THE HAND EMBODIED

IP in FP7-ICT-2009-4-2-1
"Cognitive Systems and Robotics"

HANDS.DVI

A DeVice-Independent programming and control framework for robotic HANDS

ECHORD Experiment

L'Aquila, SIDRA 2010

Project Highlights

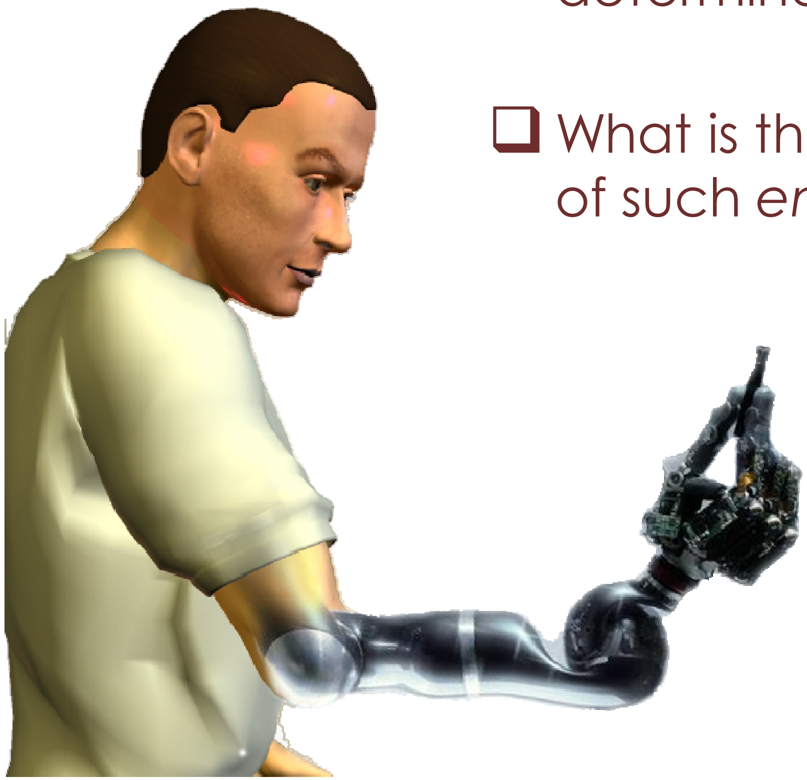
- ***THE Hand = Cognitive organ***

  active touch **and** its physical embodiment;

- How the **embodiment constraints** affect and determine the **learning and control strategies**

- What is the **conceptual structure and** the **geometry** of such *enabling constraints*:

  - **motor synergies**: correlations in redundant hand mobility
  - **sensor synergies:** correlations in redundant receptors (cutaneous, kinaesthetic, multi-cue integration and saliency)
  - **sensorimotor synergies**



Enabling Constraints

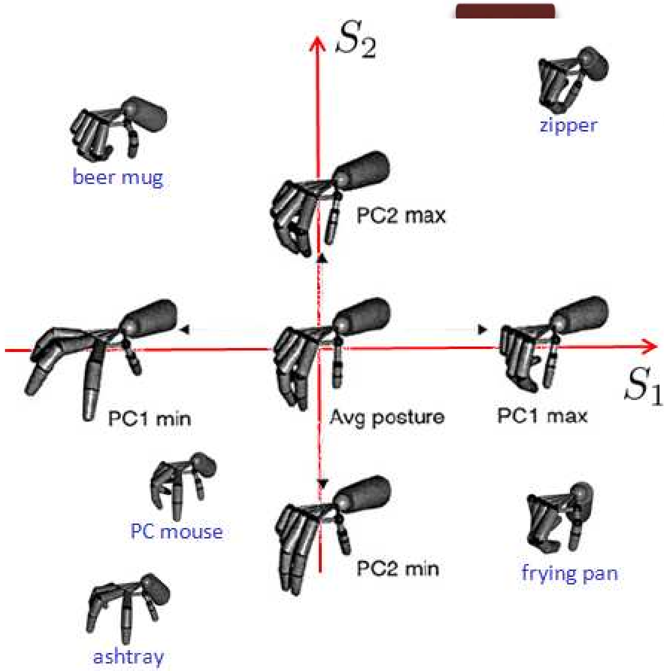
- Central Concept: *constraints* that the hand embodiment imposes on the learning and control of its strategies
  - Not merely bounds limiting performance
  - Rather, making it possible for the brain to deal with the huge redundancy of sensory and motor apparatuses
  - Ultimately, dominating factors in affecting and determining how cognition has evolved into the admirable form we observv on Earth
- "*Enabling constraints*" organizing THE Hand Embodied

