Event-Driven Sensing for Autonomous Robots

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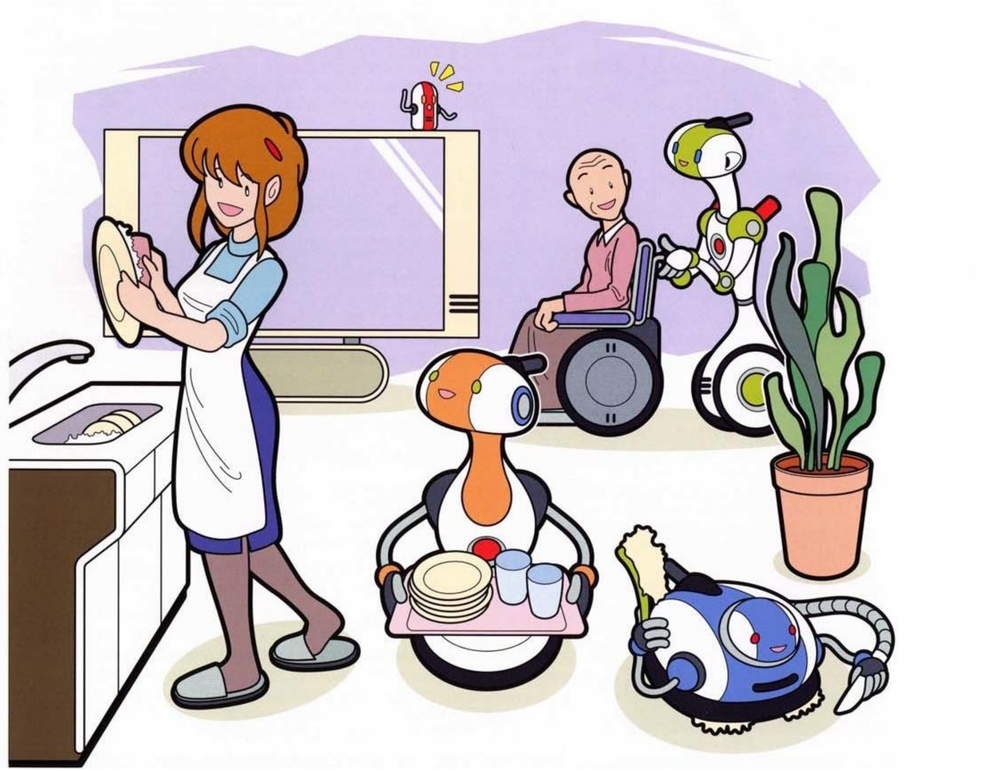
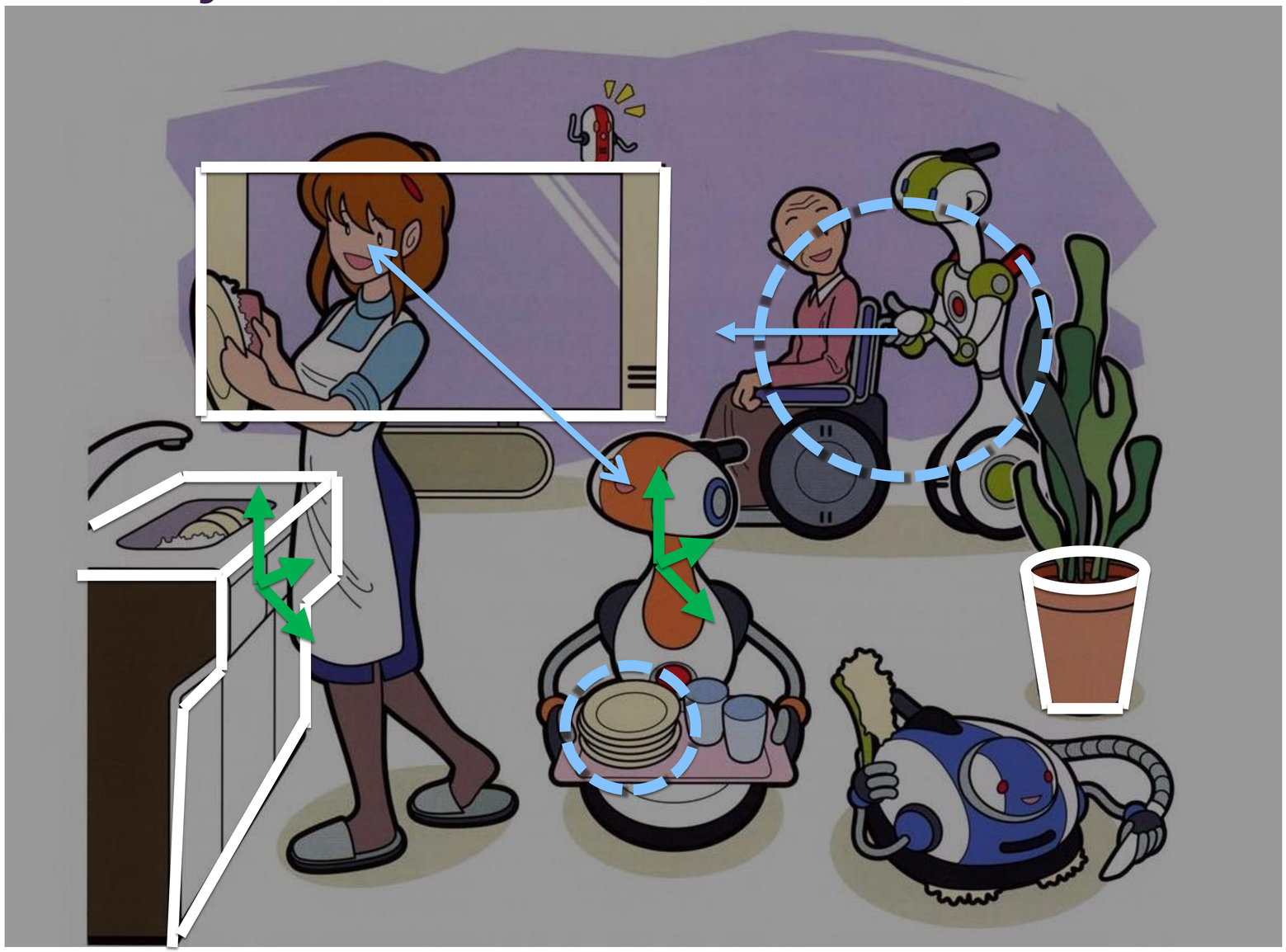
DI TECNOLOGIA

The iCub Humanoid Robot



What is required for autonomy?

