Projecting from human-in-the-loop control to cognitive robot design

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Recent focus

For having robots in everyday life we need to find new methods for equipping them with skillful behavior

Roboticists' dream: eliminate the need for roboticists for robot skill acquisition!!

- Developmental robotics (e.g. self learning)
- Teaching by demonstration
  - Open loop
    - Human mocap -> fixed mapping to control robot
  - Almost open loop (no dynamics)
    - Direct teaching
      - Keyframe method (classical, i.e. for factory settings)
      - Human haptic interaction -> Robot trajectory
    - Haptic scaffolding (cf. tomorrows talk; E. Ugur, H. Celikkanat, Y. Nagai, E Sahin, E. Oztop)
  - Closed loop
    - Real-time teleoperation
    - Human in the loop paradigm (Erhan Oztop, Jan Babic)

Human sensorimotor learning

THE CRITICAL ISSUE:

Engaging the human sensorimotor learning system!

Why?

Because it is the best learning engine for dynamic tasks we know of.

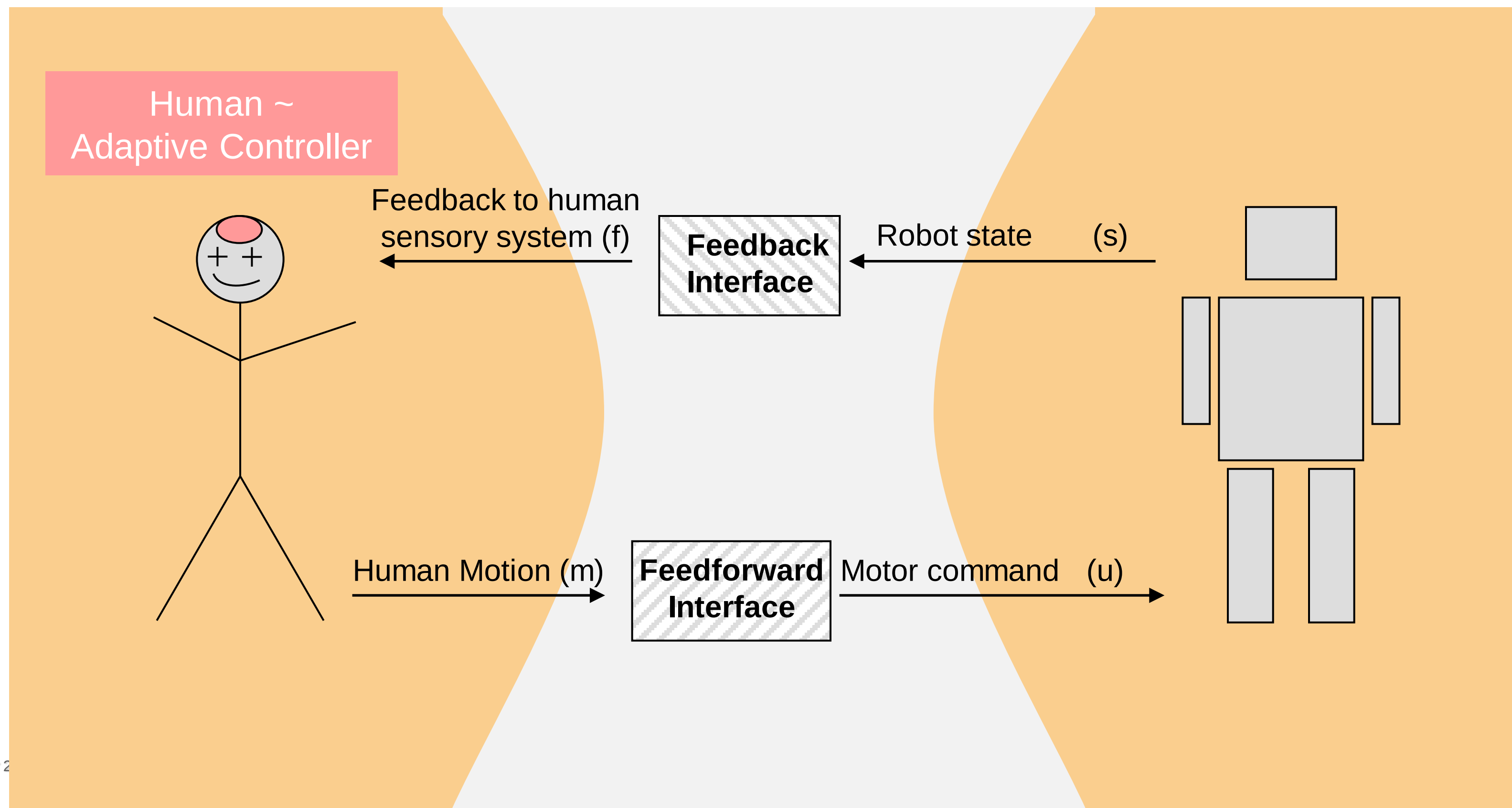
Human demonstration, direct teaching etc. engages the Cognitive System of the human operator but not the motor system

(One good research point to investigate is to what extent teleoperation etc. engages the human motor system)

The human-in-the-loop paradigm: robot, a novel tool

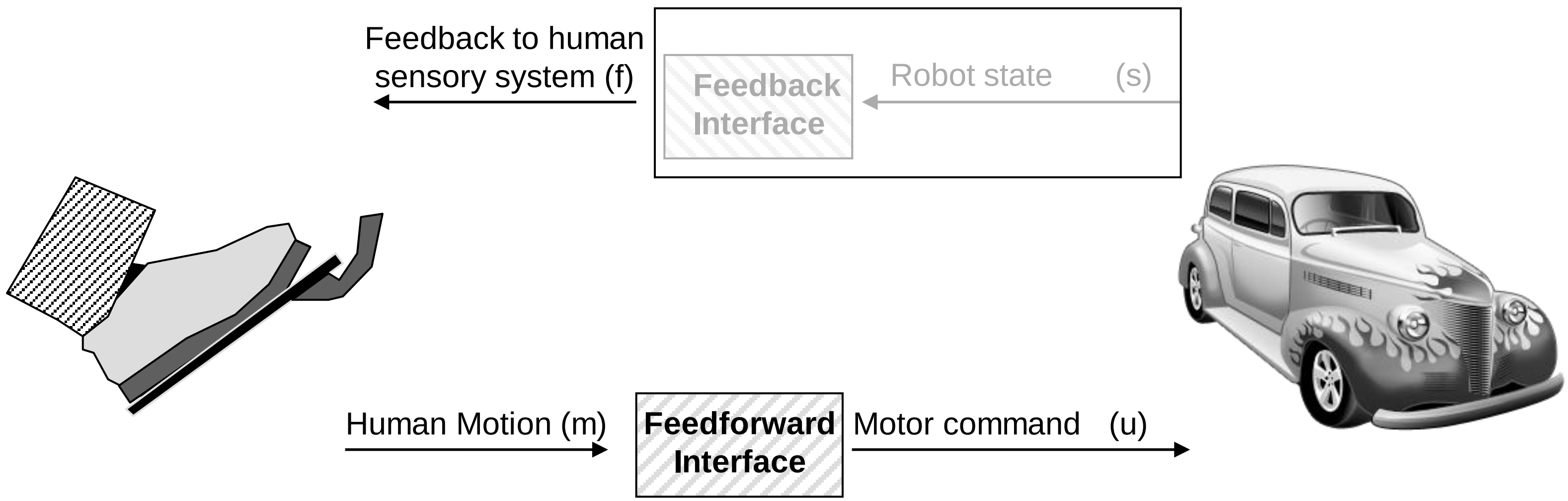
- Engage human sensorimotor learning to obtain robot behaviors

- Include the human in the control loop
- May ask human to do extensive training
- Utilize the human brain as the adaptive controller



