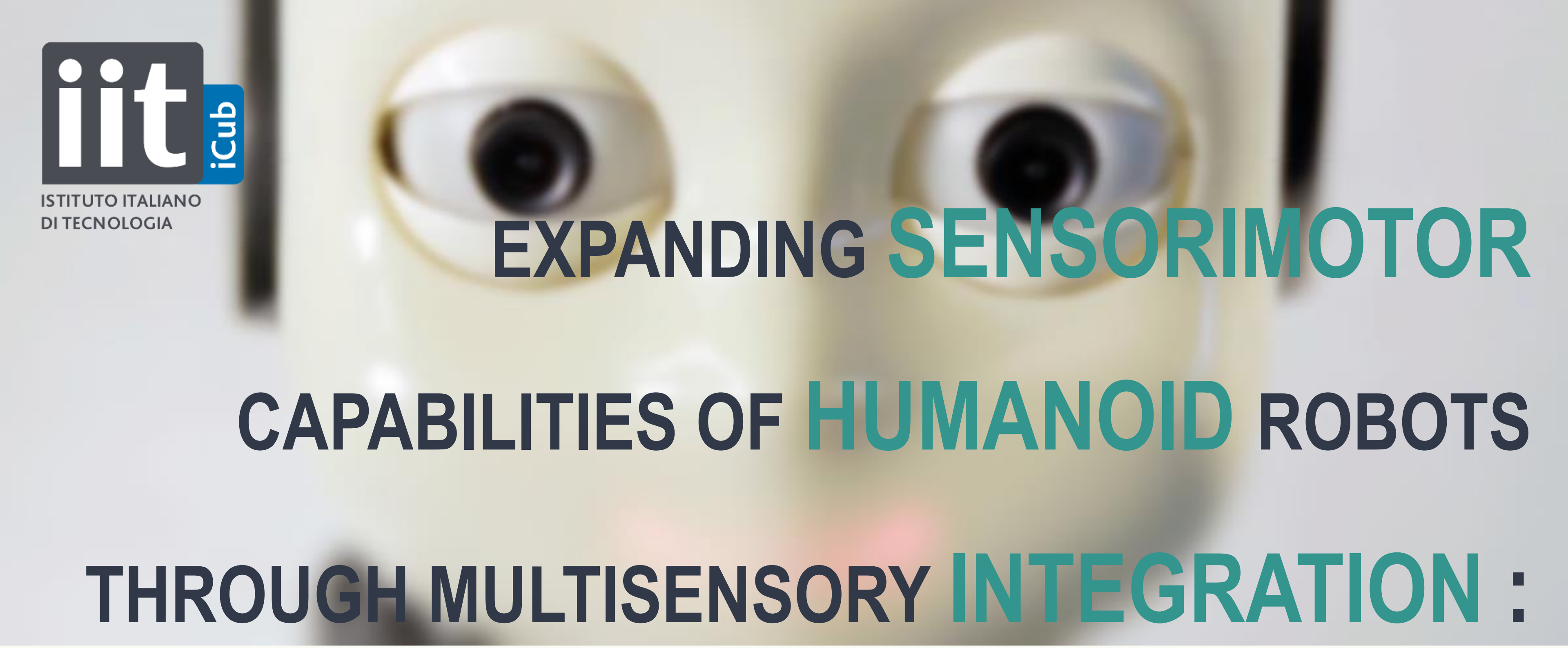


EXPANDING SENSORIMOTOR CAPABILITIES OF HUMANOID ROBOTS THROUGH MULTISENSORY INTEGRATION :

PeriPersonal Space on the iCub

Alessandro Roncone, iCub Facility
Matej Hoffmann, Ugo Pattacini, Giorgio Metta, Luciano Fadiga

The importance of PERIPERSONAL SPACE in humans .

"THE SPACE AROUND US" [Rizzolatti et al.,1997]

It is the **SPACE SURROUNDING OUR BODIES**

It acts as an **INTERFACE** between the body and the external world

MULTIMODAL REPRESENTATION of space

[vision, tactile, proprioception, auditory, motor system]

The importance of PERIPERSONAL SPACE in humans .

NEUROPHYSIOLOGY

- Bottom-up approach
- Focus on **PROPRIOCEPTION** and its role in the **CONTROL OF MOVEMENT**

PPS

PSYCHOLOGY

- Top-down approach
- Focus on the **MULTISENSO-RY** aspect

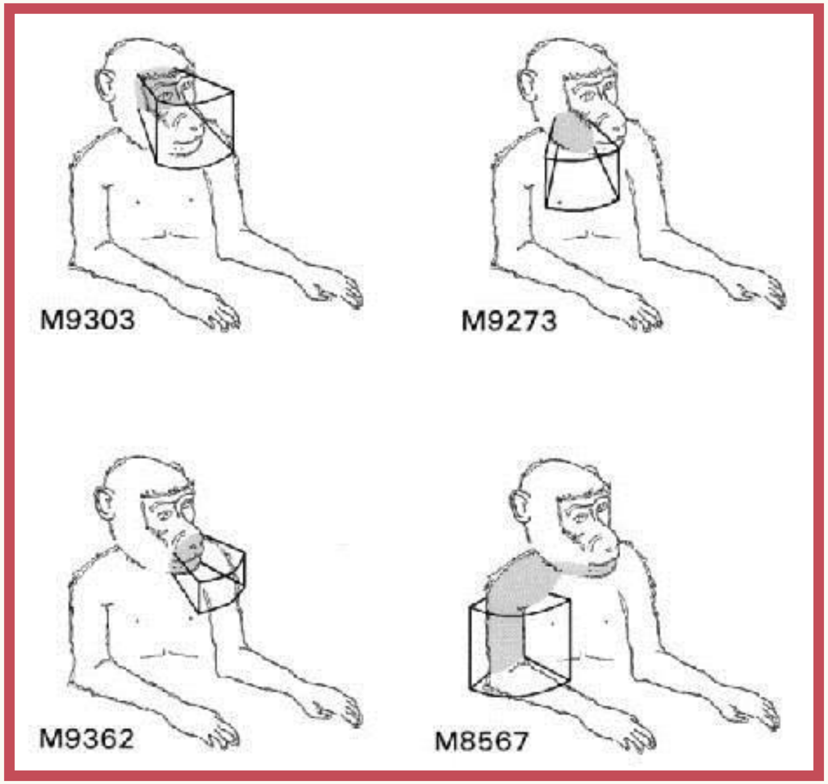
The importance of PERIPERSONAL SPACE in humans .

DIFFERENT REFERENCE FRAMES for different modalities (and goals)

Figure removed due to copyright restrictions. Please see the video.

The importance of PERIPERSONAL SPACE in humans .

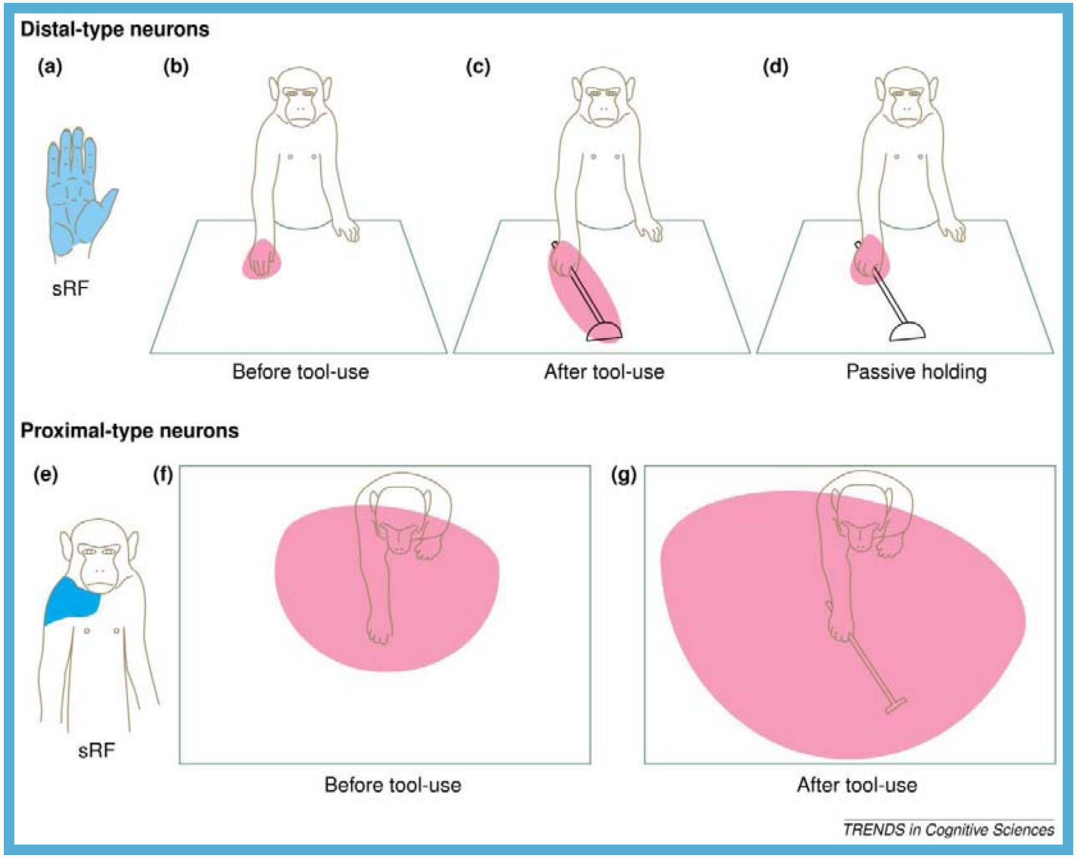
MULTISENSORY INTEGRATION to form a coherent view of the body and the space surrounding it [Fogassi et al. 1996]



Source: Fogassi, Leonardo, Vittorio Gallese, Luciano Fadiga, Guiseppe Luppino, Massimo Matelli, and Giacomo Rizzolatti. "Coding of peripersonal space in inferior premotor cortex (area F4)." Journal of neurophysiology 76, no. 1 (1996): 141-157.