- Model of environment
- Robot pose relative to environment
- Tasks requires searching for objects
- Track dynamic objects (avoiding/interacting)
- Interaction with humans (learning)



Roadblocks to autonomy?

Sensors

- Aren't suitable for the task
- Don't work under all conditions

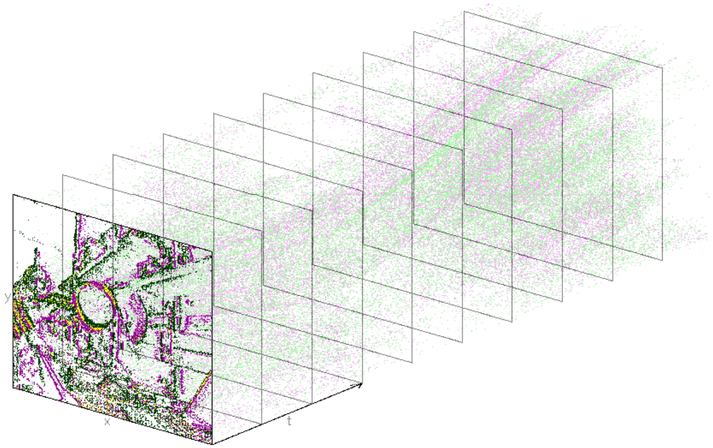
Processing

- Shouldn't rely on wireless communications for safety critical systems
- On-board systems need to be low resource consumers

System Integration

What role does neuromorphic engineering play?

Event-Driven iCub



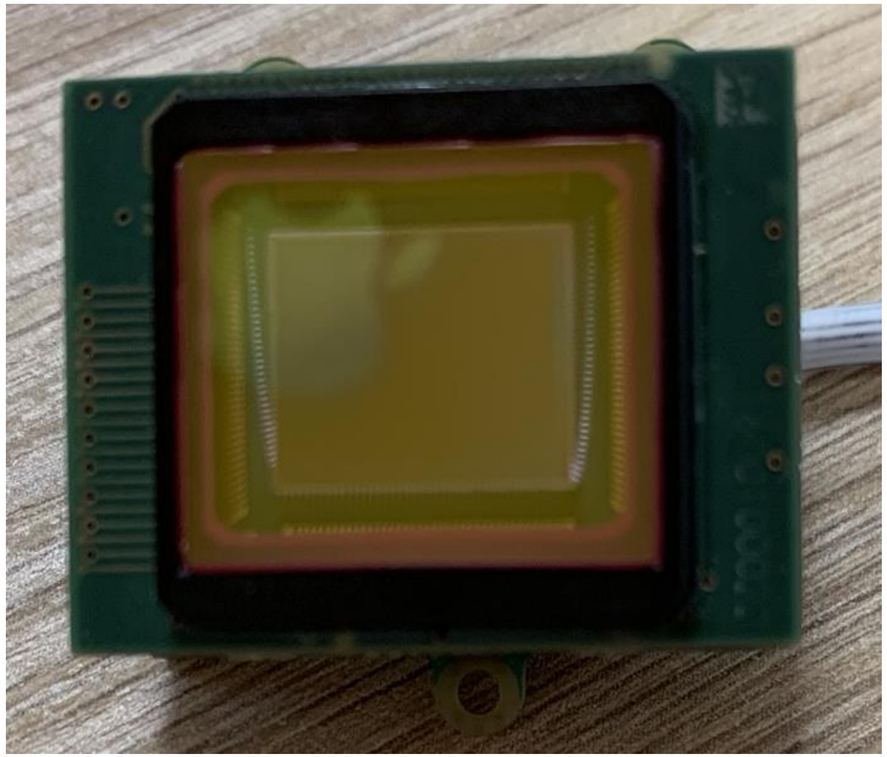
Vision

Touch

Communication

Computation

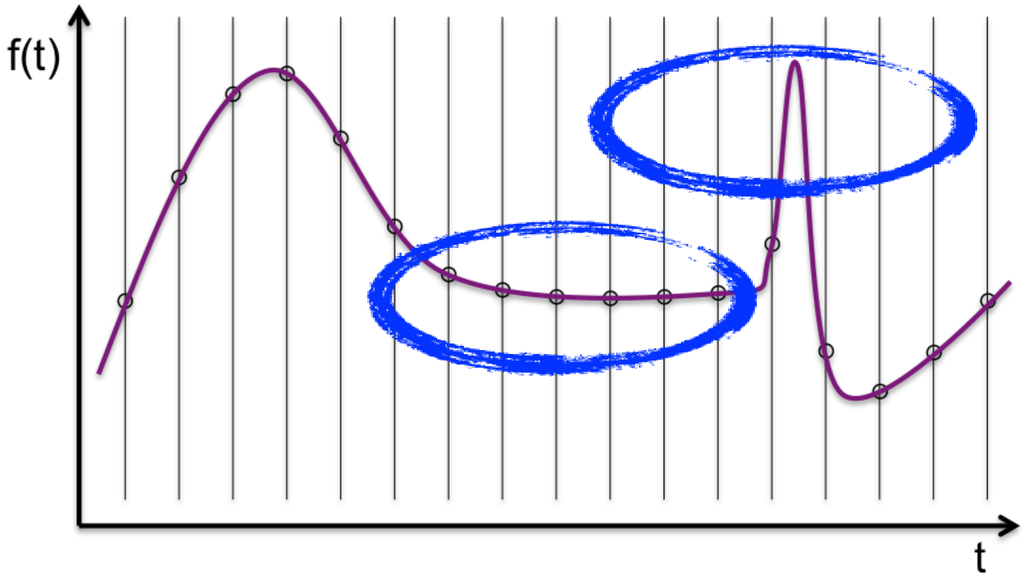
Event cameras (ATIS)