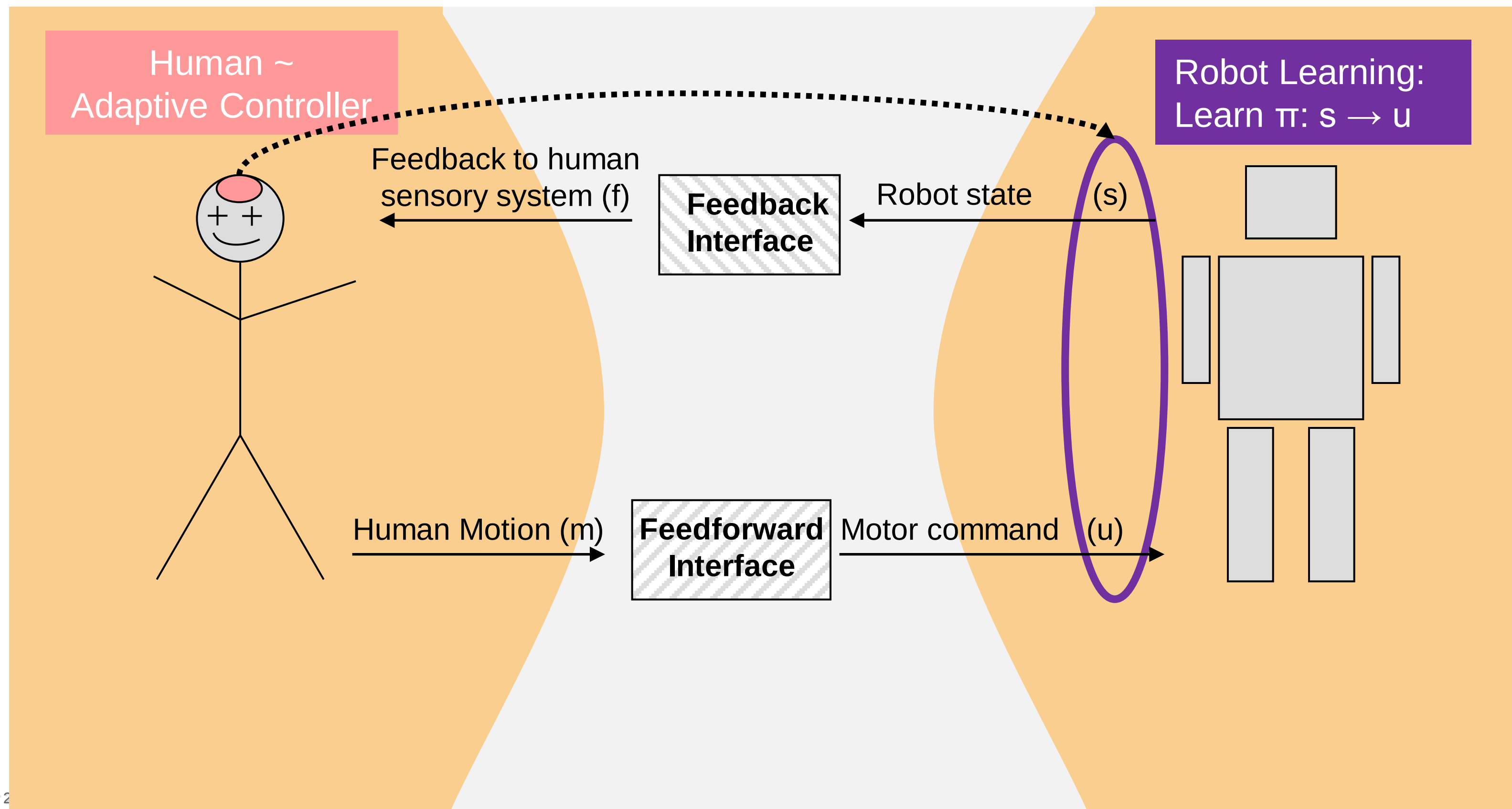
Sensorimotor learning

- Sensorimotor learning is fundamental for adaptive and intelligent behavior
- Driving a car
- Using a pair of chopsticks
- Using a computer mouse
- …
- …
- …



Behavior synthesis for autonomy

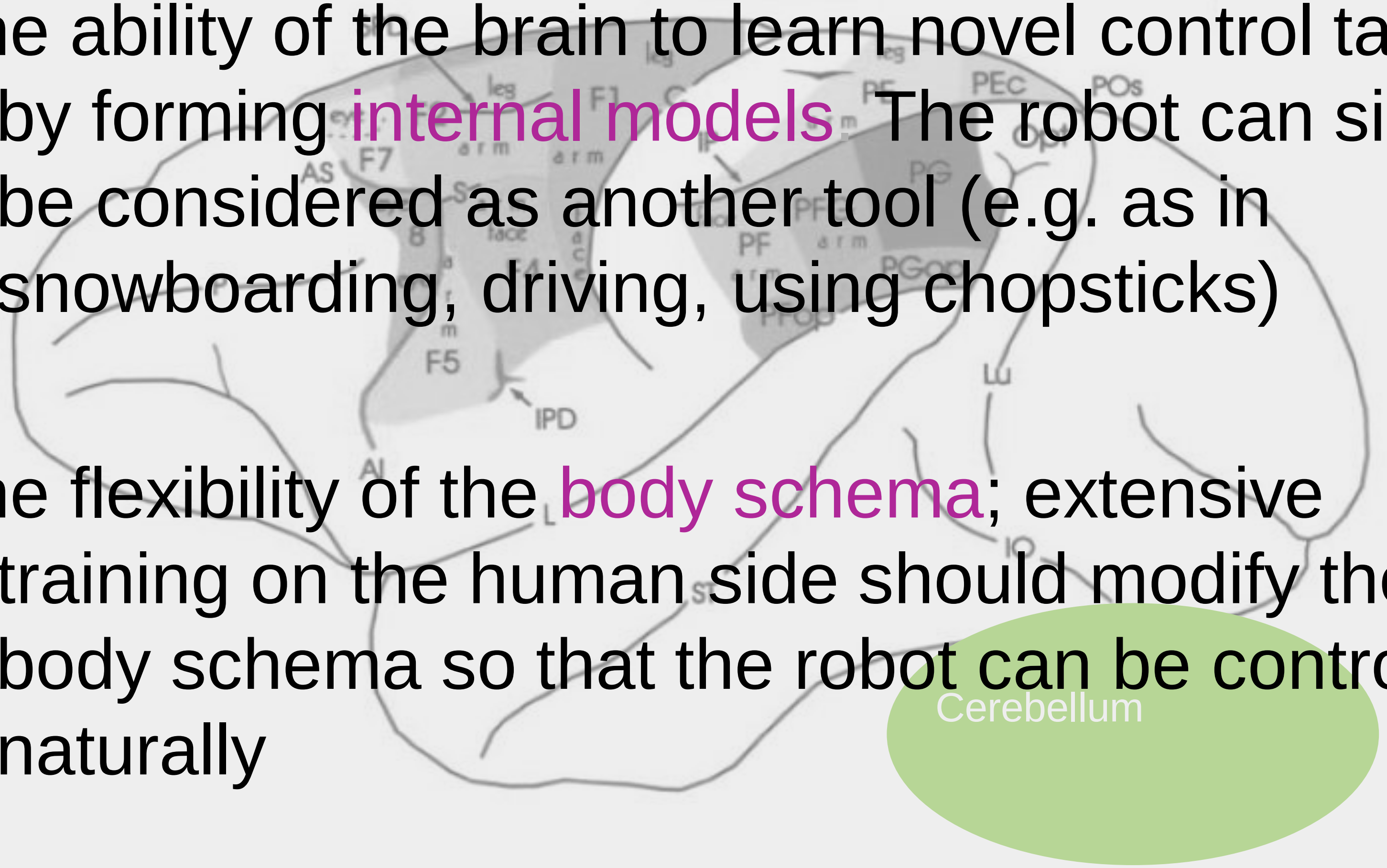
For autonomous operation, the key issue is transferring the **control policy** learnt by human to the robot



Why should this paradigm work?

