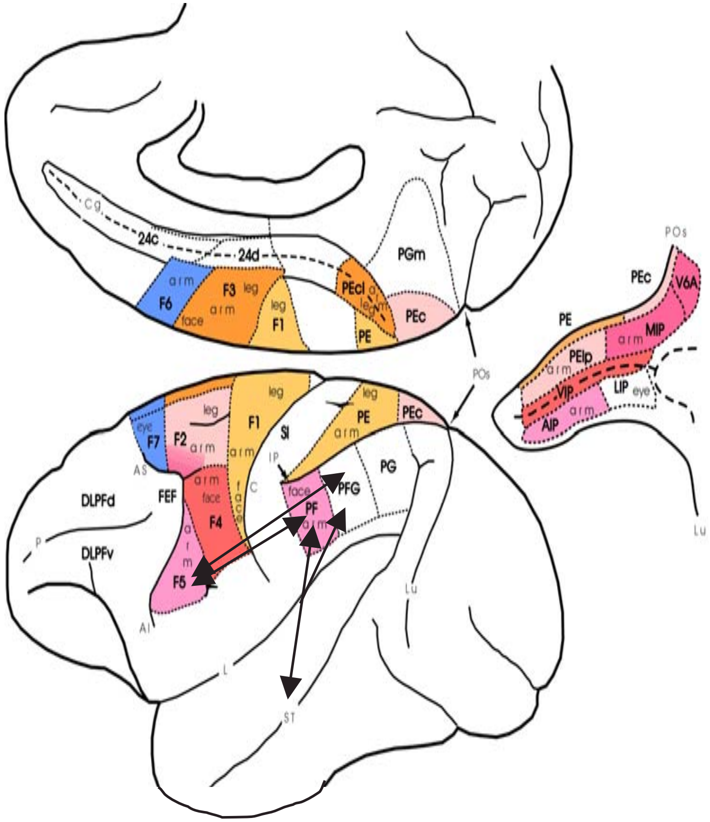


The neuron discharged both when the monkey observed an experimenter grasping an object and when it made an identical action. Observation of object grasping made by a tool was not effective.

- Refined study of the mirror-properties of neurons in different areas:
- Interplay between areas PF, F5 and STSa (Superior Temporal Sulcus)



Ib: The mirror neuron system



Experimental goals:

- *Properties of PF neurons:* clarify the mechanisms through which the observation/execution matching system can take place
- Two-thirds of PF neurons responding to action observation have F5 mirror and mirror-like properties. *Hypotheses*:
  - The mirror-system, matching action observation on action execution, is not a prerogative of the premotor cortex, but extends also to the posterior parietal lobe.
  - Area PF represents an intermediate step between a “pictorial” description of actions, carried out in STSa, and a motor description of the same actions as coded in the premotor cortex.