Postural Synergies

- Extensive neuroscientific evidence for the ***existence of sensorimotor synergies and constraints*** Babinski (1914!), Bernstein, Bizzi, Arbib, Jeannerod, Wolpert, Flanagan, Soechting, Sperry, …

- Quantitative work on hand postural synergies dates back a decade only

Postural Synergies



Santello, Flanders, Soechting
J. Neuroscience, 1998

- Santello et al. (1998) investigated the hypothesis that "*learning to select appropriate grasps is applied to a series of inner representations of increasing complexity, which varies with experience and degree of accuracy required.*"
  - 5 subjects were asked to shape their hands in order to mime grasps for a large set (57) of familiar objects;
  - Joint values were recorded with a CyberGlove;
  - Principal Components Analysis (PCA) of these data revealed that the first two Principal Components or postural synergies account for $\sim 84\%$ of the variance, first three $\sim 90\%$;
  - PCs (eigenvectors of the Covariance Matrix) can be used to define a basis for a subspace of the joint space.

The Shape of Synergies

Postural synergies (aka eigengrasps or principal grasp components) are the eigenvectors of the joint data covariance matrix;

First synergies contain most of hand posture information;
Higher-order synergies used for fine adjustments

PCs can be collected in a synergy matrix:

$$S = \left[\begin{array}{c:c:c:c:c} \vdots & \vdots & \vdots & \vdots & \\ S_1 & S_2 & S_3 & \cdots & S_n \\ \vdots & \vdots & \vdots & \vdots & \end{array} \right]$$

S_1 (1-st synergy) S_2 (2-nd synergy) S_3 (3-rd synergy)

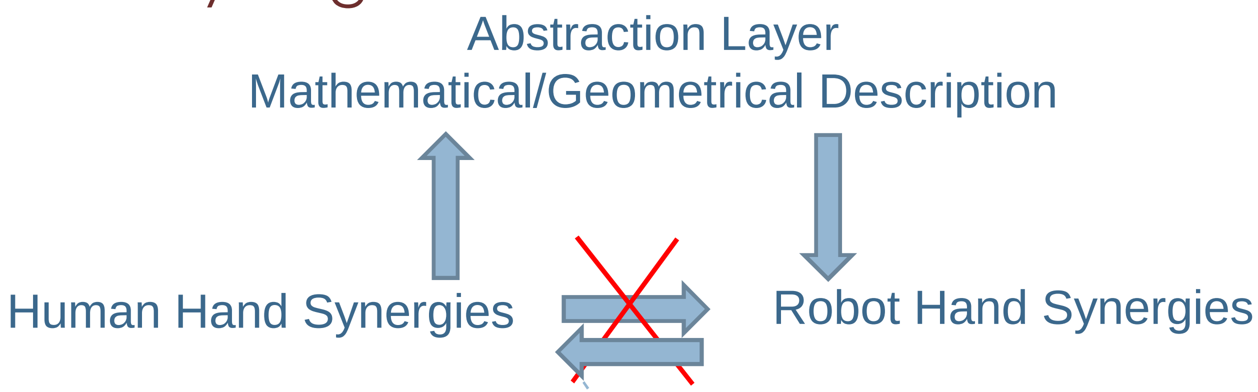
Project Highlights

- **Integration of the idea of synergies** from Neuroscience, Robotics and Haptics in a coherent theory and method for the design of :
  - simpler and more performing **system architectures** for the "hand" as a cognitive organ;
  - **robot hands** more simply programmed and more robustly adapting to different task/environment conditions;
  - radically new and improved **control architectures for haptic interfaces**;
  - new **neuro-prosthetic devices** based on seamless bidirectional sensorimotor information flow.

