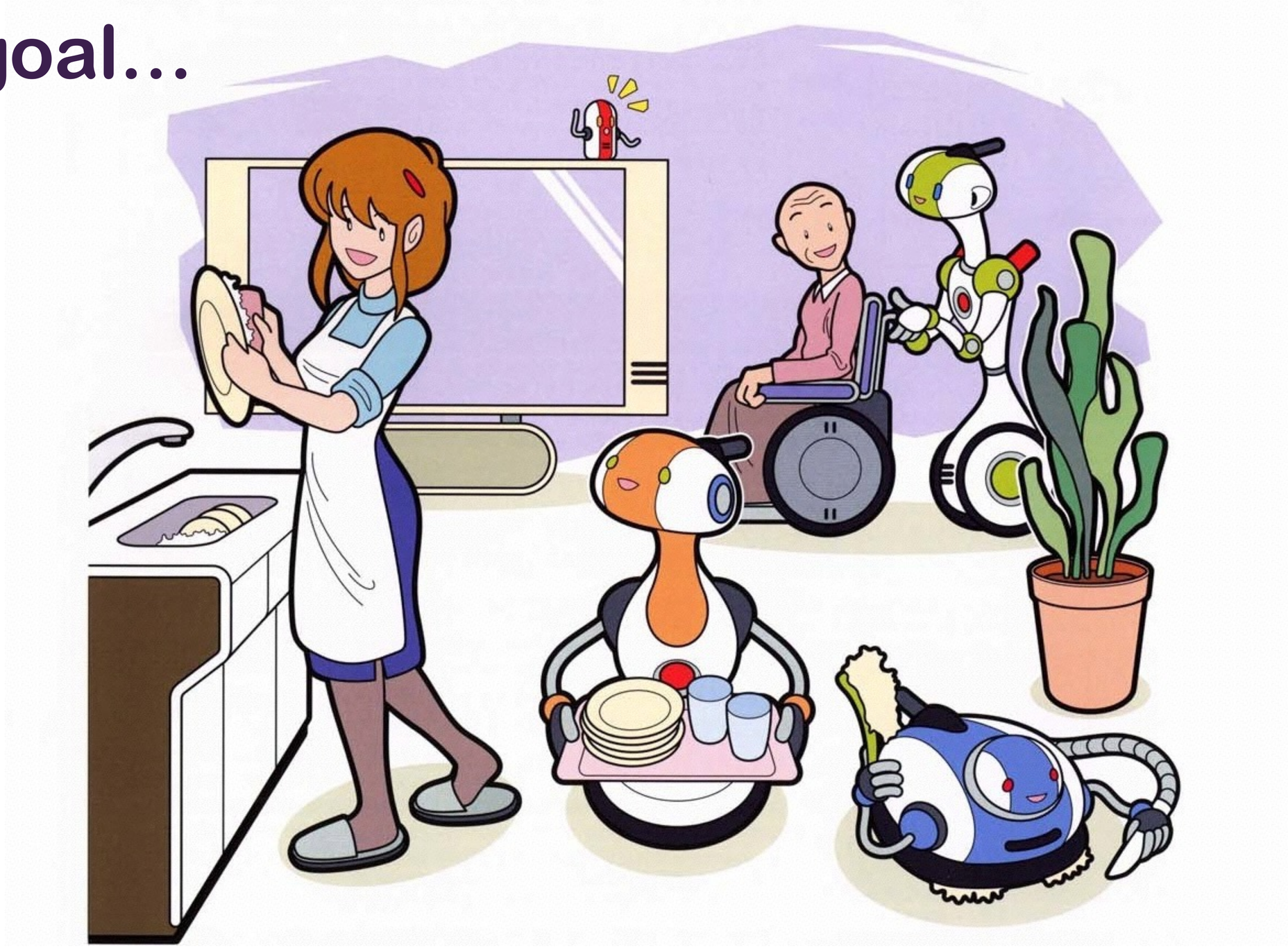
Event-Driven Sensing for a Humanoid Robot