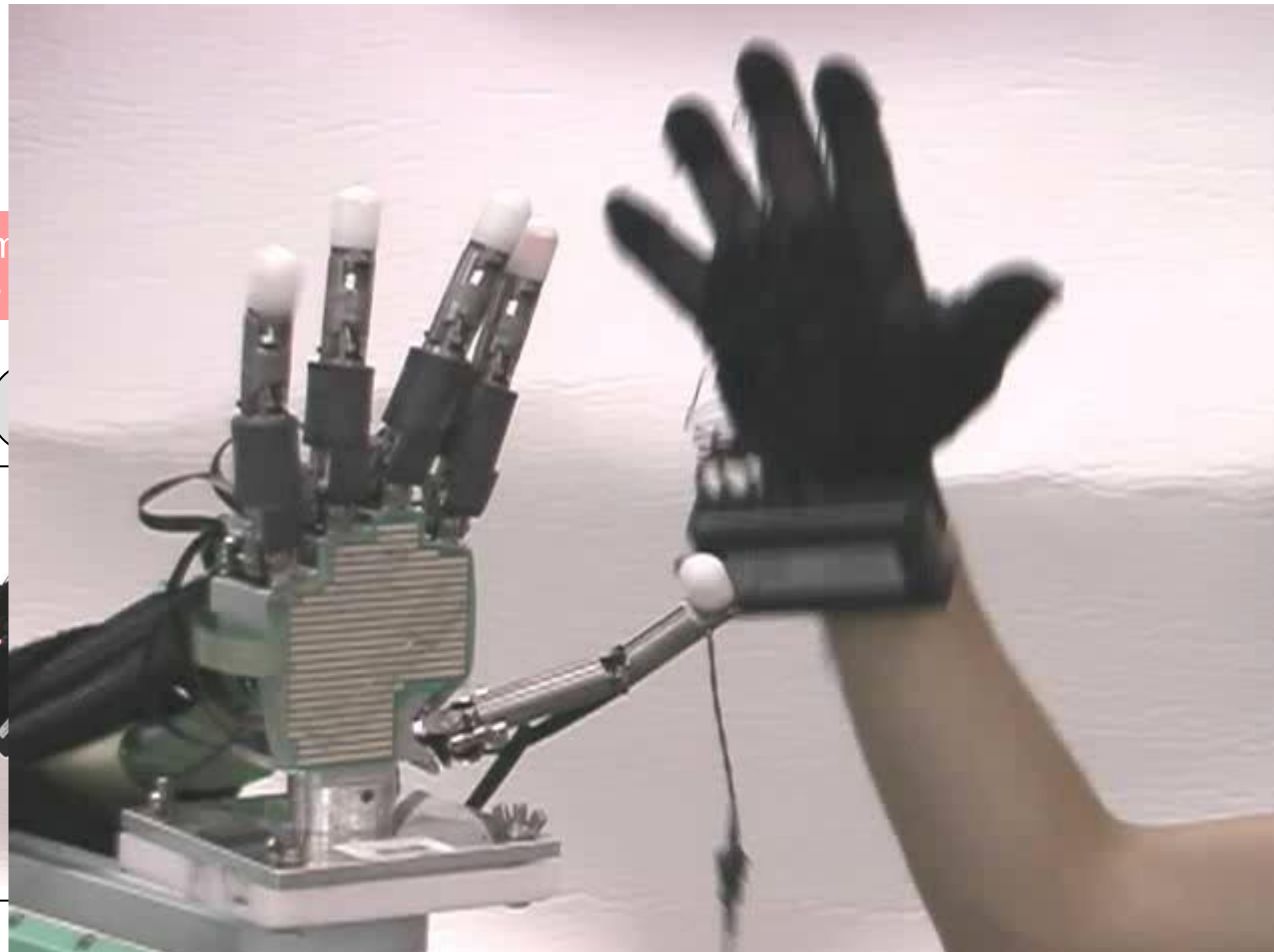
The ability of the brain to learn novel control tasks by forming internal models. The robot can simply be considered as another tool (e.g. as in snowboarding, driving, using chopsticks)

The flexibility of the body schema; extensive training on the human side should modify the body schema so that the robot can be controlled naturally