The importance of PERIPERSONAL SPACE in humans .

Intrinsic **PLASTIC BEHAVIOR** [Iriki et al. 2004]



Source: Maravita, Angelo, and Atsushi Iriki. "Tools for the body (schema)." Trends in cognitive sciences 8, no. 2 (2004): 79-86.

PERIPERSONAL SPACE in robotics .

MODELS

- [Antonelli et al. 2012]
- [Hikita et al. 2009]
- [Fuke et al. 2009]

PPS

IMPLEMENTATIONS

- [Mittendorfer et al. 2015]

Outline .

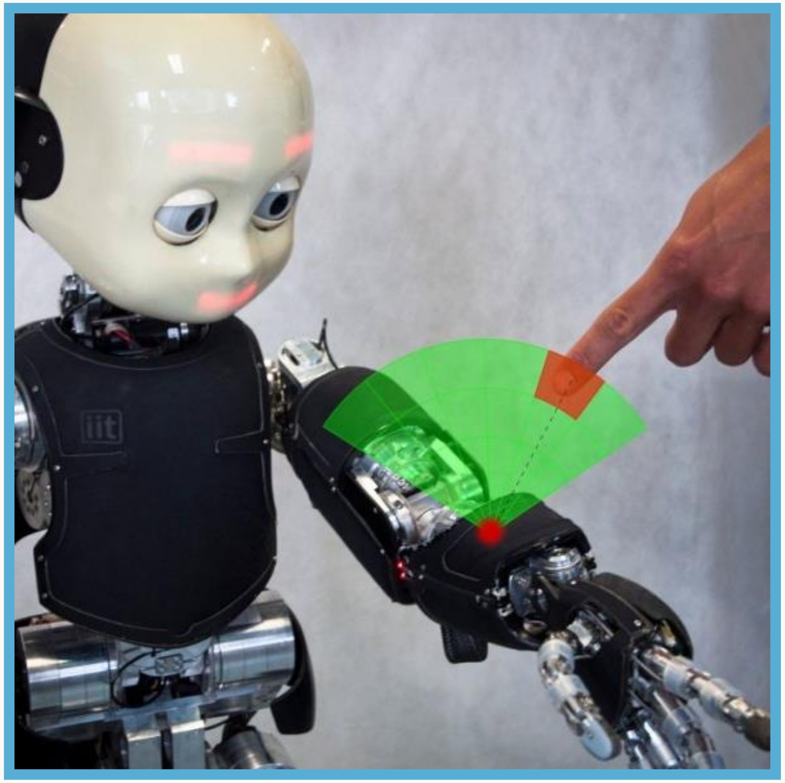
Learning visuo-tactile associations on the iCub

Application[s]: Margin of Safety and Catching with Any Body Part

Discussion

PERIPERSONAL SPACE on the iCub

Representation of space around the body .



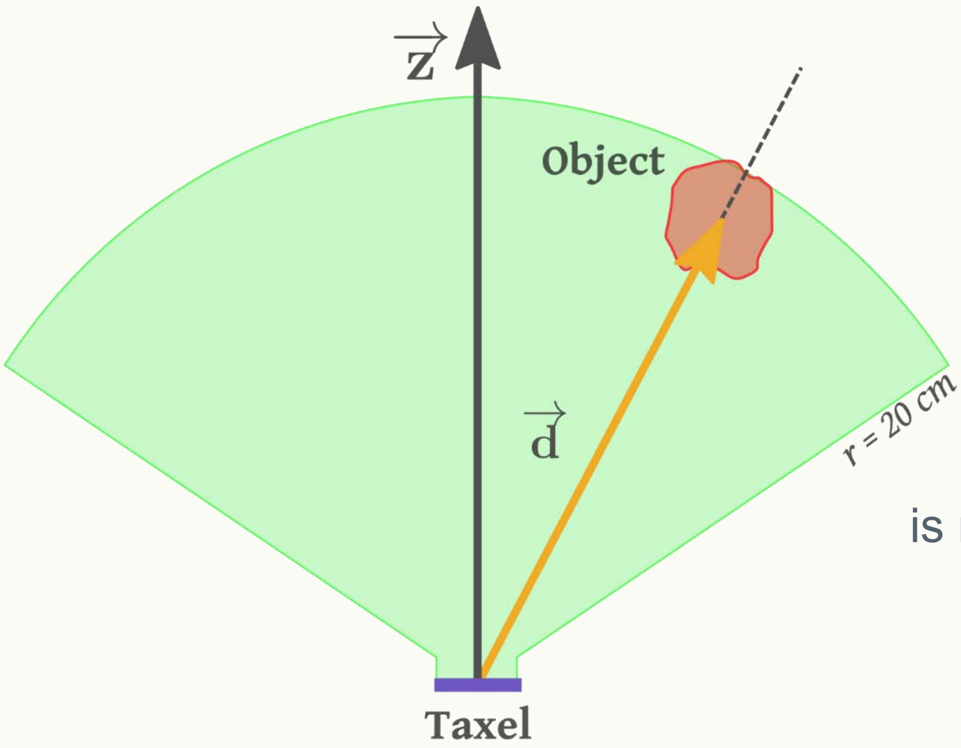
Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission. Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

DISTRIBUTED REPRESENTATION
of the nearby space

Each taxel possess a
SPATIAL RECEPTIVE FIELD
growing out from it

each taxel learns a
PROBABILITY of **BEING TOUCHED**

Representation of space around the body .

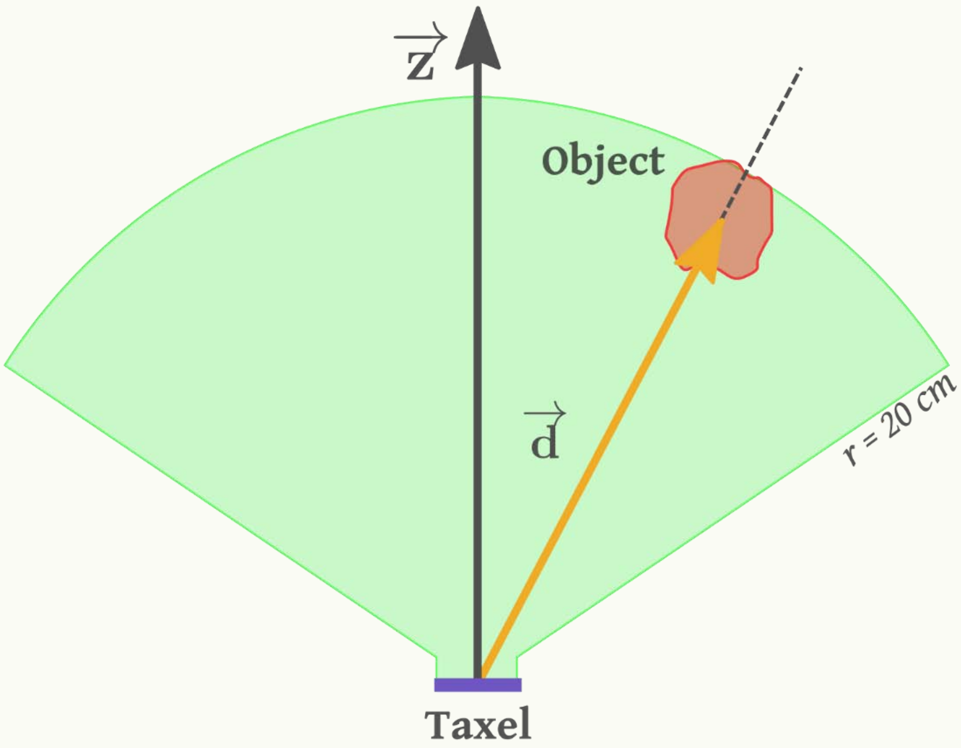


For any input event,

its **DISTANCE** wrt the taxel

is recorded in a **3 seconds** buffer

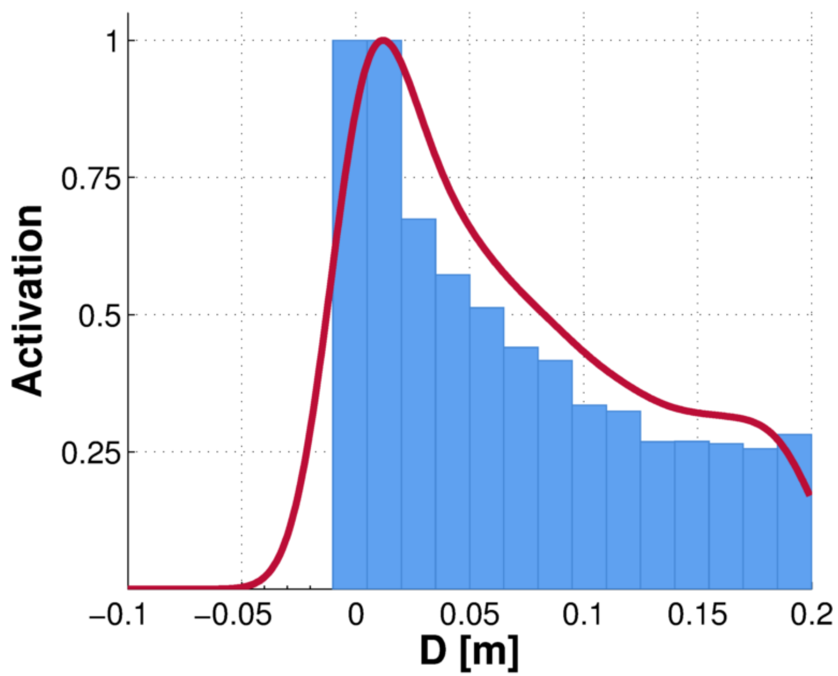
Representation of space around the body .