A key point

- ❑ Human postural synergies can not be applied to robotics blindly – rather suggest a suitable abstraction layer
- ❑ There is also something Robotics can contribute towards the understanding of human synergies:

– A mathematical description of the geometry of sensorimotor synergies



– An abstract, more parcimonious, *device-independent* description of different *hands* and a common framework for programming → **HANDS.DVI** – UNISI, IIT, UNIPI

Sensory Synergies

Example: The Bayesian Approach

$$P(stim \mid sensory\ data) = \frac{P(sensory\ data \mid stim) \cdot P(stim)}{P(sensory\ data)}$$

Cue Integration
=
Reduction of Redundancy

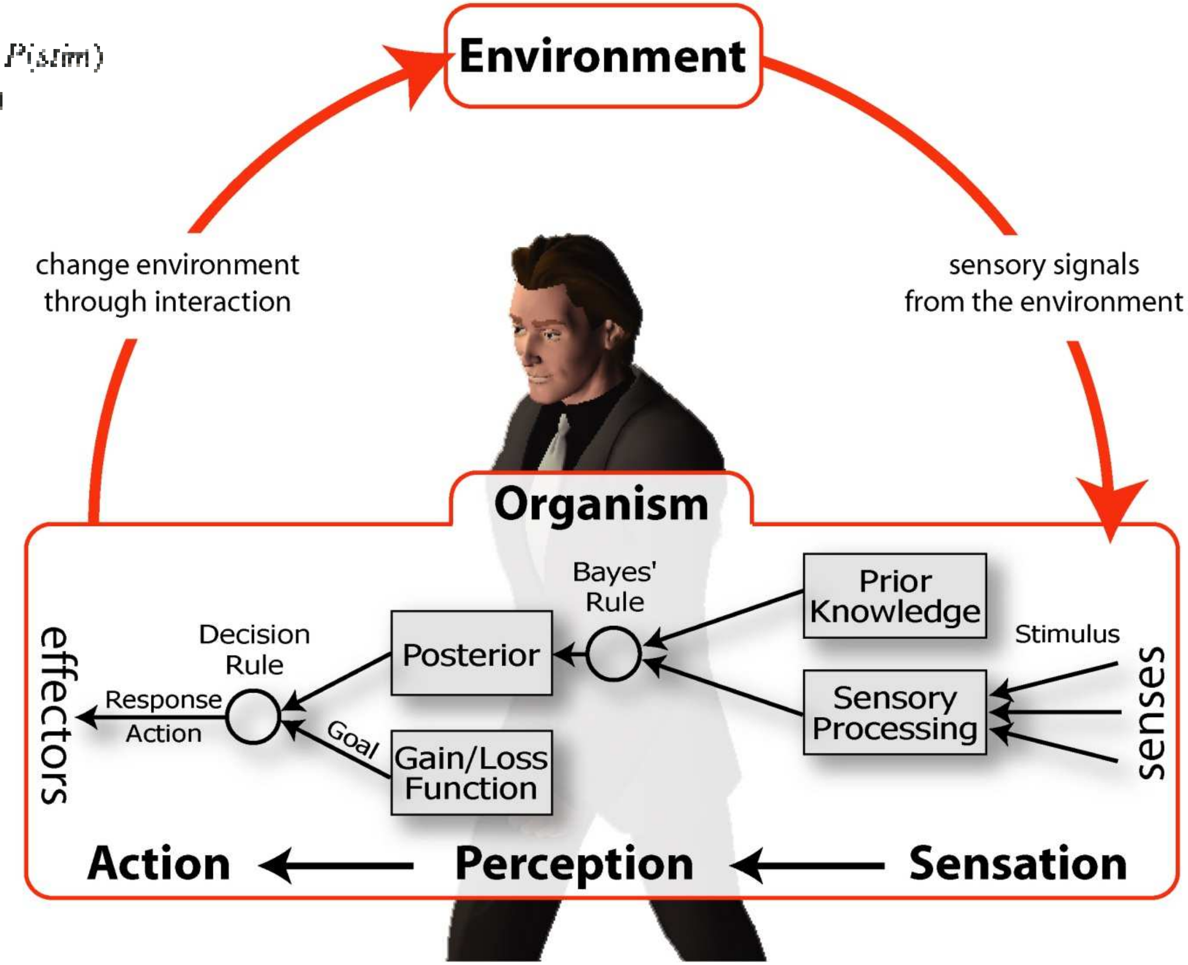
$$r = 1/\sigma^2$$

$$L = \sum w_i L_i$$

$$w_i = r_i / \sum r_j$$

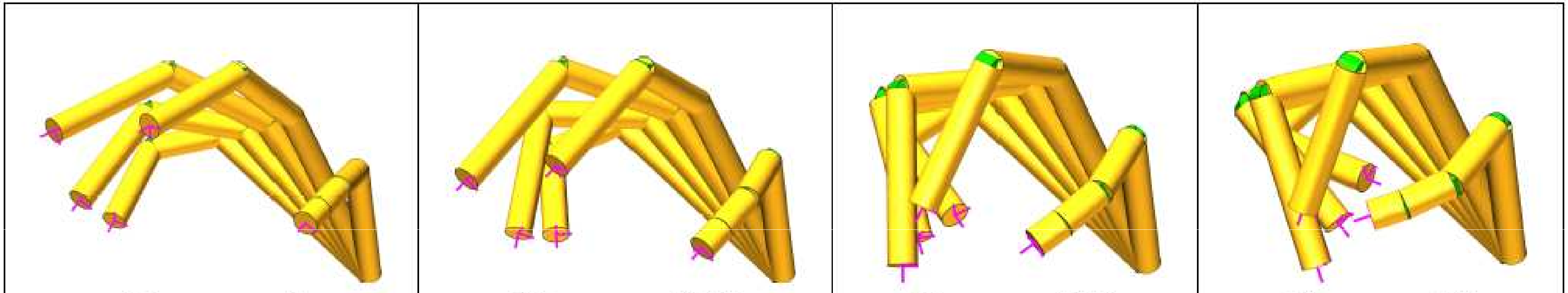
$$r = \sum r_i$$

E.g. force and position cue to haptic shape



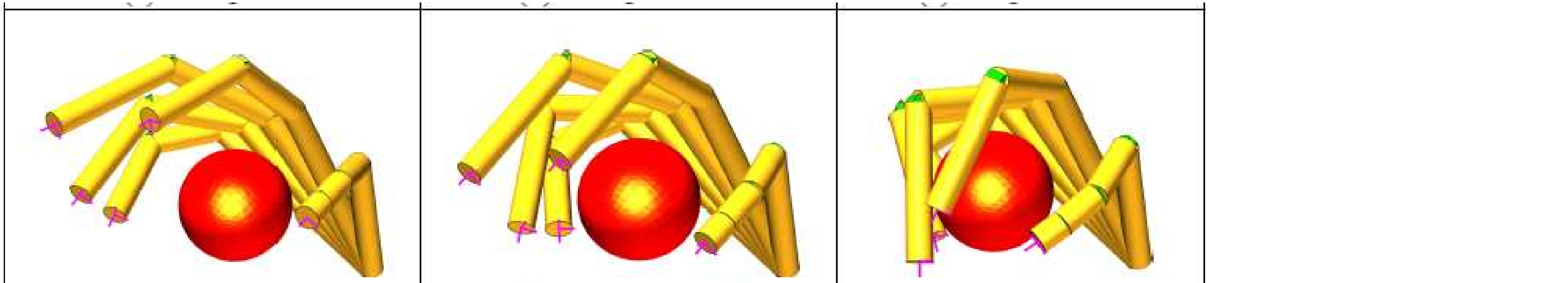
Motor synergies

- First synergy only



(a) $\sigma_1 = 0$ (b) $\sigma_1 = 0.35$ (c) $\sigma_1 = 0.70$ (d) $\sigma_1 = 1.0$