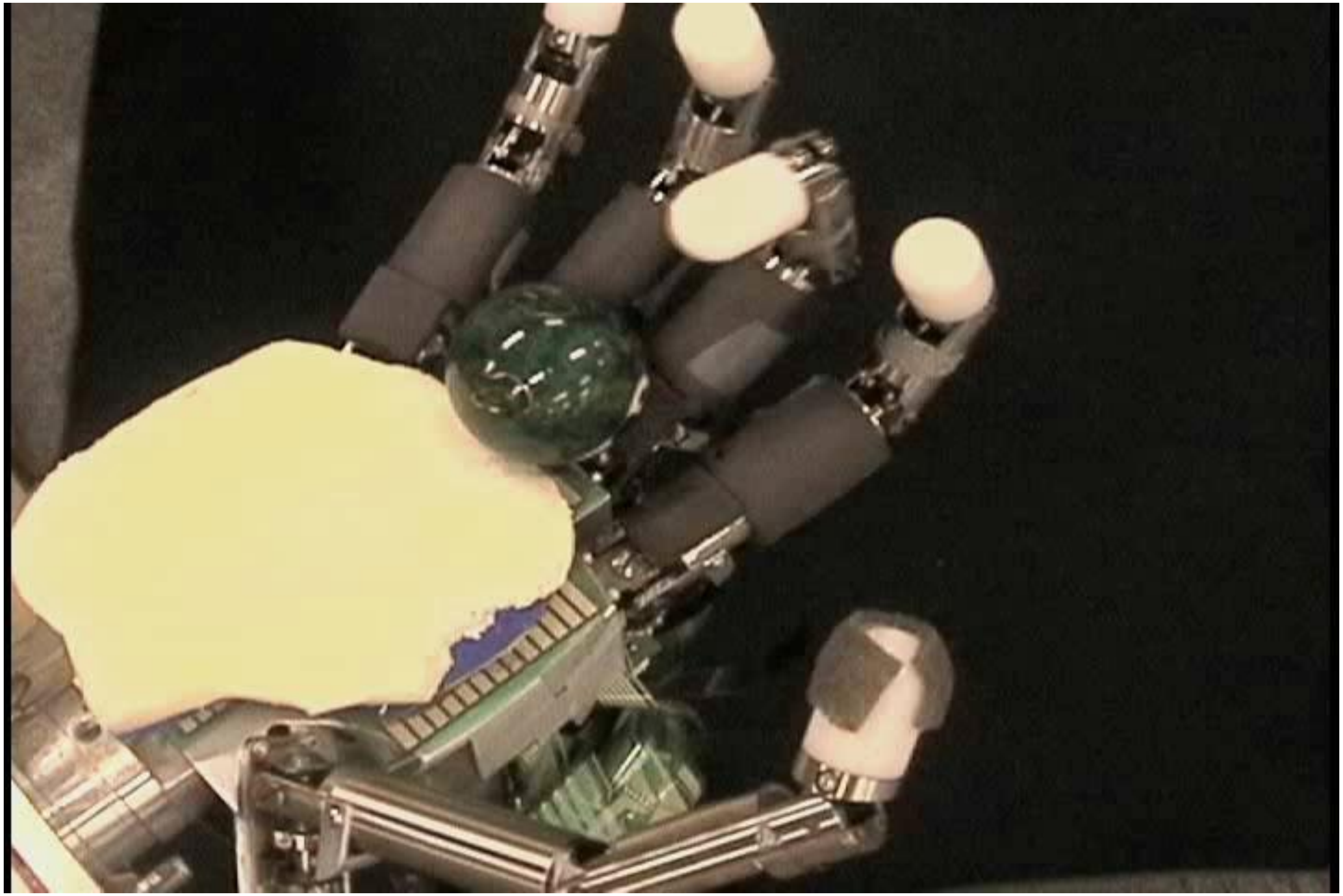


The paradigm at work for manipulation

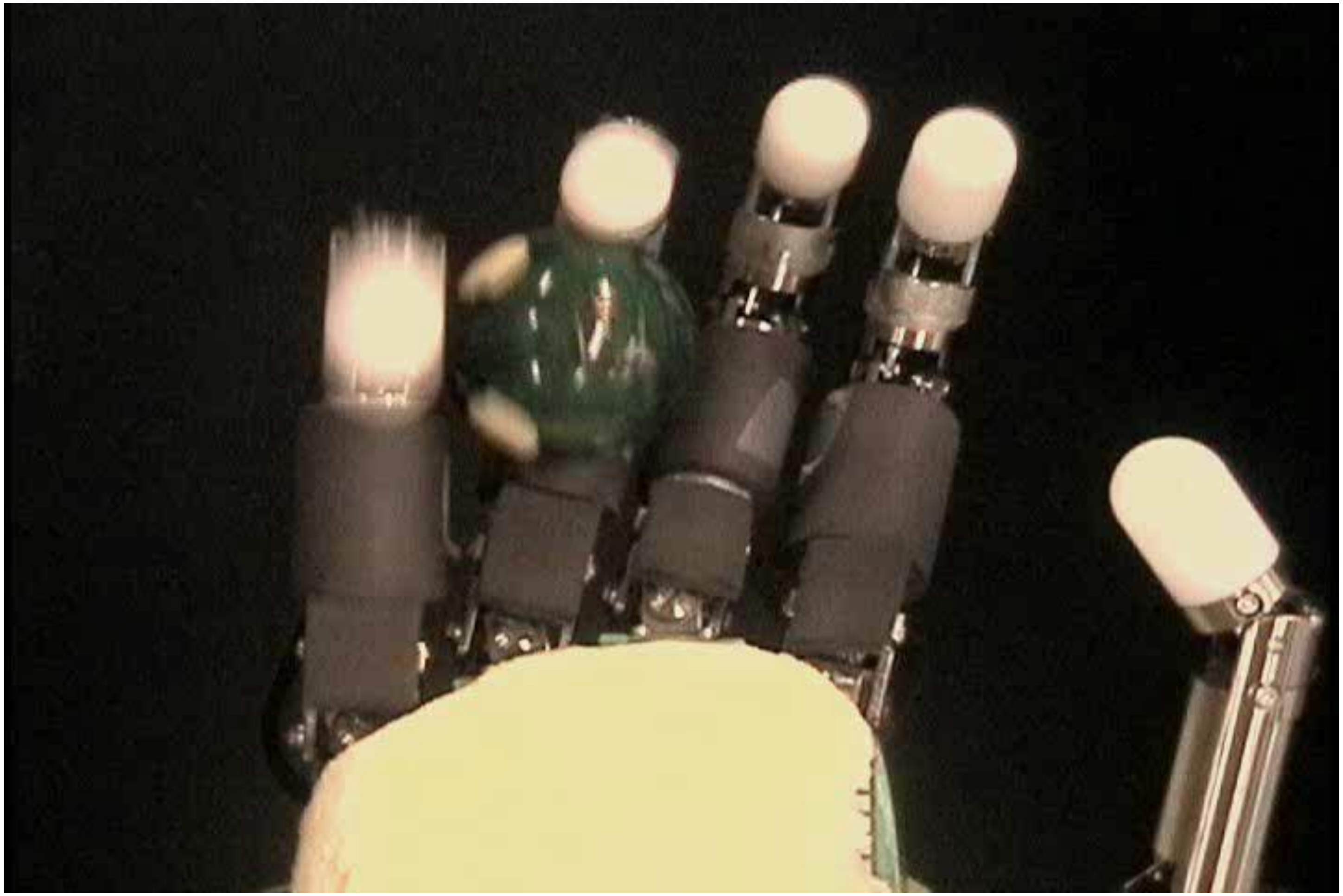
Hum
Adaptive



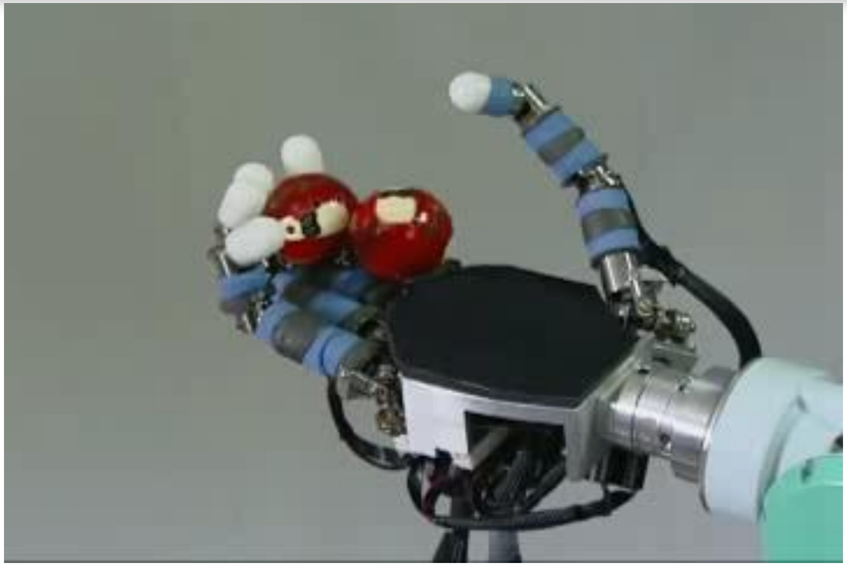
Human learning…



Autonomous ball swapping

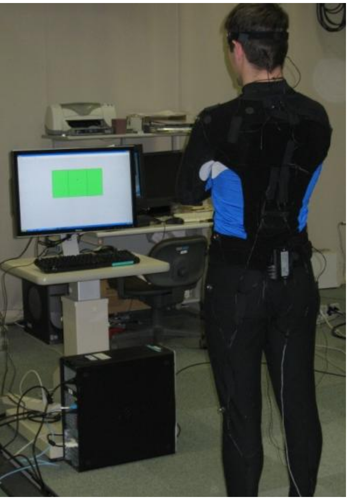


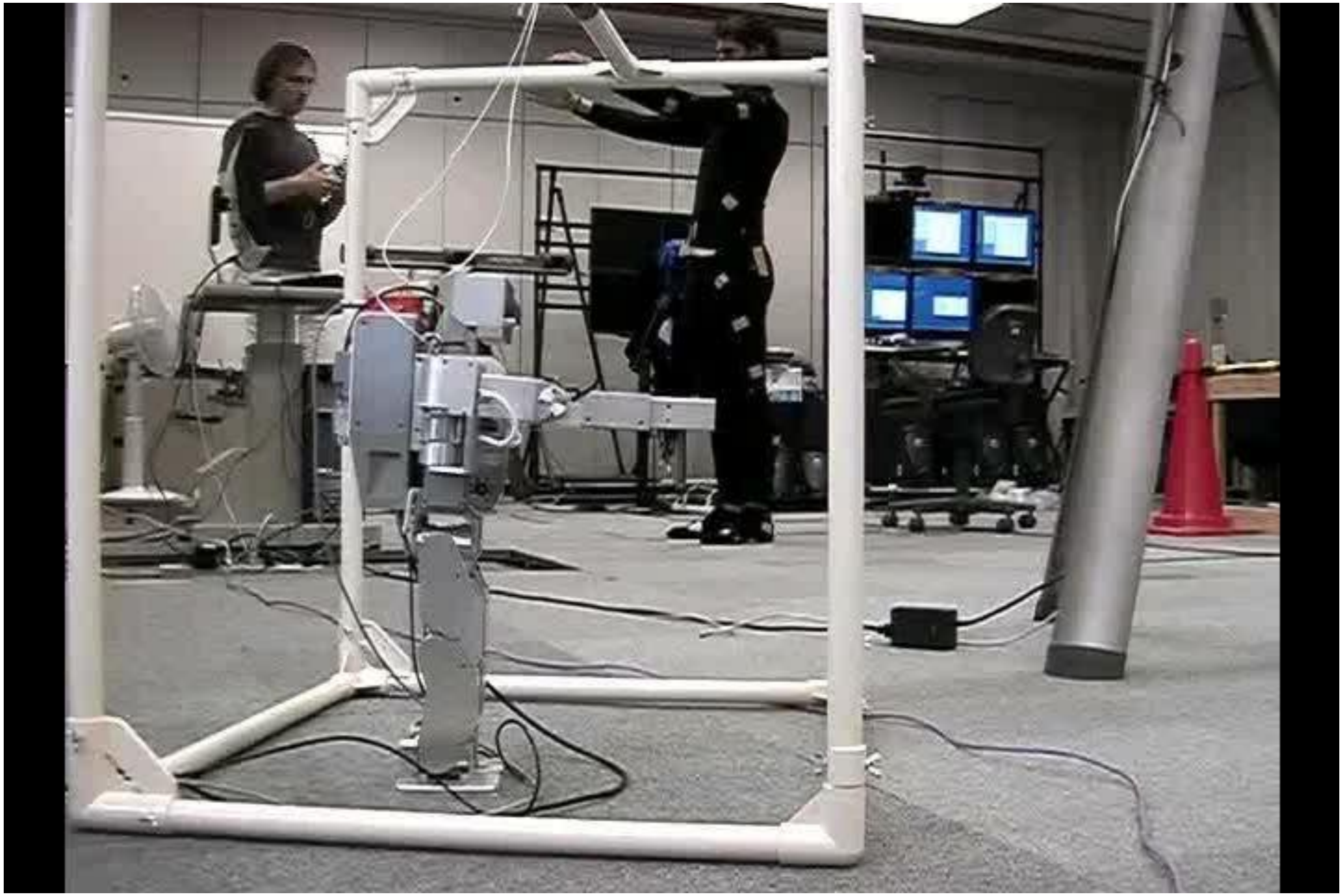
The paradigm for grasp synthesis



Moore B, Oztop E (in press, Robotics and Autonomous Systems)

