Designing Human-Robot Interactions: The Good, the Bad and the Uncanny

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Outline

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Introduction

Questions

Scope

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Questions

- How do people interpret the motion of a humanoid robot?
- How do we formulate the visual processes by which action understanding is obtained?
- How does answering one question inform the other?
- How does this relate to standardization?

Scope

- In this talk I concentrate on visual interpretation of humanoid movement. I leave out important issues such as
  - language
  - social aspects (Kaplan, IJHR 2004)

Robots

Playing Sticky Hands with a Humanoid Robot
Visual Evaluation of Humanoid Movement

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Special thanks to ***Josh Hale (jhale@atr.jp)***, Ales Ude, Gordon Cheng and Mitsuo Kawato of the ATR Computational Neuroscience Labs

DB

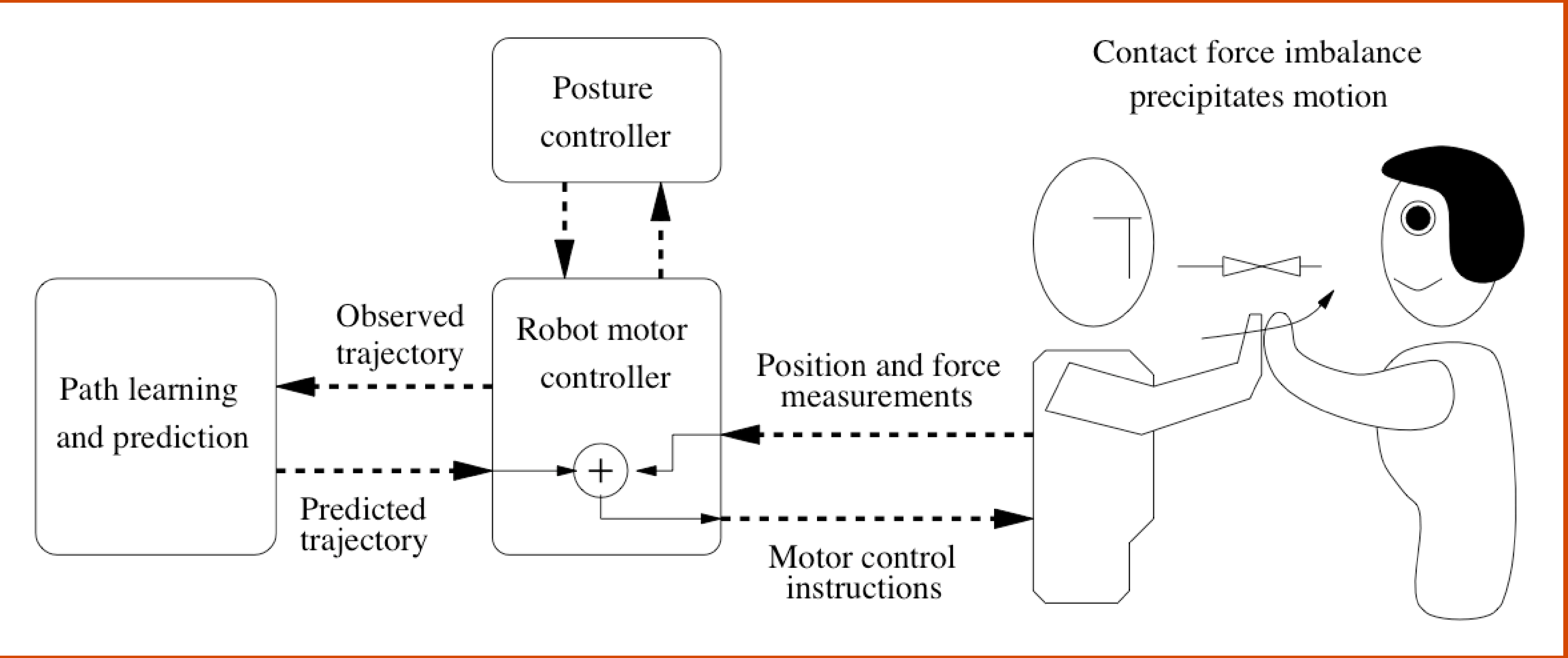
This section of the talk describes research done with DB, the 30 DOF humanoid robot located at the ATR Computational Neuroscience Labs in Kyoto, Japan

The Sticky Hands Game

- Exercise from tai chi between two partners
  - goal is to smoothly obtain mutually satisfying path

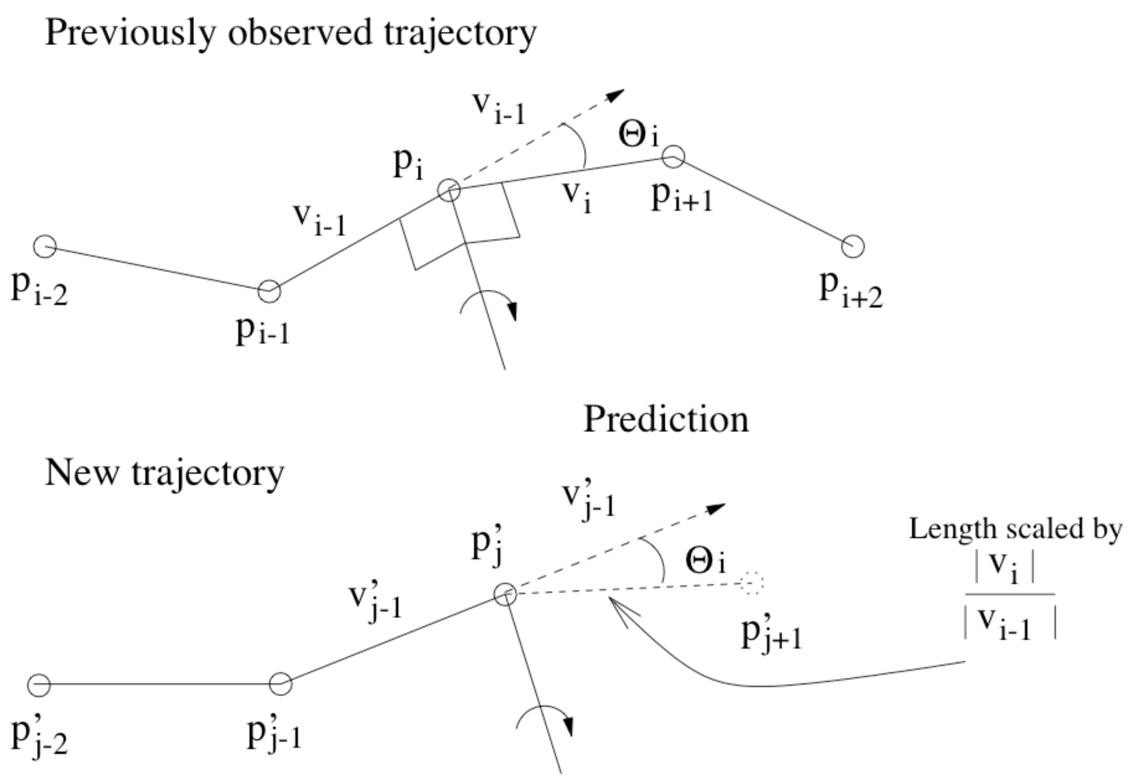
Hale, J. & Pollick, F.E.(in press) “Sticky Hands” Learning and generalization for cooperative physical interactions with a humanoid robot. IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews

Overview



Posture
controller
Contact force imbalance
precipitates motion
Path learning
and prediction
Observed
trajectory
Robot motor
controller
Position and force
measurements
Predicted
trajectory
Motor control
instructions

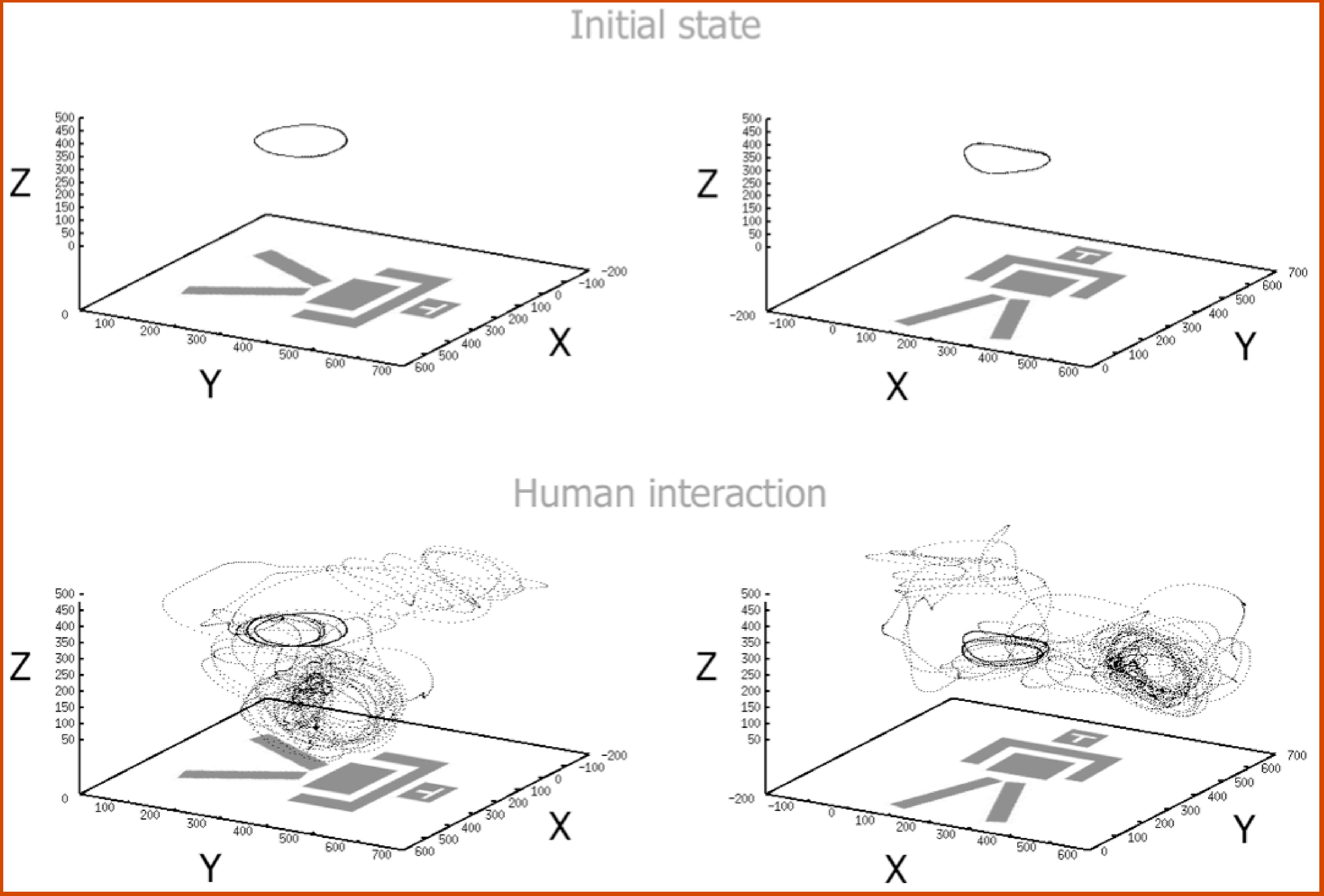
Path Learning



$$
\begin{aligned}
P_i &= (p_i, v_i, a_i, T_i) \\
v_i &= p_{i+1} - p_i \in \mathbf{R}^3 \\
a_i &= \frac{|p_{i+1} - p_i|}{|p_i - p_{i-1}|} \in \mathbf{R} \\
T_i &= \left(\cos\left(\frac{\theta_i}{2}\right), \sin\left(\frac{\theta_i}{2}\right)(p_{i+1} - p_i) \times (p_i - p_{i-1})\right) \\
\theta_i &= \cos^{-1}\left(\frac{(p_i - p_{i-1}).(p_{i+1} - p_i)}{|p_i - p_{i-1}||p_{i+1} - p_i|}\right) \in \mathbf{R}
\end{aligned}
$$

- Paths are locally represented by prototypes
- As interaction progresses prototypes are stored into a “motor tape” and used as the basis of predictive movements of the robot

Learning the “Motor Tape”