Chiara Bartolozzi

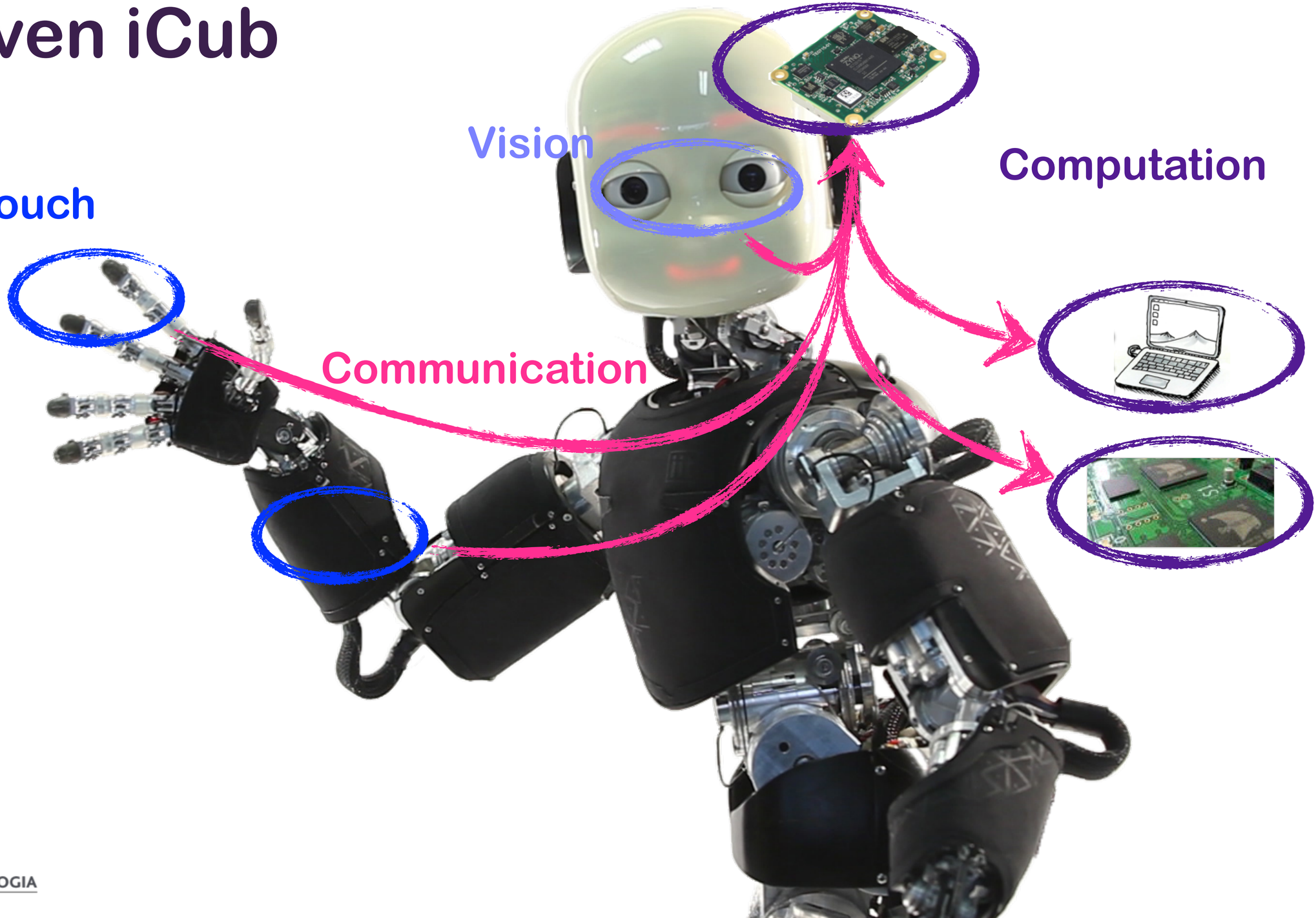
ISTITUTO ITALIANO
DI TECNOLOGIA

Our goal…

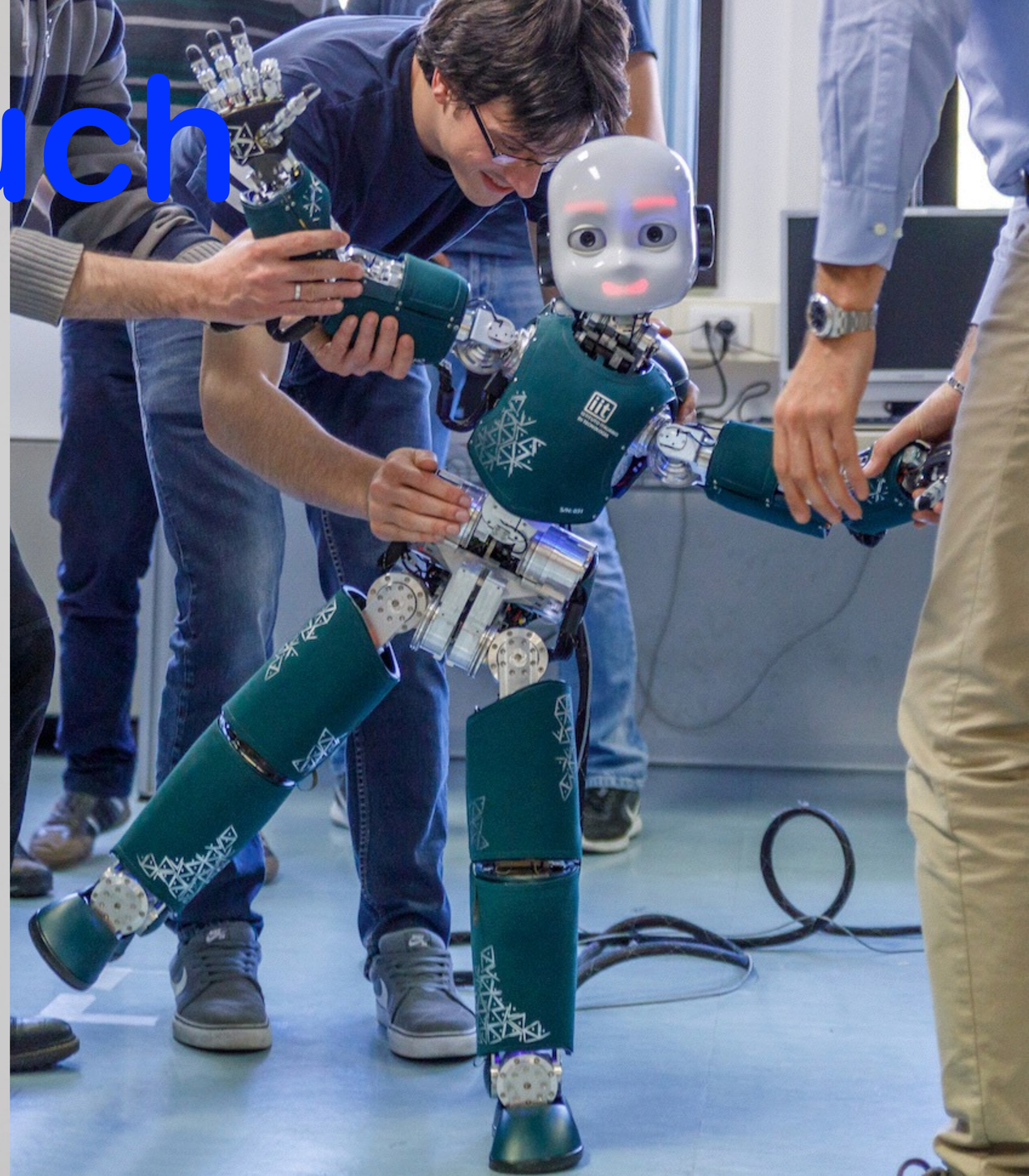


Smart Autonomous Systems

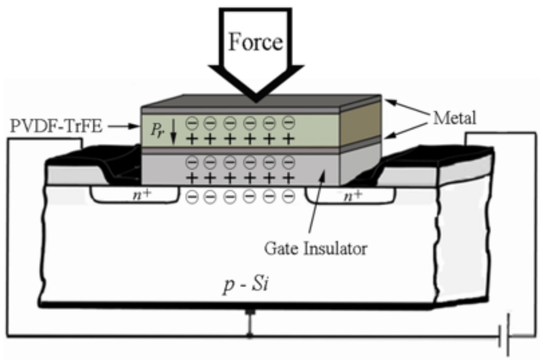
Event-Driven iCub

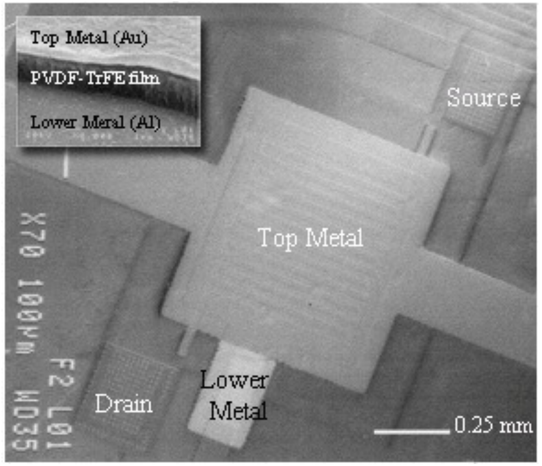


Touch

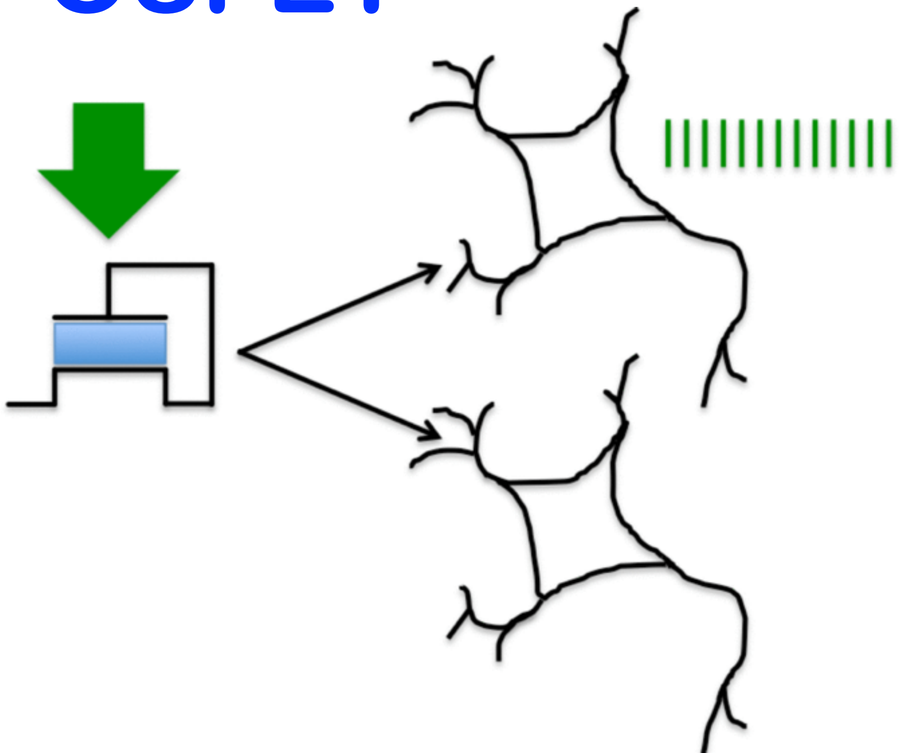


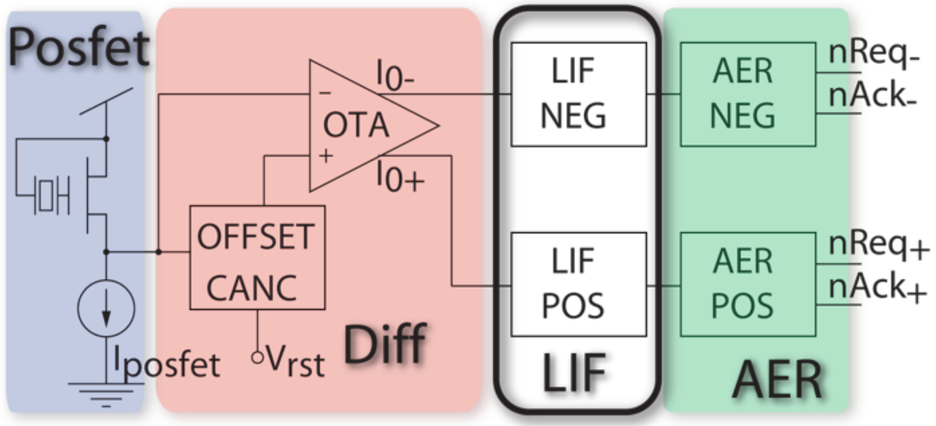
ED Sensors — Touch



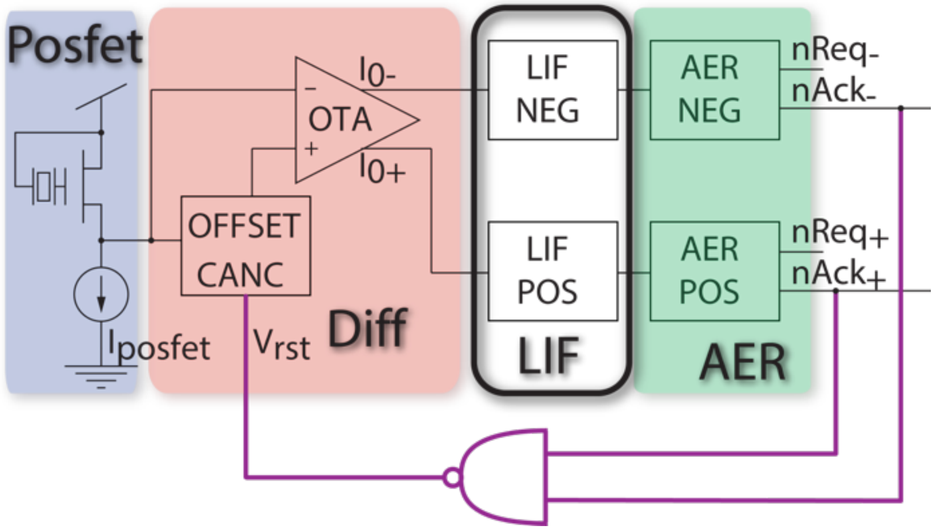


POSFET