Distance [D]

$$D = sgn(\overrightarrow{\mathbf{d}} \cdot \overrightarrow{z})||\overrightarrow{\mathbf{d}}||$$

Representation of space around the body



$$P(D) \approx f(D) = \frac{n_{positive}(D_i)}{n_{positive}(D_i) + n_{negative}(D_i)}$$

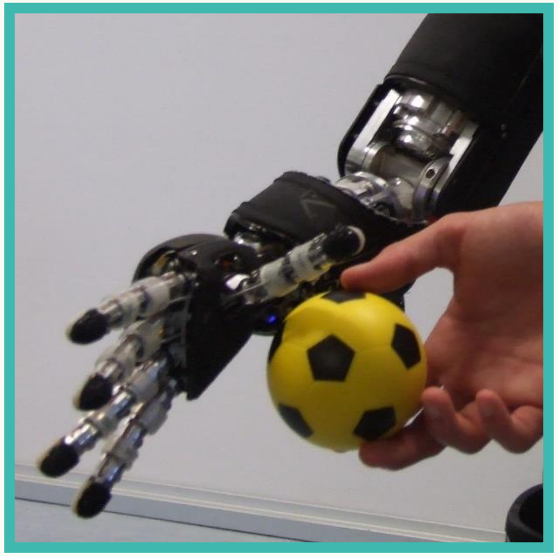
$$p(\mathbf{x}) = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(\mathbf{x}_i - \mathbf{x})^2}{2\sigma^2}\right)$$

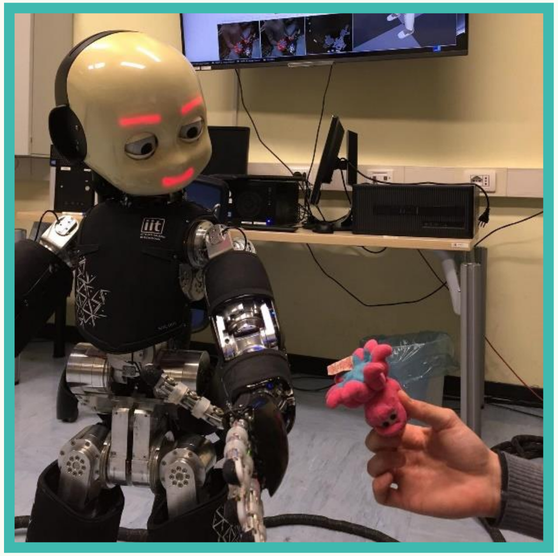
Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission. Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

Experiments .

A MONTE CARLO SIMULATION : single taxel model

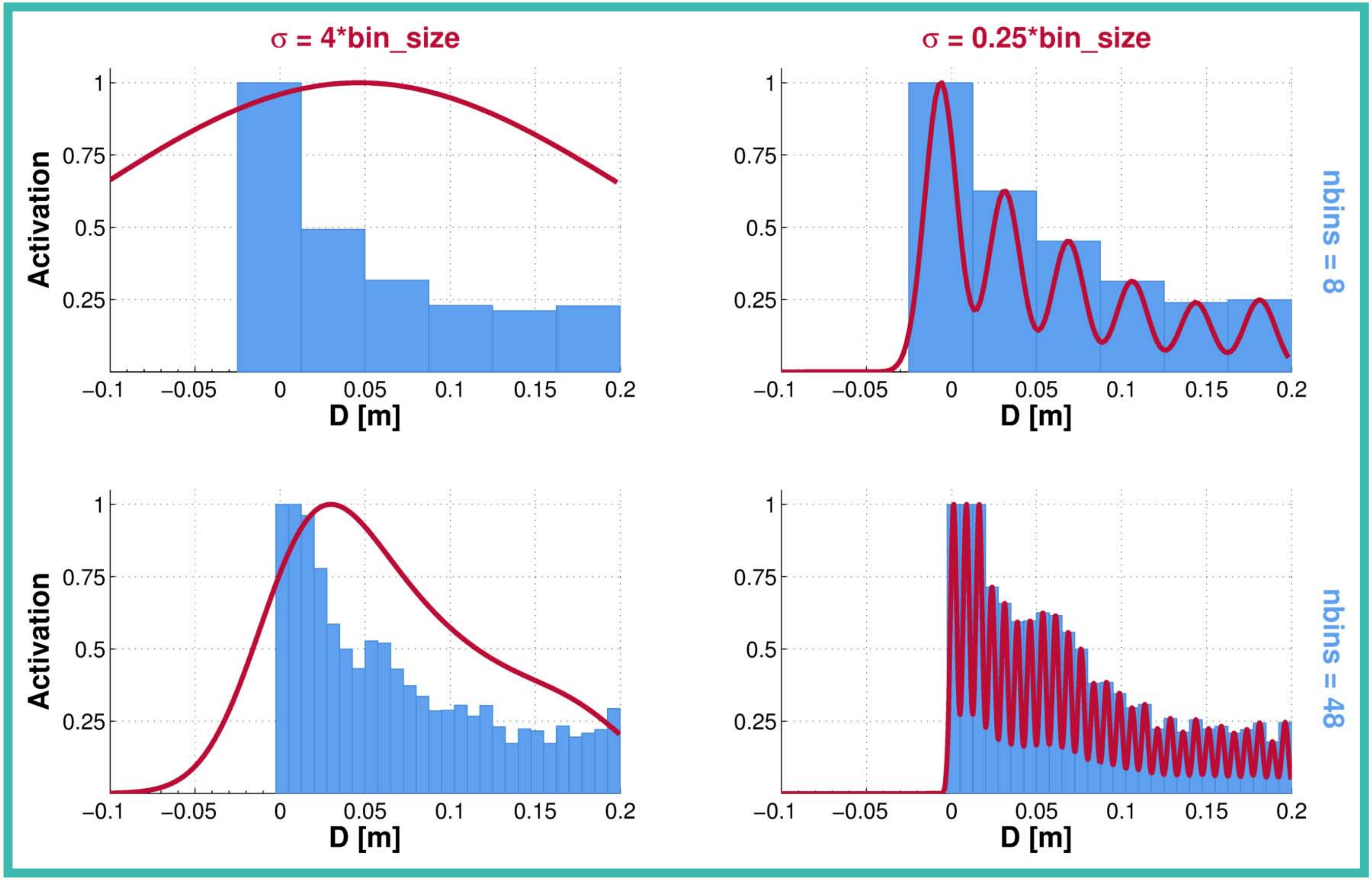
B TACTILE - VISUAL LEARNING : external objects detected through 3D optical flow





Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

Exp A - Single Taxel Model - Tuning of the parameters .