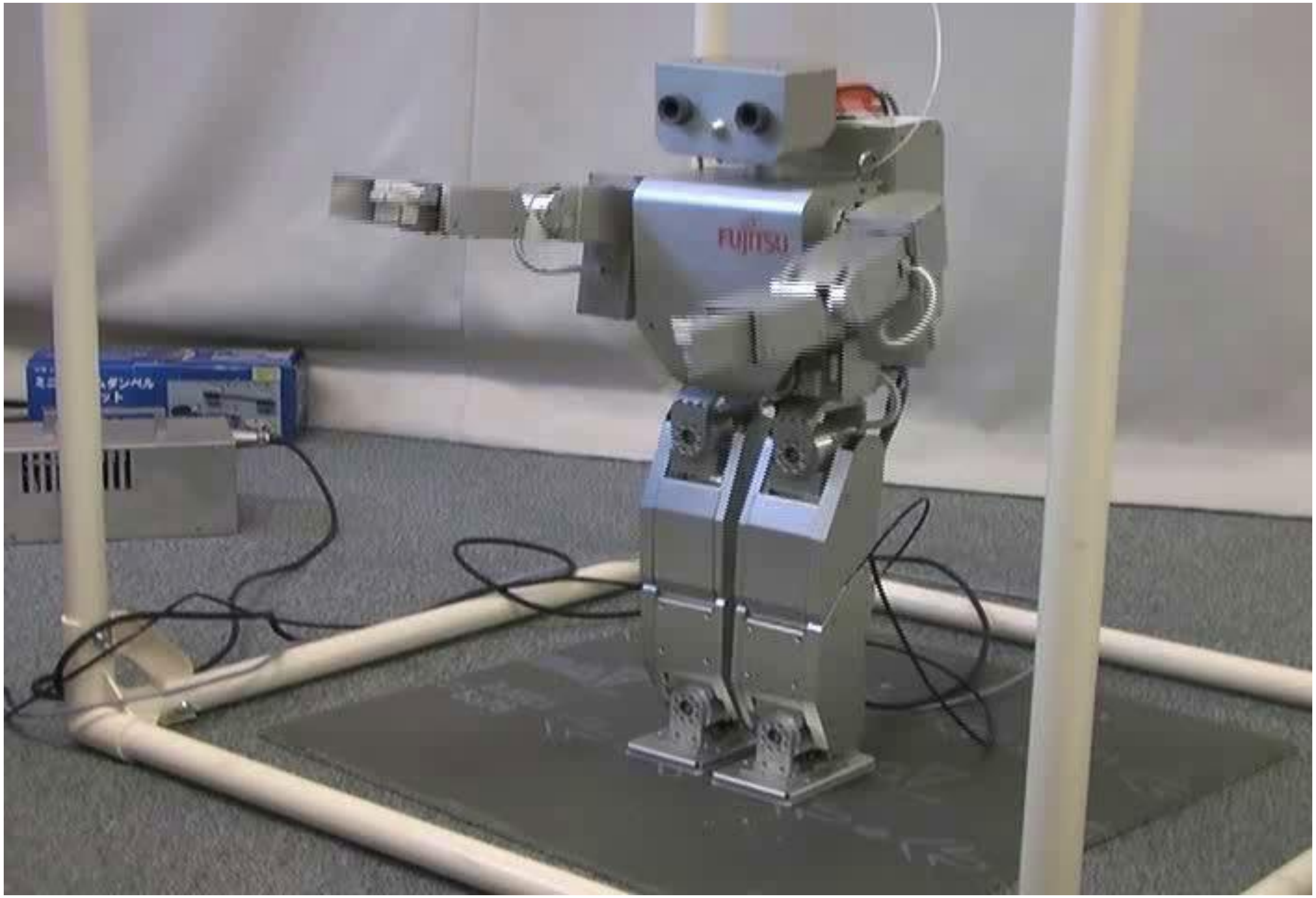
Paradigm for balanced IK





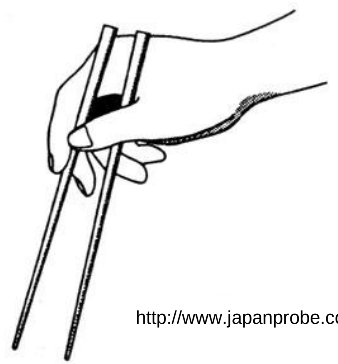
Babic J, Hale J, Oztop E, (2011, Adaptive Behavior)

Autonomous stable trajectory tracking

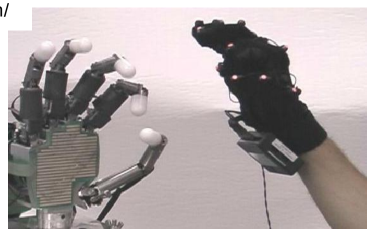


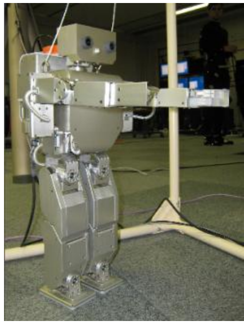
Brain mechanism of real-time control of external agents

Which are body schema altering agents?