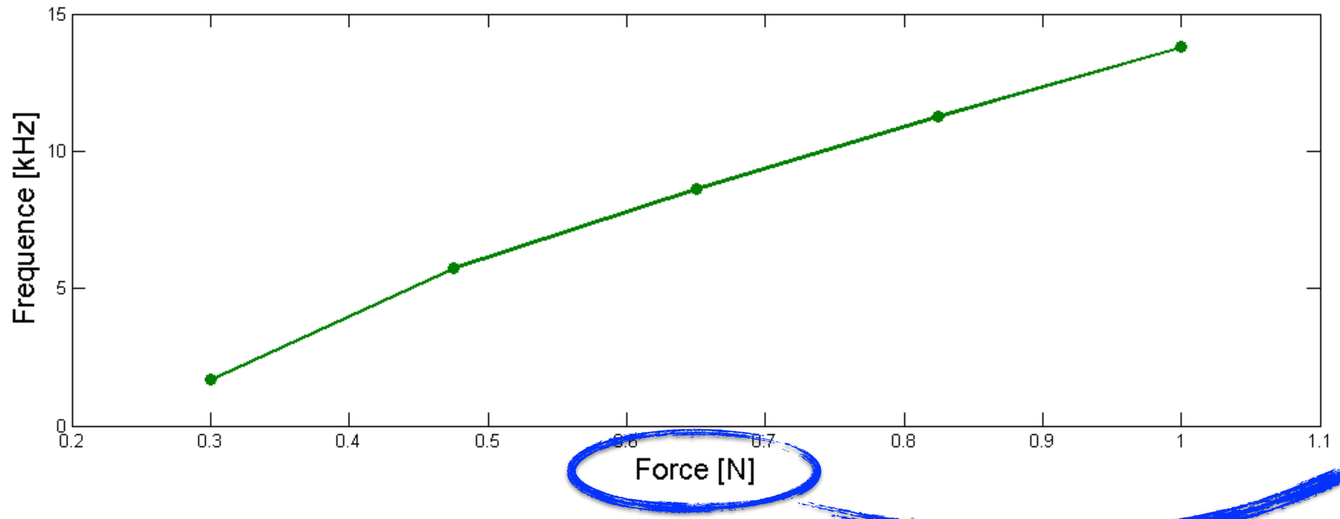


"Sustained" taxel

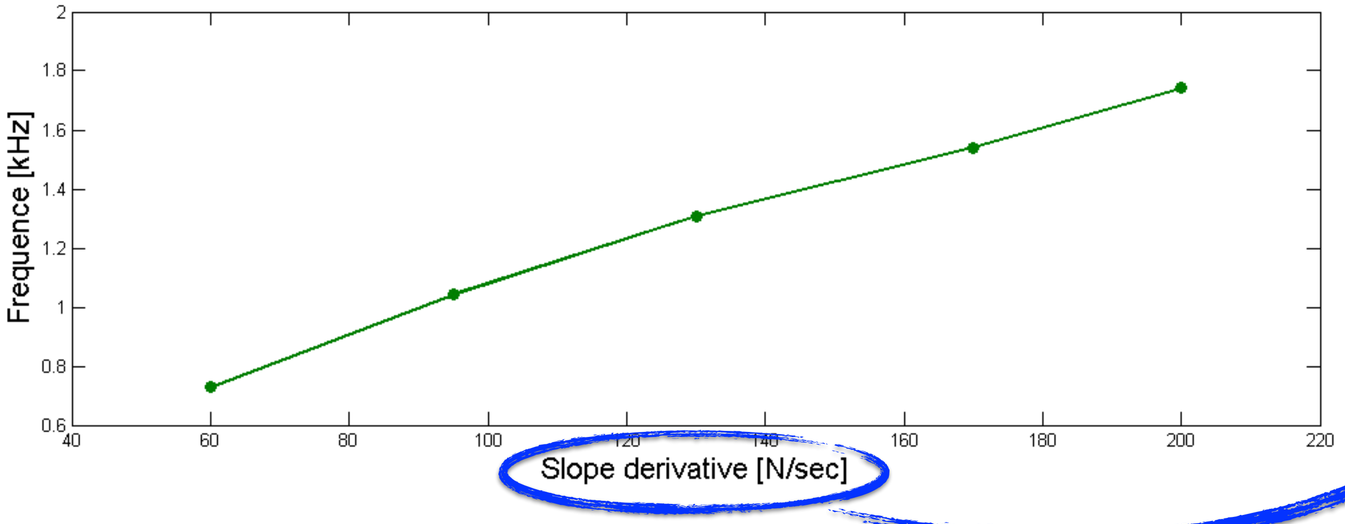


"Transient" taxel

ED Sensors — Touch



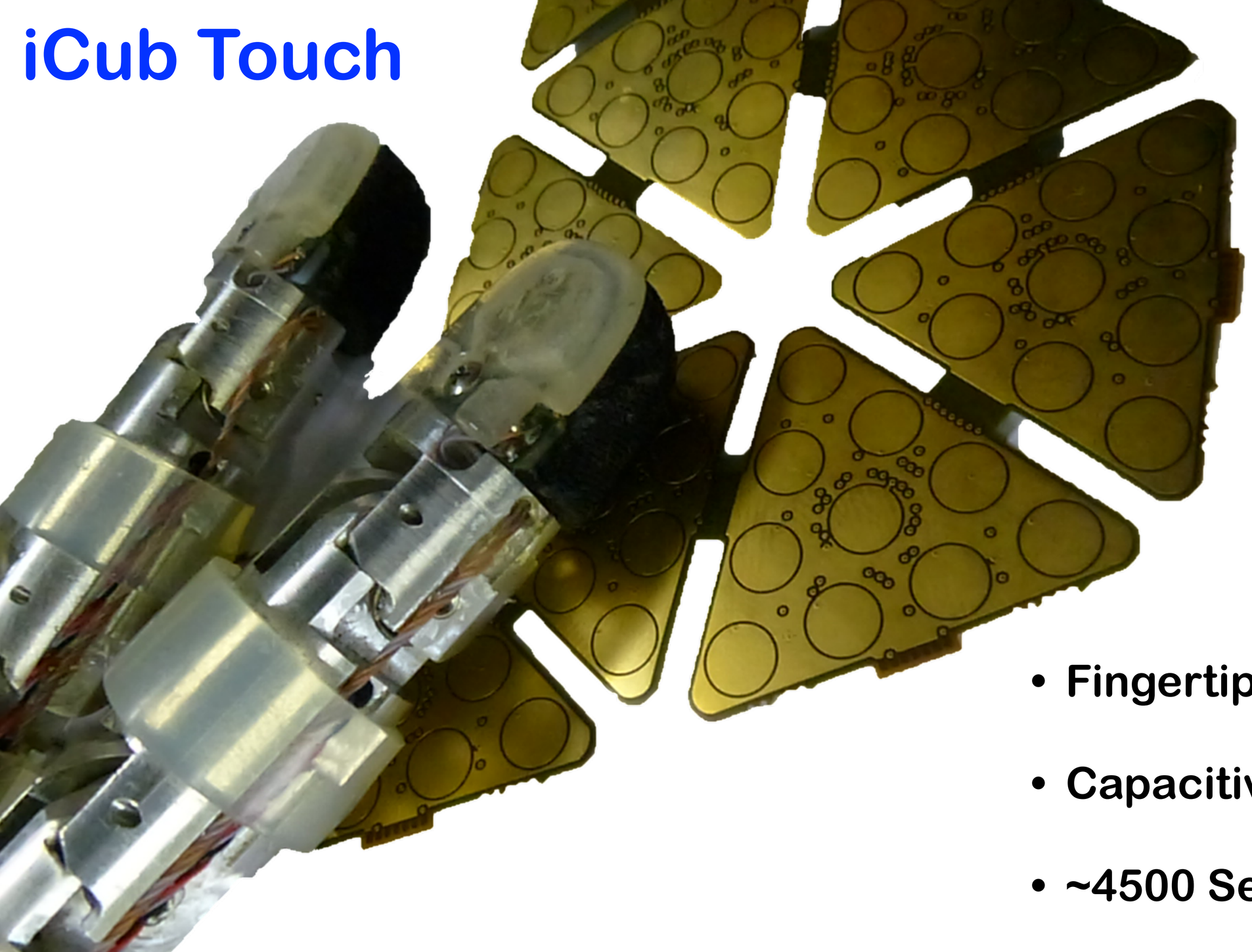
Sustained



Transient

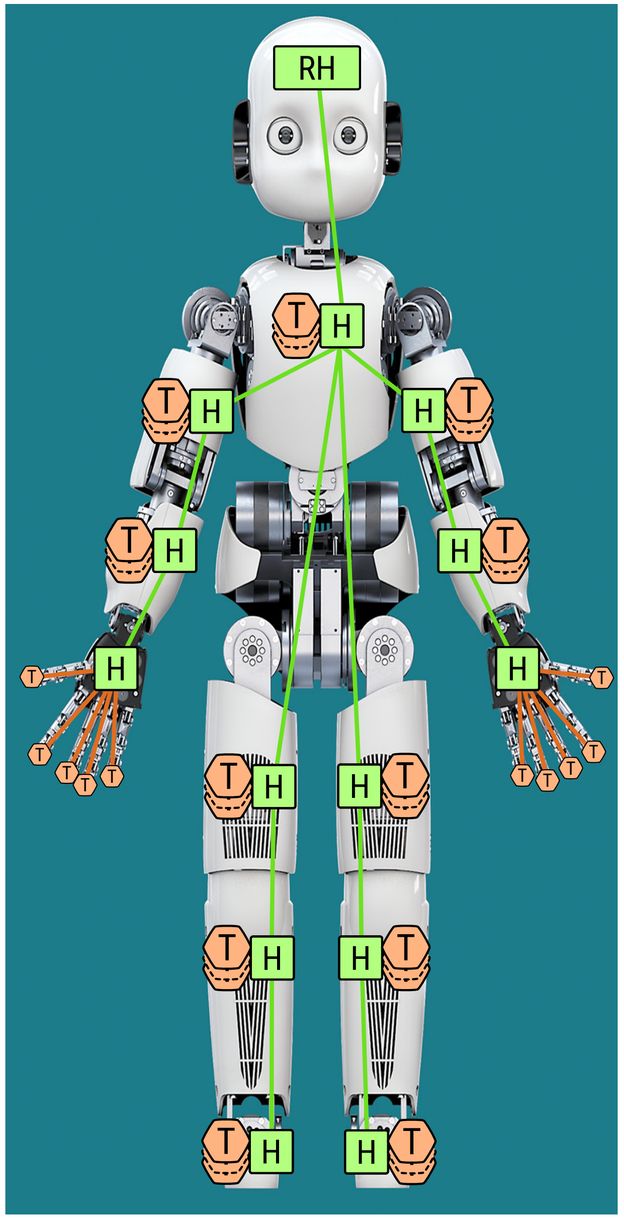
Caviglia et al. ISCAS 2016

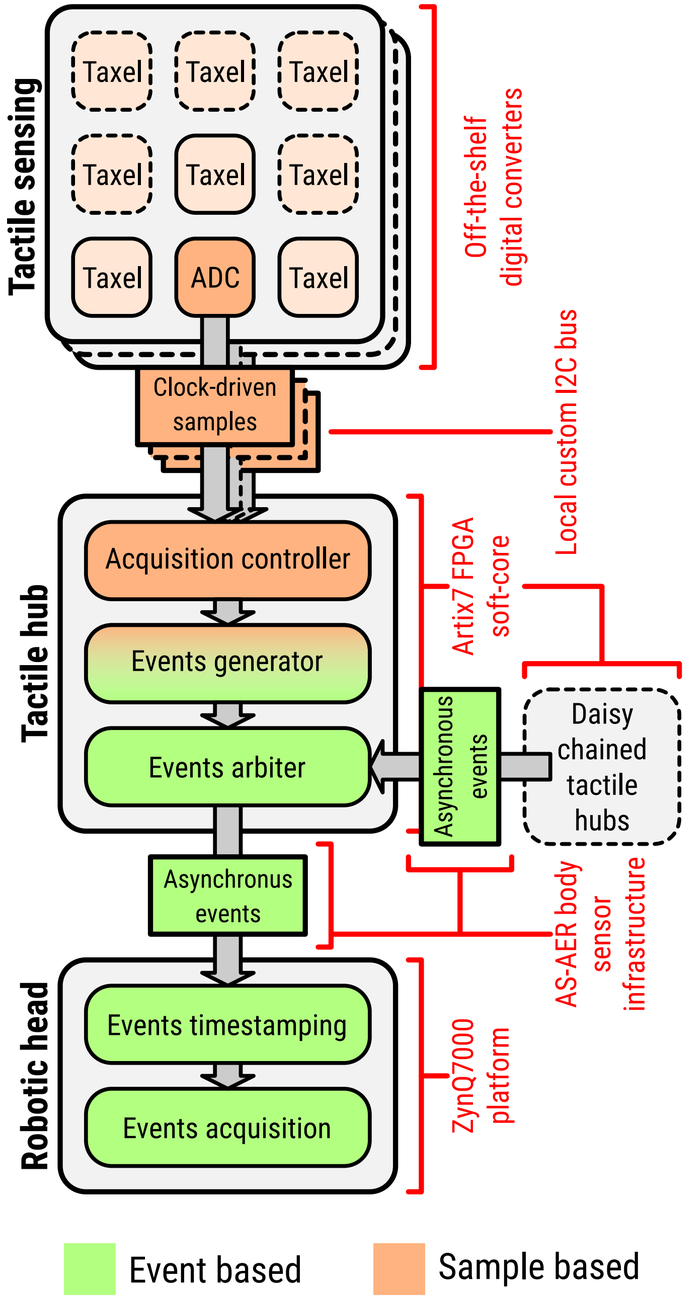
iCub Touch



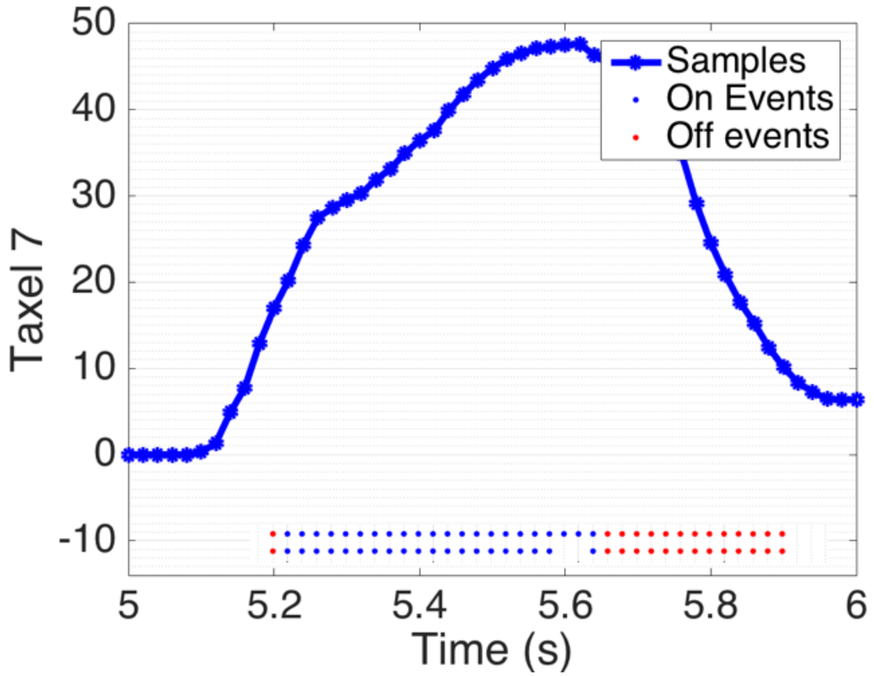
- Fingertips & Skin
- Capacitive Sensors
- ~4500 Sensors (taxels)