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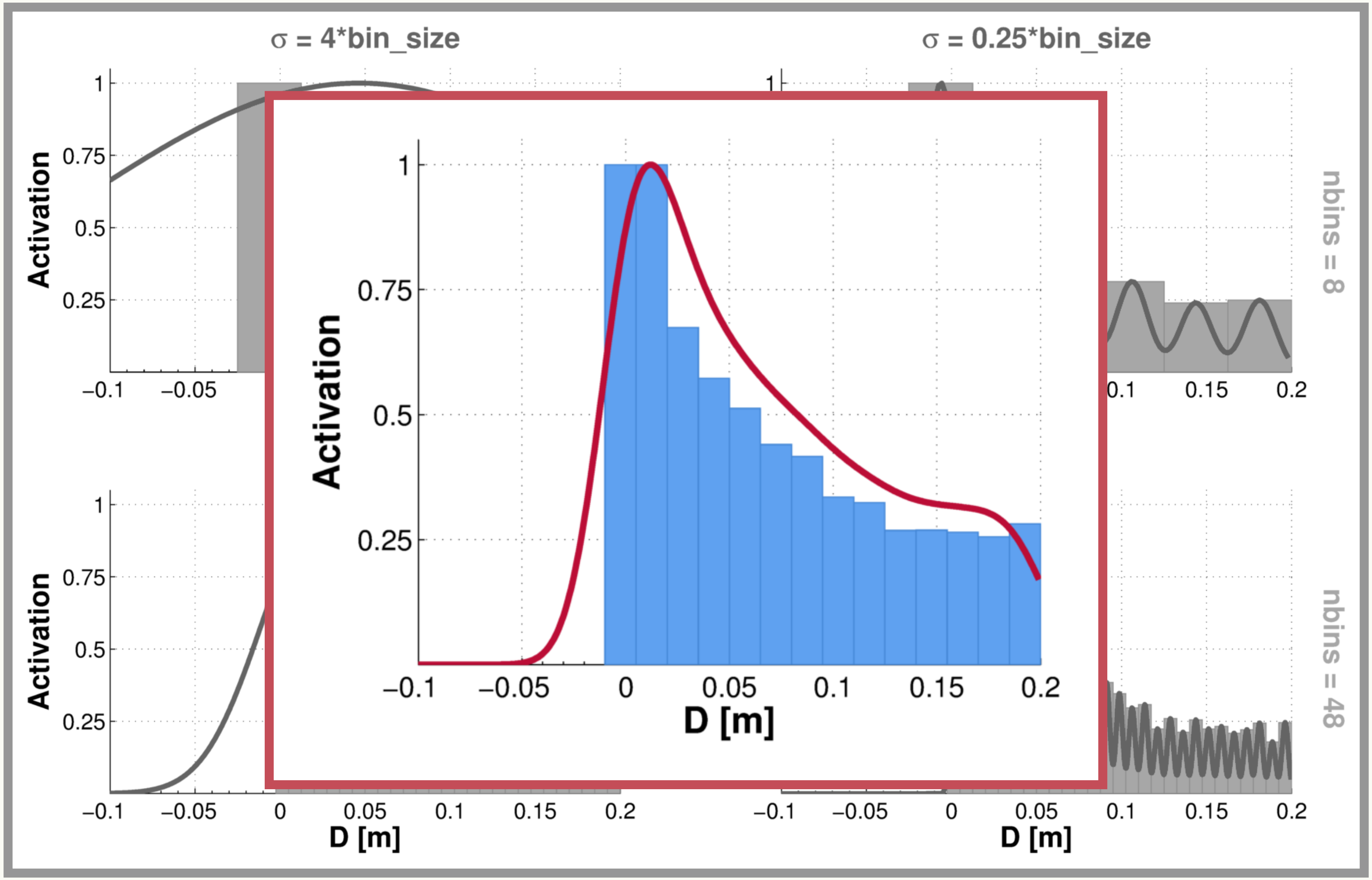
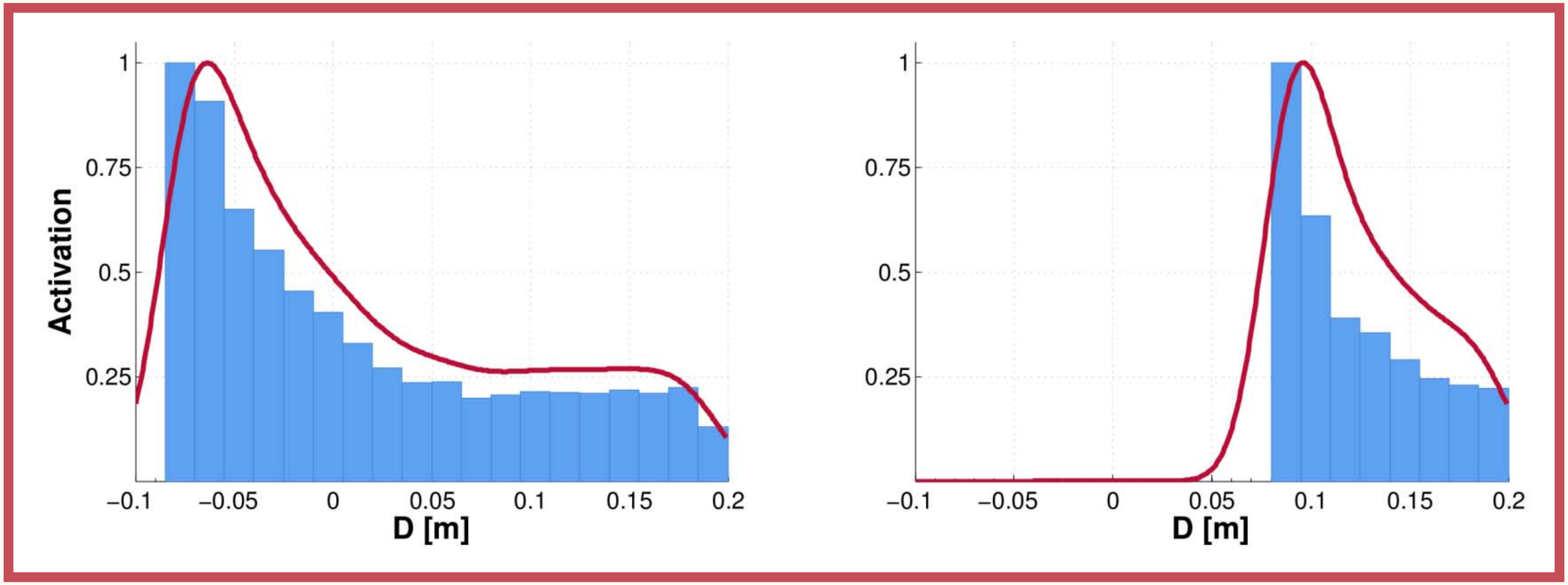


Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

Exp A - Single Taxel Model - Validation of the Model .

- On the real robot, object positions are subject to systematic errors / offsets
- The errors propagate up to the taxel, but the representation is able to account for them and compensate accordingly



Negative Offset Positive Offset

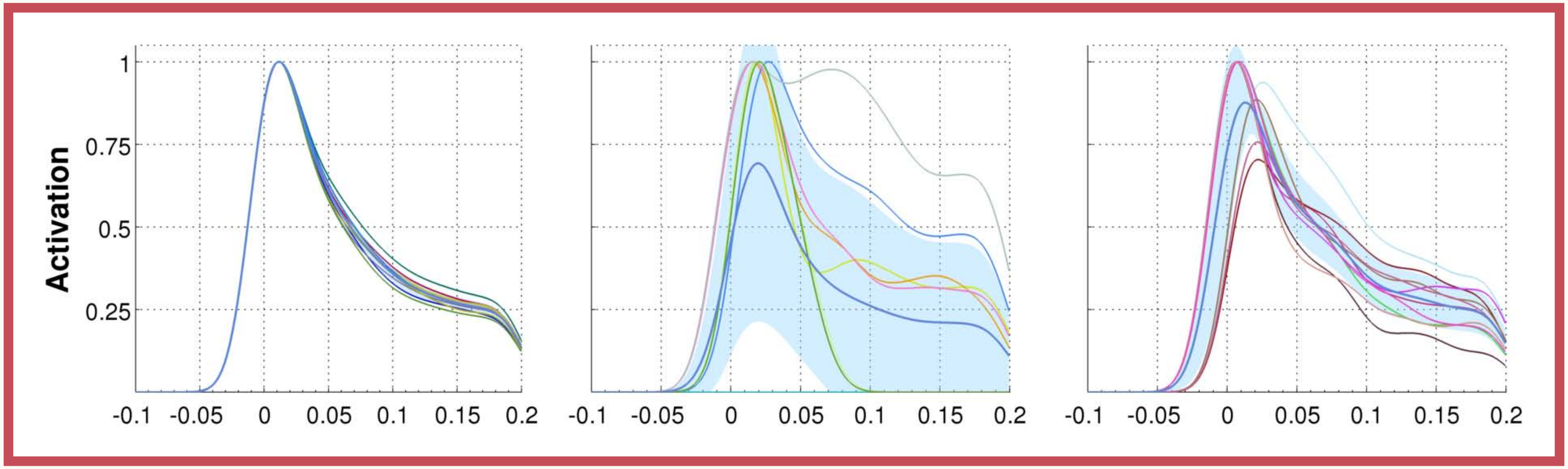
Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

Exp A - Single Taxel Model - Validation of the Model .

1000 events/trial, no noise

10 events/trial, no noise

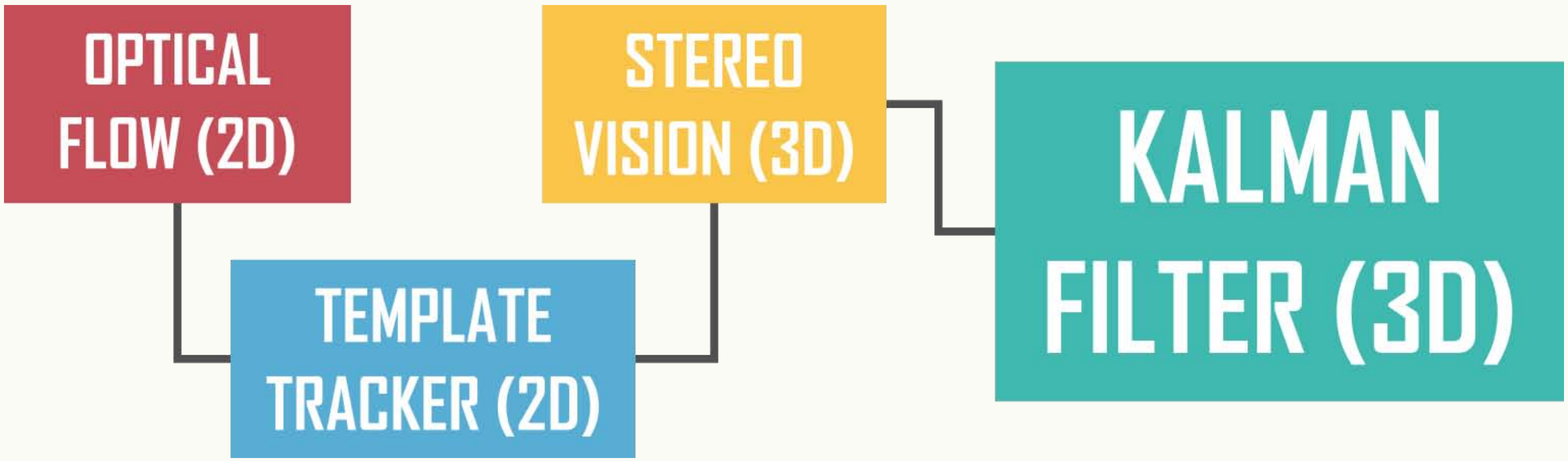
100 events/trial, noise in the measurements



Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

- Convergence of the model during ***long-term learning***
- ***"One-shot" learning*** is still meaningful (albeit noisy)
- With sufficient training, the representation converges even in ***noisy*** environments

Exp B - 3D Tracking of arbitrary objects .