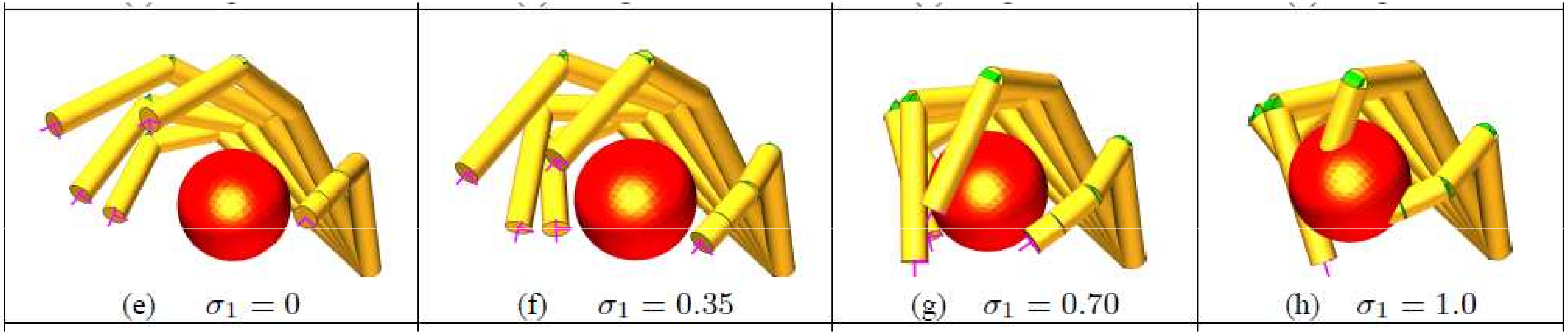
- Grasping an object



(e) $\sigma_1 = 0$ (f) $\sigma_1 = 0.35$ (g) $\sigma_1 = 0.70$ (h) $\sigma_1 = 1.0$

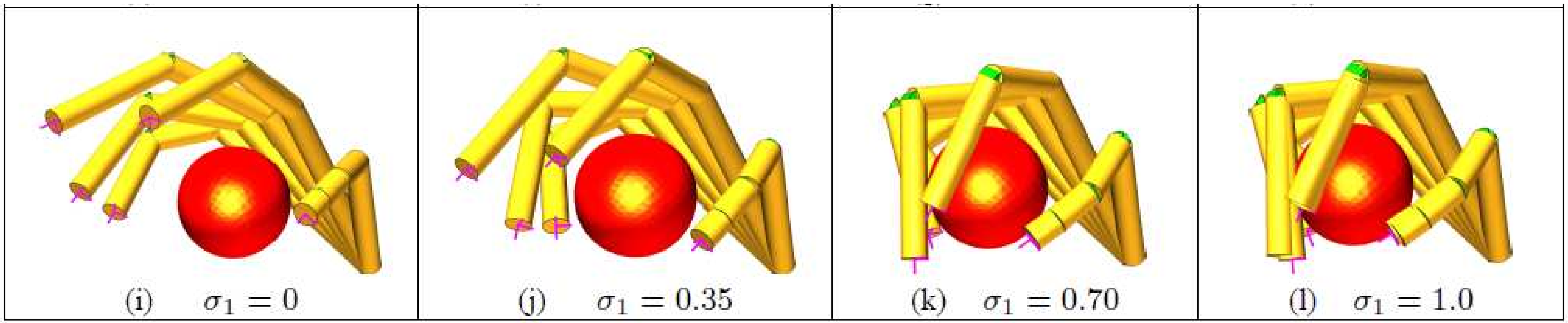
Soft Synergies

- Rigid Synergy



(e) $\sigma_1 = 0$ (f) $\sigma_1 = 0.35$ (g) $\sigma_1 = 0.70$ (h) $\sigma_1 = 1.0$