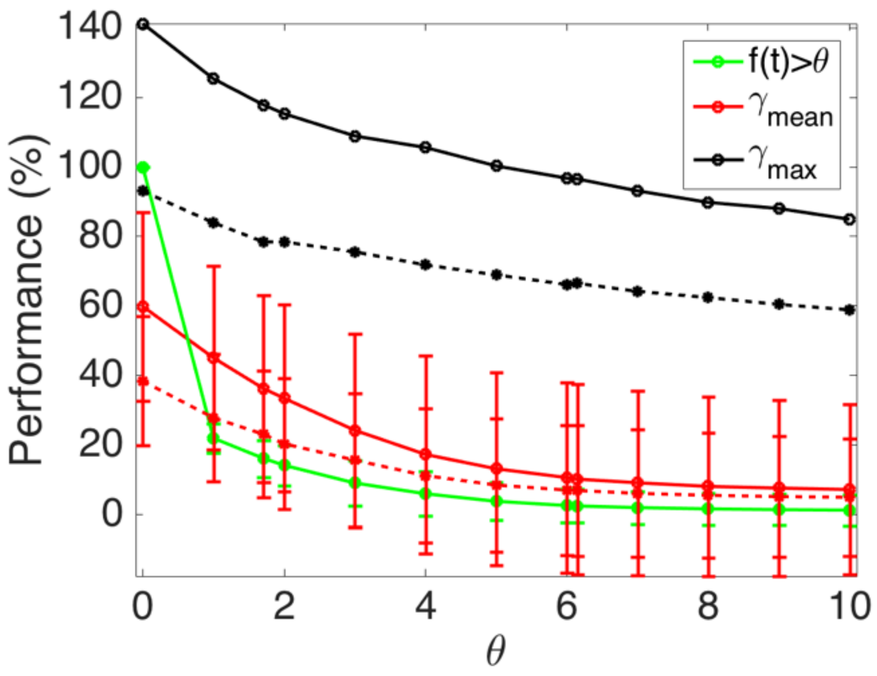
ED Sensors — Touch





ED Sensors — Touch

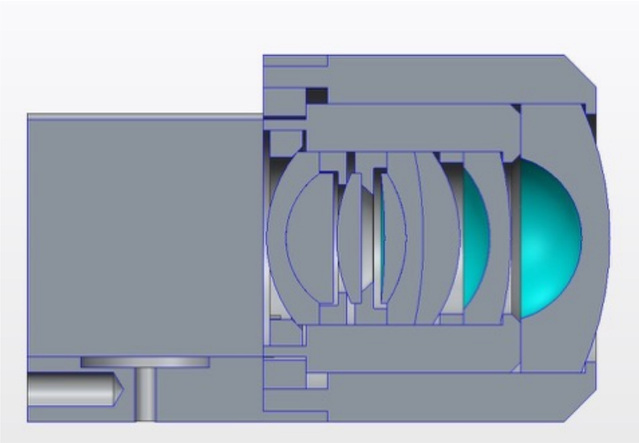


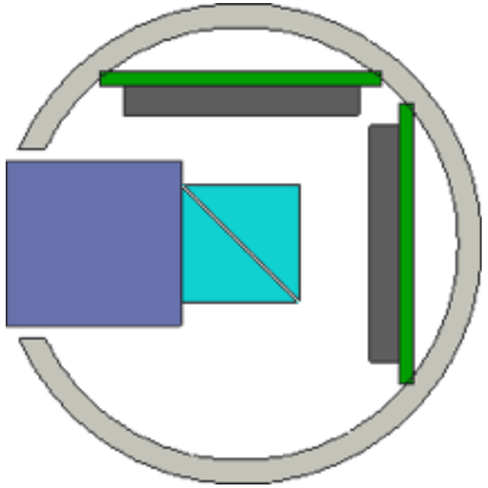


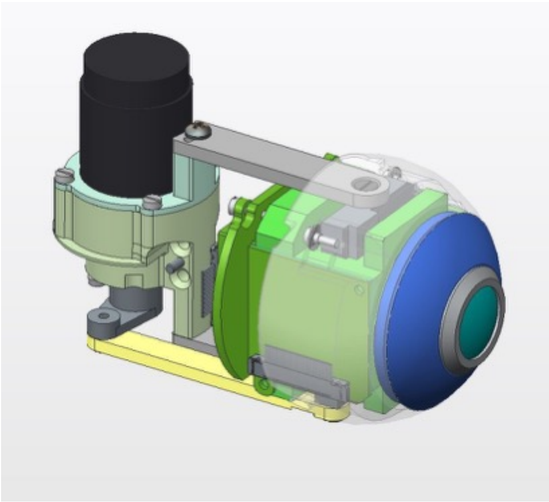
Noise Threshold - θ
Level Threshold - Δ
Fingertip - 12 taxels, #7 active

$$\gamma = \frac{e \cdot b_{ED}}{s \cdot b_{CB}}$$

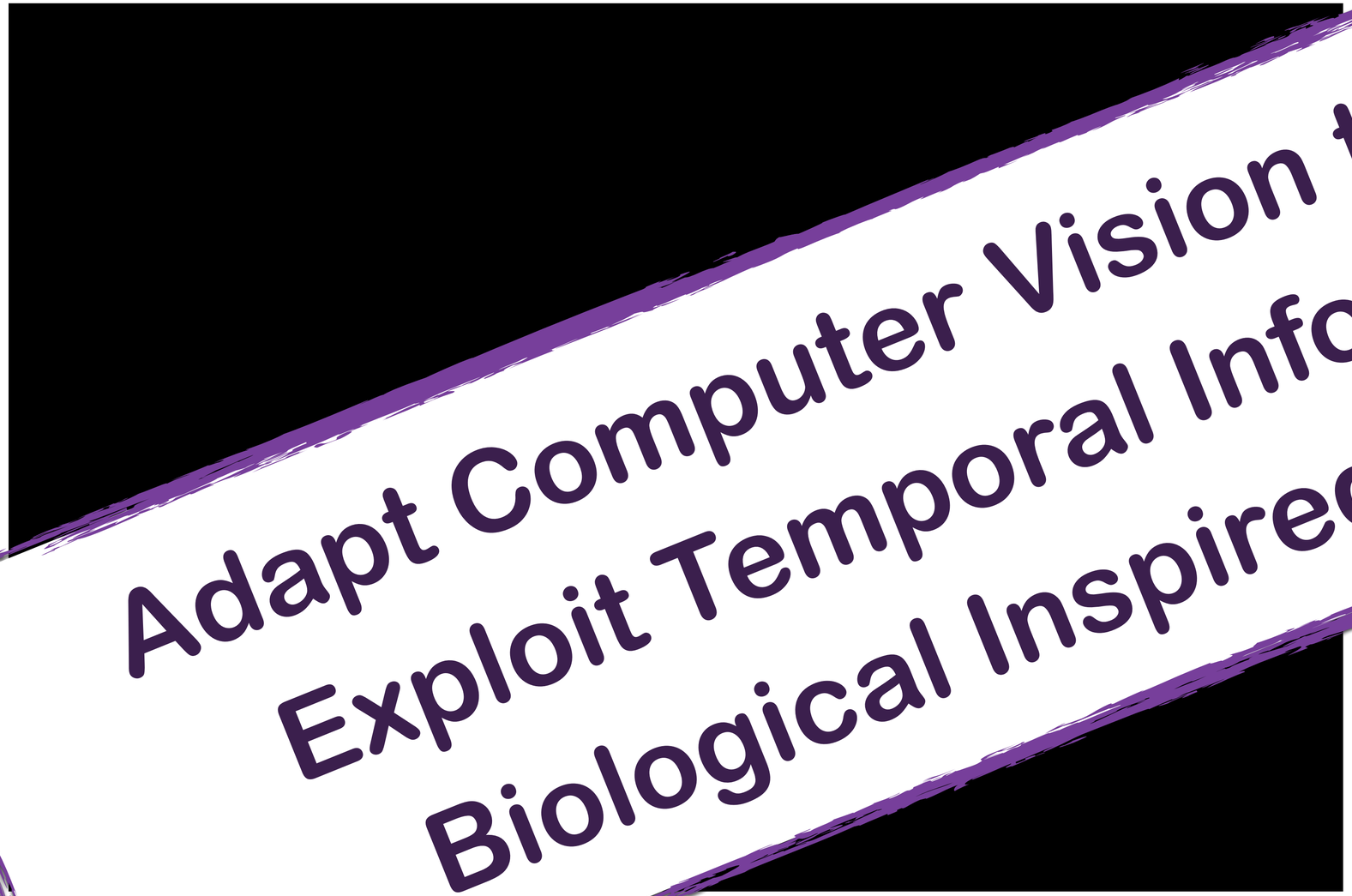
ED Sensors — iCub Vision







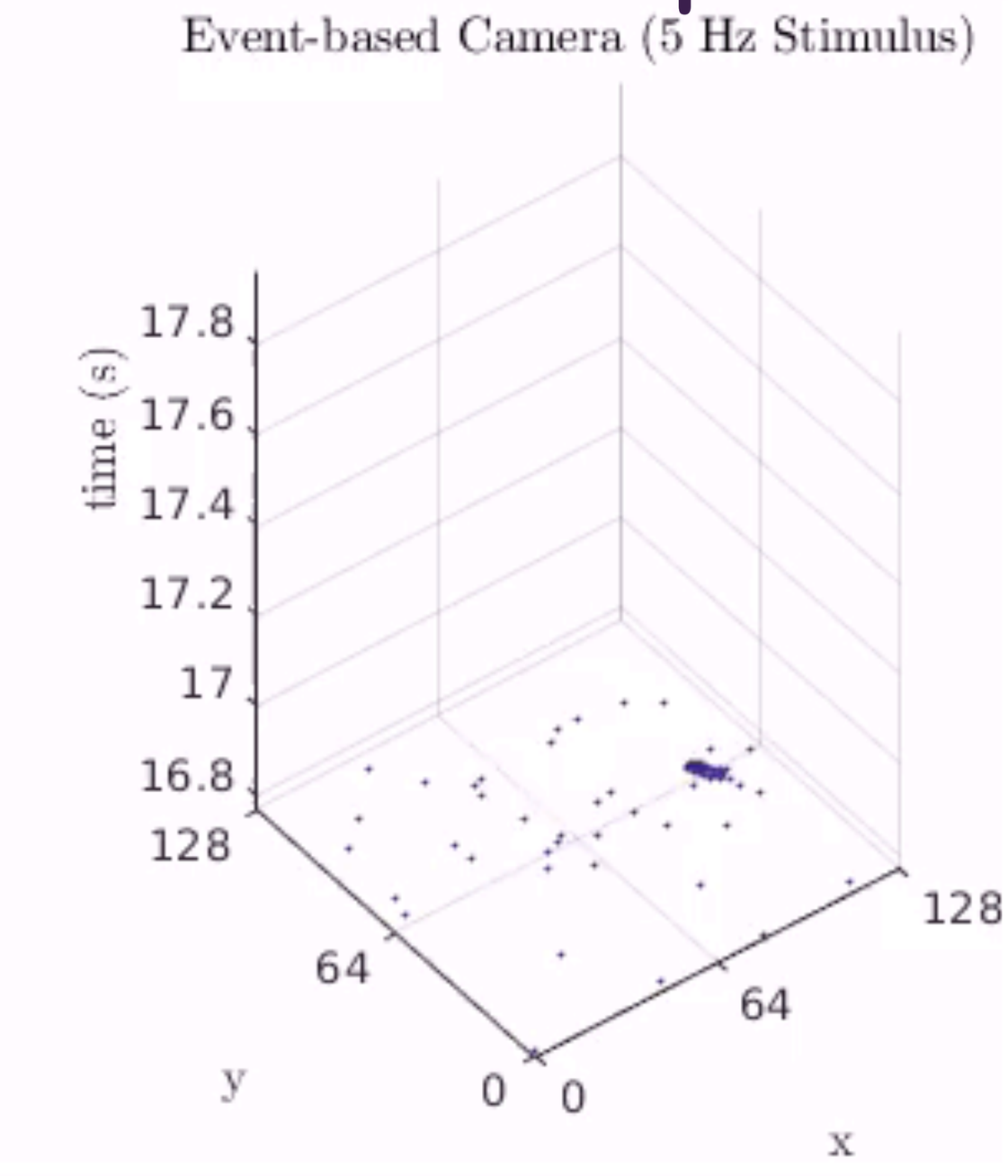
ED Sensors — Vision



Adapt Computer Vision to Events
Exploit Temporal Information
Biological Inspired Vision