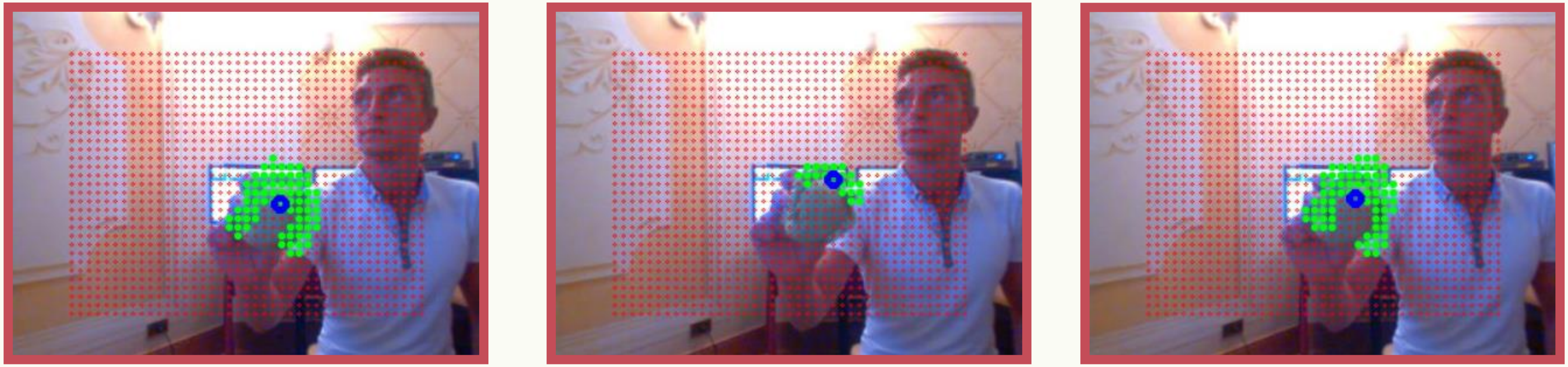
2D Optical Flow
[Ciliberto et al. 2011]

3D Stereo Vision
[Fanello et al. 2014]

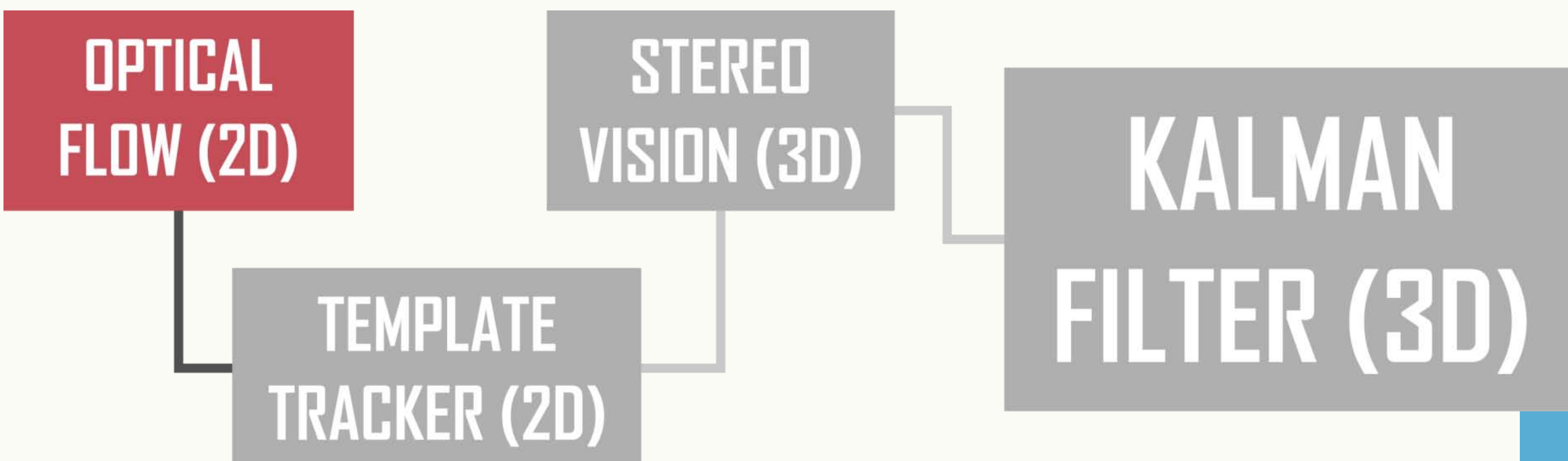
2D Particle Filter
[Tikhanoff et al. 2013]

Kalman Filter
for robust 3D tracking

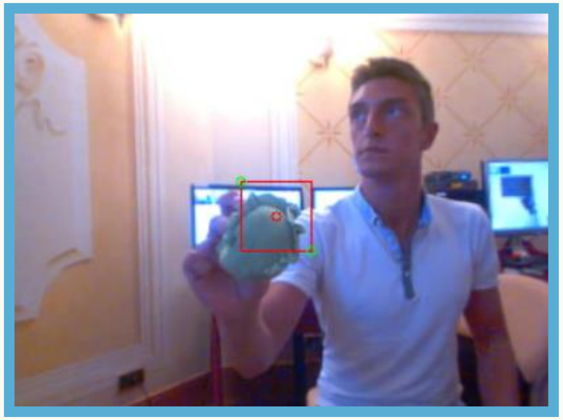
Exp B - 3D Tracking of arbitrary objects .

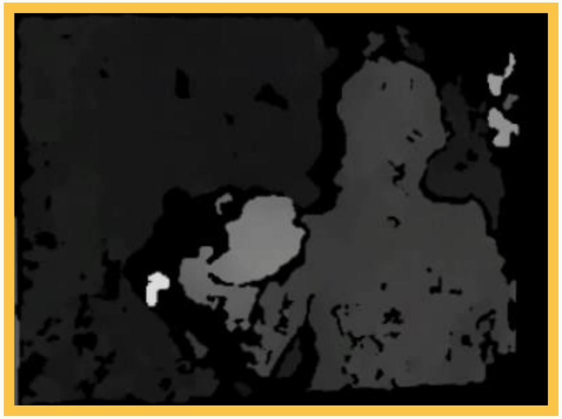


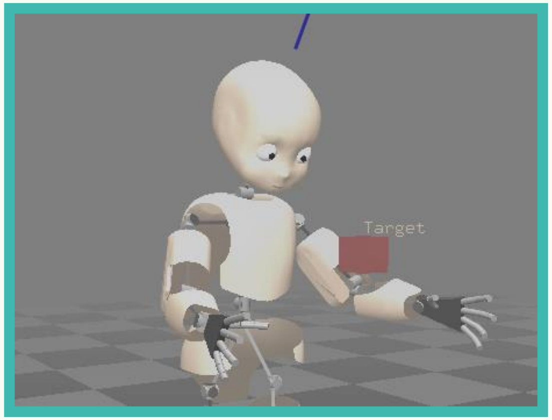
Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.



Exp B - 3D Tracking of arbitrary objects .







Courtesy of Alessandro Roncone and Matej Hoffman. Used with permission.
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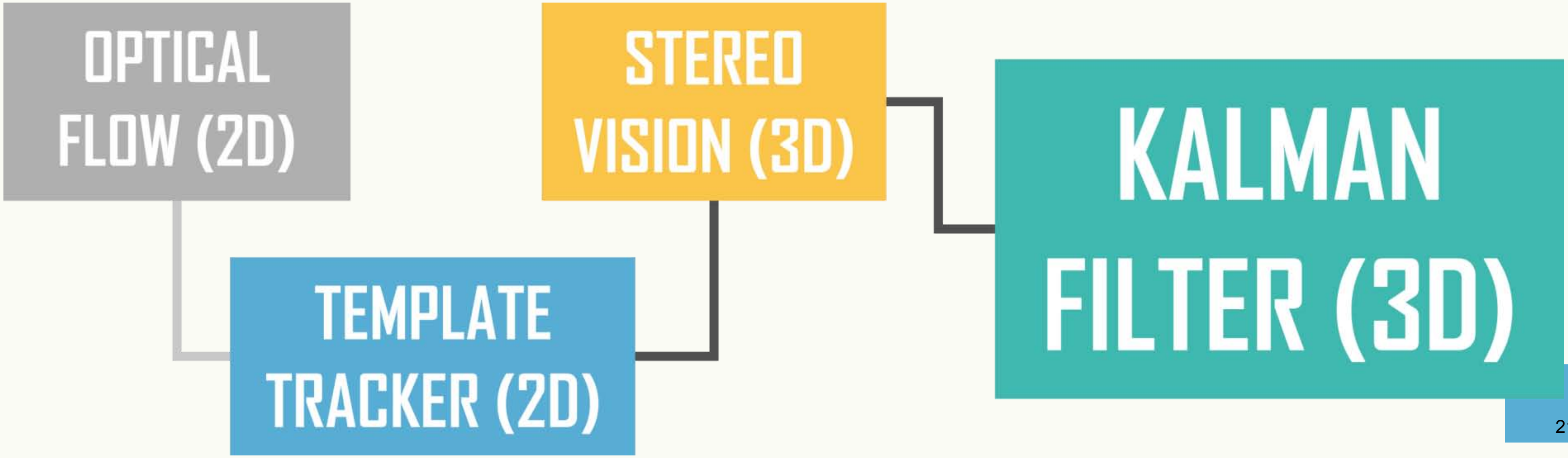
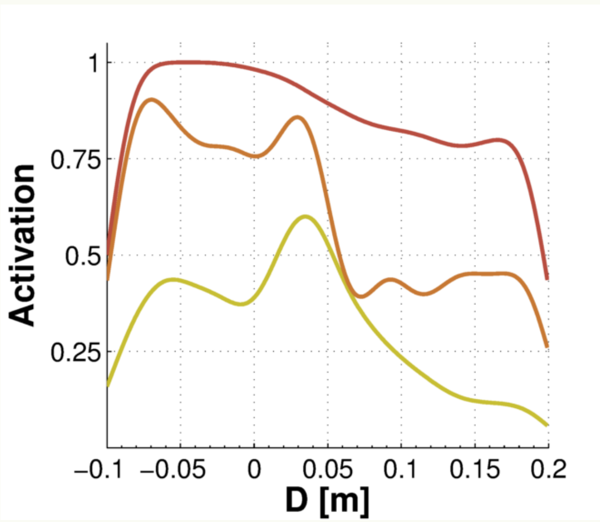