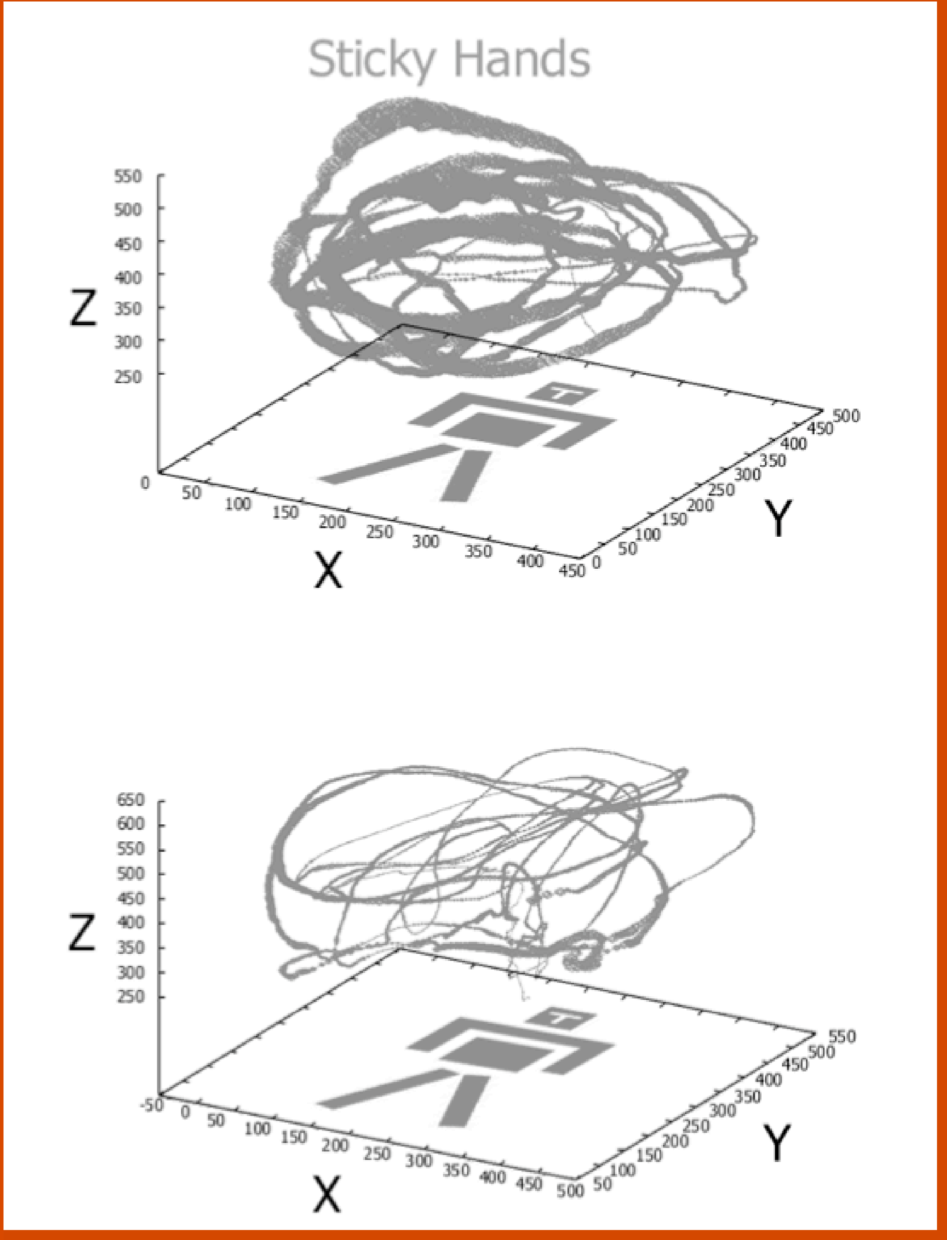


Results of Two Techniques

- Two techniques were examined to estimate the force imbalance
  - Kinematic - force is estimated indirectly from changes in limb position
  - Force transducer - force measured directly at the end of the limb

The Interaction

- To the right is shown
  - Above - force imbalance obtained using kinematic technique
  - Below - force imbalance measured using Force transducer



Summary

- Overall, we were successful in achieving a human-humanoid interaction, the details of this are given in the paper
- However, not everything was in the paper.....

Observations about the Interaction

- As a debugging tool, the robot followed its hand when it could find a prototype and looked forward when it could not
  - this simple factor had a substantial impact
- Although the robot moved only one arm it was hard for a partner to ignore the other arm
- "Accidental" motion properties were easily interpreted as being goal-directed

Visual Evaluation of Humanoid Movement

- Goal is to use psychological experiments to
  - Analyse performance of movement generation on a humanoid robot
  - Gain an understanding of what features are used to represent human and humanoid movement

Pollick, F.E., Hale, J.G. & Tzoneva-Hadjigeorgieva, M. (Submitted). Perception of humanoid movement.

Methods

- Generate movements on robot and obtain digital video of these movements as well as video of movement simulations
- Perform psychological experiments on the perception of these movements presented as digital video

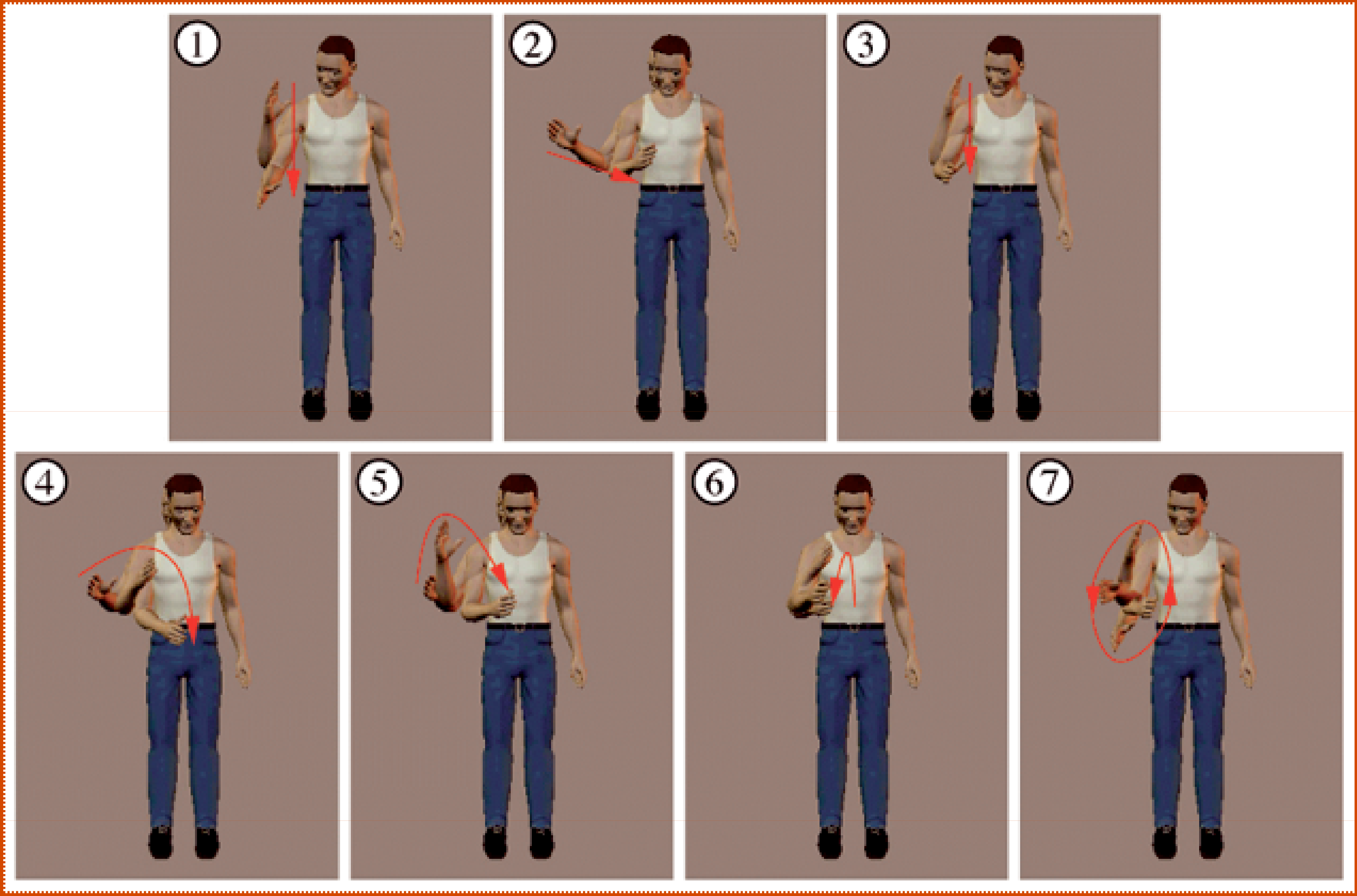
Producing Robot Movements

- Robot movements created through 14 different biomimetic control models
- Note - For purposes of this talk, detailed understanding of these models is not essential

Name	Model	Planning space	Planning level	FD
MV	Min. velocity	Extrinsic	Kinematic	No
MA	Min. acceleration	Extrinsic	Kinematic	No
MJ	Min. jerk	Extrinsic	Kinematic	No
MS	Min. snap	Extrinsic	Kinematic	No
MAV	Min. angular velocity	Intrinsic	Kinematic	No
MAA	Min. angular acceleration	Intrinsic	Kinematic	No
MAJ	Min. angular jerk	Intrinsic	Kinematic	No
MAS	Min. angular snap	Intrinsic	Kinematic	No
MJVT	Min. jerk virtual trajectory	Intrinsic	Kinematic	Yes
EPH	Equilibrium point hypothesis	Intrinsic	Dynamic	Yes
MT	Min. torque	Intrinsic	Dynamic	No
MTC	Min. torque change	Intrinsic	Dynamic	No
MTP	Min. torque postures	Intrinsic	Dynamic	No
MTPVT	MTP virtual trajectory	Intrinsic	Dynamic	Yes

Hale J.G. and Pollick F.E. (2002) Biomimetic motion synthesis for the upper limb based on human motor production, Workshop on motor control in humans and robots (SAB 2002), Edinburgh University, August 10 - 11, 2002.

7 Movement Conditions



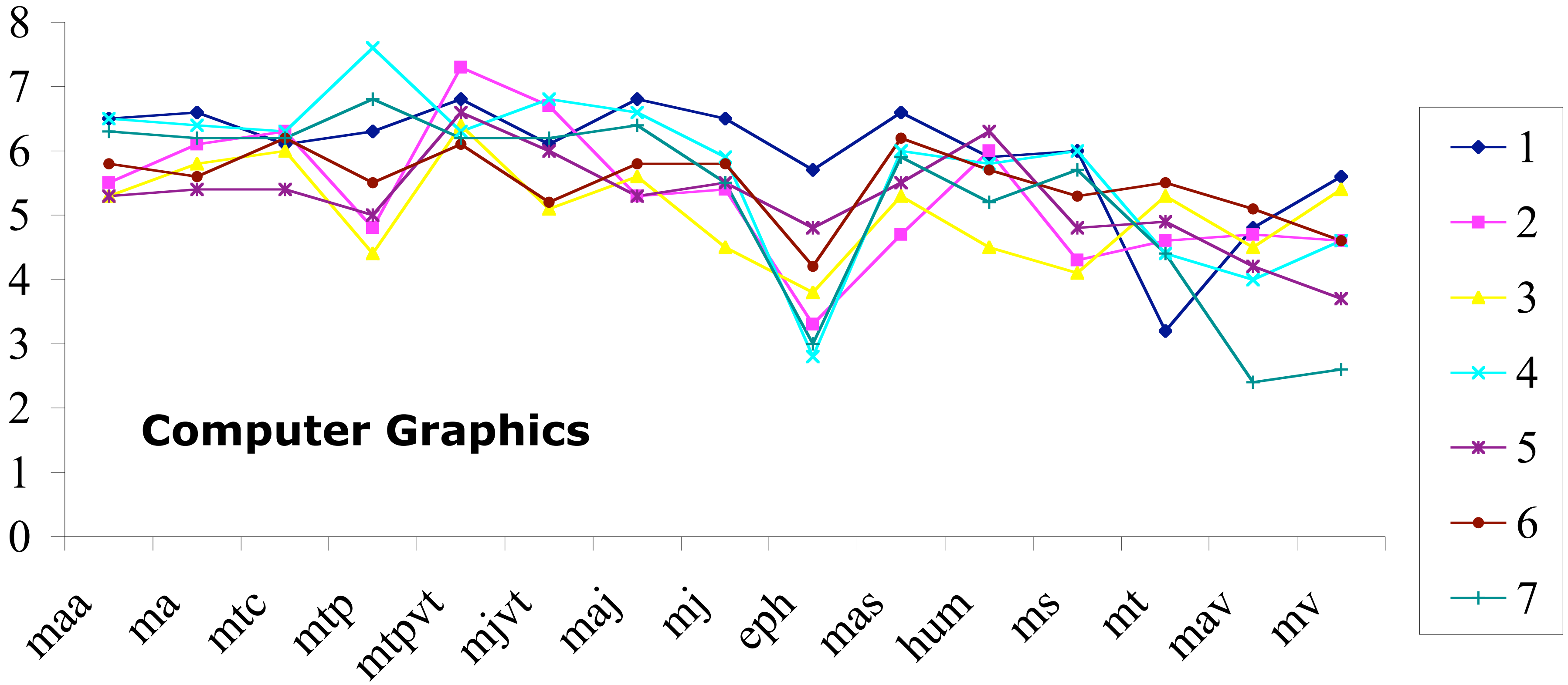
Example of Movement

Psychological Experiments

- Task
  - Participants were presented with a digital video and responded with a naturalness rating of the movement on a scale of 1-10
- Stimuli
  - Digital Video of robot
  - Digital Video of computer graphics character