http://www.japanprobe.com/





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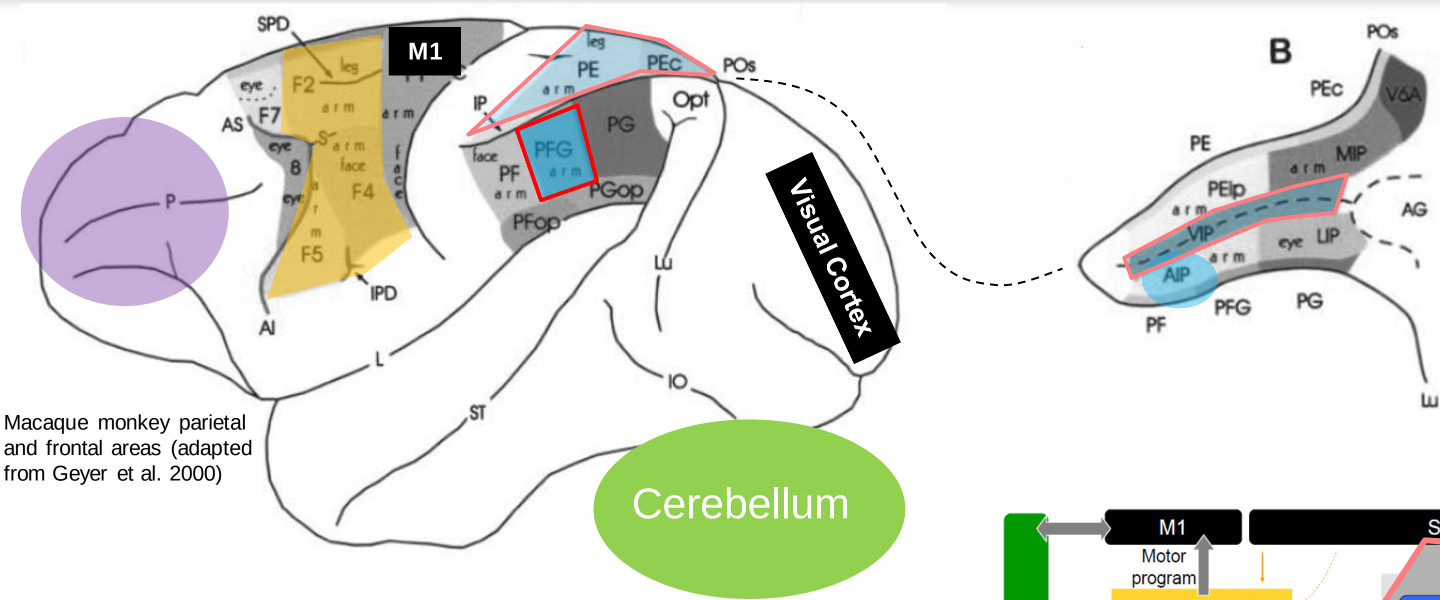
DLR’s Rollin’ JUSTIN (Kremer et al, ICRA 2009)

Ishiguro’s self android for telepresence

Brain areas involved in interacting with external agents

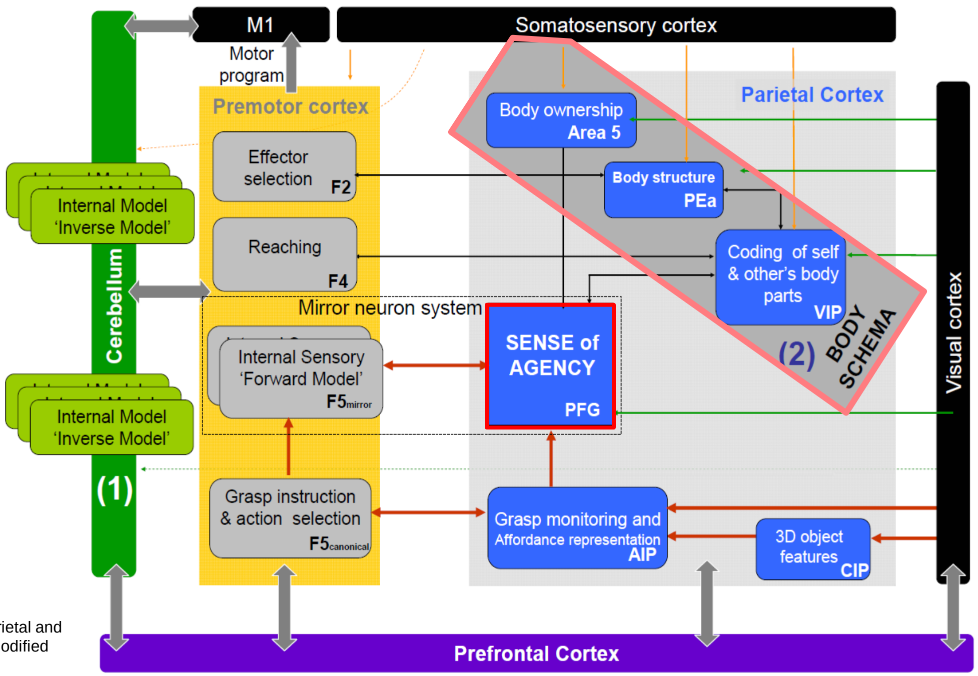


Macaque monkey parietal and frontal areas (adapted from Geyer et al. 2000)

Cerebellum: novel control tasks,
internal model formation

Parietal Cortex: body ownership, agency, assimilation of tool into body schema

Motor Cortices: execution, action observation

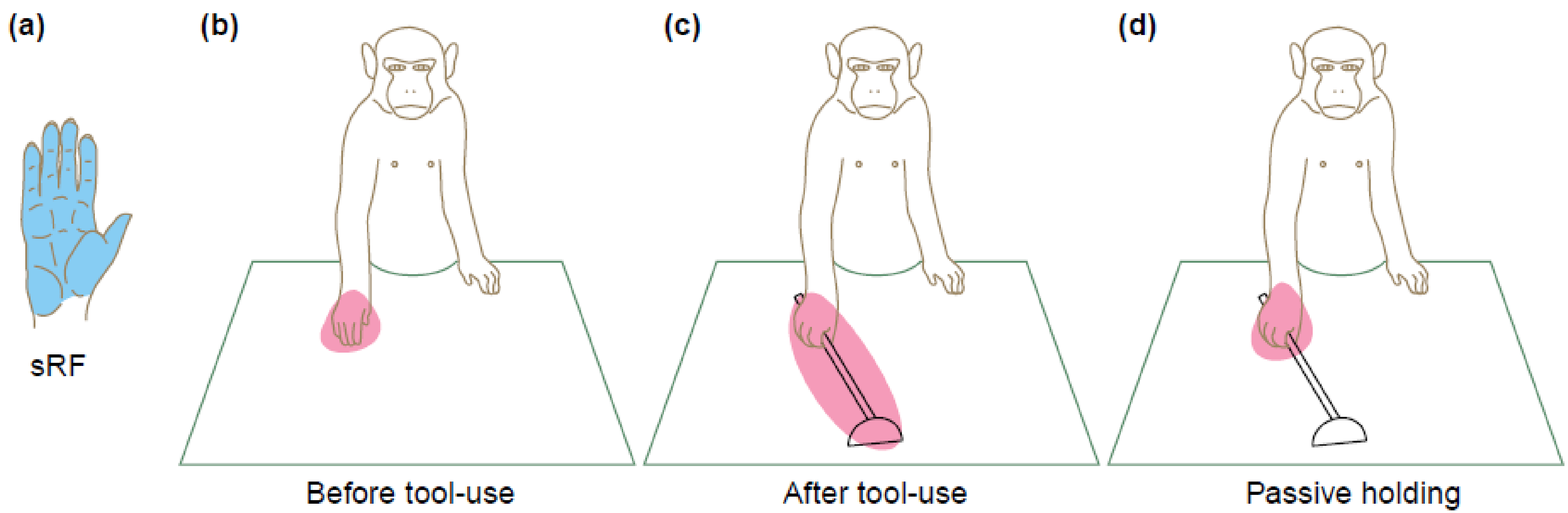


Conceptual representation of parietal and frontal areas with cerebellum (modified from Murata and Ishida 2007)

Body schema is flexible

VIP neurons integrate somatosensory and visual information with visual receptive fields anchored to the hand/arm of the monkey → representation for body schema