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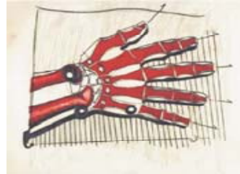
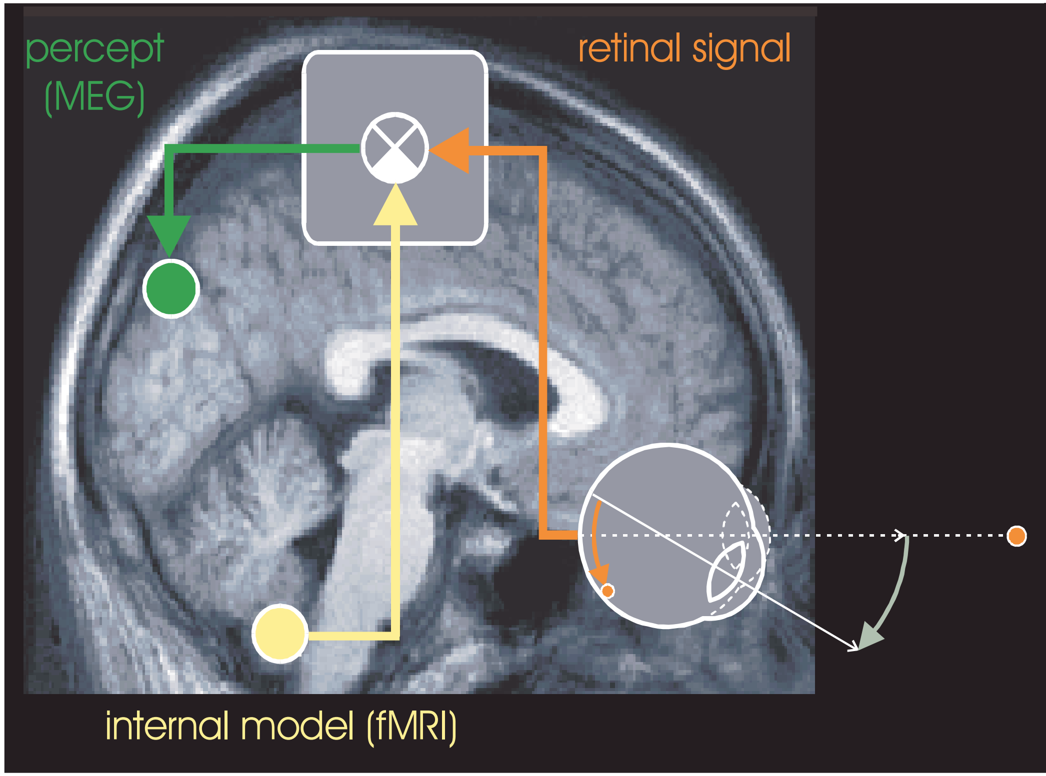
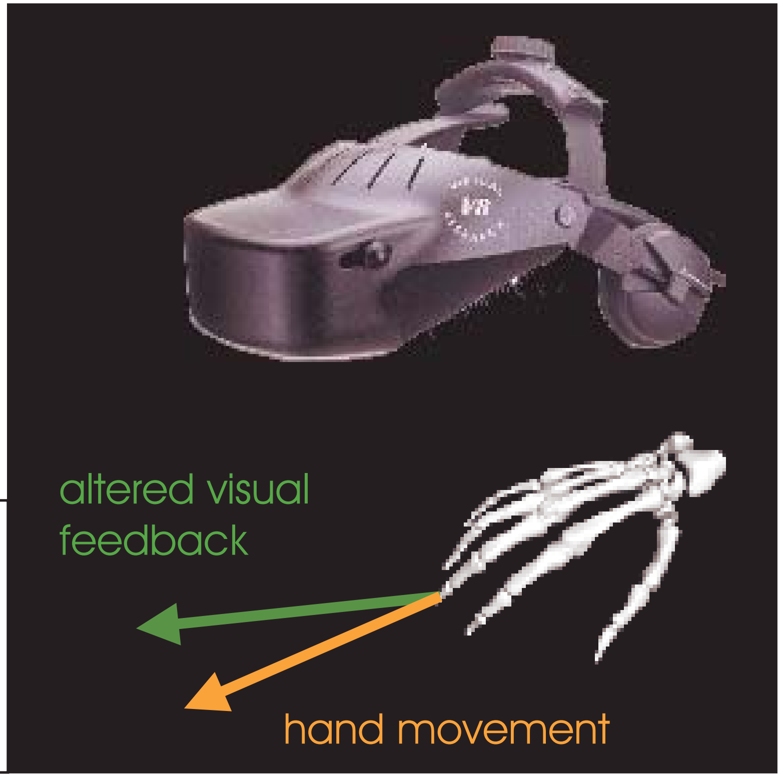
II: The cerebellum





Proof of principle work on the role of internal models in perception using MEG & fMRI - while exploiting the experimental advantages of eye movements.