	304
	2/3”
mporal	1µs
Res	
AFOV	61°

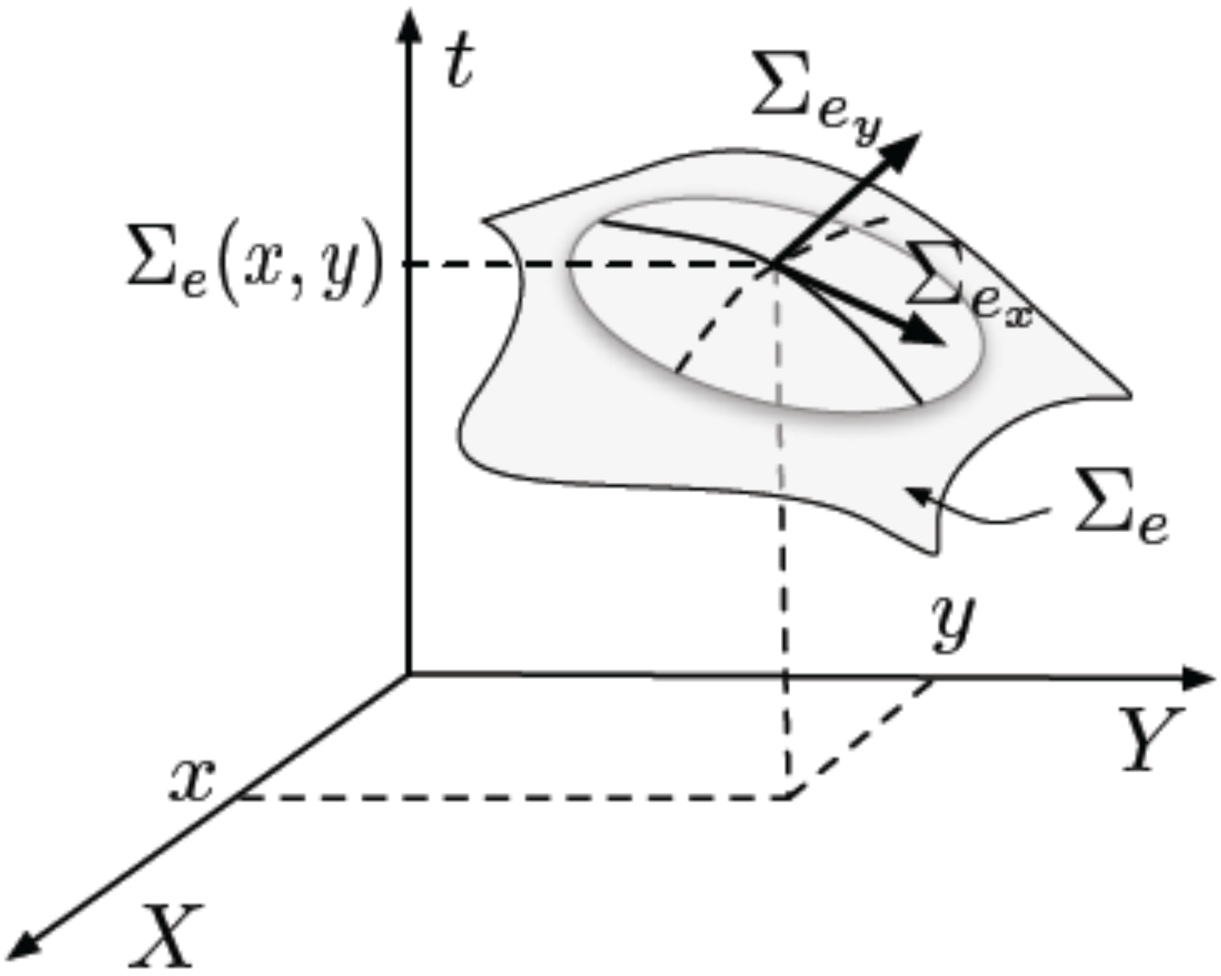
ED Vision — Optical Flow



$$e(\mathbf{p}, \mathbf{t}) :$$

$$\Sigma_e : \mathbb{N} \to \mathbb{R}$$

$$p \longmapsto \Sigma_e(\mathbf{p} = \mathbf{t})$$

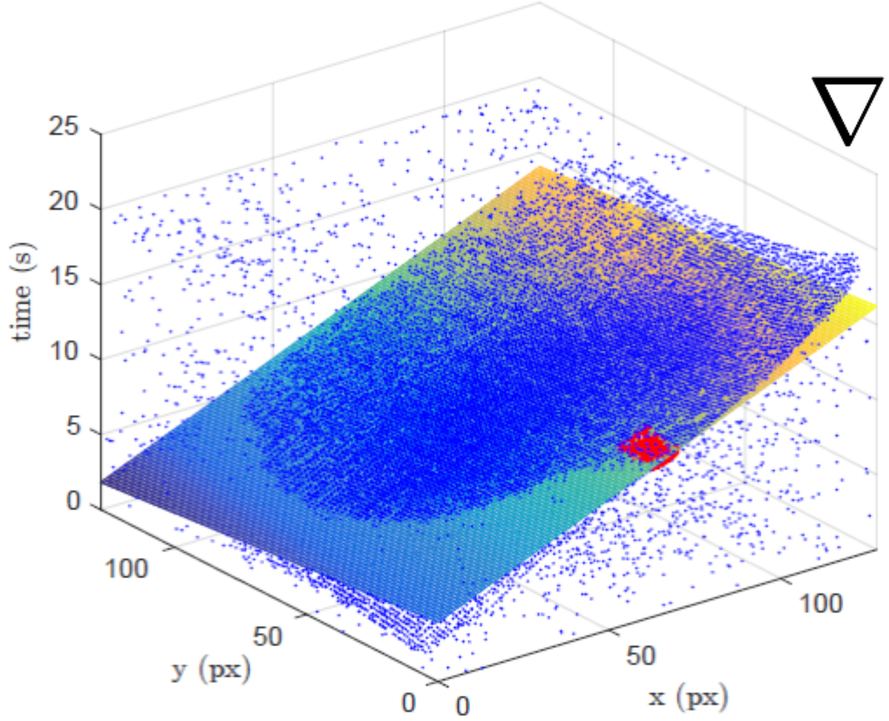


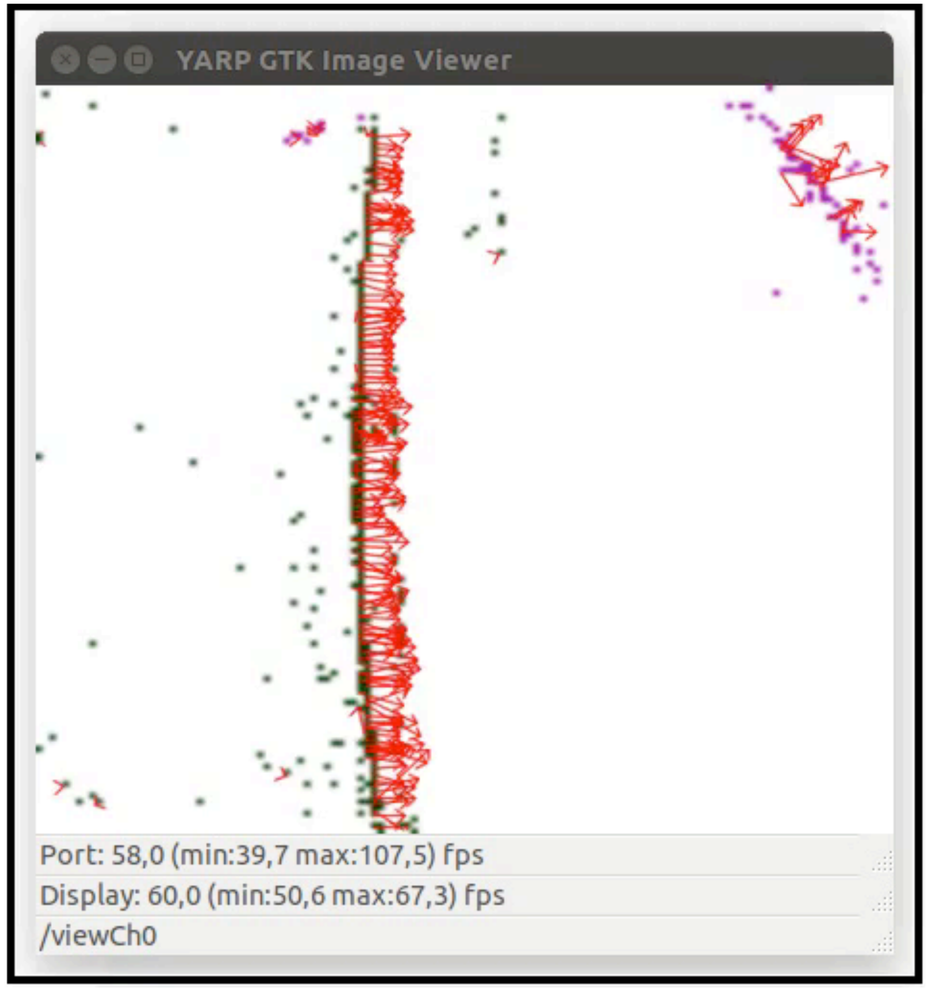
ED Vision — Optical Flow

$$\frac{\partial \Sigma_e}{\partial x}(x, y_0) = \frac{d\Sigma_e|_{y=y_0}}{dx} = \frac{1}{v_x(x, y_0)}$$

$$\frac{\partial \Sigma_e}{\partial y}(x_0, y) = \frac{d\Sigma_e|_{x=x_0}}{dy} = \frac{1}{v_y(x_0, y)}$$