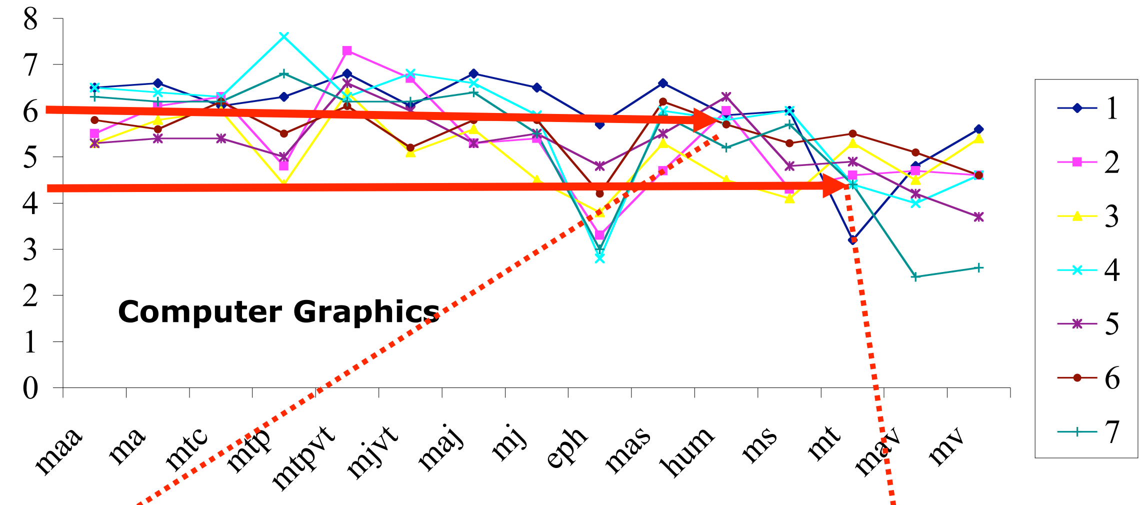
Computer Graphics (CG) Character

- Computer graphics (CG) character was developed to display movements produced by the14 control models and human motion capture data
- Movement data input to CG character were the desired trajectories output by the model. Thus, any difference between robot and CG character is likely due to the desired trajectory not being realized by the robot



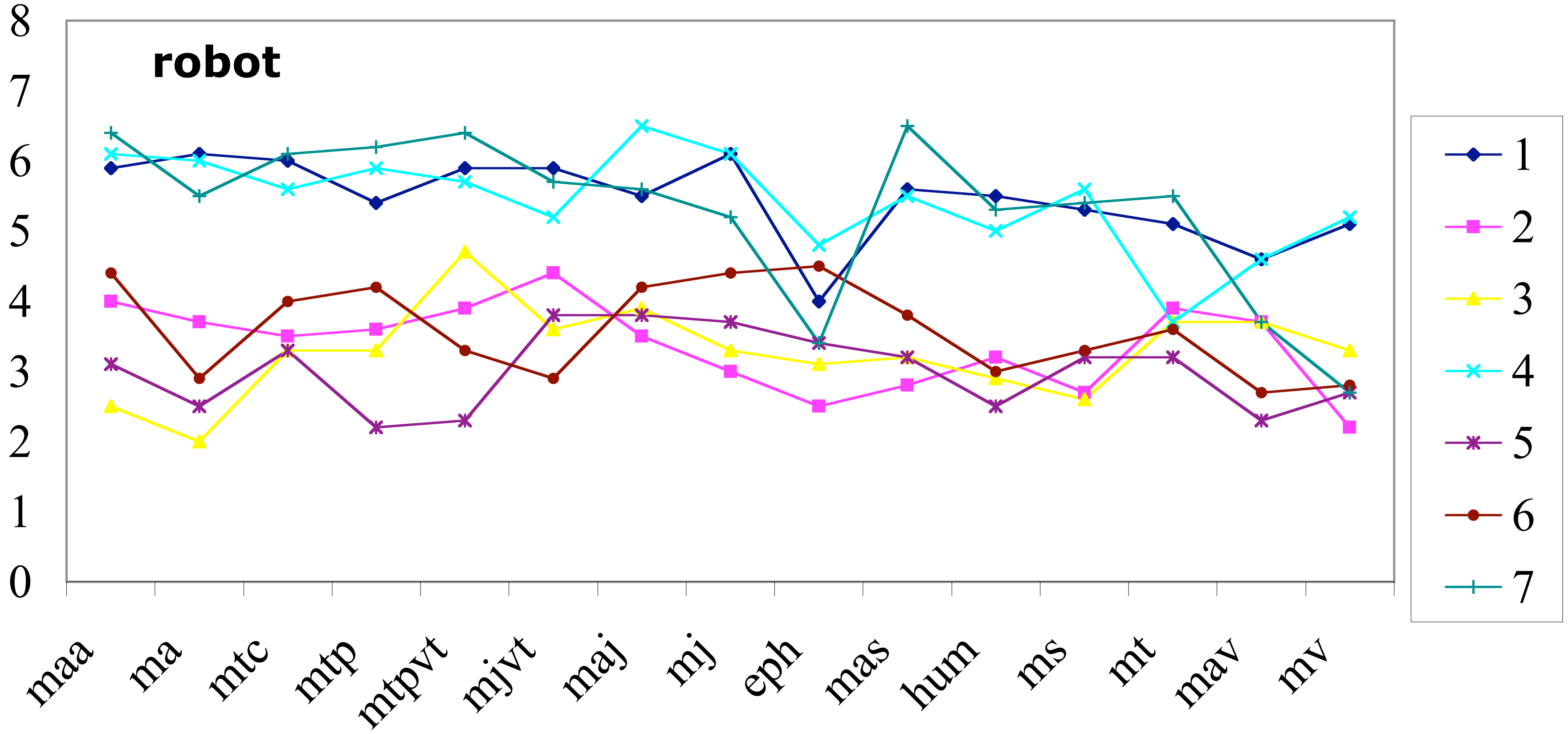
Results CG Character

However......



Human

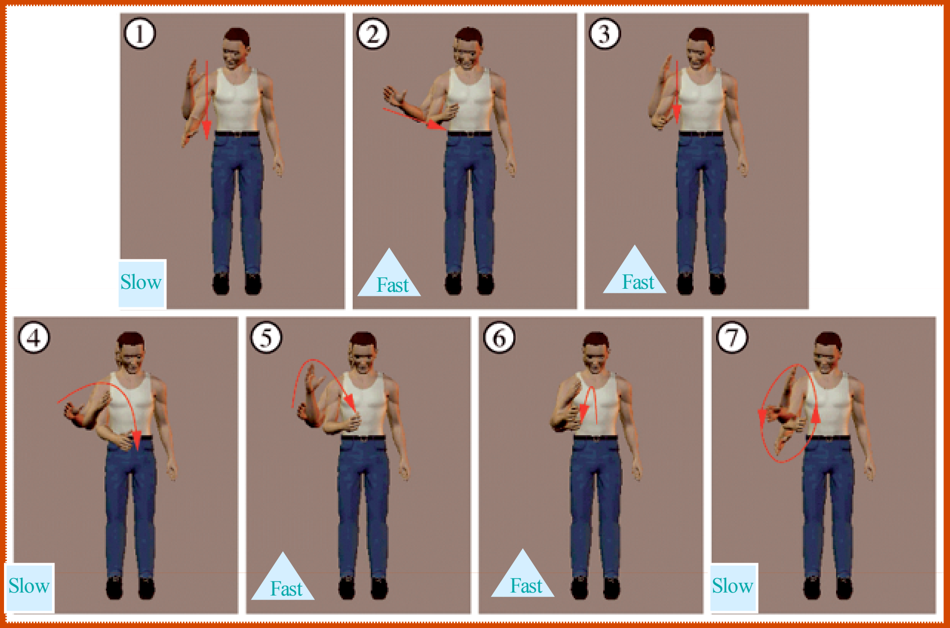
MT



Results Humanoid Robot

Velocity Explains the Difference

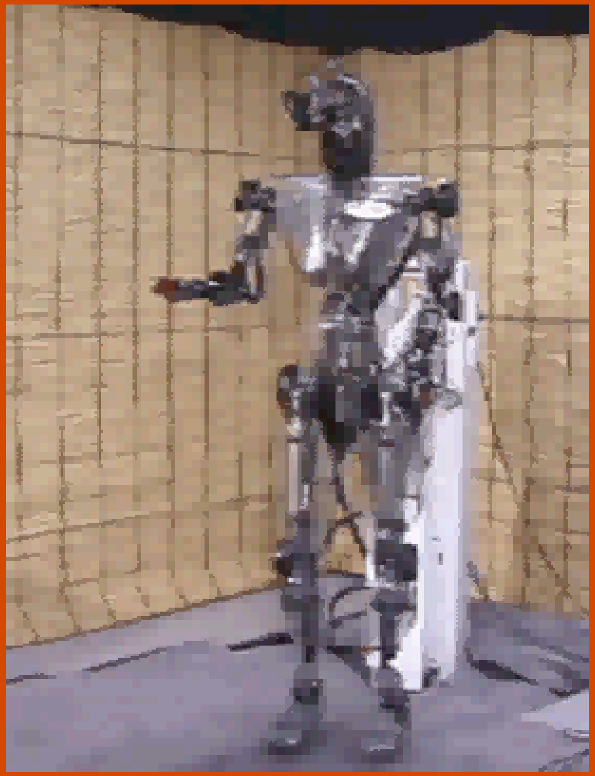
- Large variation in naturalness obtained across movements
  - movements 1, 4, 7 were seen as more natural
  - movements 1, 4, 7 are the slow movements

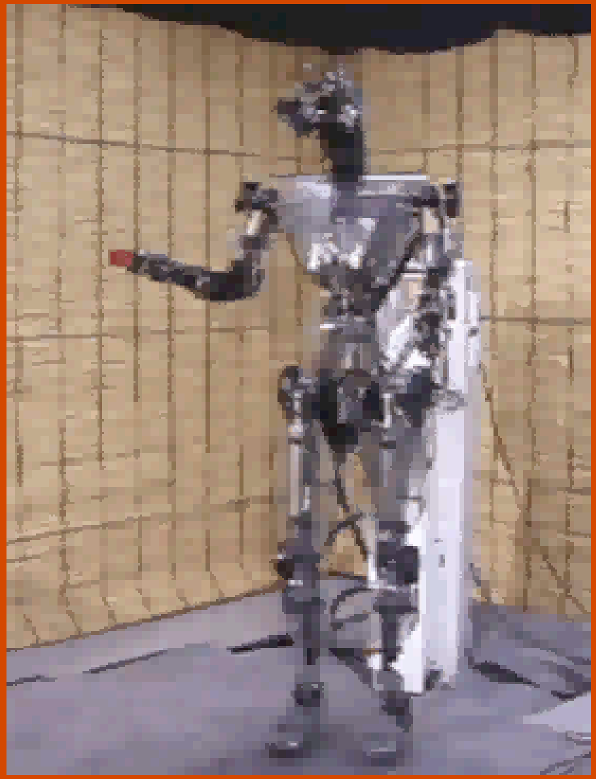


Example

Slow
(movement 4)

Fast
(movement 2)