Prompted by the eye movement work of P3, new psychophysical experiments on the visual perception of hand movements have been developed to reveal the role of internal models in action-perception.



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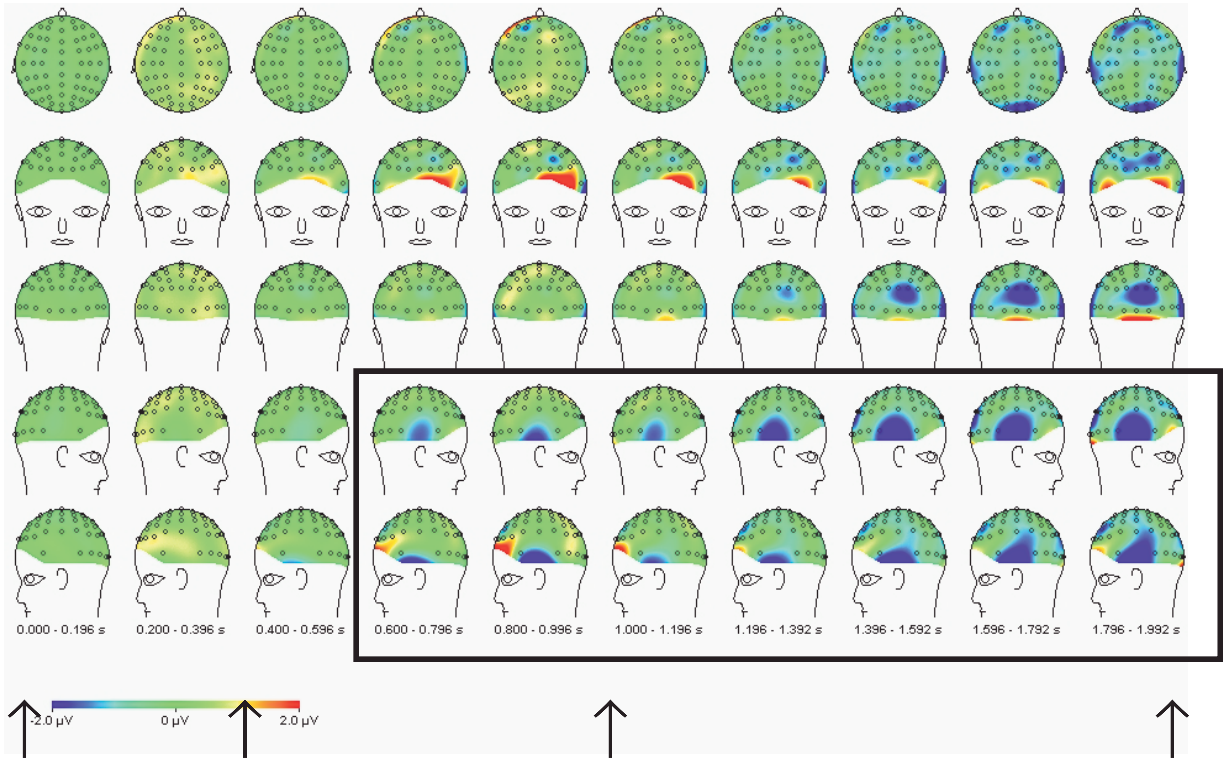
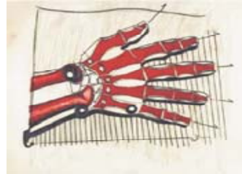
III: ERP – Grip-cueing vs. goal-cueing