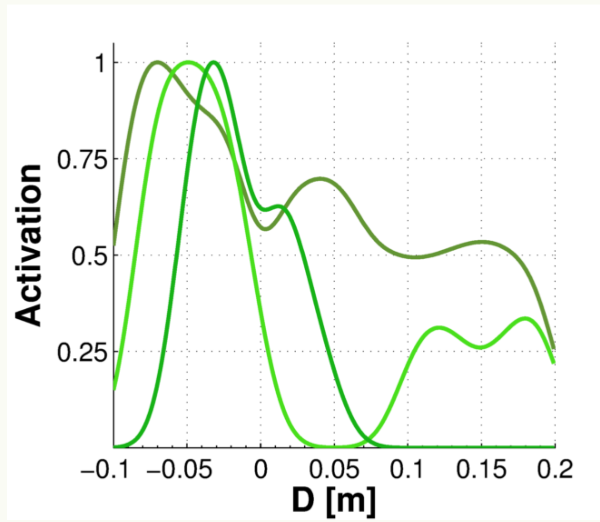
Video Time .

Exp B - Tactile-Visual learning [ext. objects] .

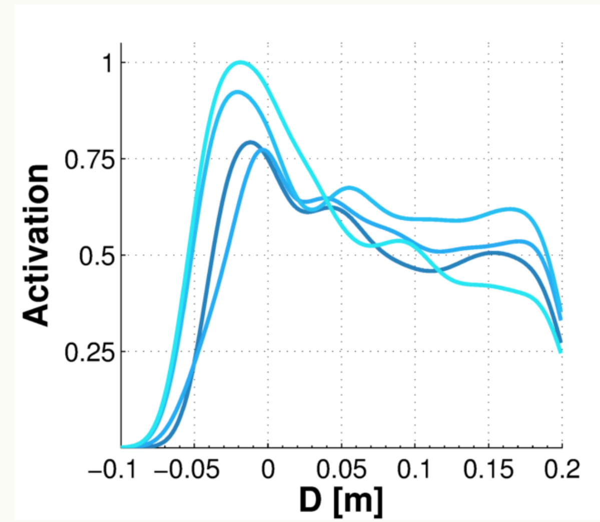
Left Forearm [int]



Left Forearm [ext]



Right Hand



Source: Roncone, Alessandro, Matej Hoffmann, Ugo Pattacini, and Giorgio Metta. "Learning peripersonal space representation through artificial skin for avoidance and reaching with whole body surface." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 3366-3373. IEEE, 2015.

126 iterations

864 samples

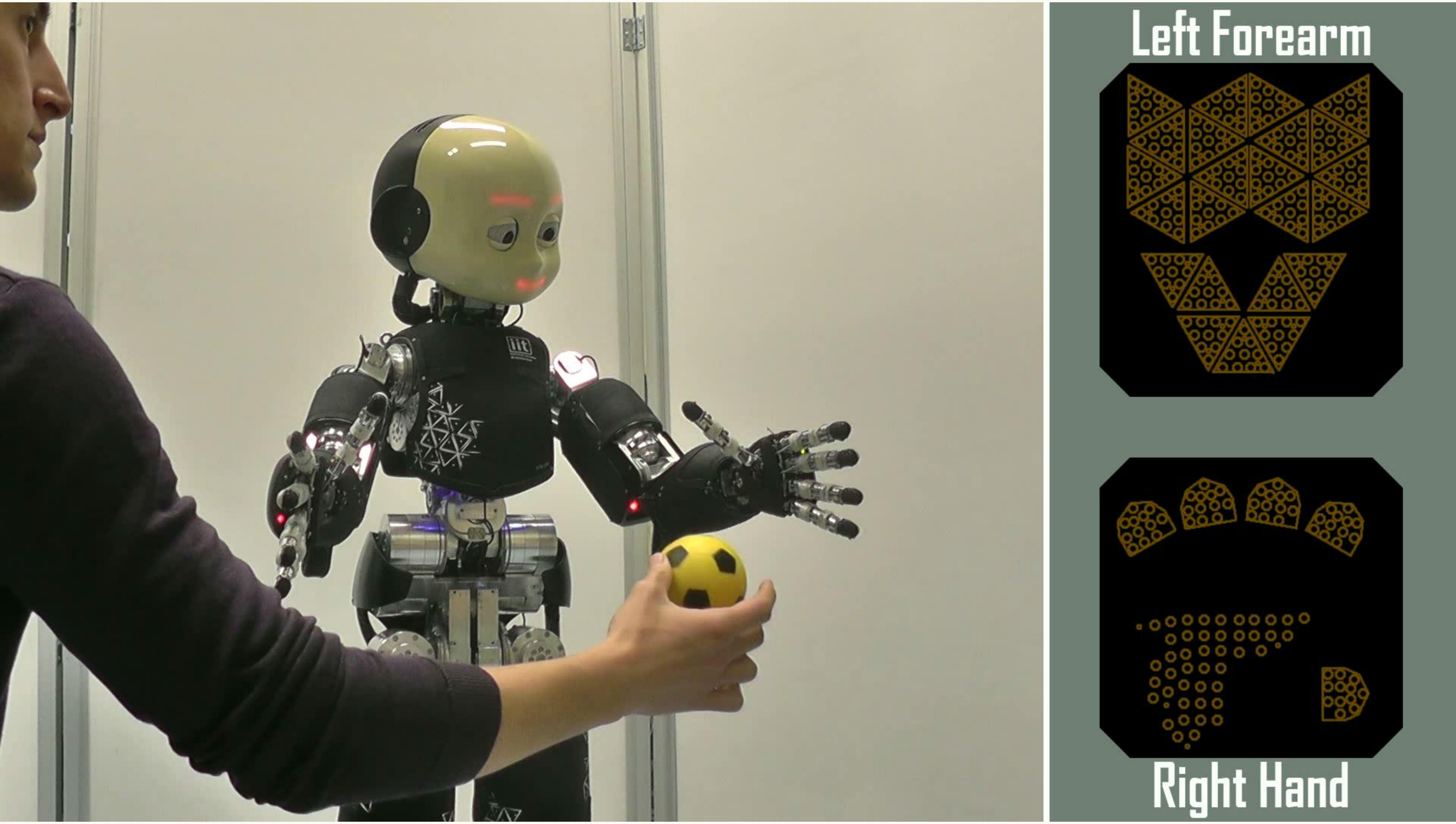
76 iterations

246 samples

138 iterations

1916 samples

Video Time .