$$\nabla \Sigma_e = \left(\frac{1}{v_x}, \frac{1}{v_y}\right)$$



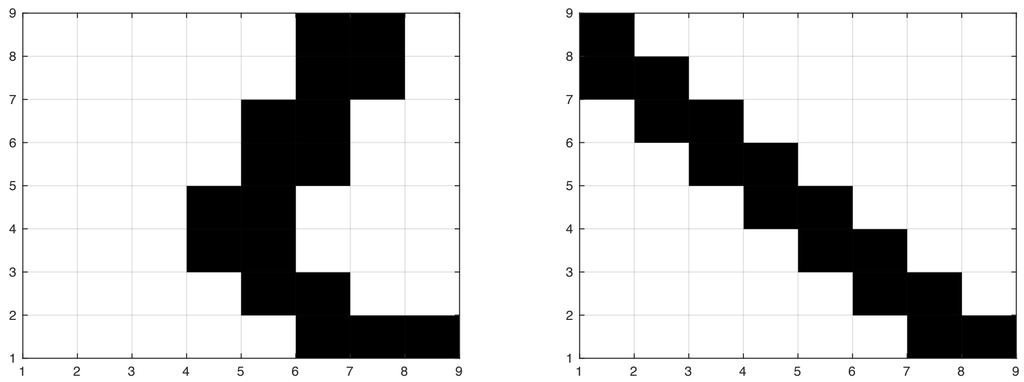


Benosman et al. TNNLS 2014

ED Vision — Corner Detection

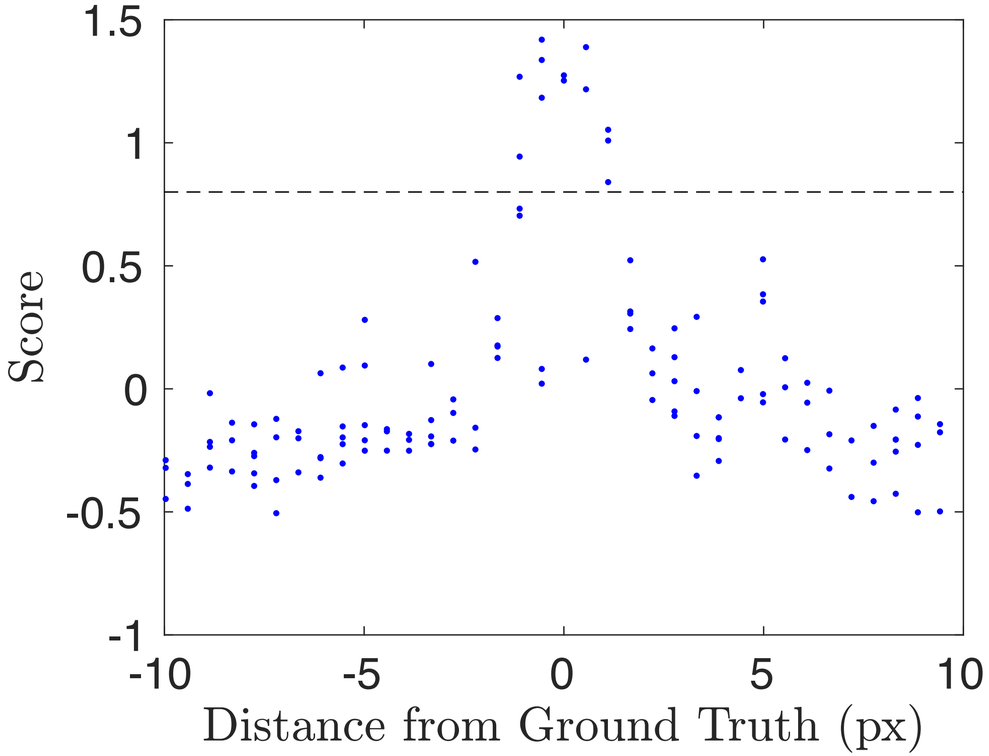
Binary Image Patch

- spatial derivatives



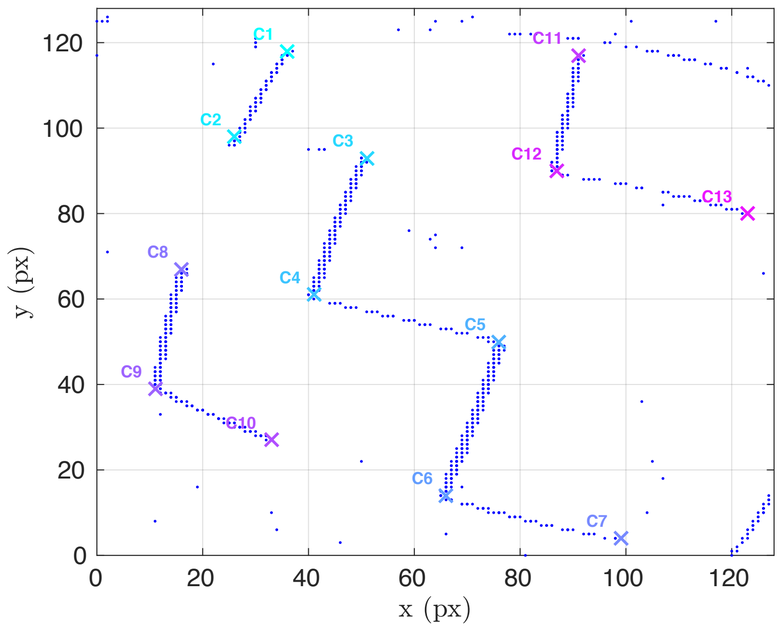
ED Harris Score — R

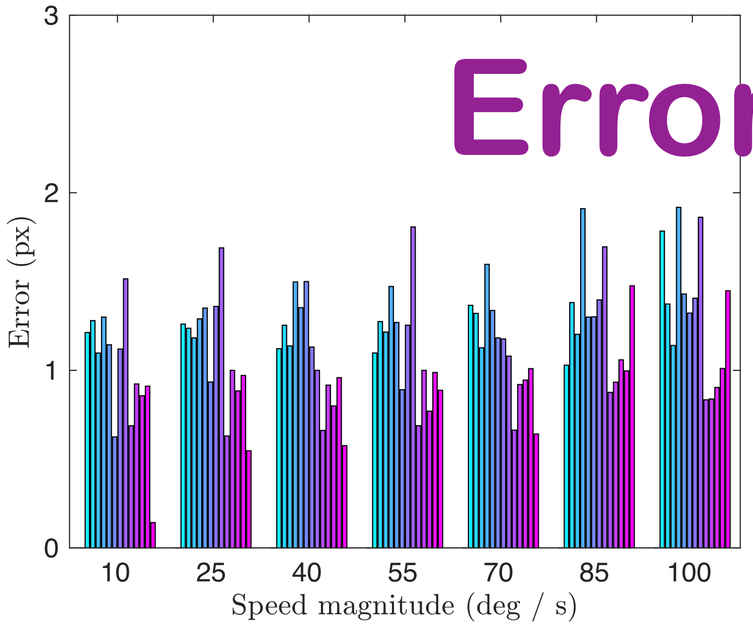
- flat: two small eigenvalues
  R small
- edge: one small and one big
  R negative
- corner: two large eigenvalues
  R big

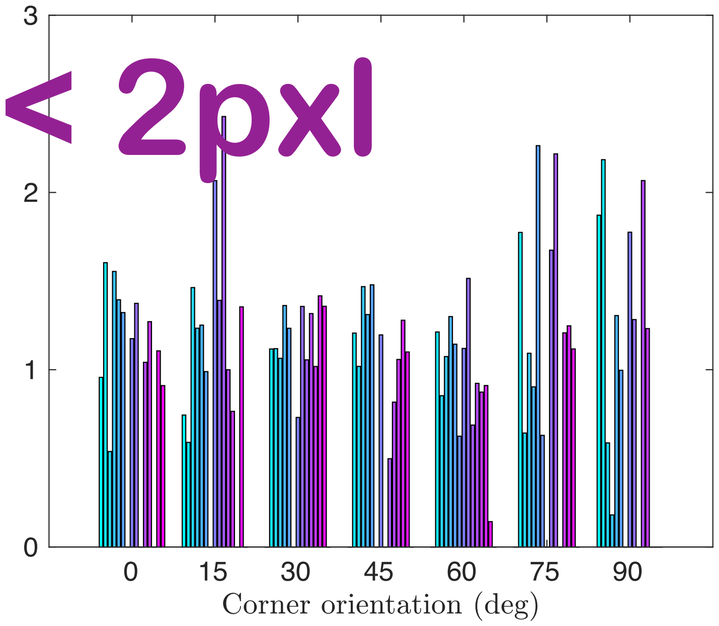


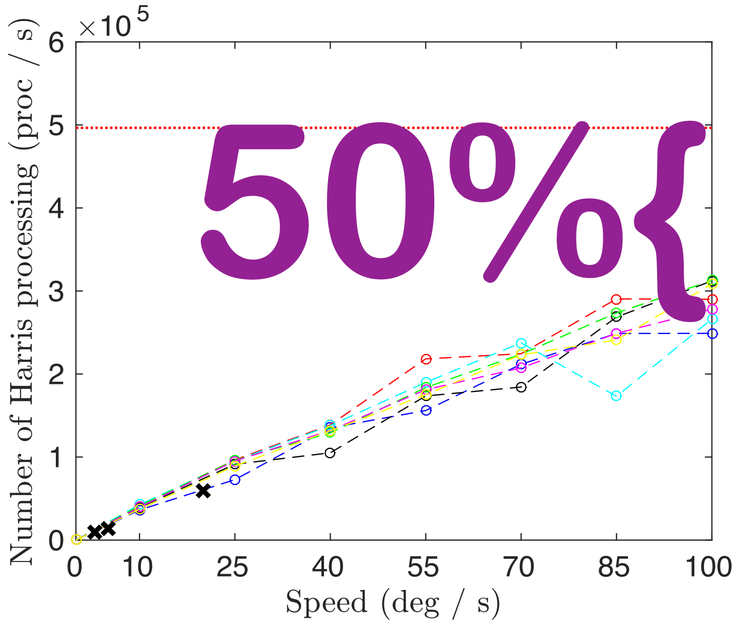
Creating Asynchronous Local Contrast Map