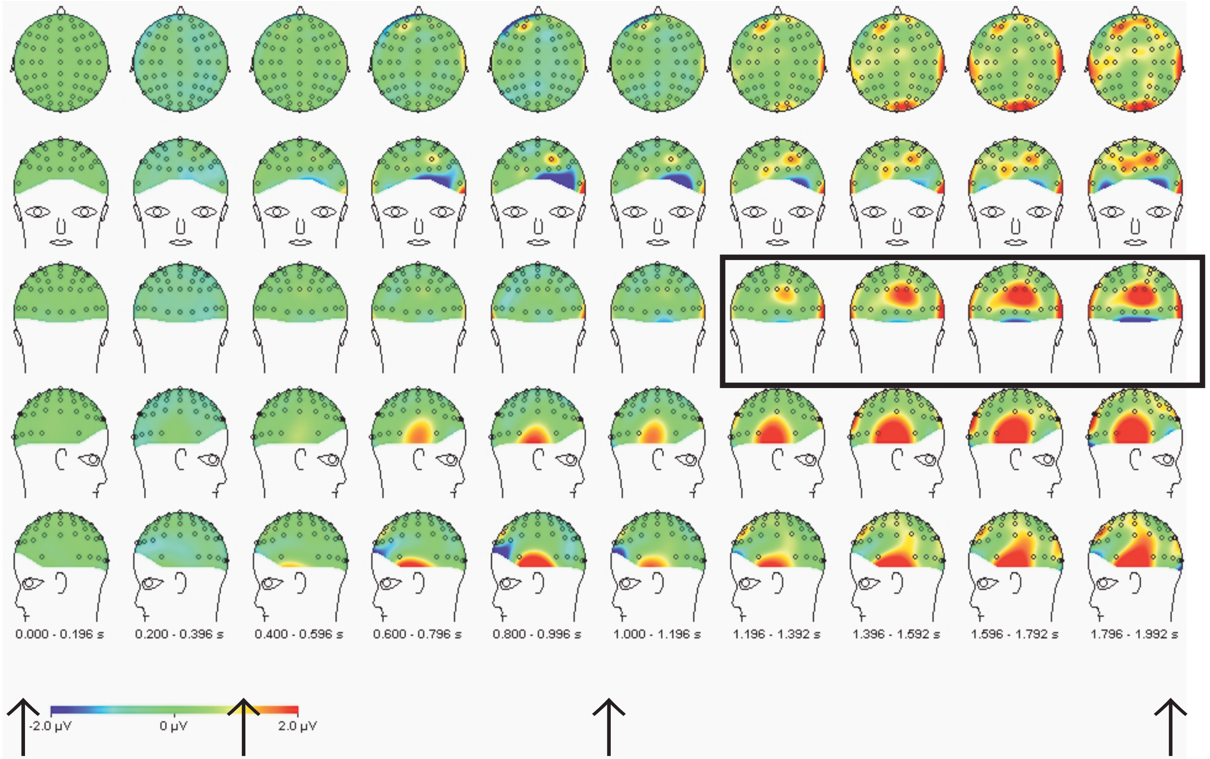
- Goal Cueing: more activation over premotor/ Broca's area!

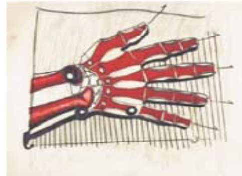




III: ERP – Grip-cueing vs. goal-cueing

- Grip Cueing: more activation over visual-parietal areas!