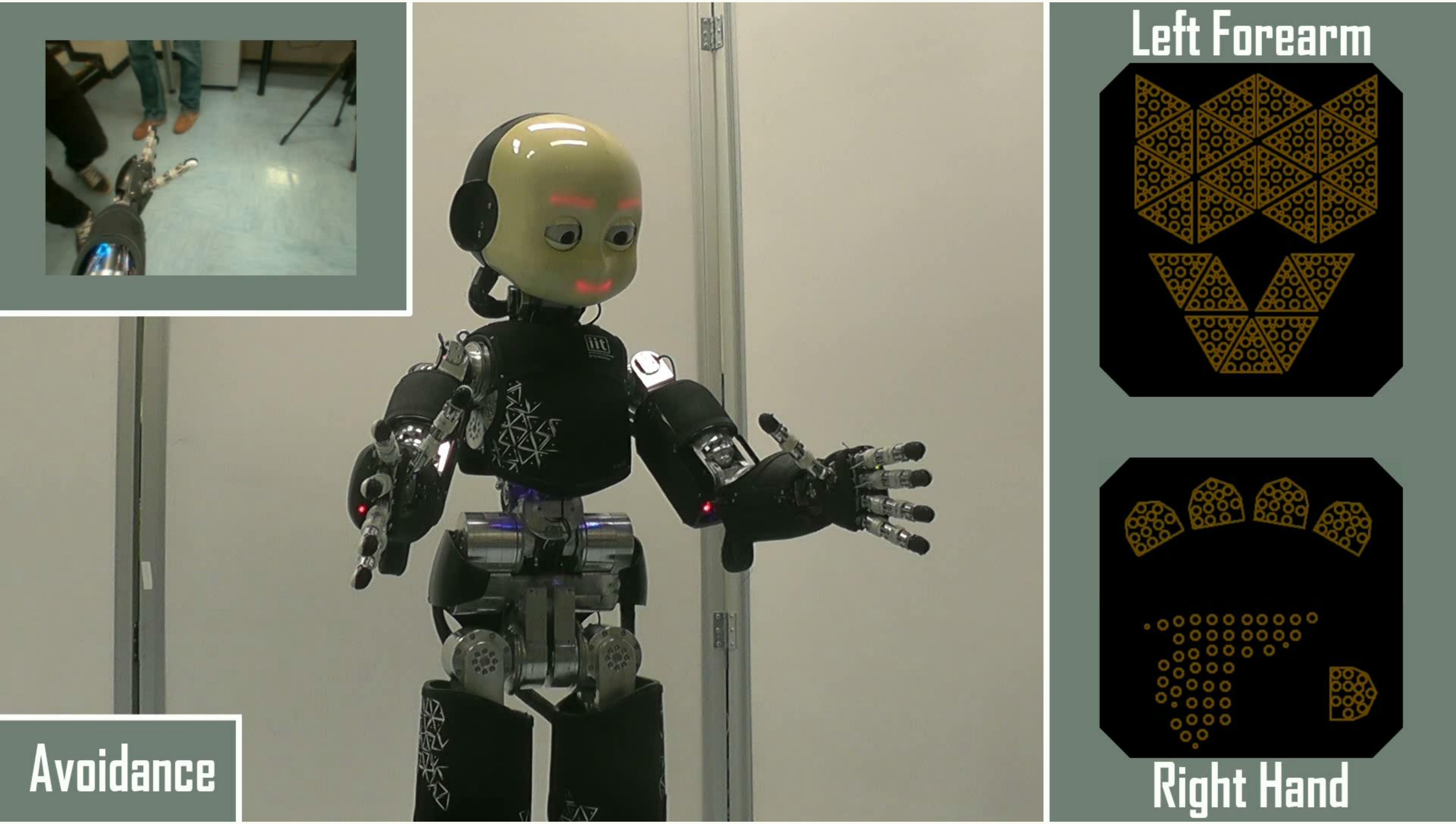
Applications of the visuo-tactile associations: AVOIDANCE and CATCHING with any body part

Avoidance and Catching Controller .

Distributed control (i.e. avoidance and catching with any body part)

Sensory based guidance of the motor actions by means of the visuo-tactile associations

Video Time - AVOIDANCE .



Avoidance and Catching Controller .

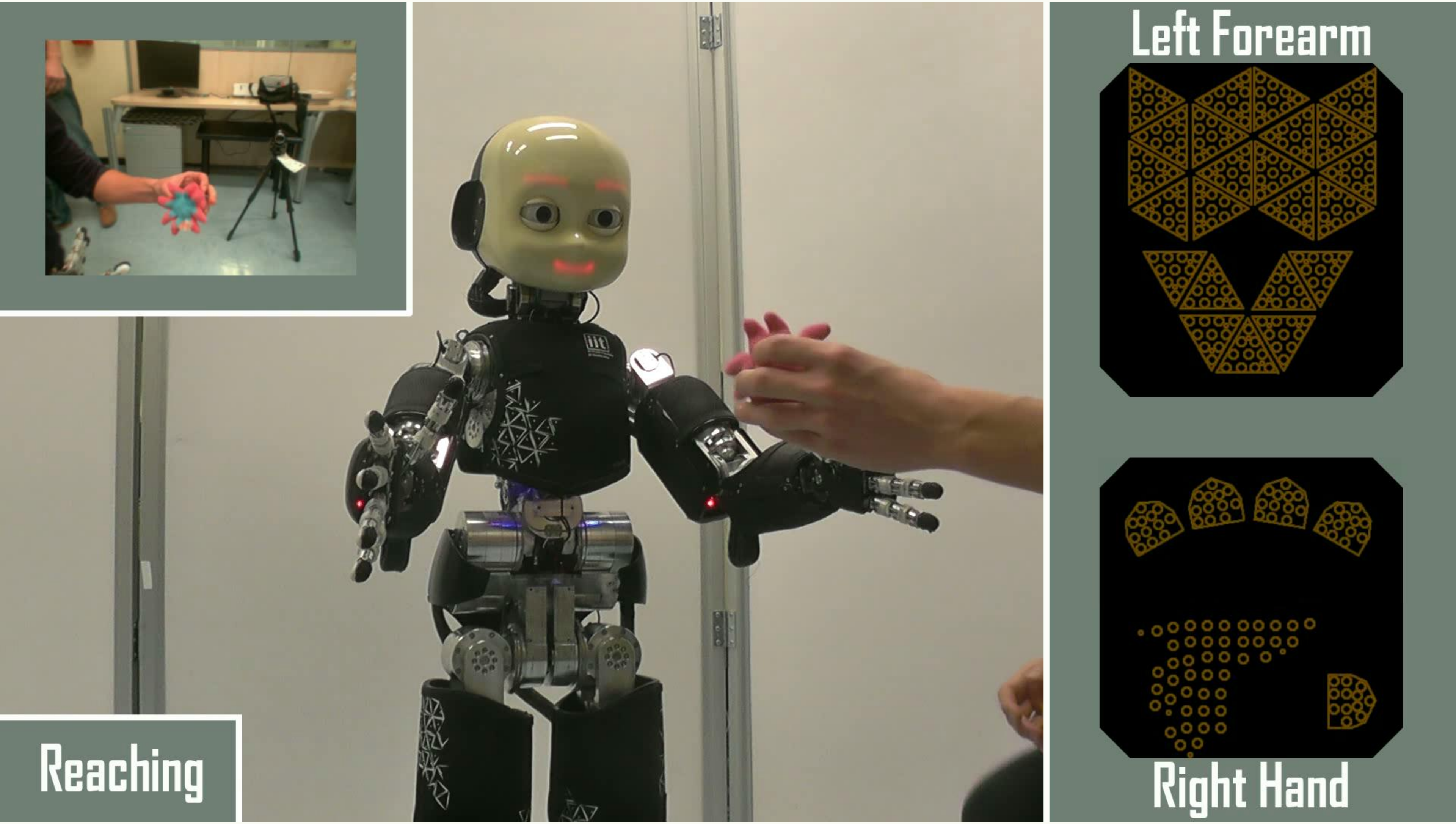
Distributed control (i.e. avoidance and catching with any body part)

Sensory based guidance of the motor actions by means of the visuo-tactile associations

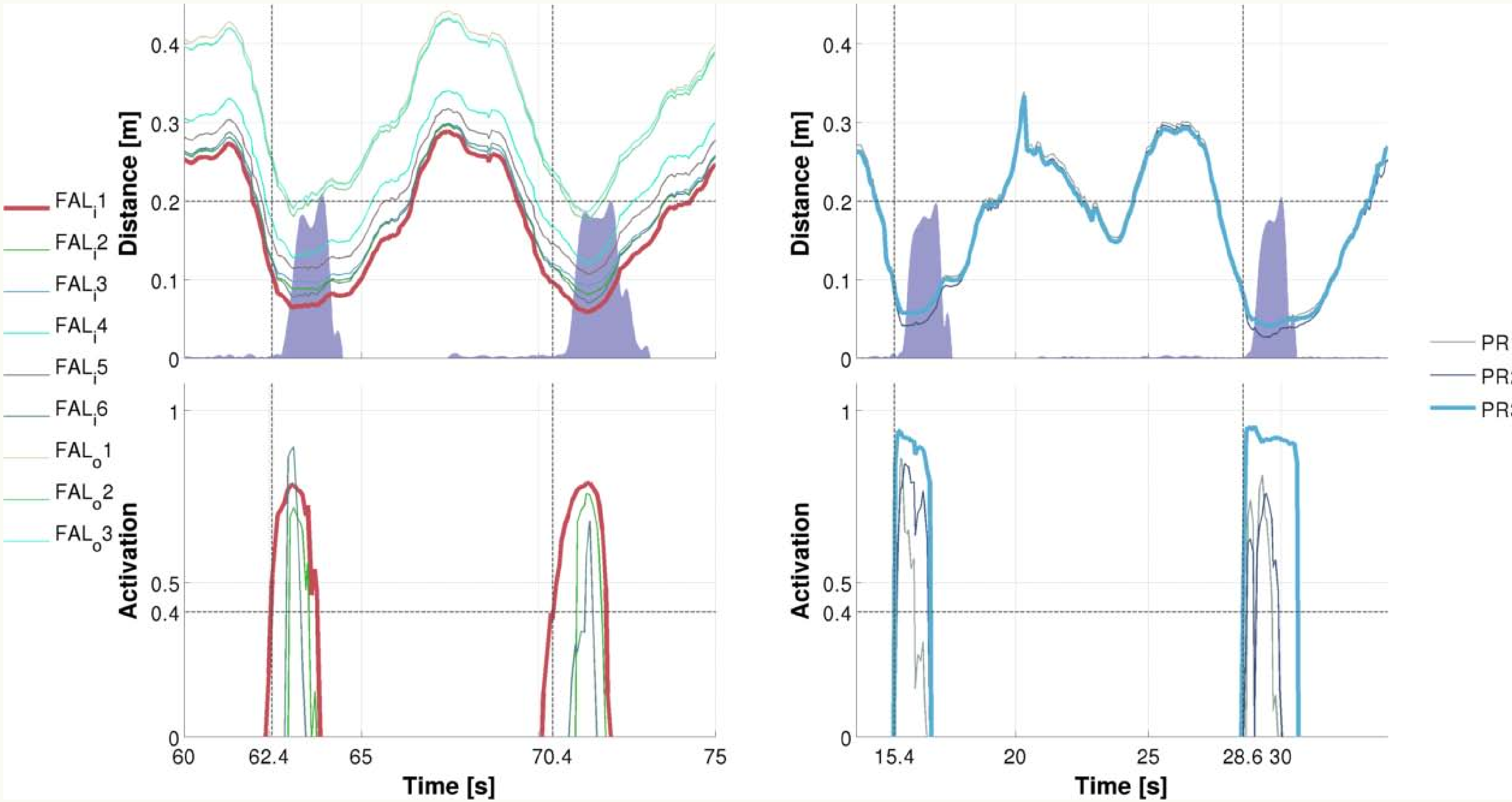
$$\mathbf{P}(t) = \frac{1}{k} \sum_{i=1}^{k} [a_i(t) \cdot \mathbf{p}_i(t)]$$