Question

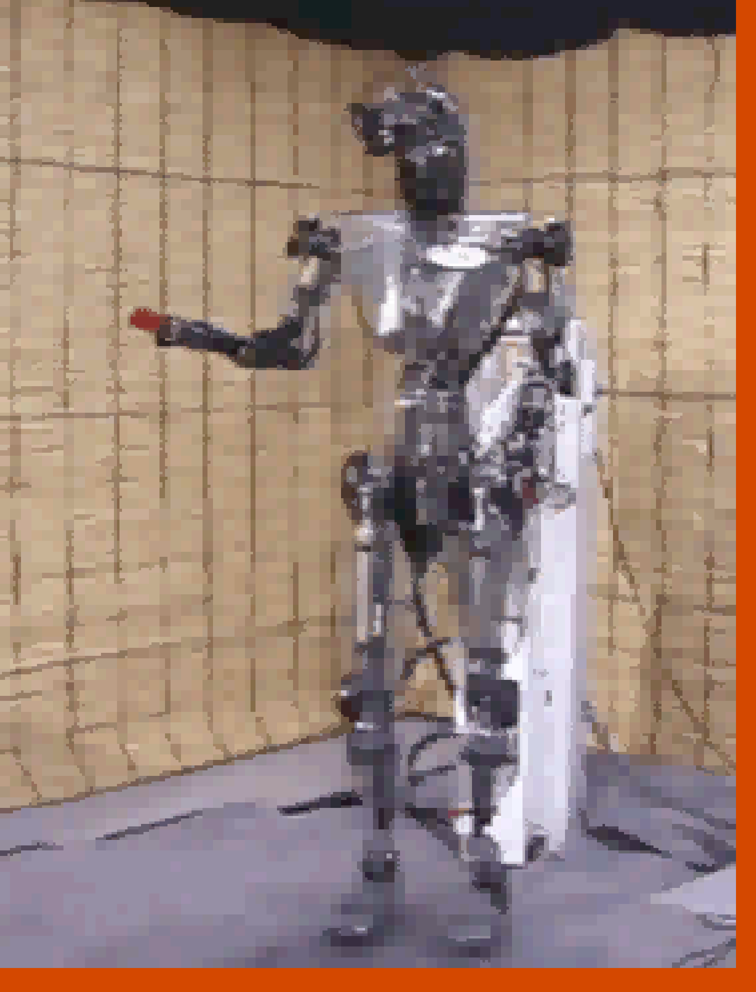
- Why are the fast movements on the robot seen as less natural?
- Our hypothesis was that movement artifact at the beginning and end of movement was causing the decrease in naturalness ratings

New Experiment

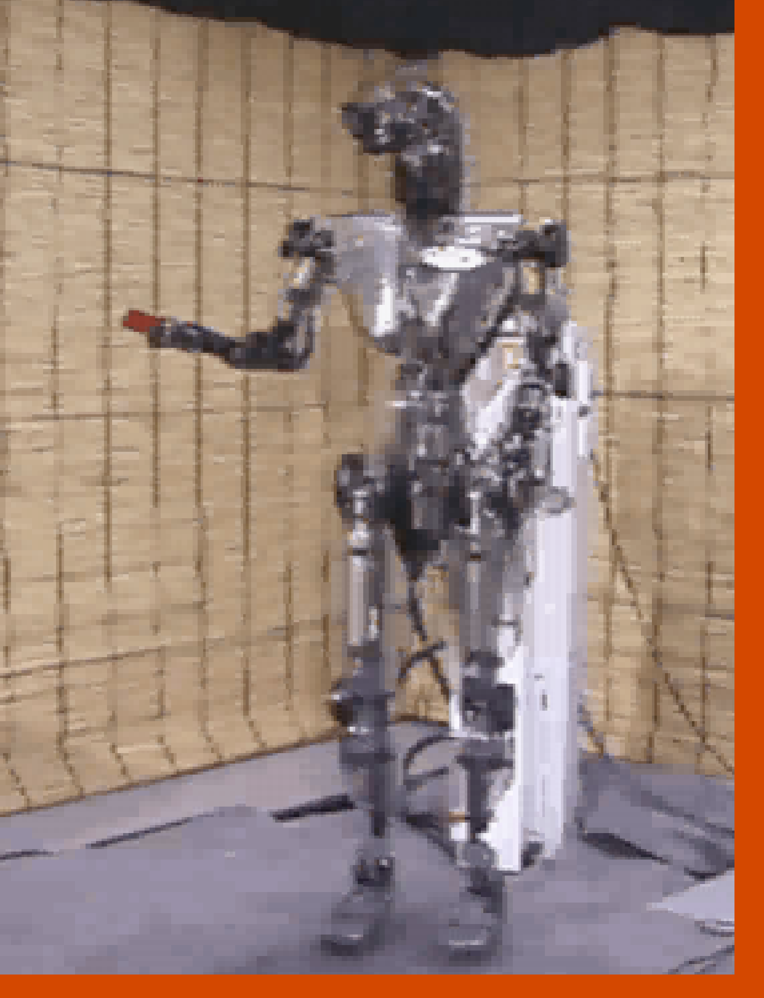
- Participants rated naturalness of the original movies as well as edited versions of these movies
- Editing eliminated any wind-up at the beginning of the movement or overshoot at the end of the movement

Example

Original

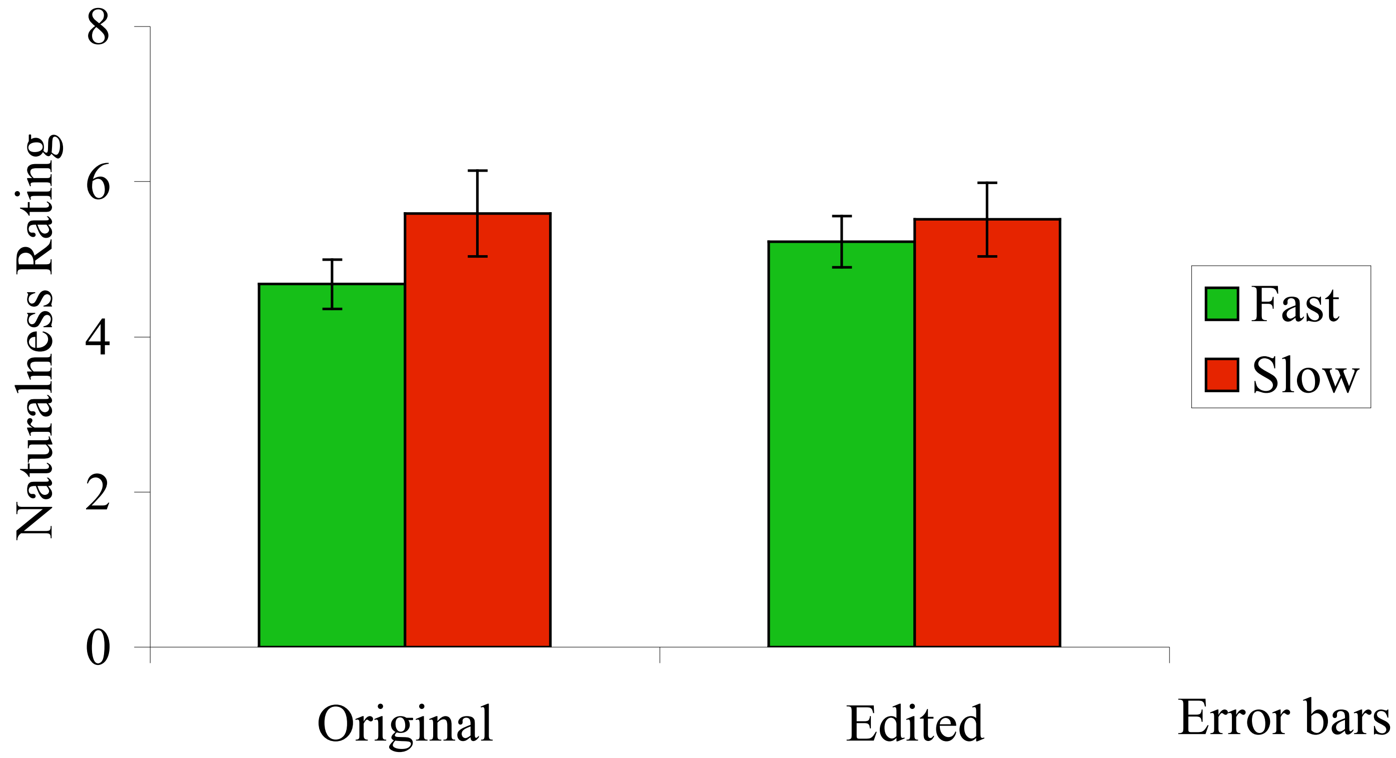


Edited



Prediction

- A comparison of average ratings of naturalness for fast vs. slow movements should reveal:
  - Original movements have lower ratings of naturalness for fast movements compared to slow movements
  - Edited movements will show no difference between fast and slow movements

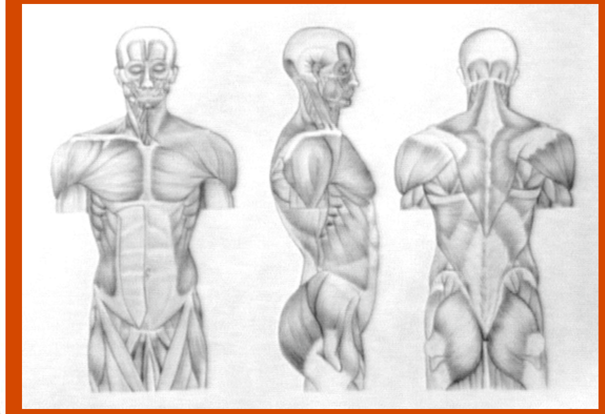


Error bars indicate 95% confidence intervals

Results of Naturalness Ratings

What is the source of this movement artifact on the robot?

- Speculations
  - Actuator bandwidth
  - Low level controller
  - Mechanical Design



Summary

- Substantial differences were noted between the visual perception of the simulated and actual robot motion
- Naturalness ratings, although general purpose, seem limited in what they reflect about a perceived movement

Brains

Neural Pathways for Action Understanding

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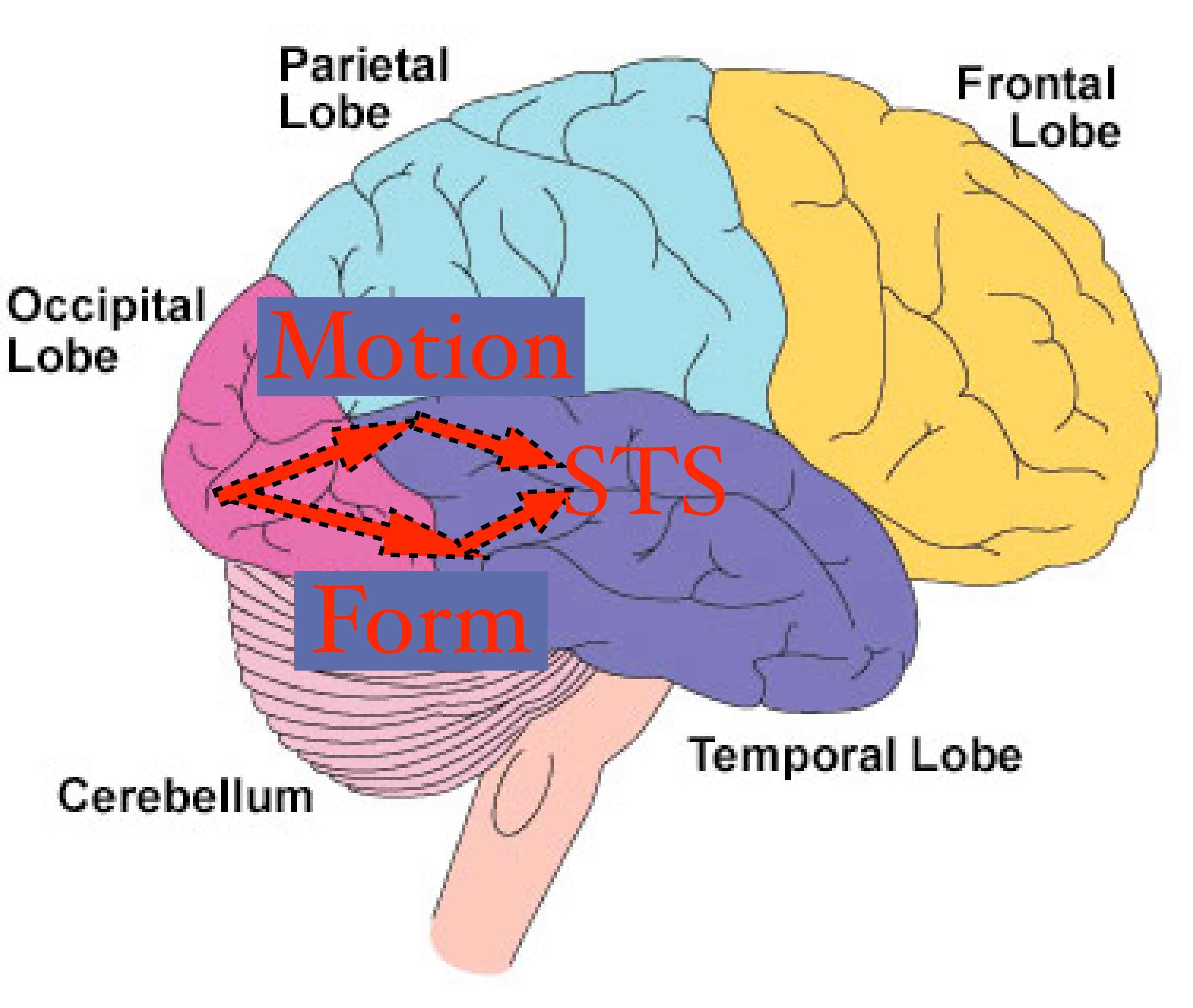
Special thanks to Vaia Lestou at Glasgow and Zoe Kourtzi at the Max Planck Institute for Biological Cybernetics