Iriki et al. 1996: Tool use modifies the body schema



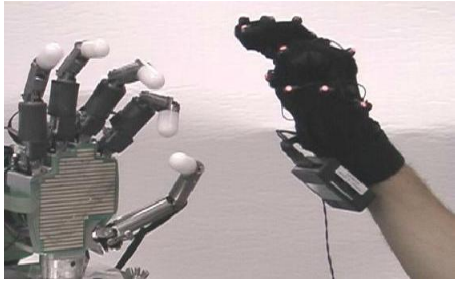
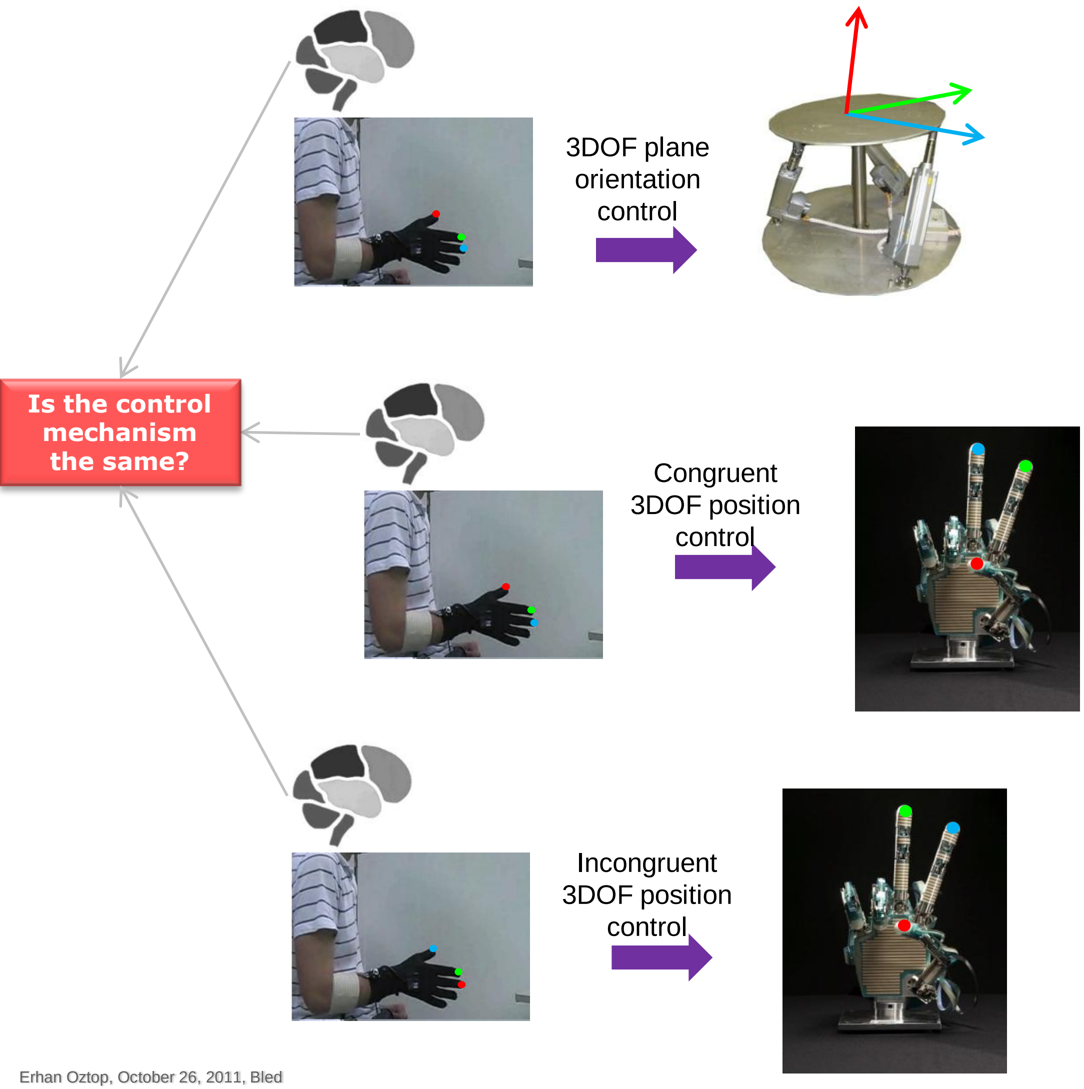


Figure from
(Maravita & Iriki 2004)

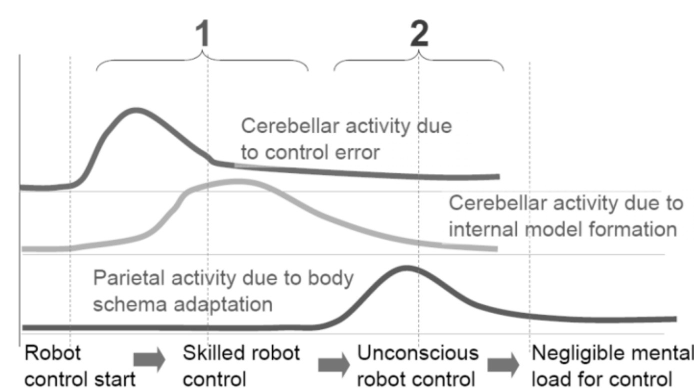
The fMRI experiment plan…



Hypothesis

According to the **anthropomorphic** nature of the robot and the **manipulation congruence**, the way the brain handles the control will be different

fMRI imaging predictions for the human control of an anthropomorphic robot: The control of the robot initially induces an (1) internal model formation at the cerebellum then, after fluency is reached with training, (2) the body schema representation in the parietal cortex is modified to assimilate the robotic 'extension' of the body.