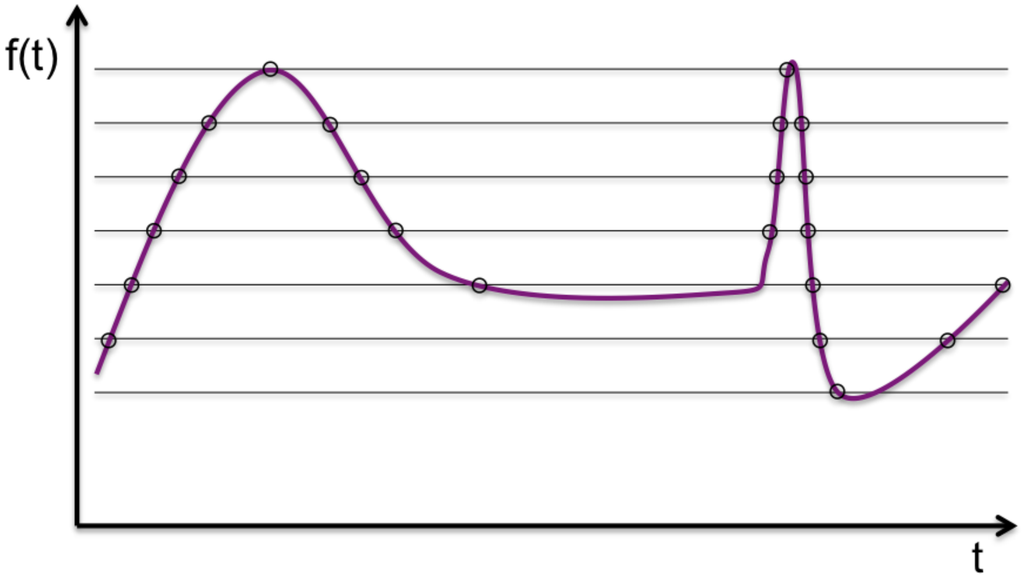
- Inspired by biological vision
- Each pixel has an independent circuit
- Measures change in light
- Produces an output when change occurs