$$\mathbf{N}(t) = \frac{1}{k} \sum_{i=1}^{k} [a_i(t) \cdot \mathbf{n}_i(t)]$$

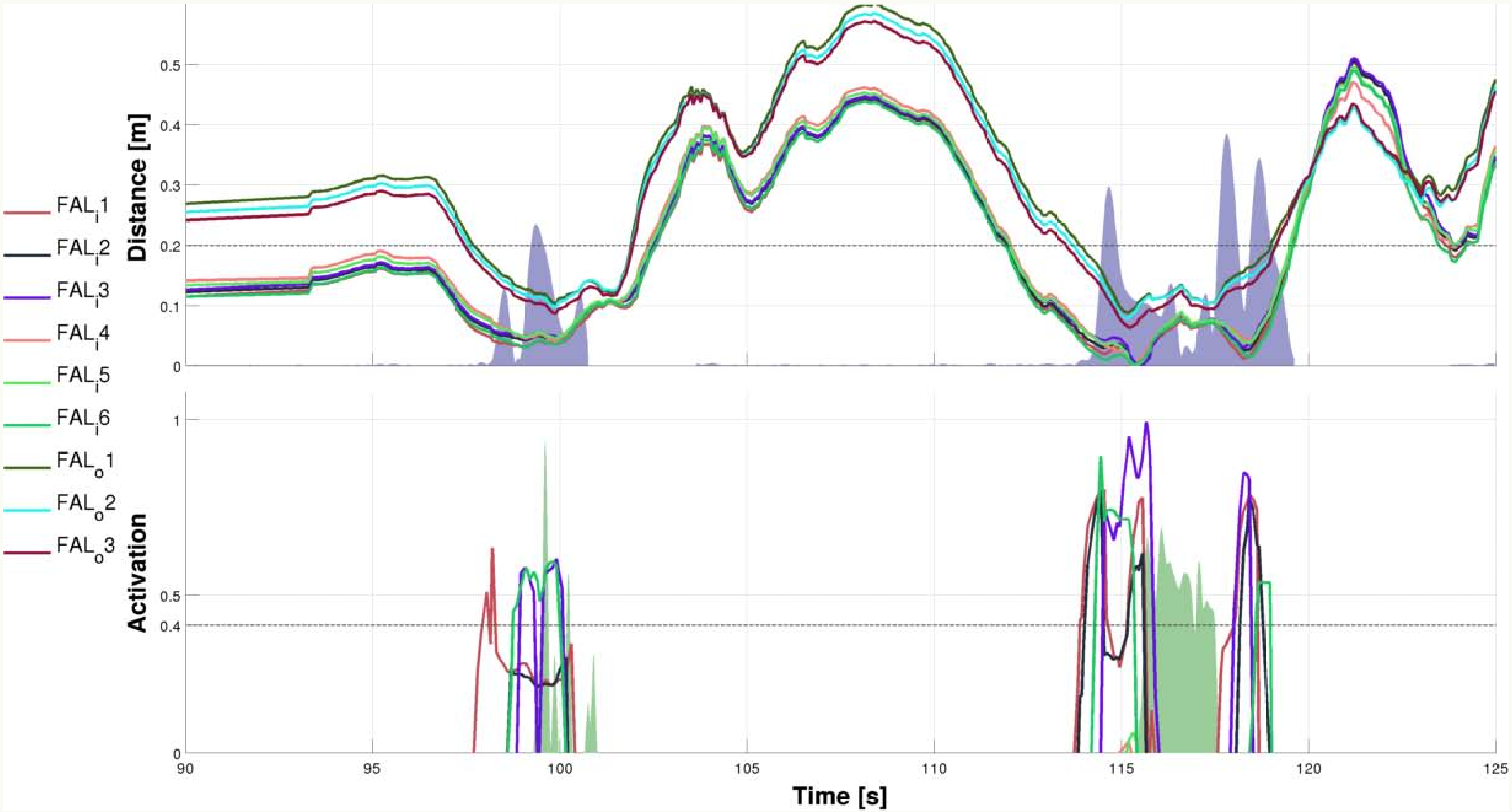
Video Time - CATCHING .



Avoidance Experiments .



Catching Experiments .



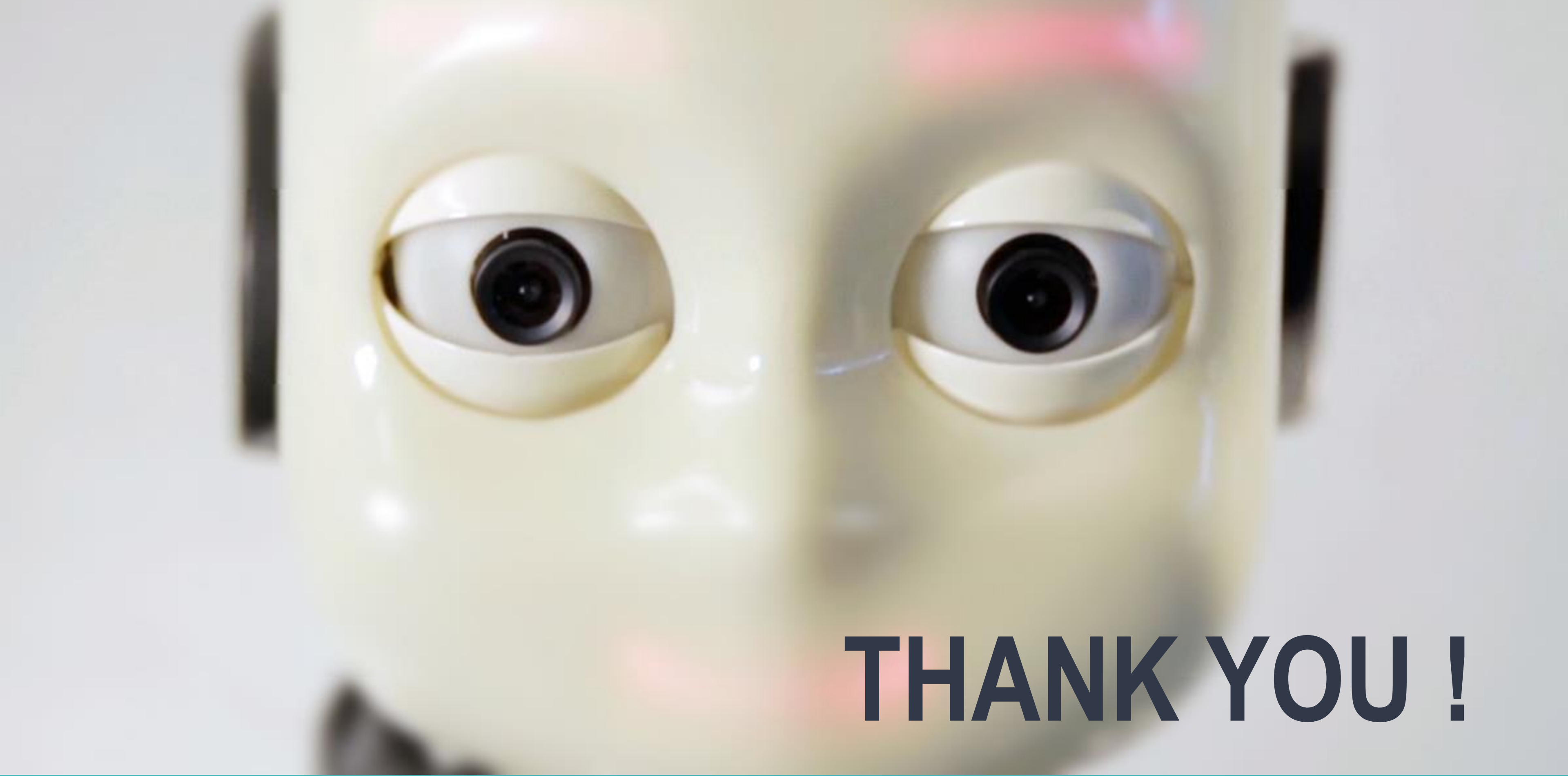
Conclusions

Contribution and Discussion .

Distributed representation of the space around the body able to learn tactile visual associations and prior-to-contact activations

Learning is fast, proceeds in parallel for the whole body, and is incremental

Learning is adapted from experience, thus automatically compensating for errors in the model



THANK YOU !

ANY QUESTIONS ?