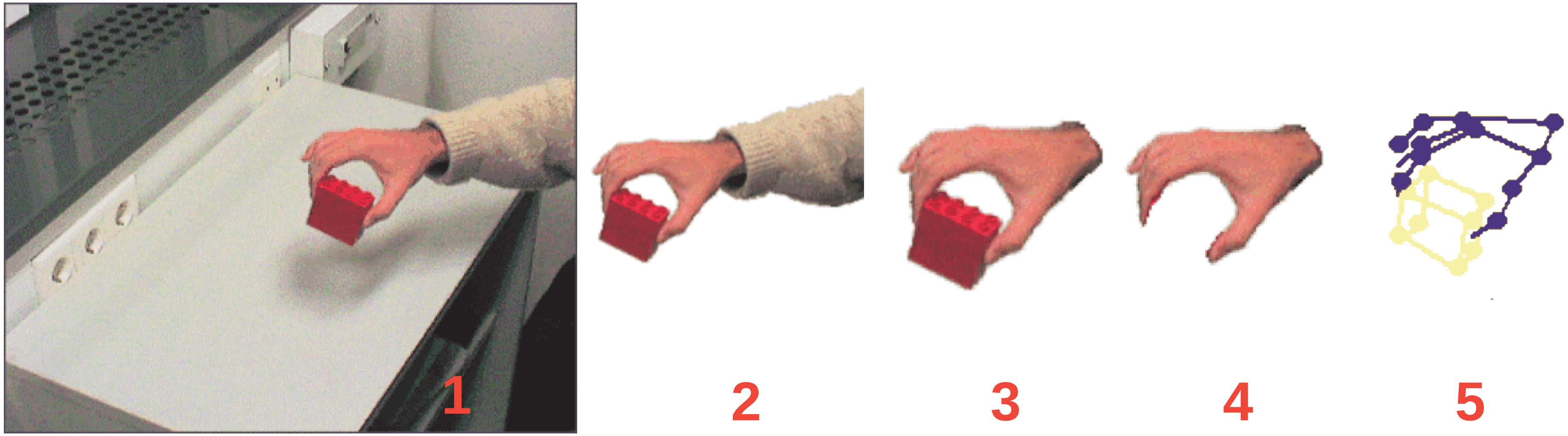




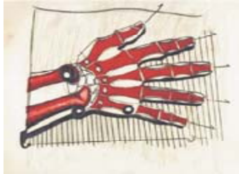
Tracking the instructor's hand

- Learning & run-time planning requeire exact knowledge of the instructor's hand and finger movements.
- Vision subsystem:
  - uses several colour cameras,
  - a multitude of feature extractors,
  - data fusion techniques and adequate modeling techniques

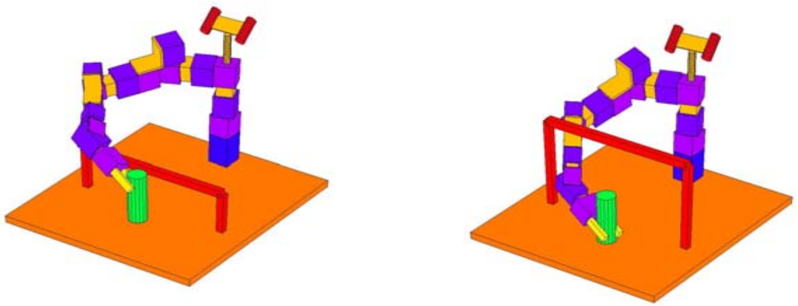
to continuously track a human hand and to determine all finger joint angles *without using markers or data gloves*.



Making the artefact work: the neuro-model



- **Objectives**:
  - Learning the link between action goal and motor acts
  - Mapping of action observation on action execution
  - Decision making
- **Characteristics**:
  - Model architecture inspired by the **STS-PF-F5** circuit
  - Model allows for a comparison with neurophysiological and reaction time data
  - Test of the integrated model architecture in a robot simulator
  - Input from both the neurophysical investigations for setting up and calbrating the model
  - Input from the hand-tracking system for driving the model to produce output to control the artificial hand