Overview

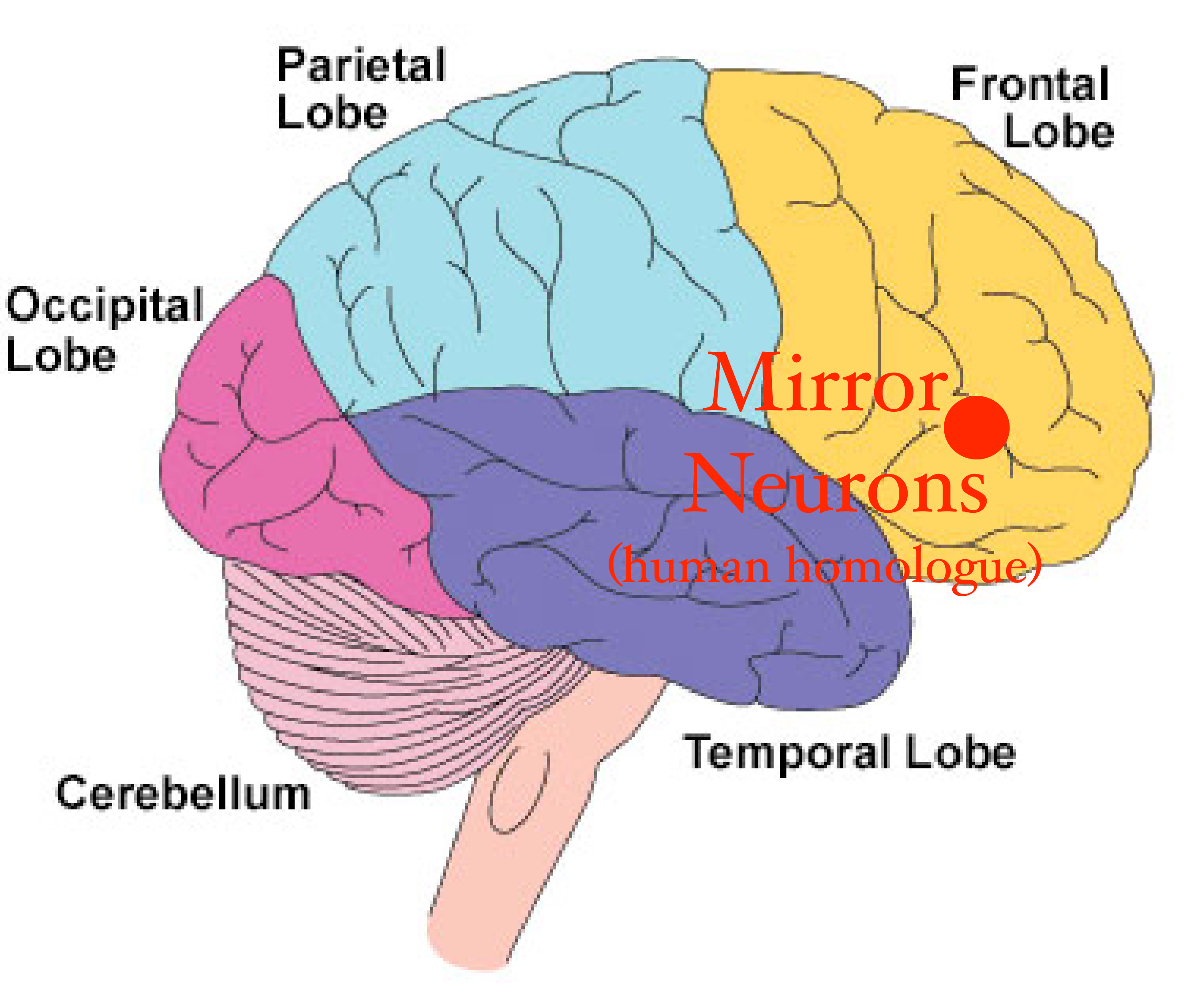
- Review brain areas established to be involved in action recognition
- Discuss a proposed brain circuit that includes these areas
- Our approach to exploring this circuit

Form and Motion



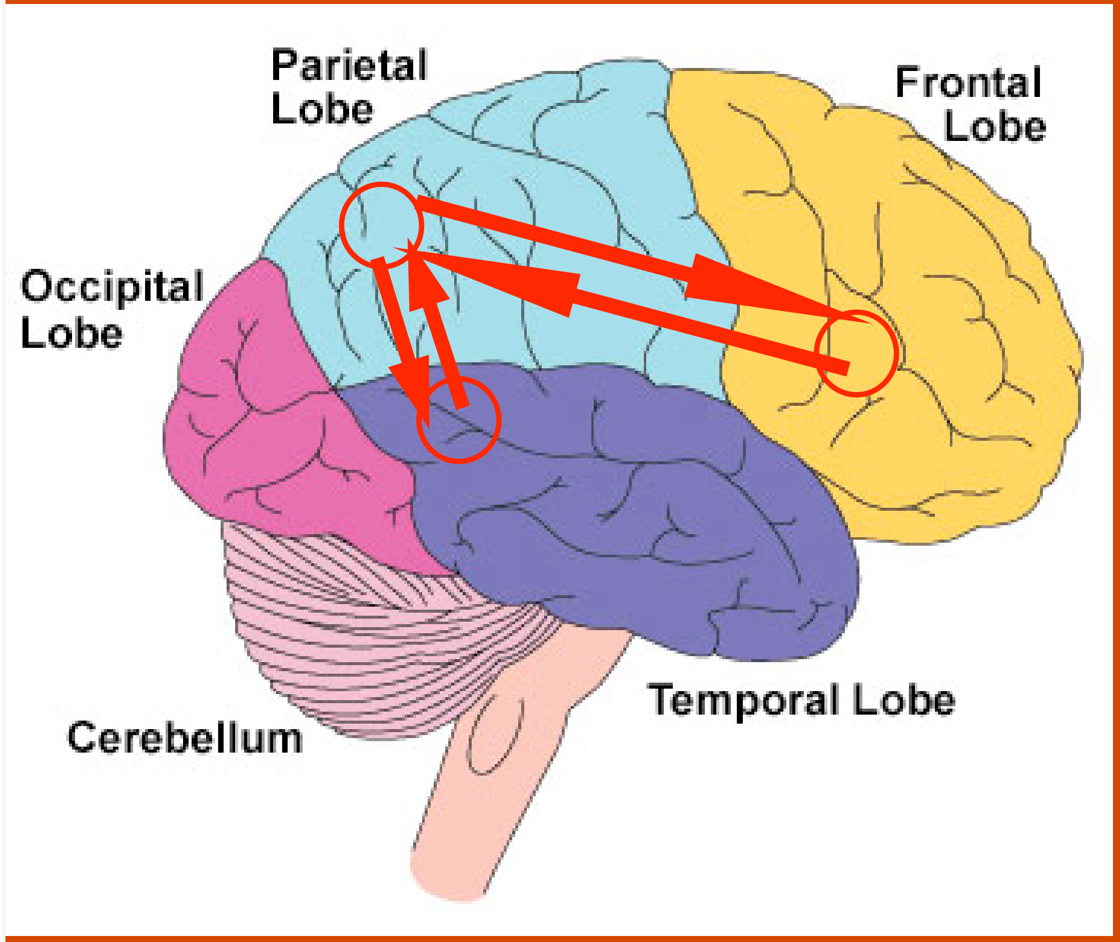
- It is proposed that body posture is processed separately from body motion in early visual processing
- posture and motion of human movement are reunited at the superior temporal cortex (STS), (Oram & Perrett, 1994)

Mirror Neurons



- Special visuomotor neurons located in premotor cortex termed Mirror Neurons are active both during performing an action and observing it being performed (di Pellegrino, Fadiga, Fogassi, Gallese, Rizzolatti, 1992)

Brain Circuit

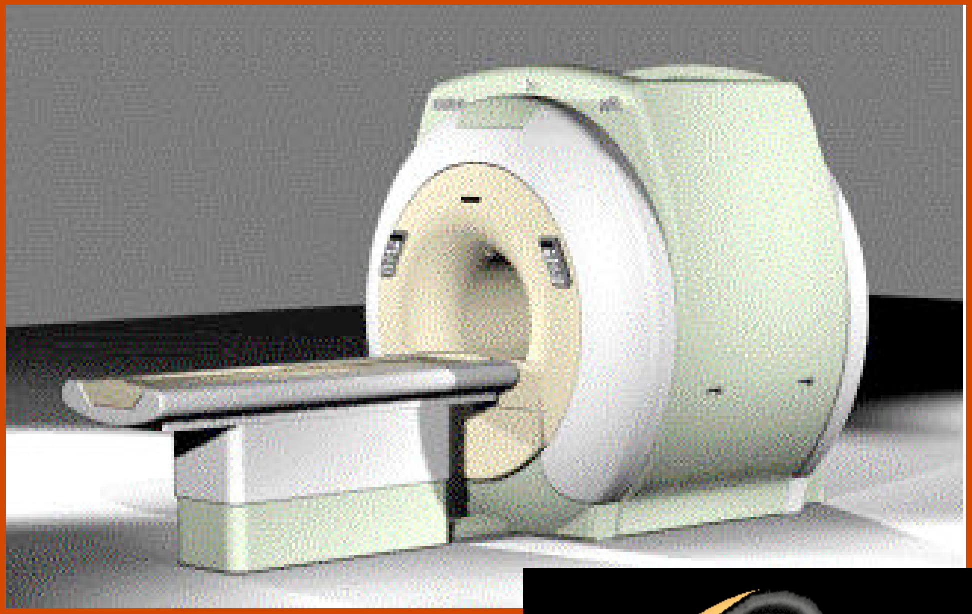


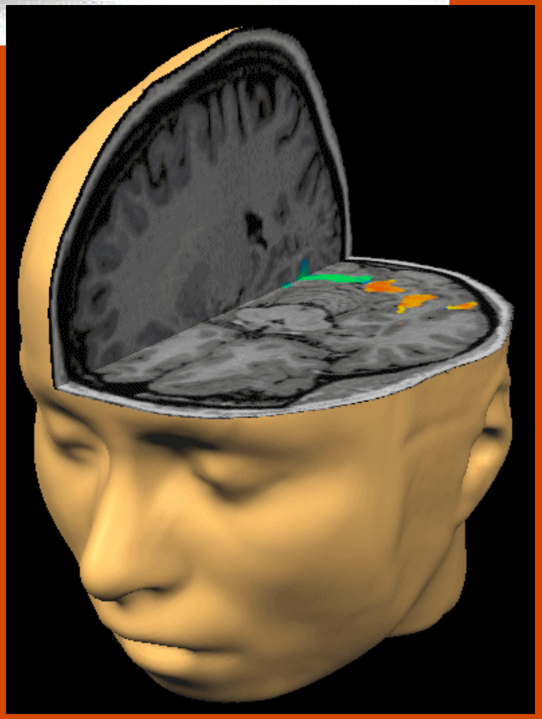
- It has been proposed that the temporal and frontal areas are connected via links in the parietal cortex
- This circuit has been explored via analysis of its mirror properties (Rizzolatti & Lupino, 2001; Iacaboni, in press)