Event-Driven Sensing and Processing

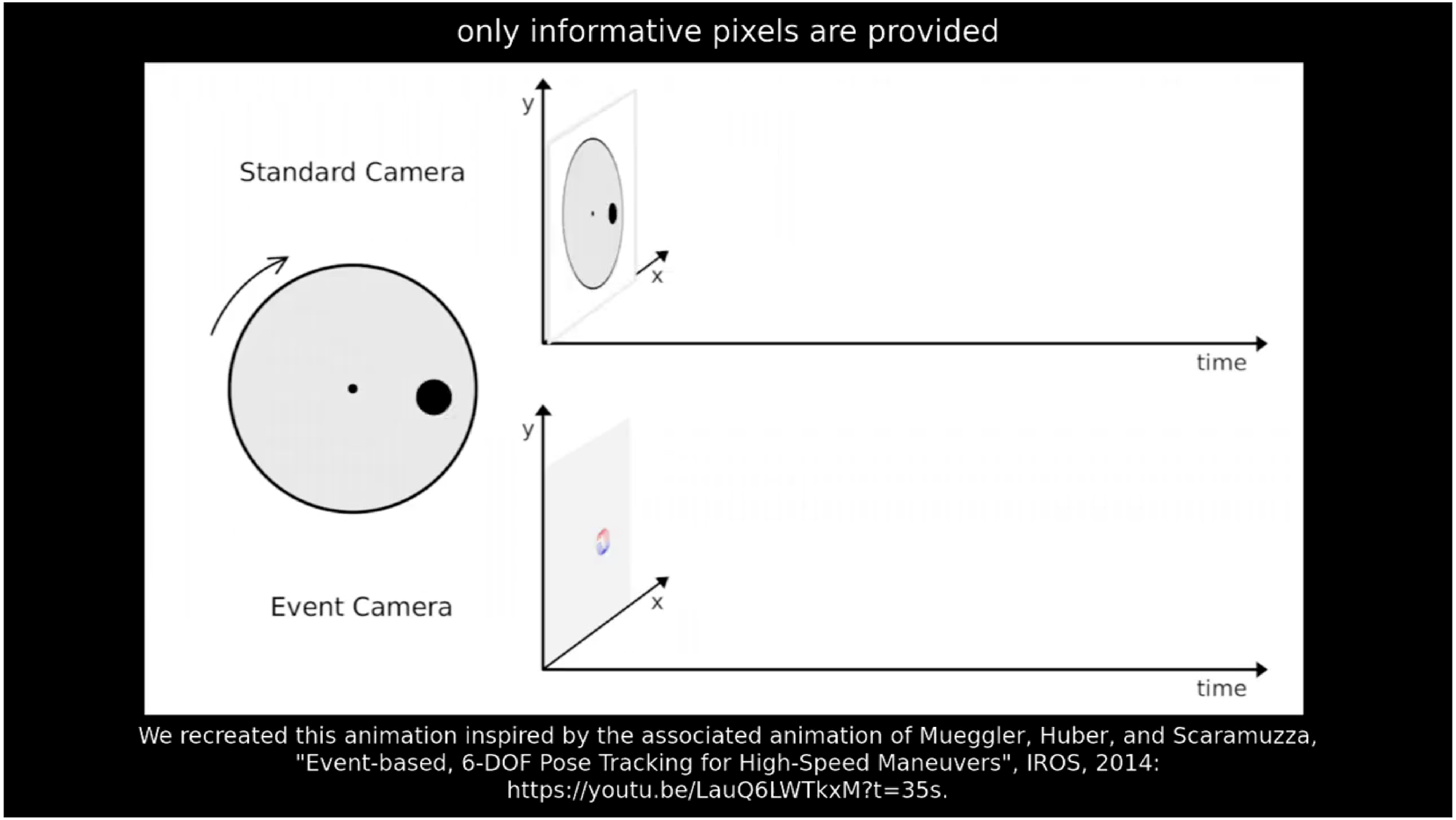
Clock-Based Sampling — fixed Δt



Data-Driven Sampling — fixed Δf



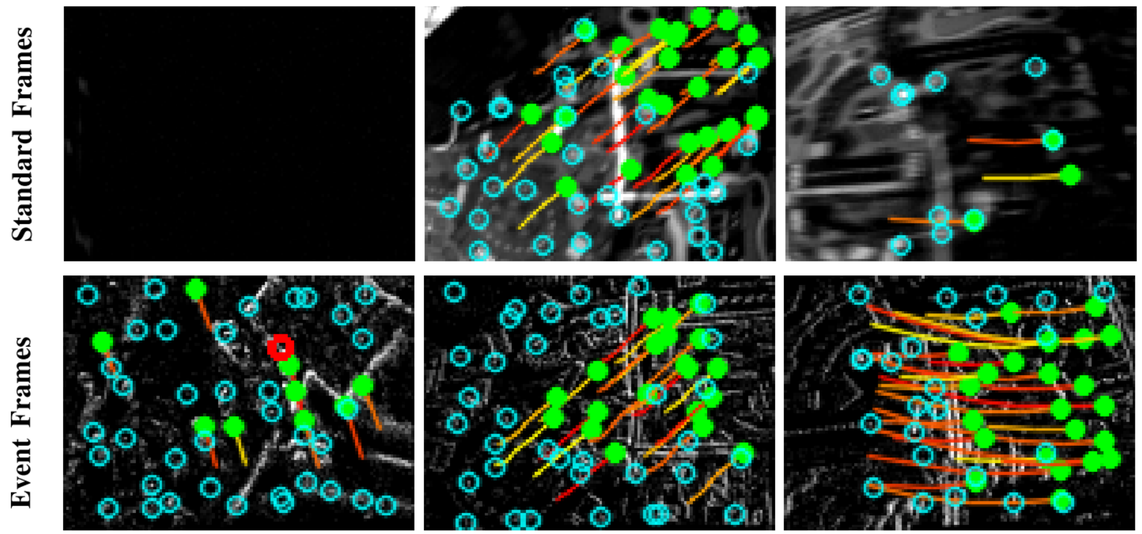
Event-Driven Vision [1]



[1] Hanme Kim

Event-cameras for Robotics

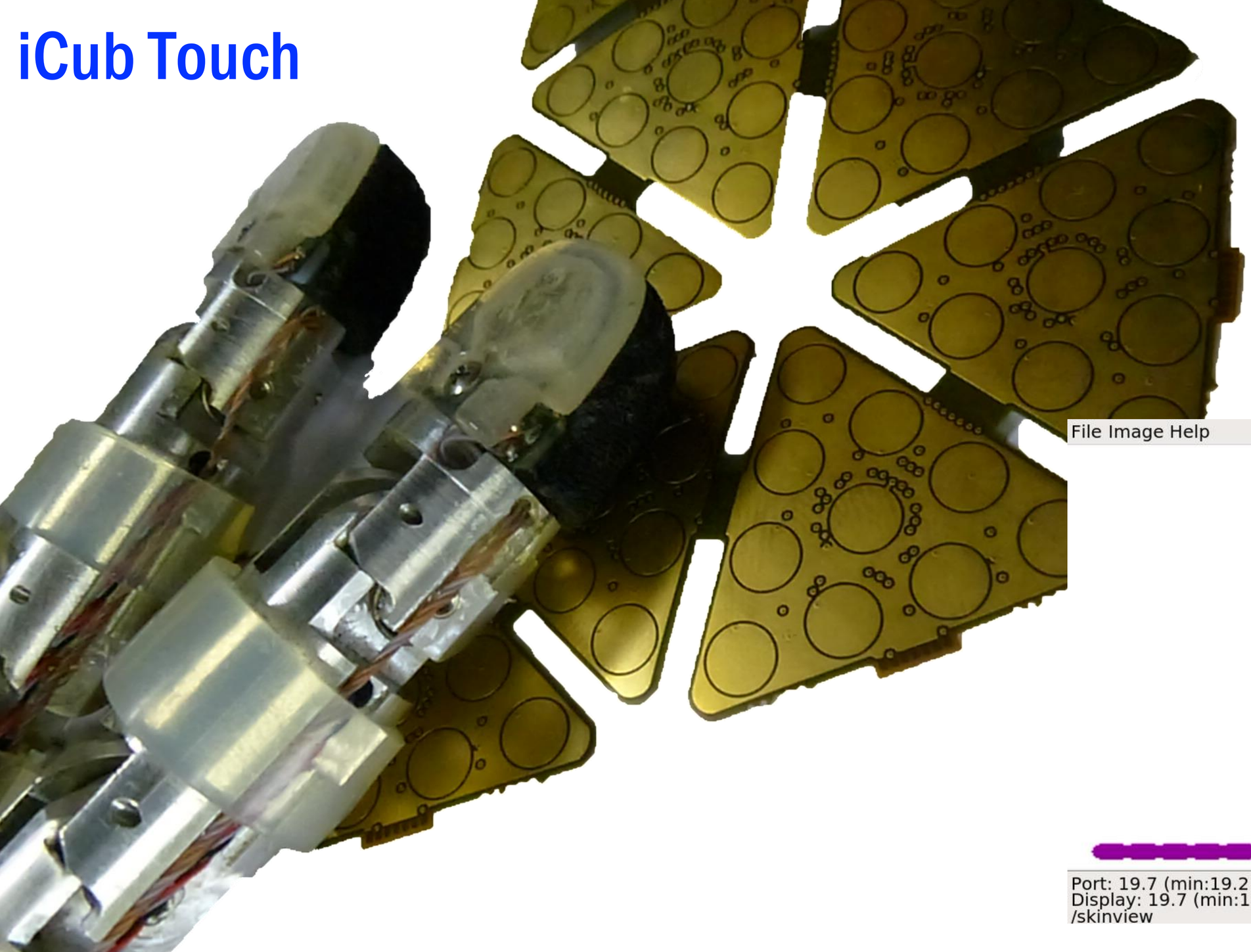
- High dynamic range
- Temporal precision
  - Understand what happens “between frames”
  - Avoid motion-blur
- Signal compression
  - 0 mbps with no motion
  - 10 – 120 mbps normal/heavy conditions
  - > 300 mbps frame-based cameras
- Integration with spiking networks / neural systems