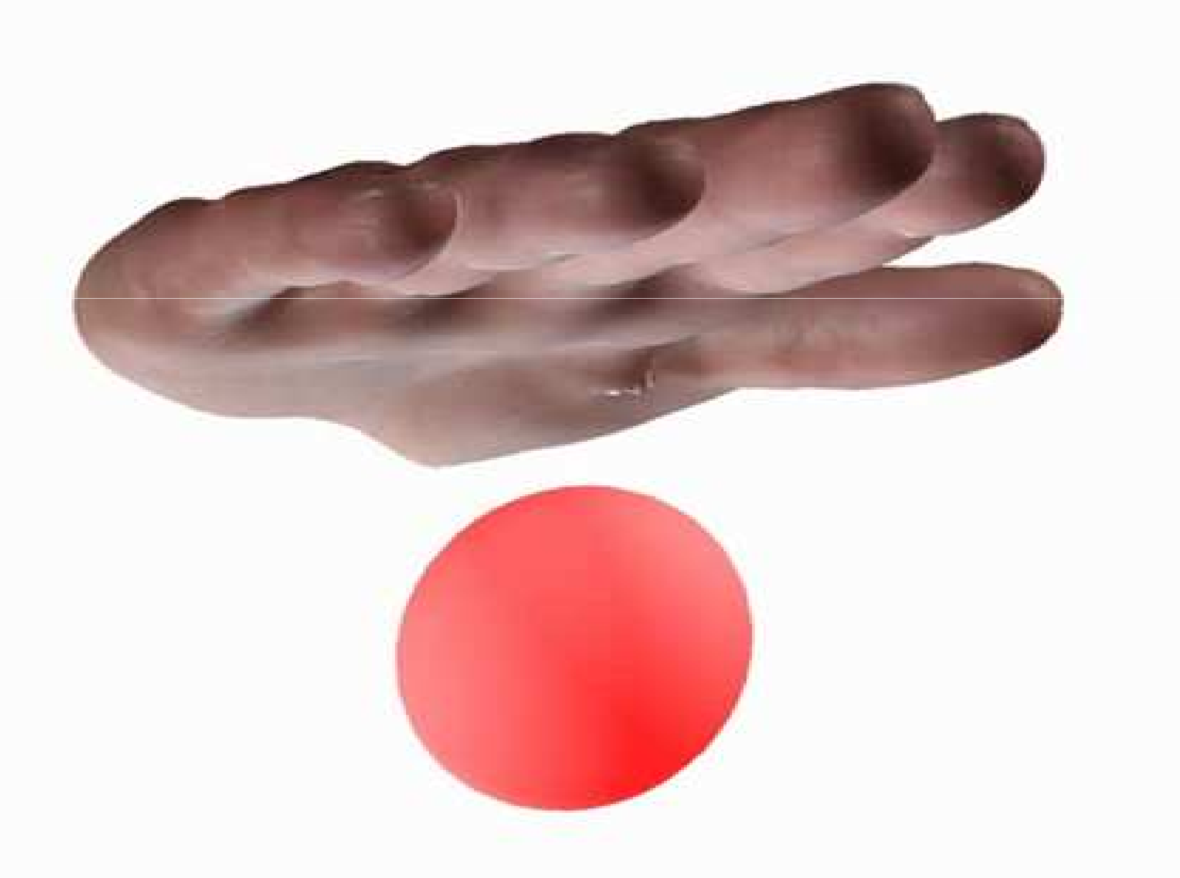
- Soft Synergy

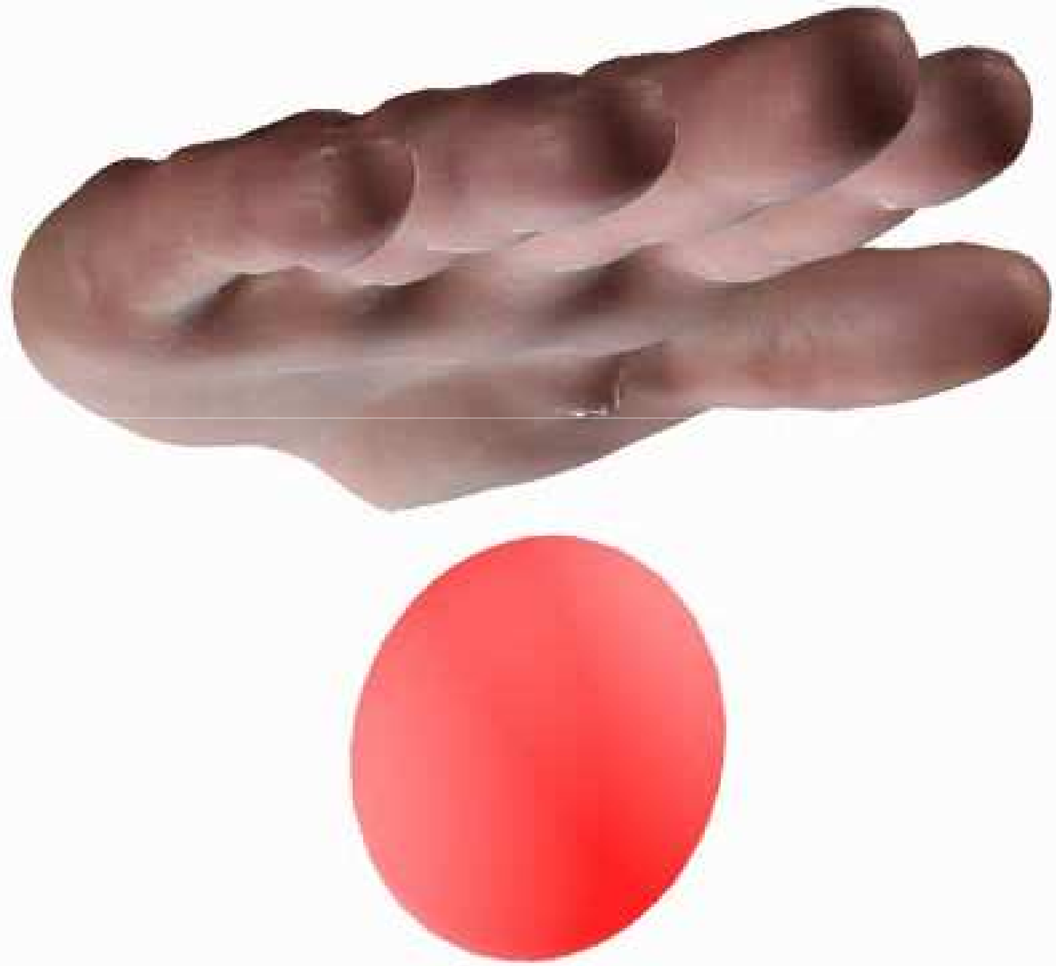


(i) $\sigma_1 = 0$ (j) $\sigma_1 = 0.35$ (k) $\sigma_1 = 0.70$ (l) $\sigma_1 = 1.0$