Our Approach

- Movement decomposition into:
  - Goals - the purpose of the movement
  - Kinematics - the pattern of limb motion
- Examine how the brain circuit for action understanding differentially processes goals and kinematics

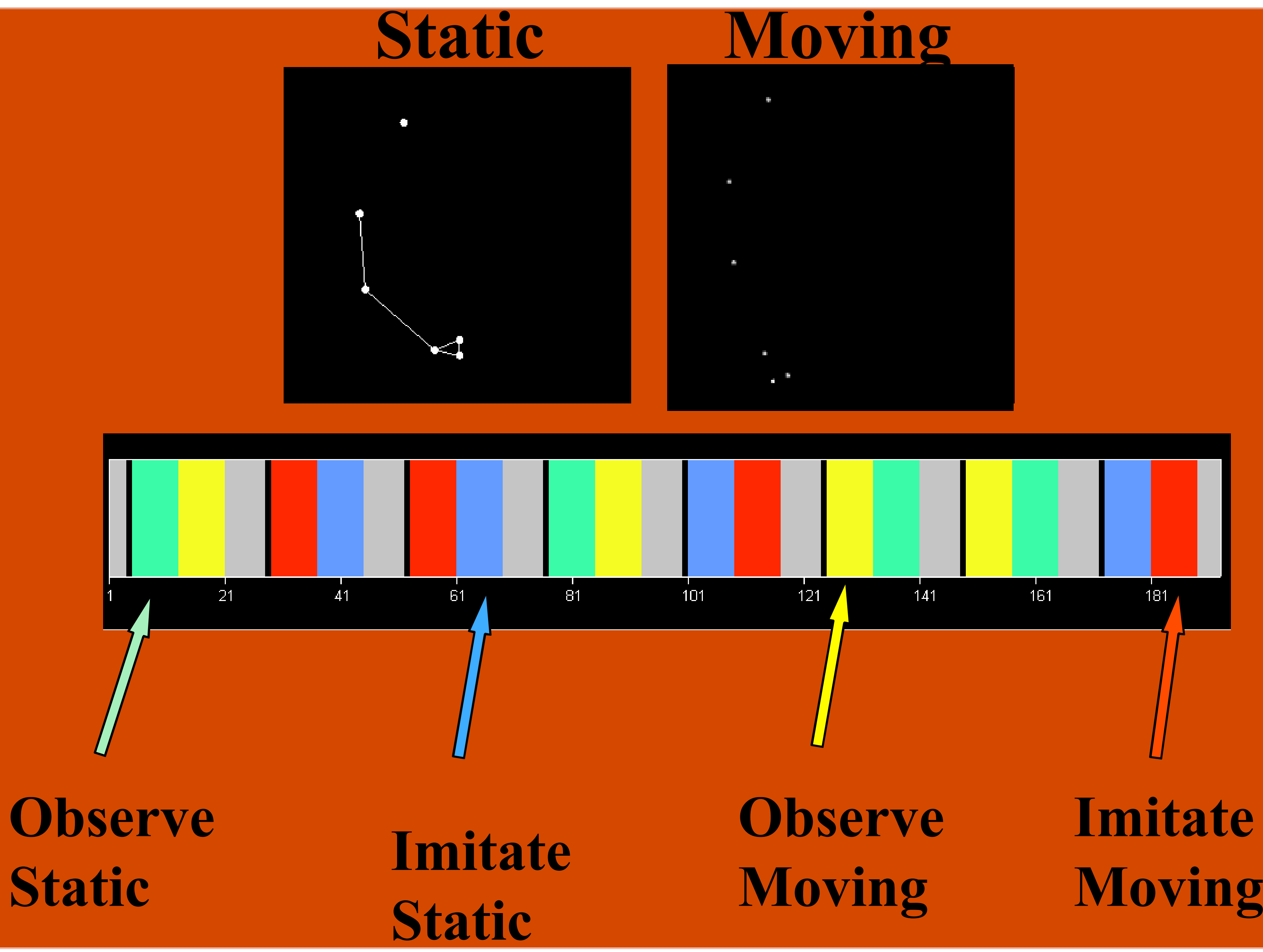
fMRI Experiments

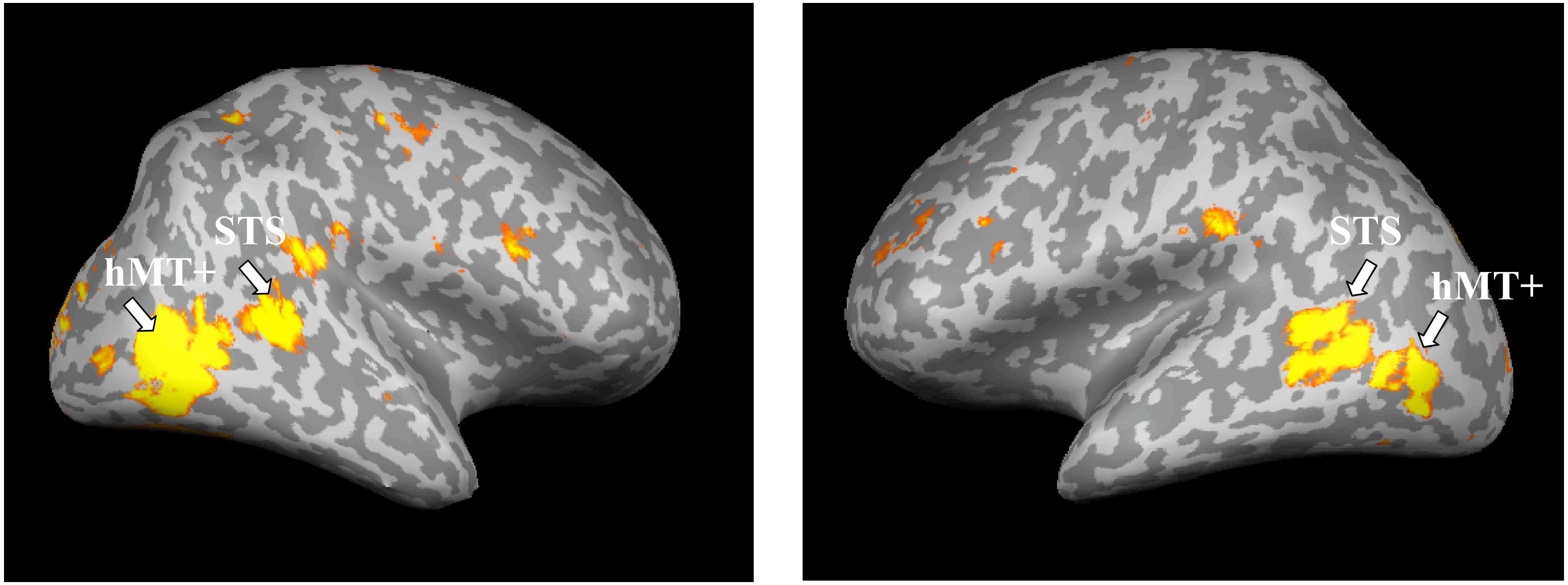




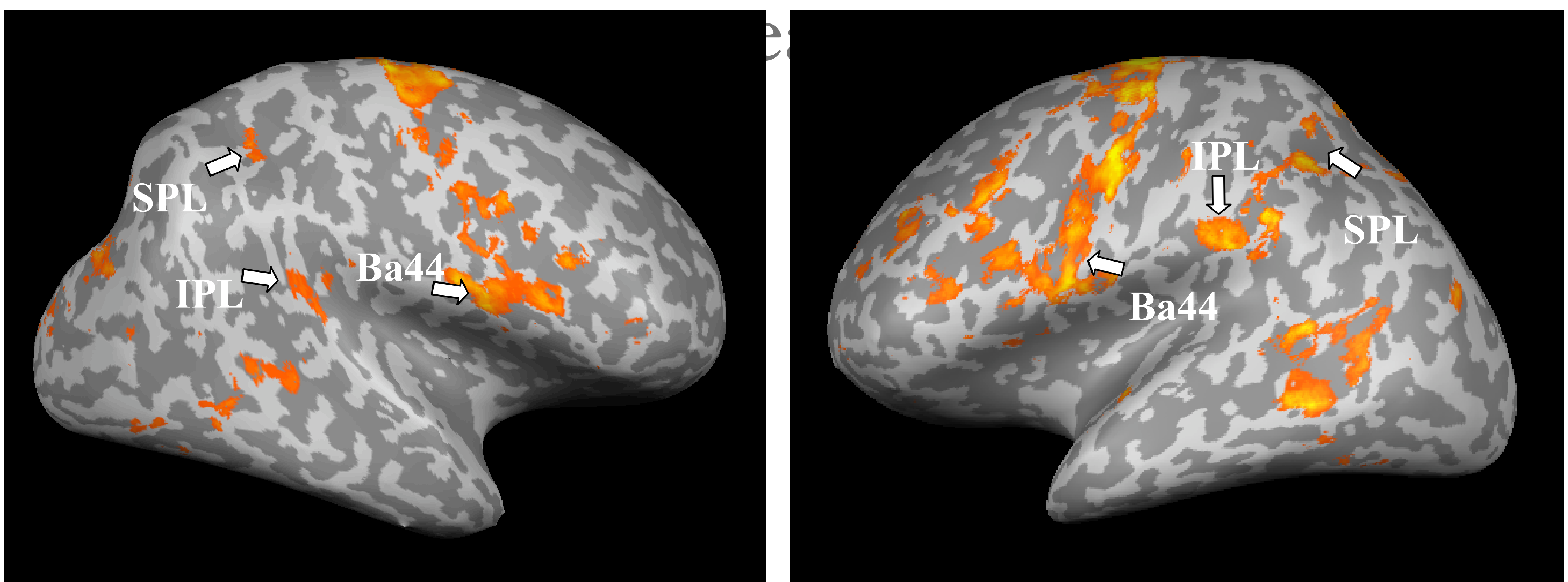
- Region of interest adaptation design
  - define regions of interest (ROI)
  - measure adaptation of ROI across different conditions of stimuli pairs