(a) Low-light. (b) Good lighting, moderate speed. (c) Motion blur.

[1] A. R. Vidal, H. Rebecq, T. Horstschaefer, and D. Scaramuzza, “Ultimate SLAM? Combining Events, Images, and IMU for Robust Visual SLAM in HDR and High Speed Scenarios,” *IEEE Robot. Autom. Lett.*, 2018.

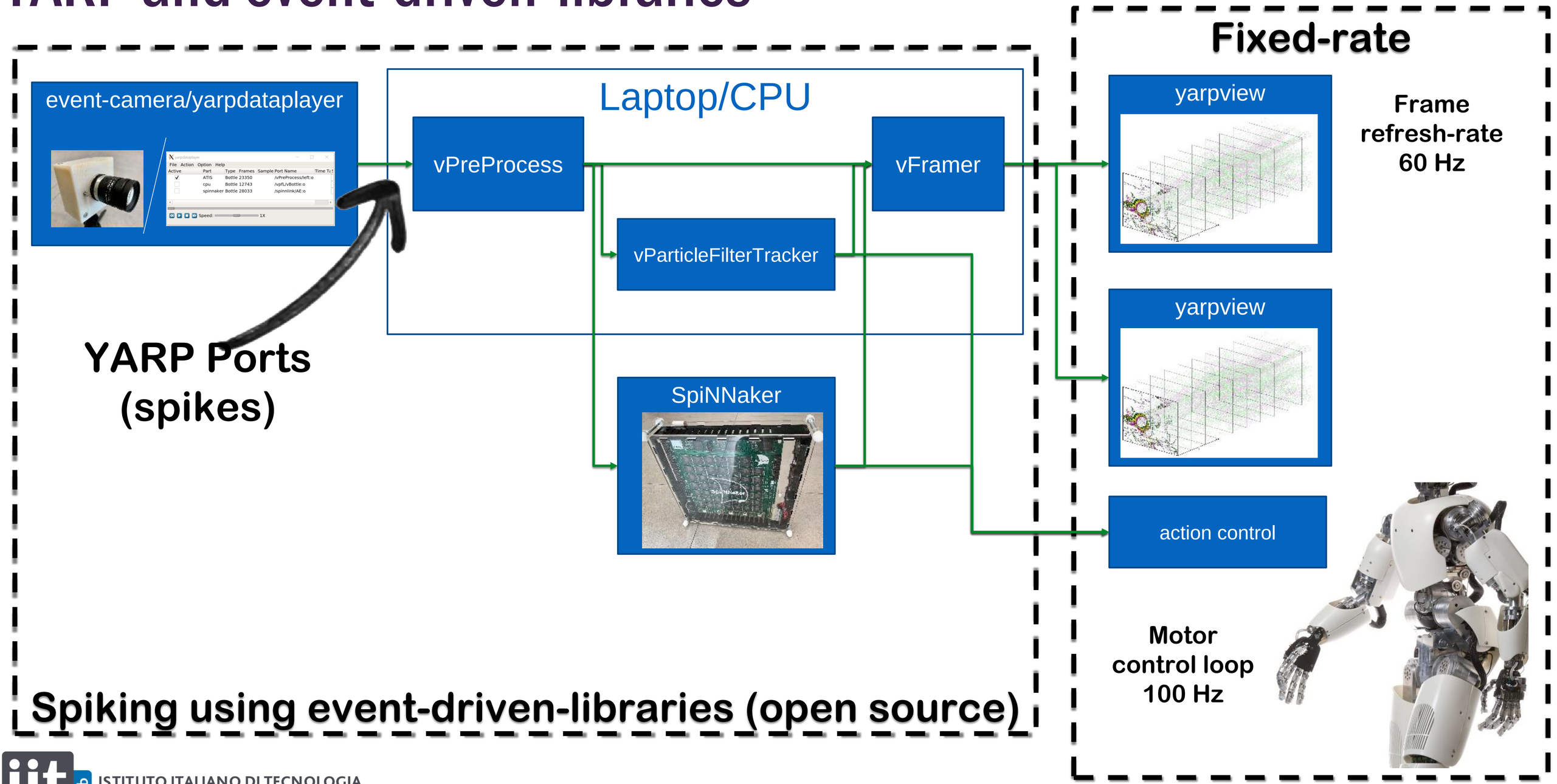
iCub Touch



File Image Help

Port: 19.7 (min:19.2 max:20.5) fps
Display: 19.7 (min:19.2 max:20.5) fps
/skinview