Pinch Grasping with 3 soft Synergies

- Cherry

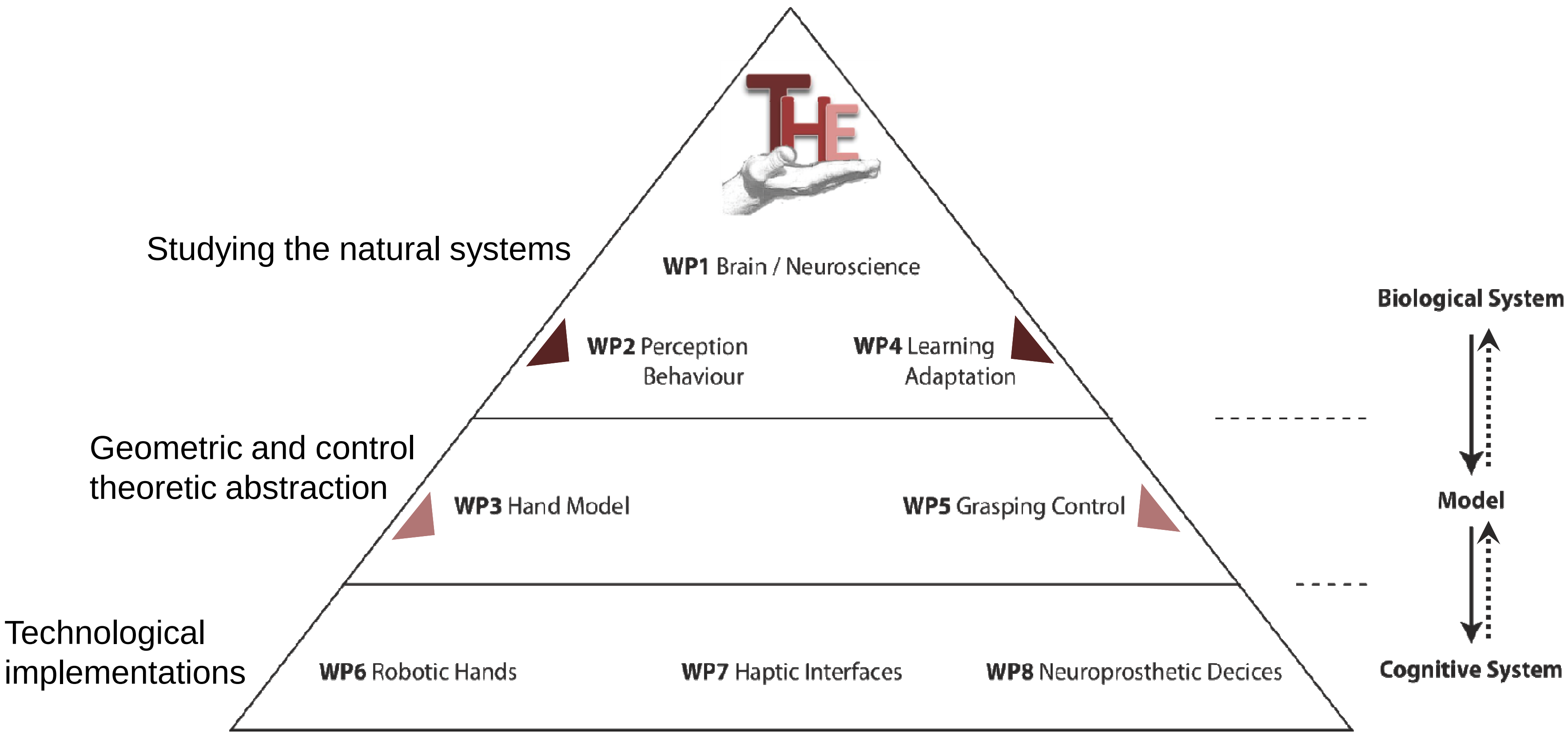




Power Grasping with 3 soft Synergies

- Ashtray

Workpackage Organization



Consortium

EXPERTISE
Hand Sensorimotor Organization (HSO)
Psychophysics of Human Haptics (PHH)
Multi-cue and Multi-sensory Integration (MCMSI)
Neuroscientific Modelling of Touch (NMT)
Design and Control of Artificial Hands (DCAH)
Haptic Interfaces (HI)
Neuroprosthetics (NP)

Participant name	**Participant short name**	**Expertise**
Centro "E. Piaggio" - University of Pisa	UNIPI	HSO, NMT, DCAH, HI
Deutsche Zentrum für Luft- und Raumfahrt - Institut für Robotik und Mechatronik	DLR	PHH, NMT, DCAH, NP
National Technical University Athens	NTUA	DCAH, NP
University of Siena	UNISI	HSO, NMT, DCAH, HI
Utrecht University	UU	PHH, MCMSI
Université Pierre et Marie Curie – Paris	UPMC	PHH, HI
Max Planck Institute for Biological Cybernetics, Tübingen	MPS-BC	PHH, MCMSI
Lund University	ULUND	HSO, NMT, NP
Arizona State University	ASU	HSO, PHH, NP, MCMSI