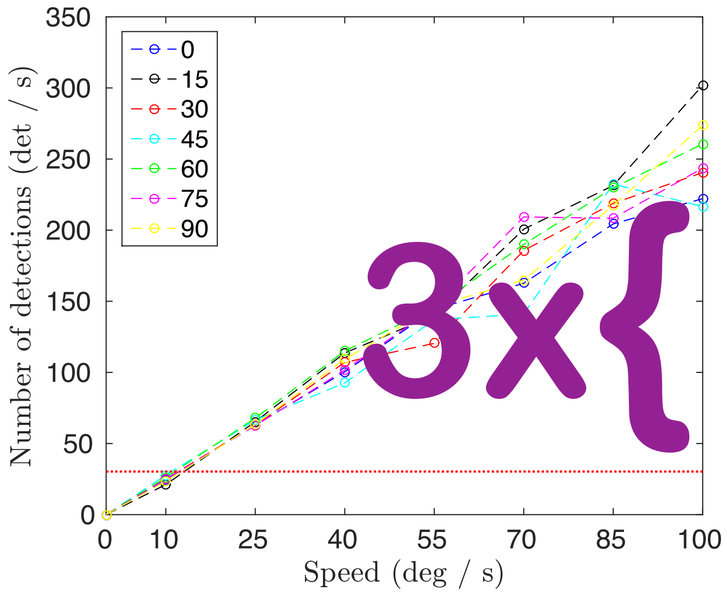
ED Vision — Corner Detection



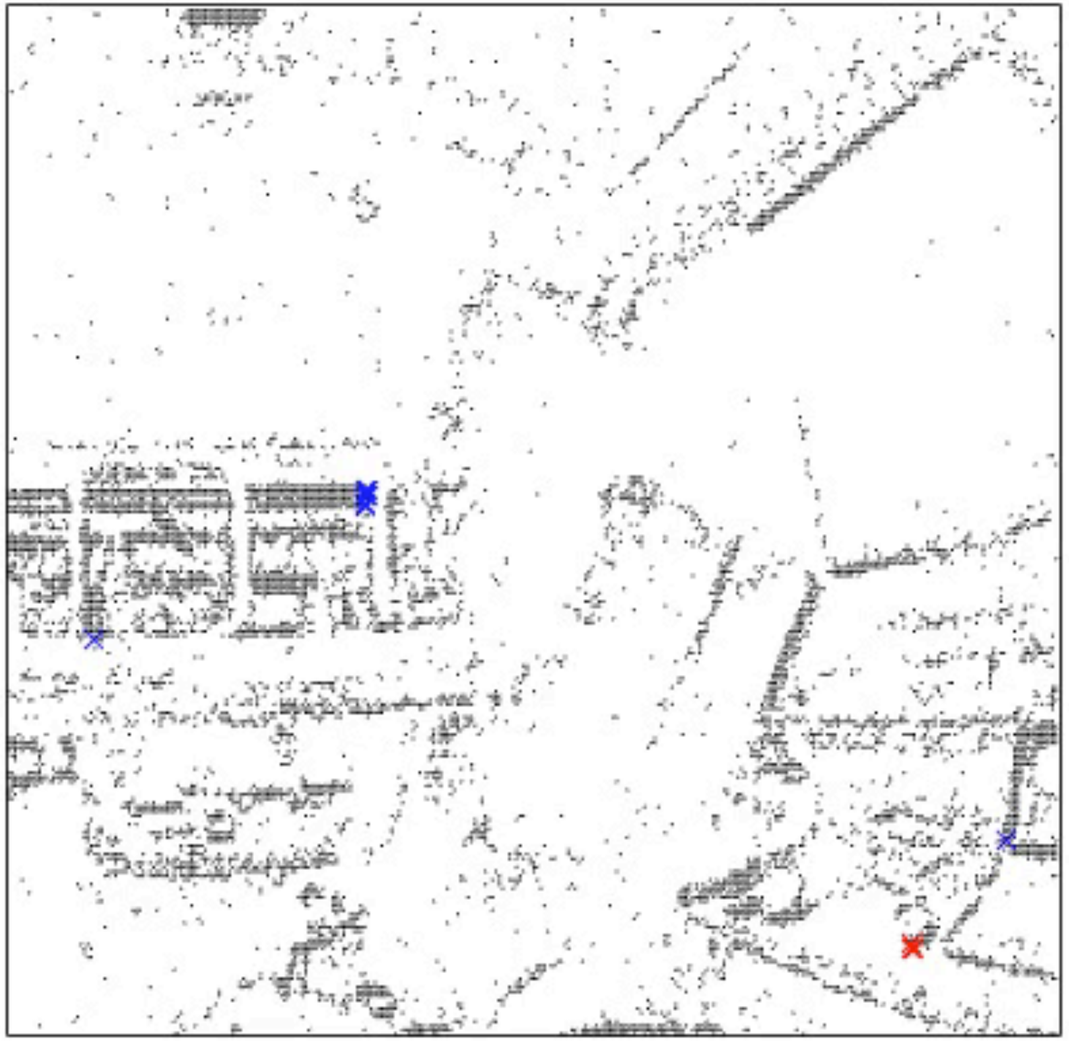


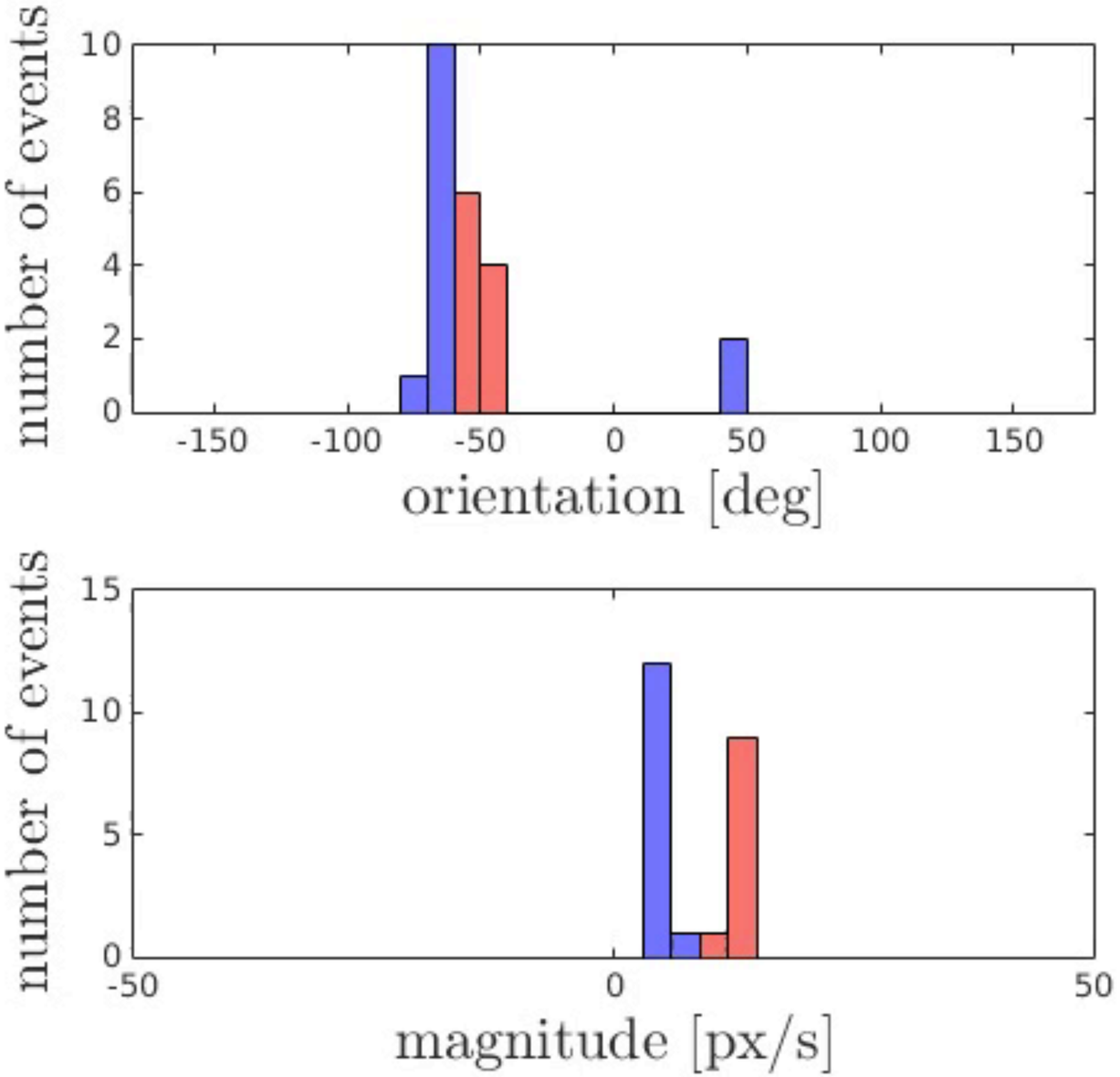






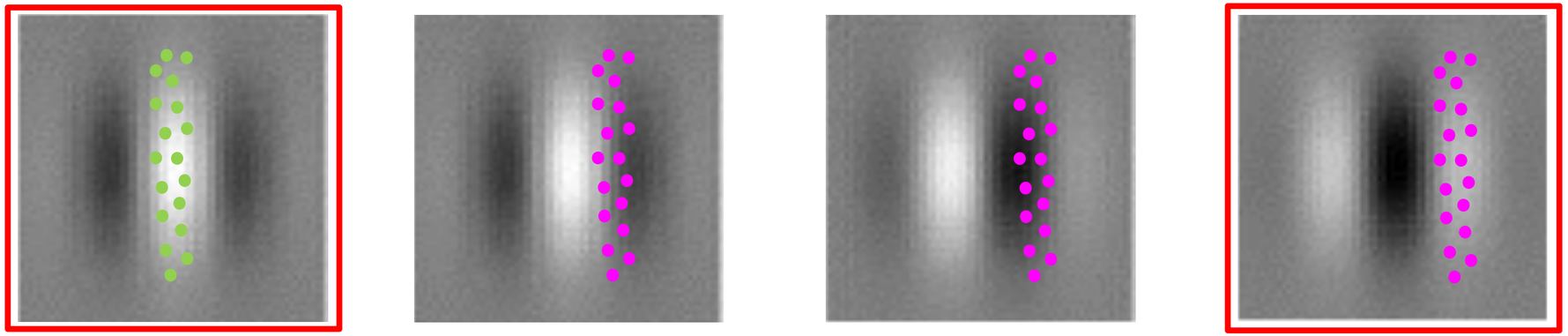
Vasco et al. IROS 2016




number of events
10
8
6
4
2
0
-150
-100
-50
0
50
100
150
orientation [deg]
number of events
15
10
5
0
-50
0
50
magnitude [px/s]

ED Vision — Disparity and Vergence

LEFT RIGHT



$\psi_L = 0$ ψ_{R1} ψ_{R2} ψ_{R3}

Disparity: Phase-Shift Model

$$g(x, y, \theta, \psi) = e^{-\frac{x^2+y^2}{2\sigma^2}} e^{j(2\pi f_s x_\theta + \psi)}$$