YARP and event-driven-libraries



Hybrid approach to neural robotics

Take advantage of Neuromorphic Hardware

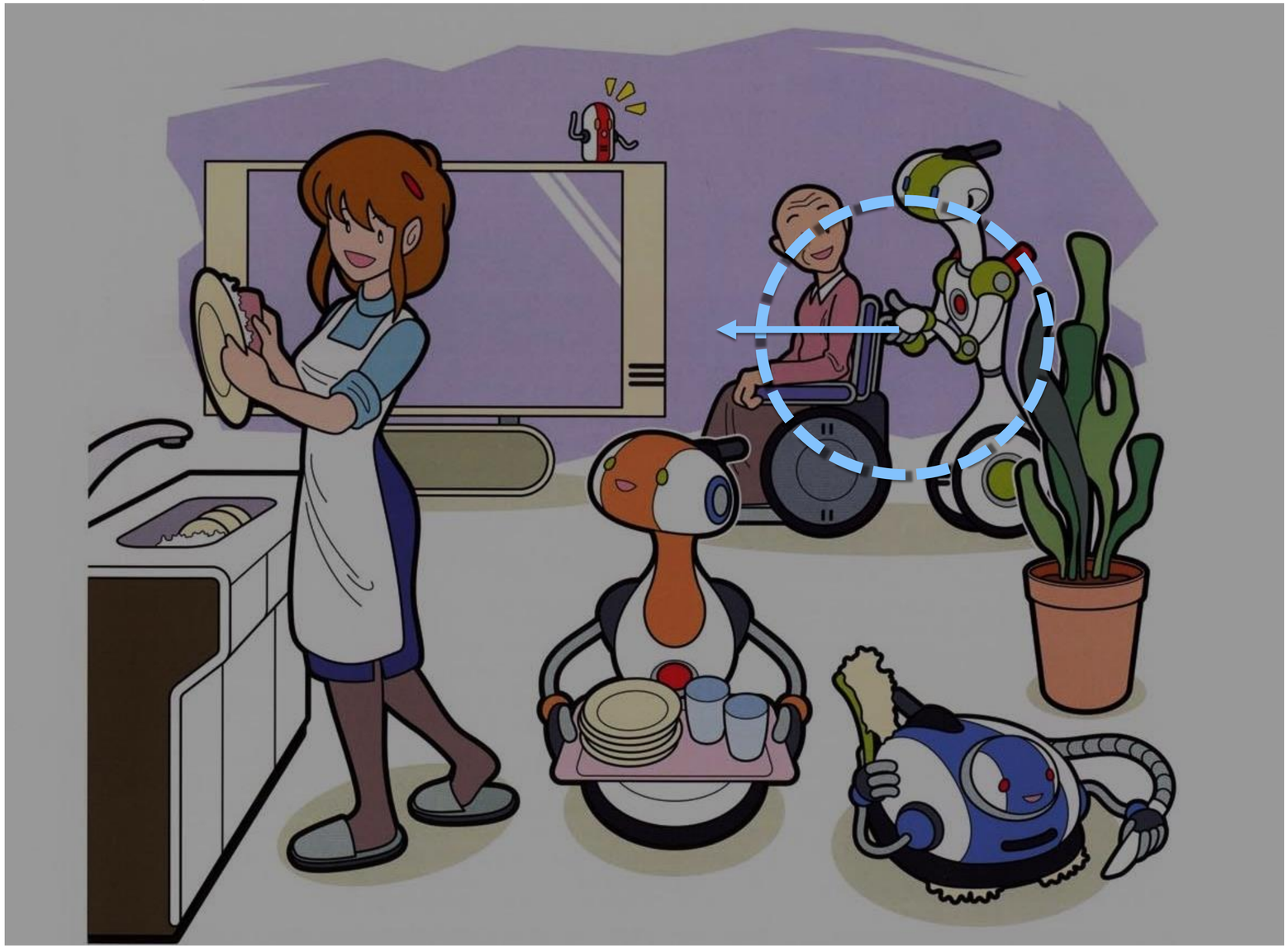
Take advantage of decades of robotics development

Choose the most appropriate algorithm for the task

Difficult to go from 0 to 100% completely neural for a complex robot.
Modularity of robot middleware allows us to start with a “working” robot and swap in neuromorphic modules

What is required for autonomy?