Defining Regions of Interest

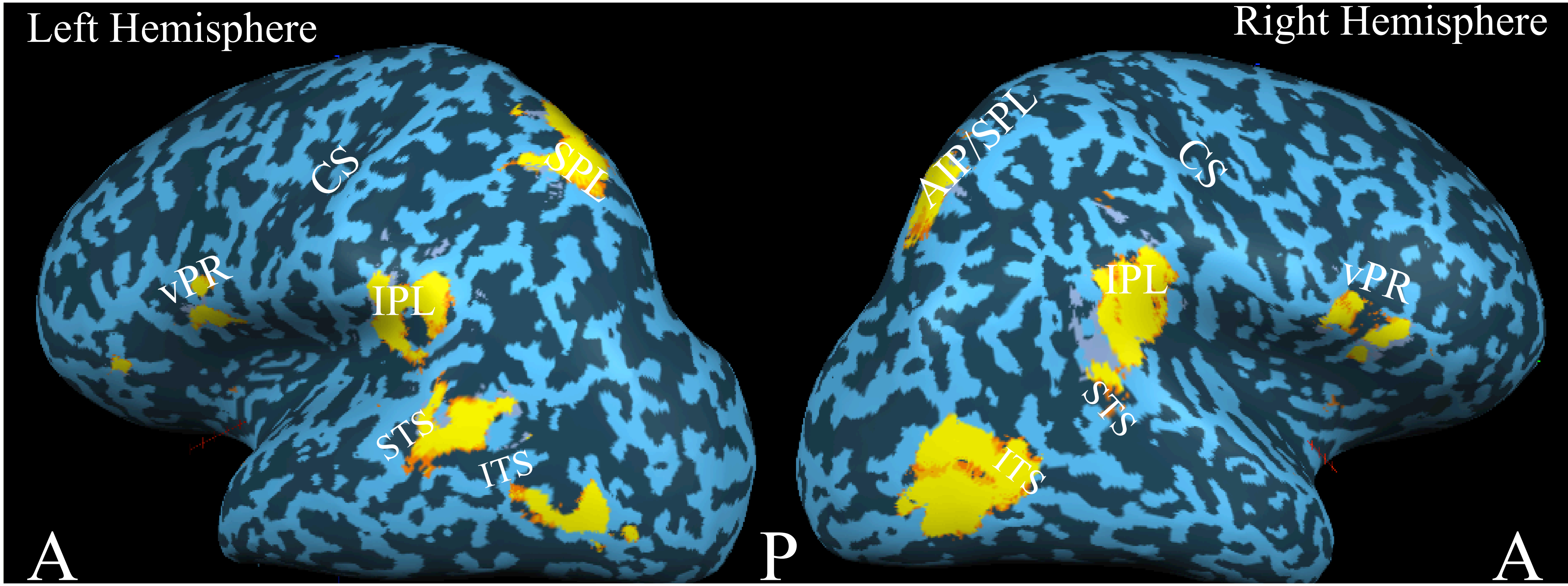




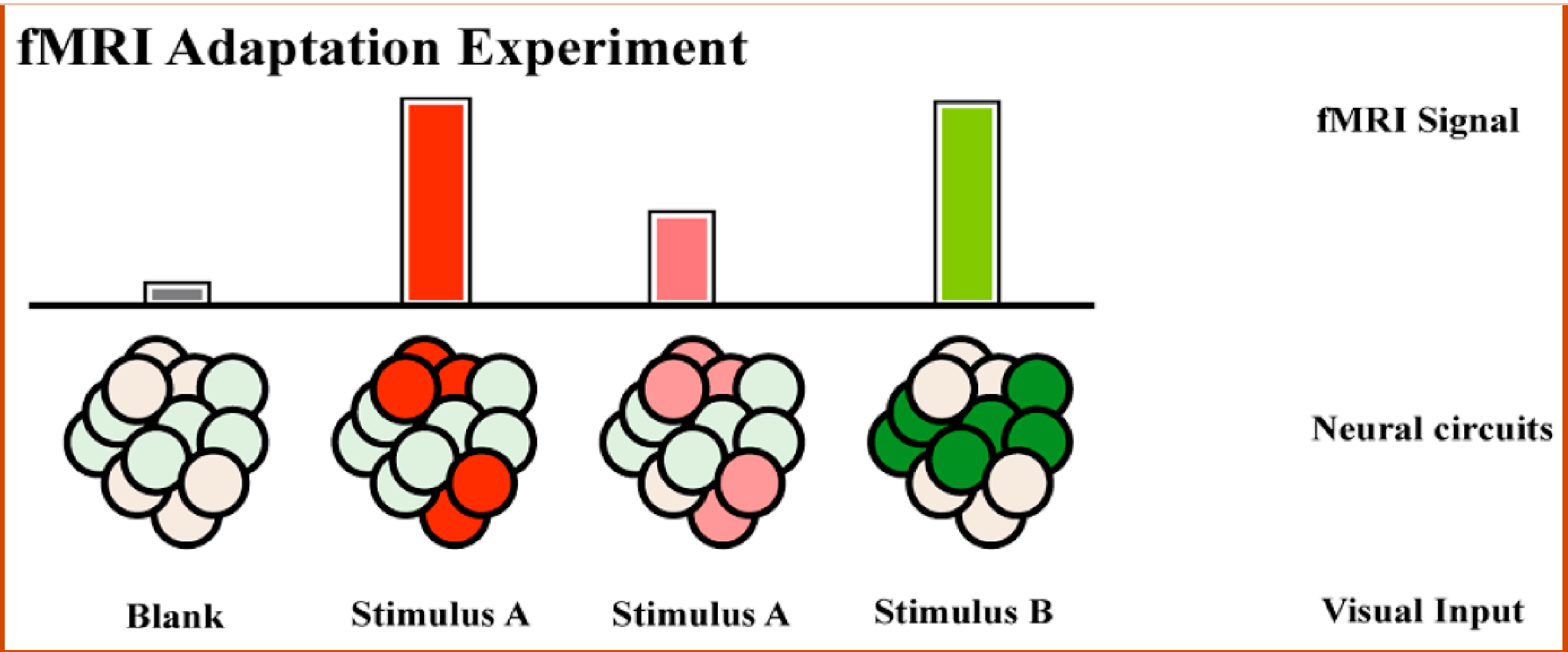
Moving > Static - motion & biological motion



Imitation > Observation - imitation



Regions of Interest



Adaptation - activity decreases as a brain region is exposed to the same stimulus property to which it is sensitive

Rebound - activity increases when a brain region is exposed to a different stimulus property to which it is sensitive

Adaptation & Rebound

Goals & Kinematics

- If a brain region is sensitive to only goals then we expect no rebound when the kinematics changes and goal stays the same
- Rebound with same goal but different kinematics reflects processing of “raw” movement properties

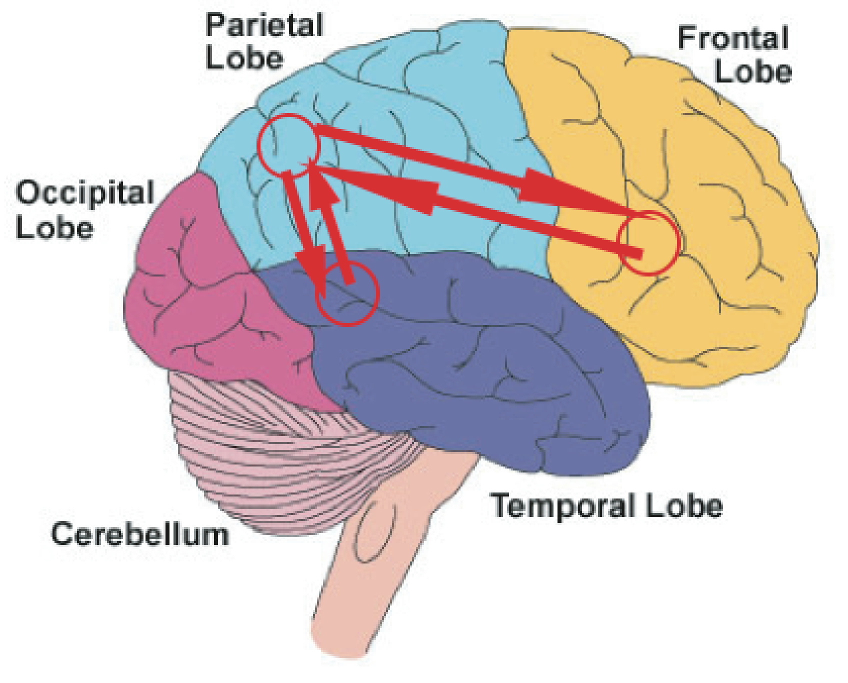
Stimuli

- Stimuli pairs designed to study adaptation to either goals or kinematics (knocking, lifting, throwing, waving)
  - same action (goal) twice
  - same action (goal) but different kinematics
  - different actions

Note on Method

- All motion displays used as stimuli derived from 3D motion capture obtained by attaching markers to actors
- To obtain different kinematics of the same movement we used the temporal morphing technique of Hill & Pollick (2000) which preserves spatial path while parametrically varying temporal sequencing

Hill, H, H., Pollick, F.E. (2000). Exaggerating temporal differences enhances recognition of individual from point light displays. *Psychological Science*, **11**, 223-228.



Summary of Results

- fMRI study of adaptation in this brain circuit revealed
  - functional distinction between goals and kinematics is evident
    - high level regions (premotor) appear to exclusively process goals, though lower level visual regions (STS) also process goals
    - parietal areas process both kinematics & goals

Design and Interaction

The Uncanny Valley
Form, Motion and Animacy
Case Study - Robot Toys

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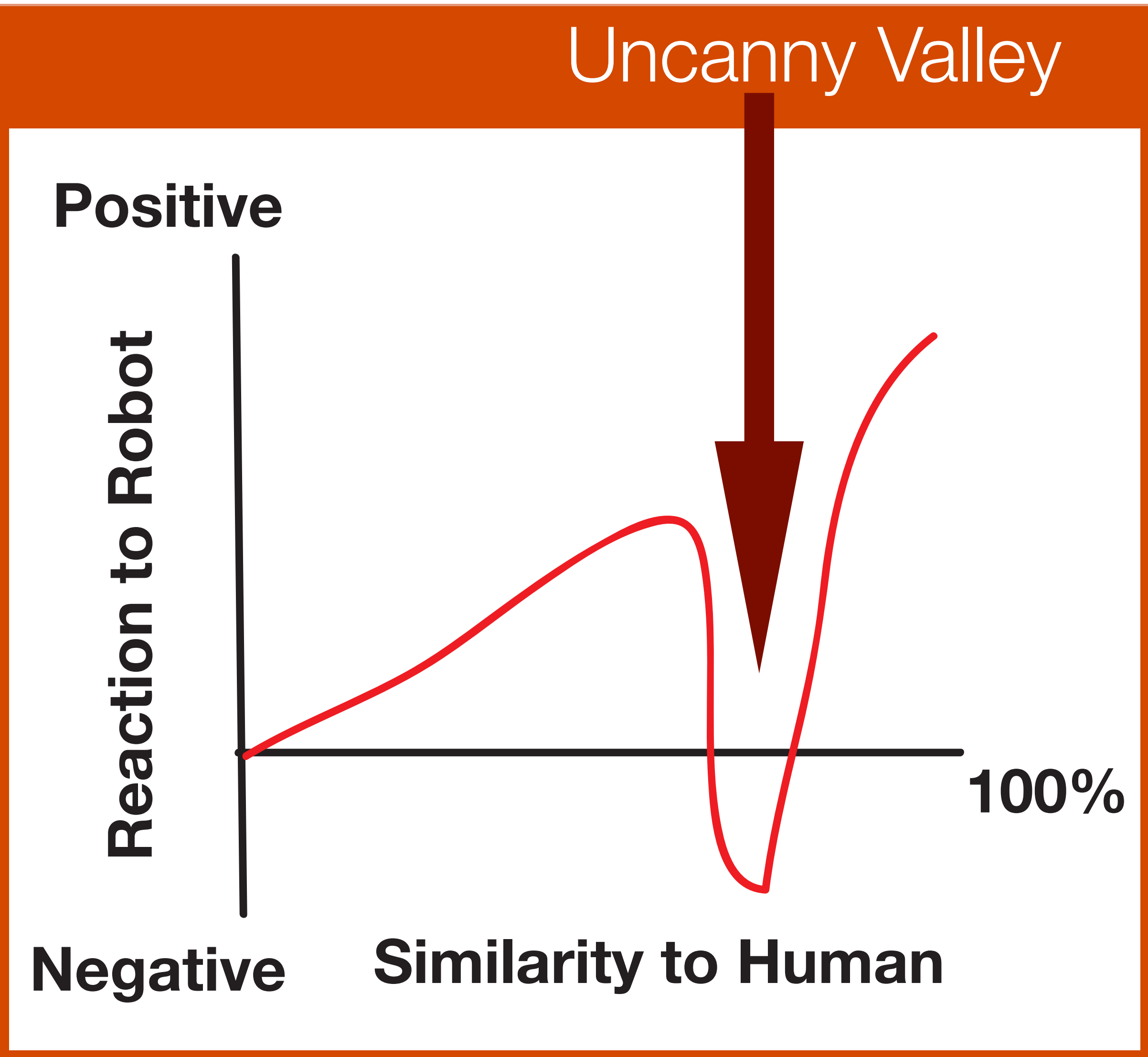
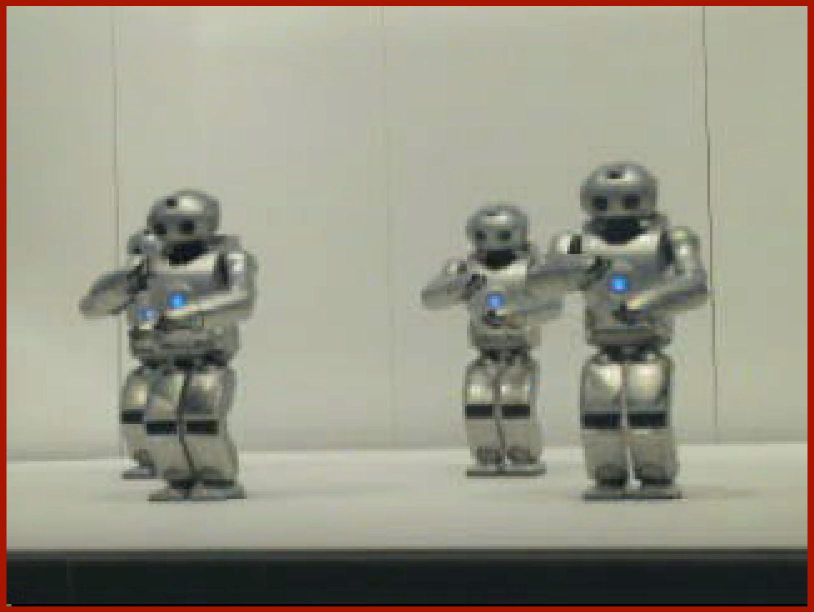
The Uncanny Valley