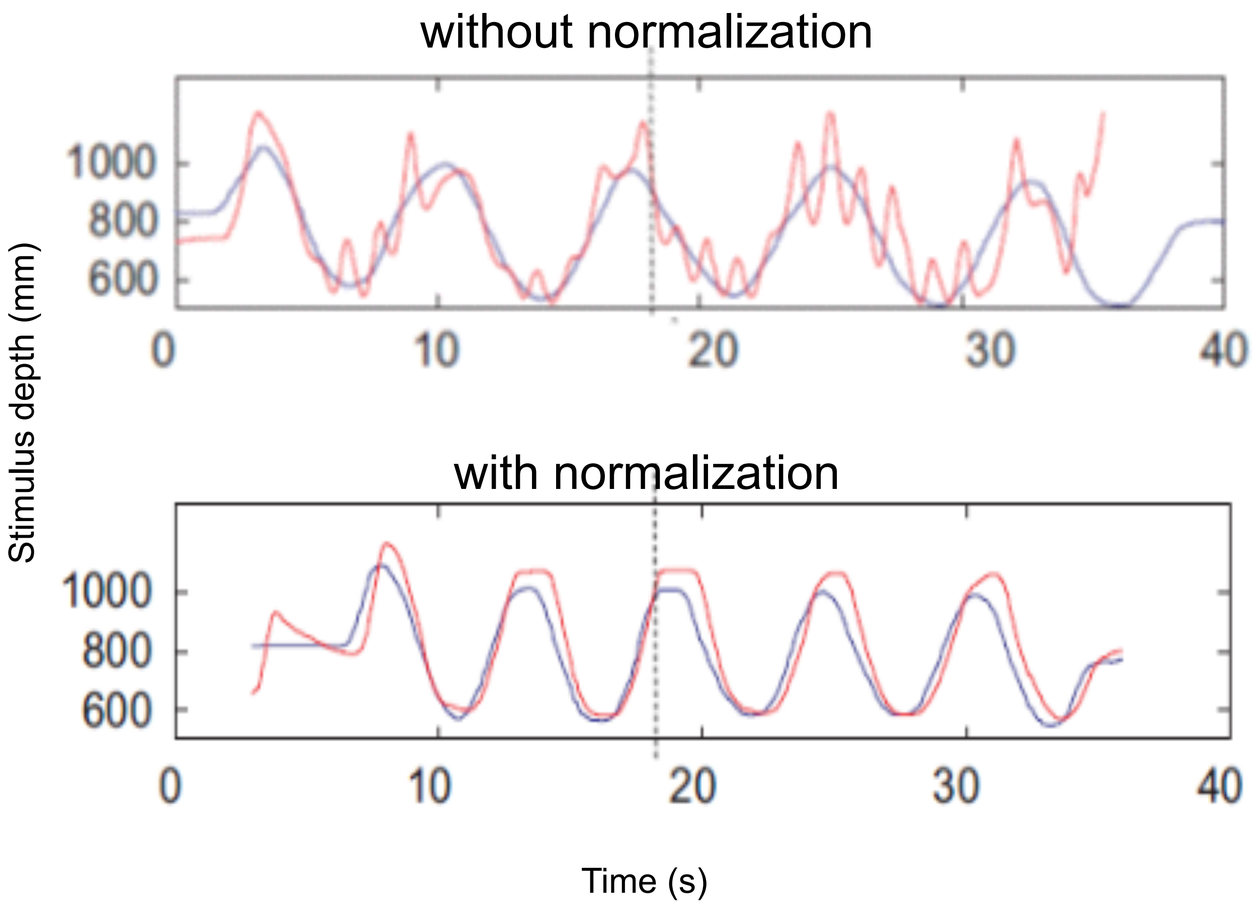
Vergence Control: Proportional Velocity

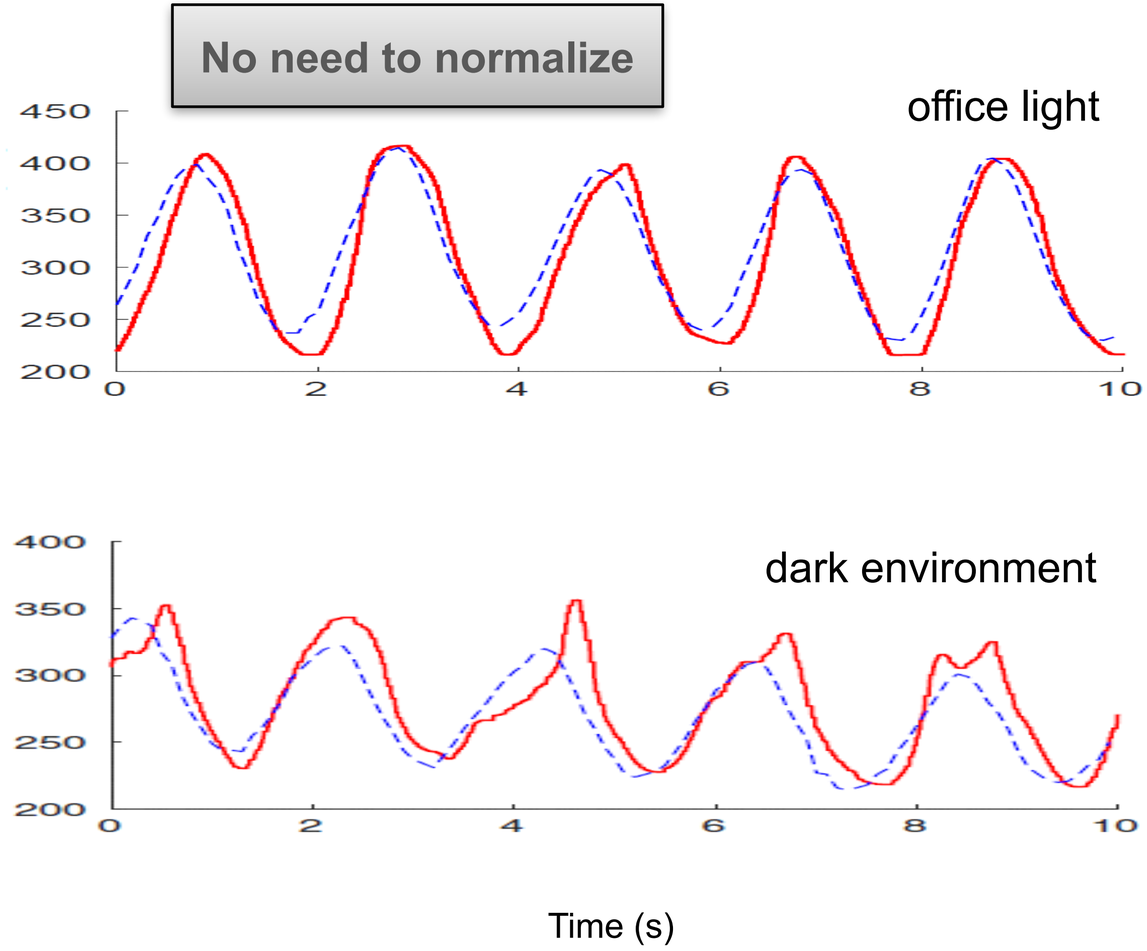
$$\dot{v} = k_p \frac{\sum_{i=1}^{N_\theta} \sum_{j=1}^{N_\psi} w_{ij} r_{ij}}{N_\theta N_\psi \sum_{i=1}^{N_\theta} \sum_{j=1}^{N_\psi} r_{ij}}$$

Event-based phase-shift model

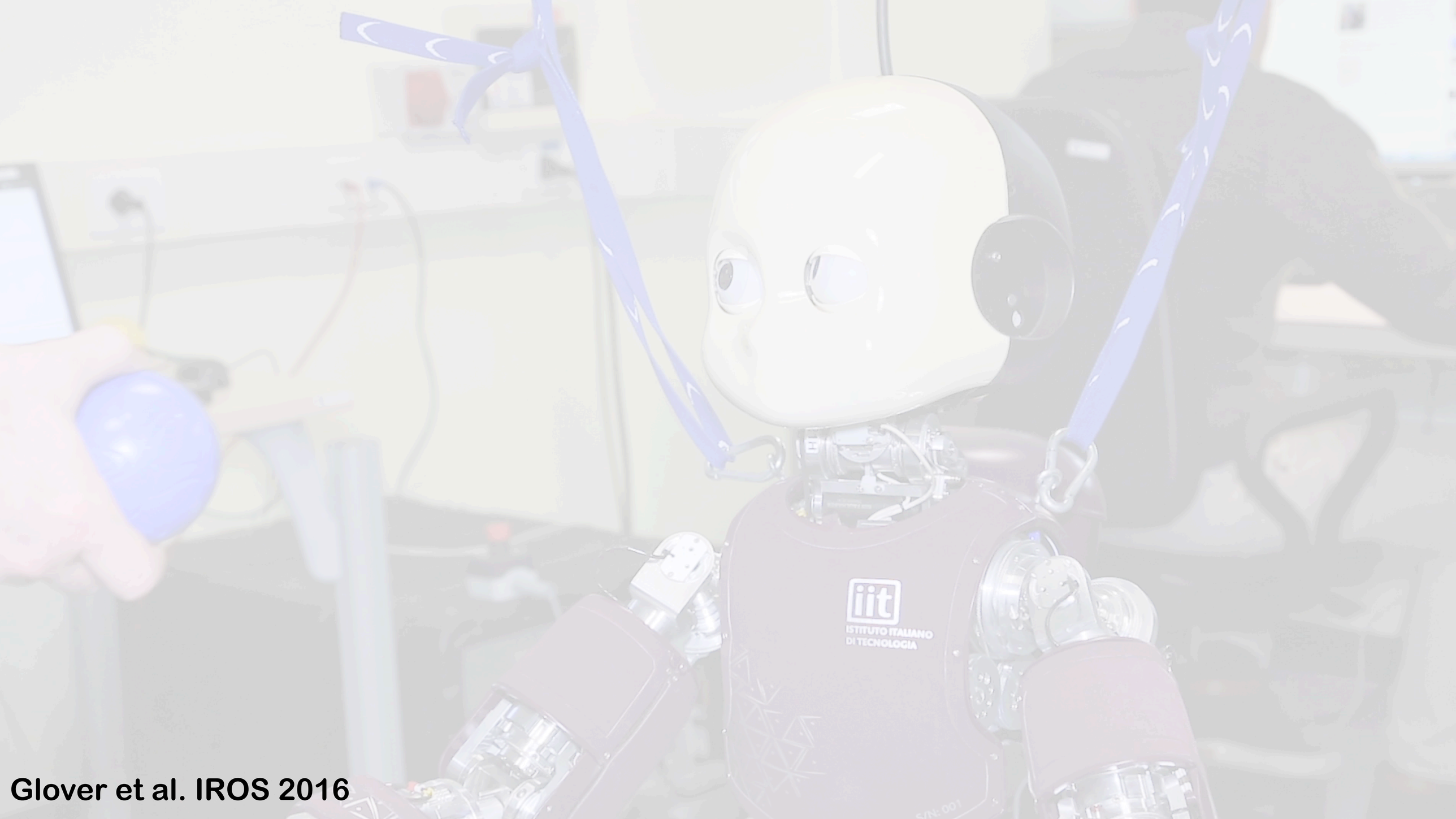
ED Vision — Vergence Control

FRAME-BASED Vs. EVENT-BASED





Vasco et al. Humanoids 2016



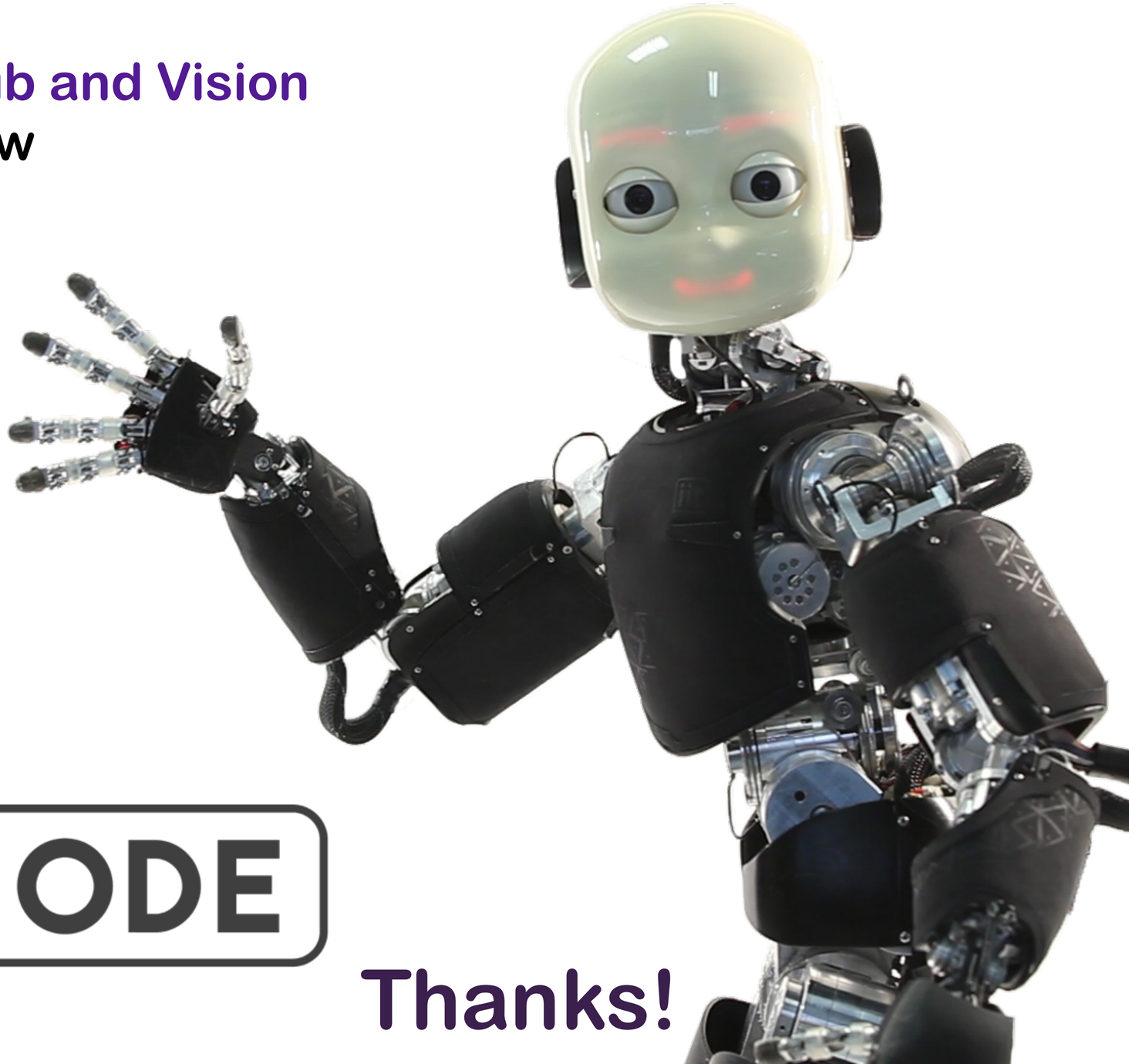
Glover et al. IROS 2016

Event-driven POSFET

S. Caviglia
M. Valle
L. Pinna
A. Abou

Event-driven iCub and Vision

iCub Facility crew
G. Metta
H. Akolkar
V. Vasco
A. Glover
F. Solari
P. Motto Ros
R. Benosman



emorph

ECOMODE

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iCUB FACILITY

Thanks!