- **Track dynamic objects (avoiding/interacting)**



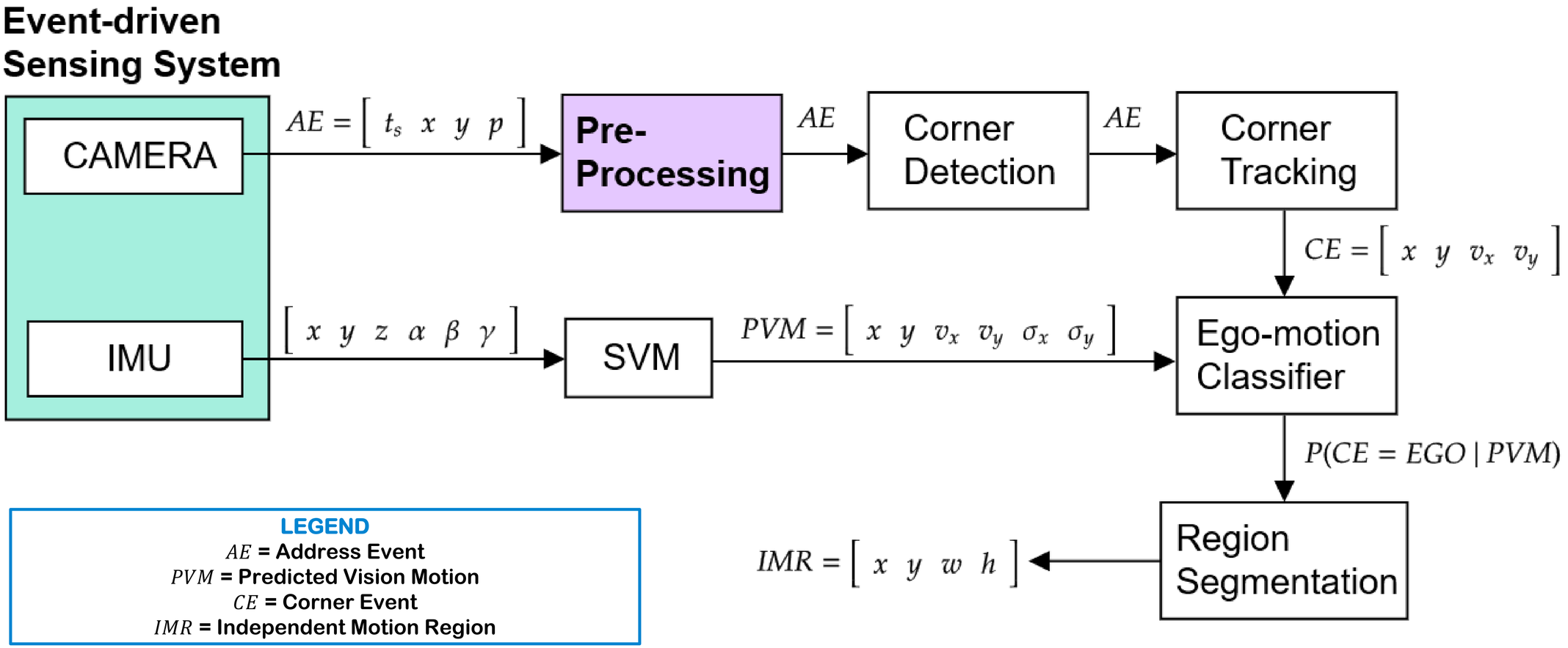
Using event-cameras on a robot

Moving object with a *stationary* ED camera

Moving object with a *moving* ED camera

Vasco. V., Glover. A., Mueggler. E., Scaramuzza. D., Natale. L., and Bartolozzi. C.: Independent Motion Detection with Event-driven Cameras. In the Prceedings of the International Conference on Advanced Robotics (ICAR) 2017