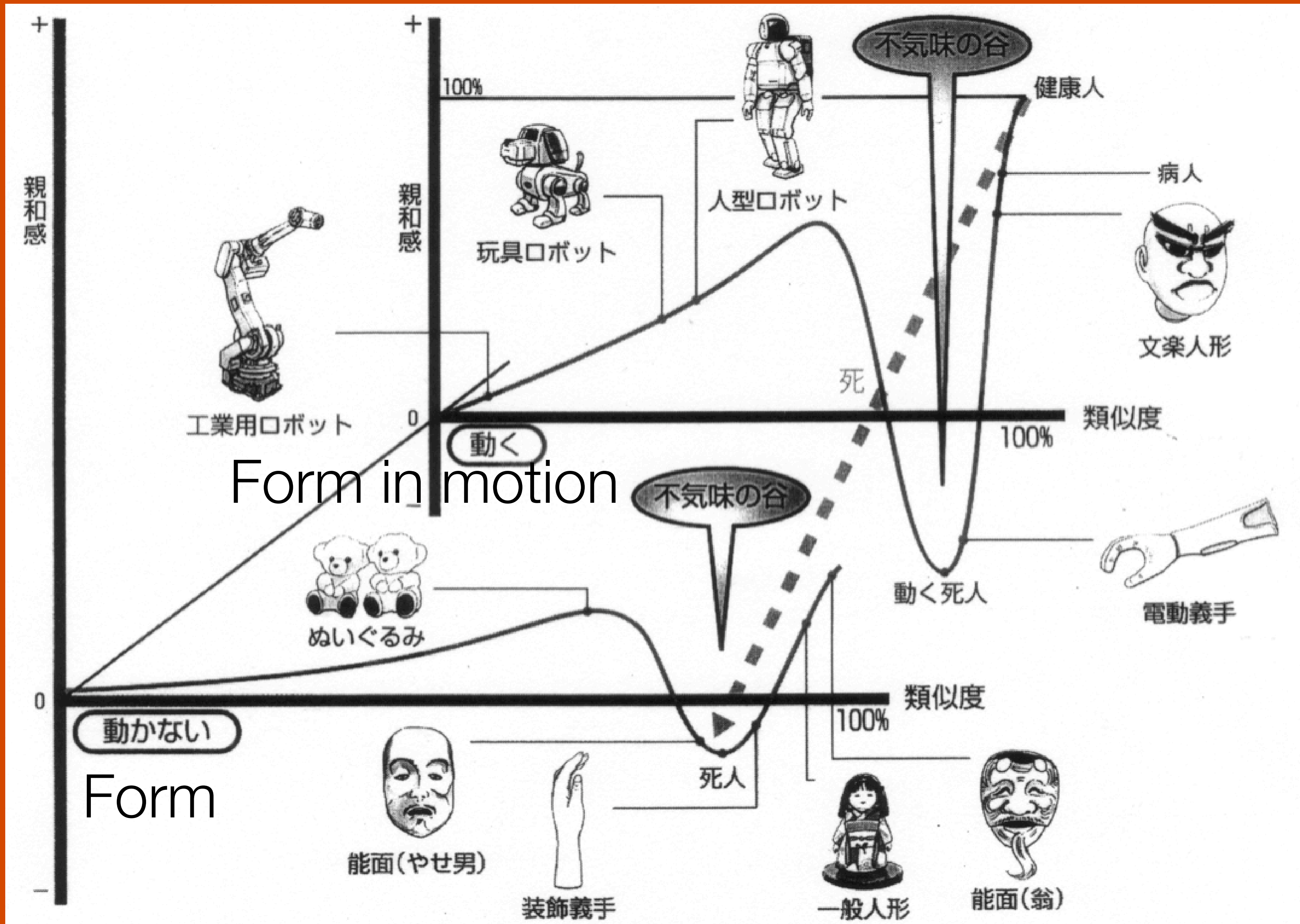
- To the right is the basic version of the uncanny valley reaction to a robot is plotted against its similarity to a human likeness
- Originally described by roboticist Masahiro Mori in 1970 and called 「不気味の谷」 or “bukimi no tani” in Japanese





What do you think about the "character" of robots?

Take QRIO as an example. We suggested the idea of an "eight year-old space life form" to the designer -- we didn't want to make it too similar to a human. In the background, as well, lay an idea passed down from the man whose work forms the foundation of the Japanese robot industry, Masahiro Mori: "the valley of eeriness". ***If your design is too close to human form, at a certain point it becomes just too . . . uncanny.*** So, while we created QRIO in a human image, we also wanted to give it little bit of a "spaceman" feel.



- Motion can interact with form to intensify the impact
- Described in original 1970 paper by Mori (in Japanese)
  - Dave Bryant review on web
  - Robocon 2003, #28 (in Japanese)

Form and Motion

Theoretical Support for the Uncanny Valley?

- As far as I can tell, no direct research exists. However, at least two factors seem plausible
  - distinction between form and motion information
  - importance of motion

Form and Motion

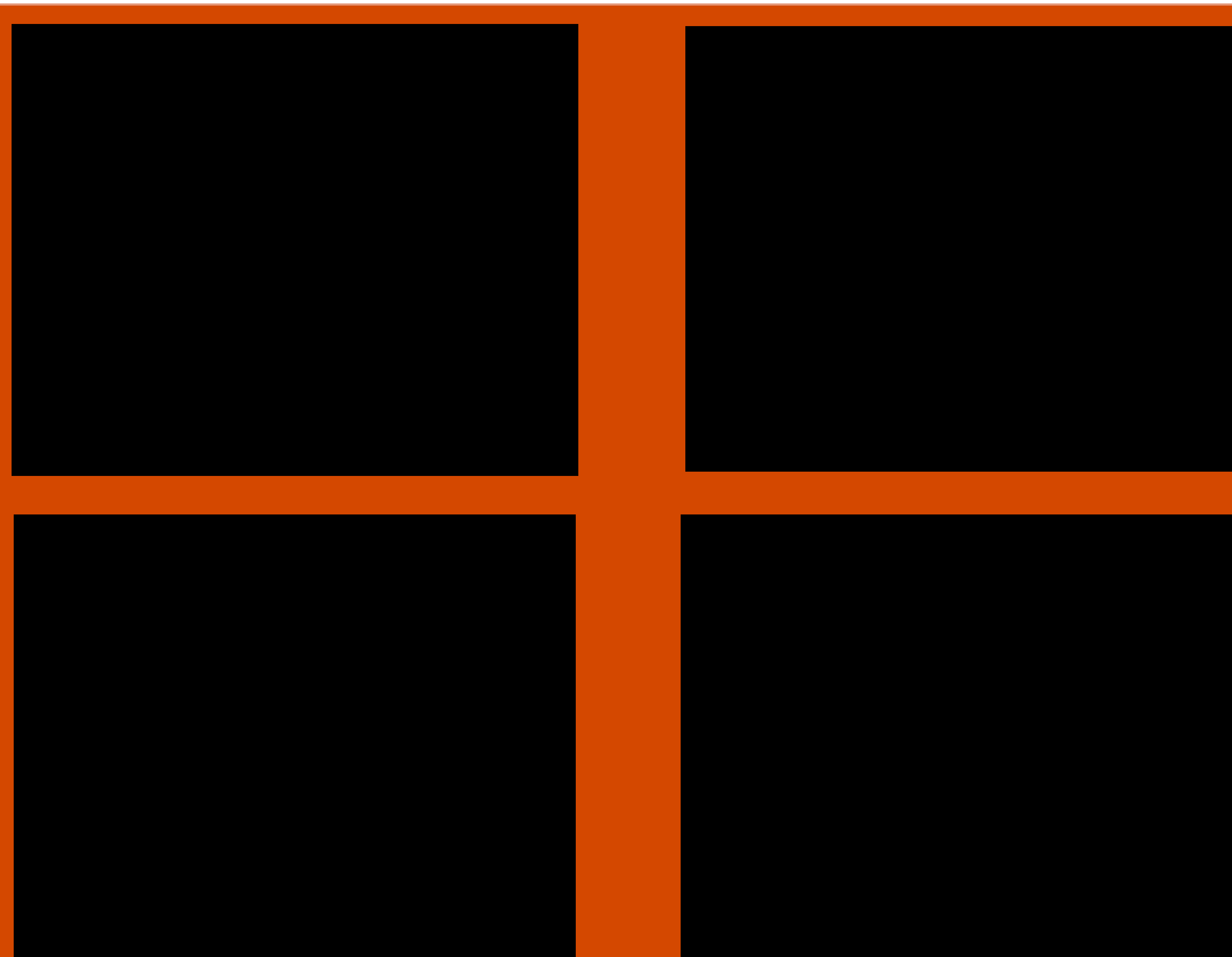
- From the analysis of visual pathways and various other sources, the processing of form and motion appear distinct and thus could independently contribute

Motion

- Motion by itself is thought to be sufficient to make complex social attributions
- Viewers of the classic Heider & Simmel (1944) sequence consistently describe it using causal attribution of social events

Heider & Simmel (1944) display provided by James Davis of Ohio State

Animacy from Video



McAleer, P., Mazzarino, B., Volpe, G., Camurri, A., Smith, K., Paterson, H., Pollick, F.E. (2004) Perceiving Animacy and Arousal in Transformed Displays of Human Interaction. Proceedings for The 2nd International Symposium on Measurement, Analysis and Modelling of Human Functions and The 1st Medditeranean Conference of Measurement, 67-71

Summary

- The Uncanny Valley appears to be a valid and important design principle
- As a psychological principle it is plausible, and is consistent with current research into movement perception. However, currently it is descriptive rather than prescriptive

Case Study: Mobile Robotic Toys for Autistic Children

- Work led by François Michaud at Université de Sherbrooke, Québec Canada
  - Francois.Michaud@USherbrooke.ca

Autism

- Autism is a pervasive developmental disorder characterized by
  - severe impairments in social skills
  - presence of stereotyped and repetitive interests and activities
  - individually unique hyper and hyposensitivity to sensory stimuli
- Unfortunately little is known of the basis of the condition

Analysis of the Potential for such an Application

- A toy misses the uncanny valley
- Sensory qualities of robot can be tuned to that of a specific child
- Pattern of social interaction can be made consistent to help guide the development of social skills
- Form and motion can be based on familiar object with clear goals

RoboToy Contest



- Annual student contest to design a robot toy for use by autistic children



RoboToy Contest 2003 Winners

Emotion Identification

Action Identification

Language Identification

Discussion

Overview

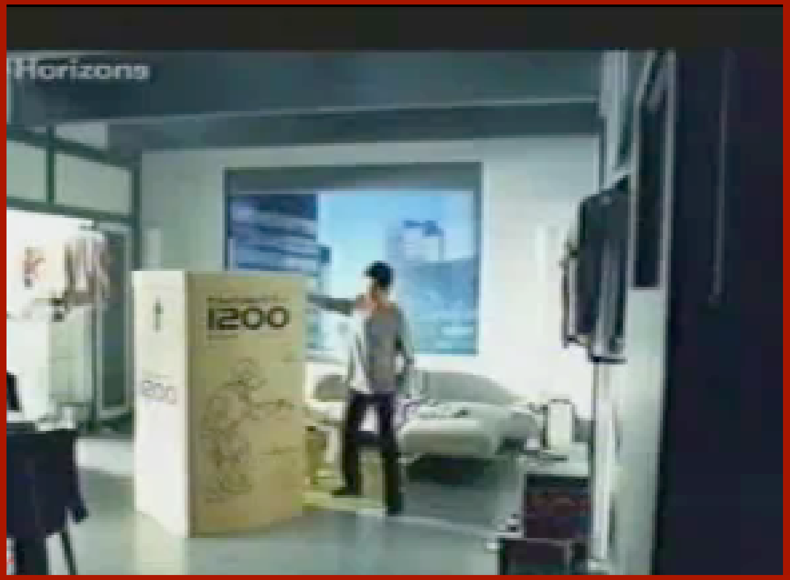
Overview 1

- During an interaction, simple aspects can lead more intelligence to be attributed to the robot
- Small mechanical deviations result in diminished appraisal of movement though huge failures of motion planning might not be detected

Overview 2

- A possible explanation to understanding human-robot interaction lies in how goals and kinematics are hierarchically processed in the human brain
- More experimental data and theoretical insight is needed to guide the development of a theory of human robot interaction

Thanks!



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