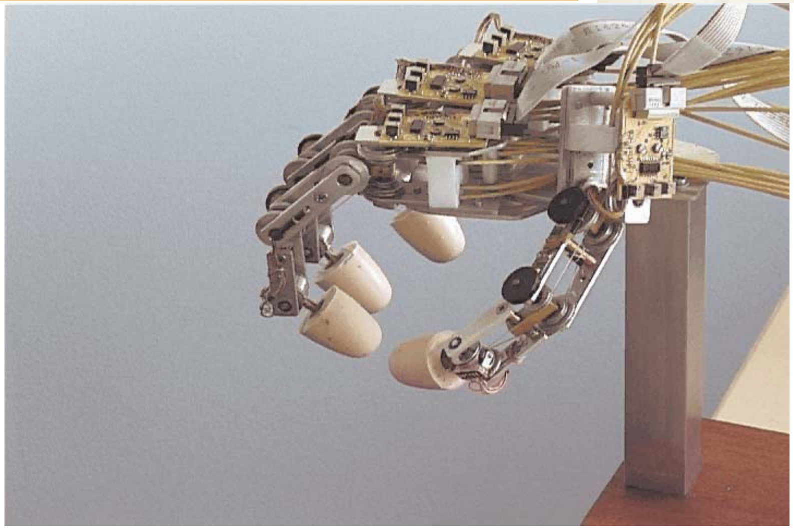
Making the artefact act: the artificial hand

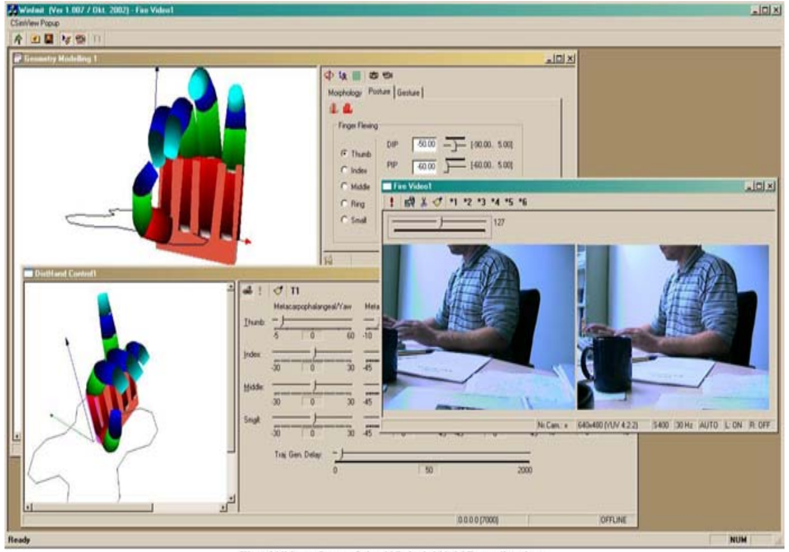
Four-finger hand:

- Elaborate control scheme using non-linear models for the tendons
- Very time-consuming robust interfacing with control computer
- Force-measurements will follow

Hand control software:

- Complete bioanalogue hand model
- High-speed rendering through Direct-X
- Complete montoring of all variables





The GUI interface of the WinImit V1.007 application

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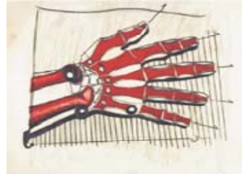

Major results obtained so far

- **P1:** Fully operational prototypes of **(i)** optical camera-based tracking system **(ii)** the physical hand and **(iii)** a complete architecture for integrating all software modules
- **P2:** Discovery of two types of mirror neurons in the inferior parietal lobule, indicating intermediate steps of visual description of actions between STS and F5
- **P3:** **(i)** MEG evidence for a medial parietooccipital substrate of self-motion awareness, **(ii)** fMRI demonstration of a vermal substrate of internal eye movement models for perception, (iii) psychophysical paradigm for testing self hand movement perception
- **P4:** **(i)** A dynamic network model for goal-directed imitation inspired by the STS-PF-F5 circuit for action understanding and imitaton **(ii)** a fully working robot simulator behaving in the setting of the ArteSImit paradigm.
- **P5:** **(i)** Human EEG data in project are consistent with neurobiological model of imitation based on monkey data (ii) Results suggest a functional architecture for goal-directed grasping, with action goals and grip selection activating different parts of the network (Broca's area and visual parietal areas respectively).

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