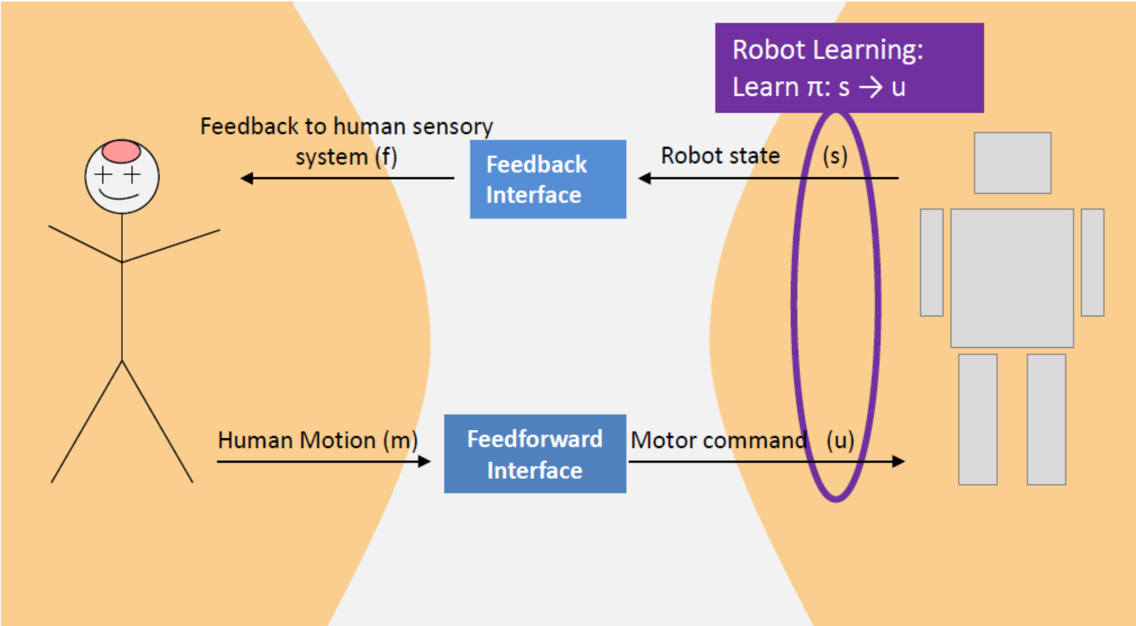
Components of the paradigm

Three components

- Feedforward Interface
- Feedback interface
- Machine learning

Two agents

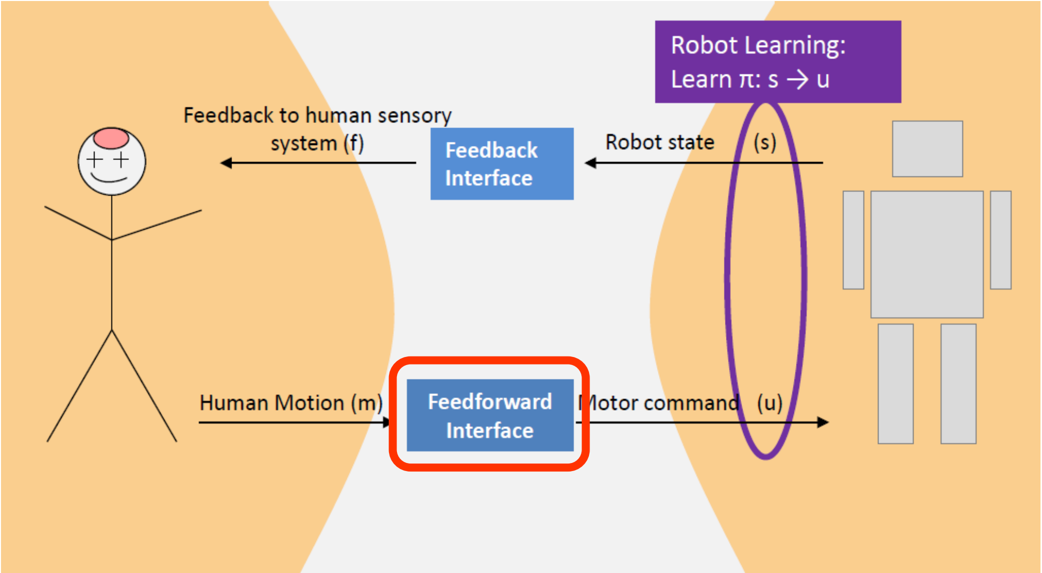
- Human
- Robot



Feedforward Interface

Repeatable
Minimum delay
Noise free

Calibration ease

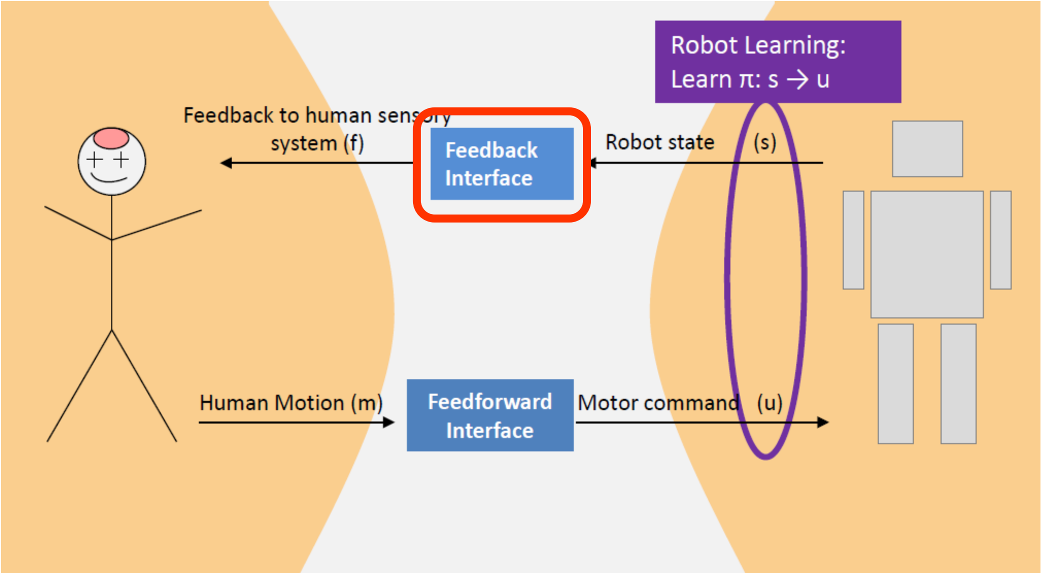


Intuitiveness

- Cartesian or Joint based
- Position, velocity or force based
- Mixing of domains e.g. control of force with position?
- Is this task dependent?

Feedback Interface

Repeatable
Minimum delay
Noise free



Feedback modality

- Abstract representation
- Compact representation
- Full representation
- Redundant representation
- Multiple modality: how?

Machine learning

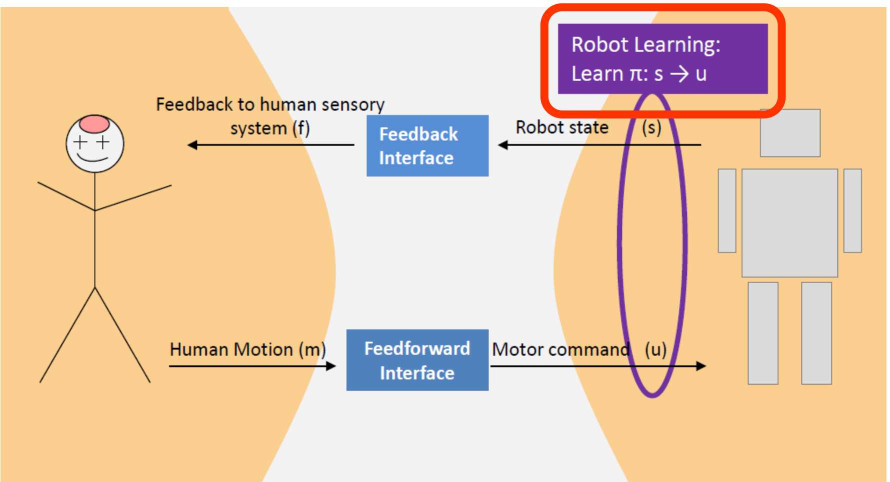
Online vs. offline

Representation of the relation between s and u

- Functional relation $f : s \rightarrow u$
- Joint pdf $P(s,u)$

Smart data sampling
How to determine that enough data is sampled

Generalization
Scaling with task and robot complexity



Human

Safety

Robot Builder Companies

- New employment area: robot trainers
- Ethical issues: how hard to push the trainers?
    - Is it any different than working 8 hours/day
    - c.f. Video game testers

Home

- Limited version of such interfaces for private use
    - Train your home robot
    - Exchange new skills with friends
    - YouTube your robot skill

Future robots must be designed to put less demand on the human sensorimotor system as much as possible → *Next slide*

Robot (design principles)

(Assuming that humin-in-the-loop skill generation will be the primary skill generation method)

For effective skill acquisition, we can project that future robots must

- Have rich and human compatible sensing ability (this will make the relaying of this information to the operator easier)
- Be readily incorporated into the body schema, i.e. anthropomorphicity (functional not necessarily form)
- Similar dynamics properties (i.e. speed, momentum etc.), so that the operator can use motor control strategies for his own limbs or accustomed tools for controlling the robot.
- Have modular control ability to lessen demand on human learning (human operator may focus on say posture and reaching at different learning sessions, so the robot hardware must allow this modularity)

Marvin Minsky 30 years ago…

Marvin Minsky (*Omni,* June 1980; reprinted by *IEEE Spectrum, September 2010*)

“Telepresence emphasizes the importance of high quality sensory feedback and suggests future instruments that will feel and work so much like our own hands that we won't notice any significant difference.”

…

“A genuine telepresence system requires new ways to sense the various motions of a person's hands. This means new motors, sensors, and lightweight actuators.”

…

“The first ten years of telepresence research will see the development of basic instruments: geometry, mechanics, sensors, effectors, and control theory and its human interface. During the second decade we will work to make the instruments rugged, reliable, and natural.”

THANK YOU FOR YOUR ATTENTION!