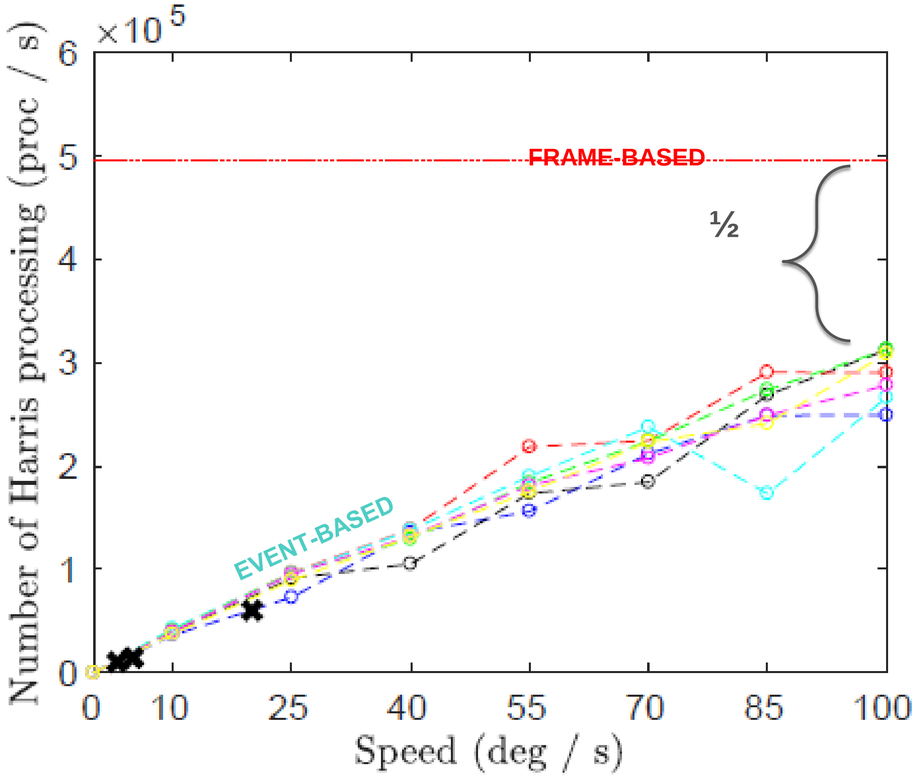
Detection of Independent Motion



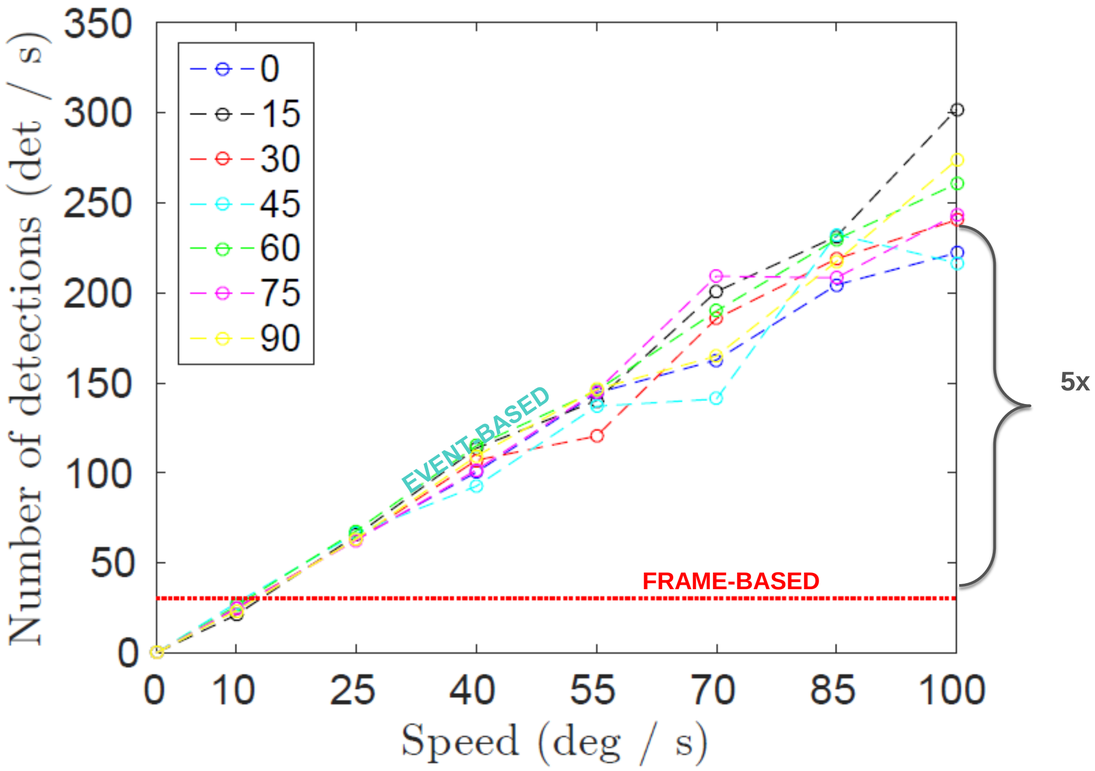
Event-based Corner Detection

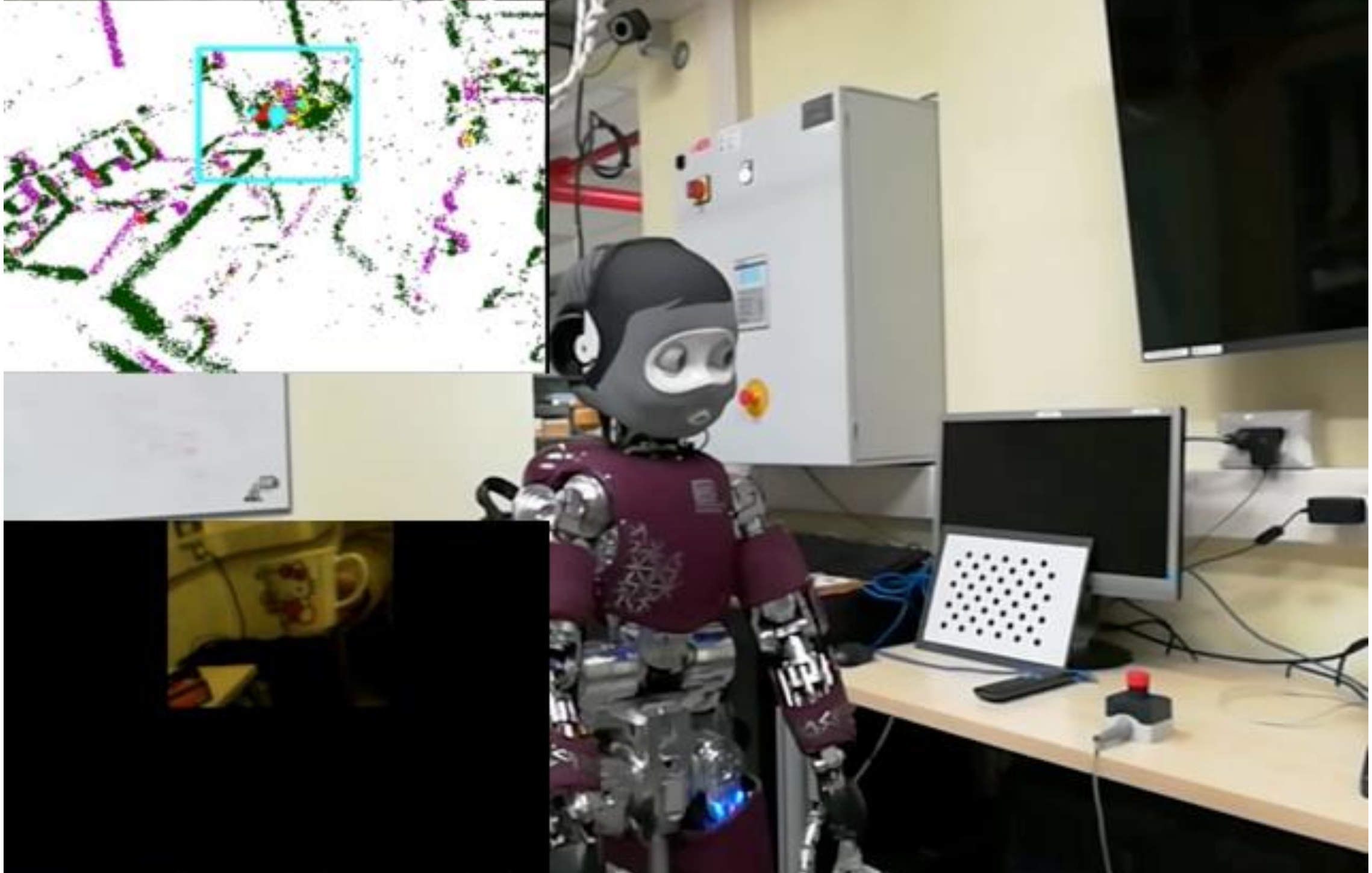
- Frame based camera:
  - frame rate: 30 Hz
  - spatial resolution: 128x128 px

COMPUTATIONAL COST



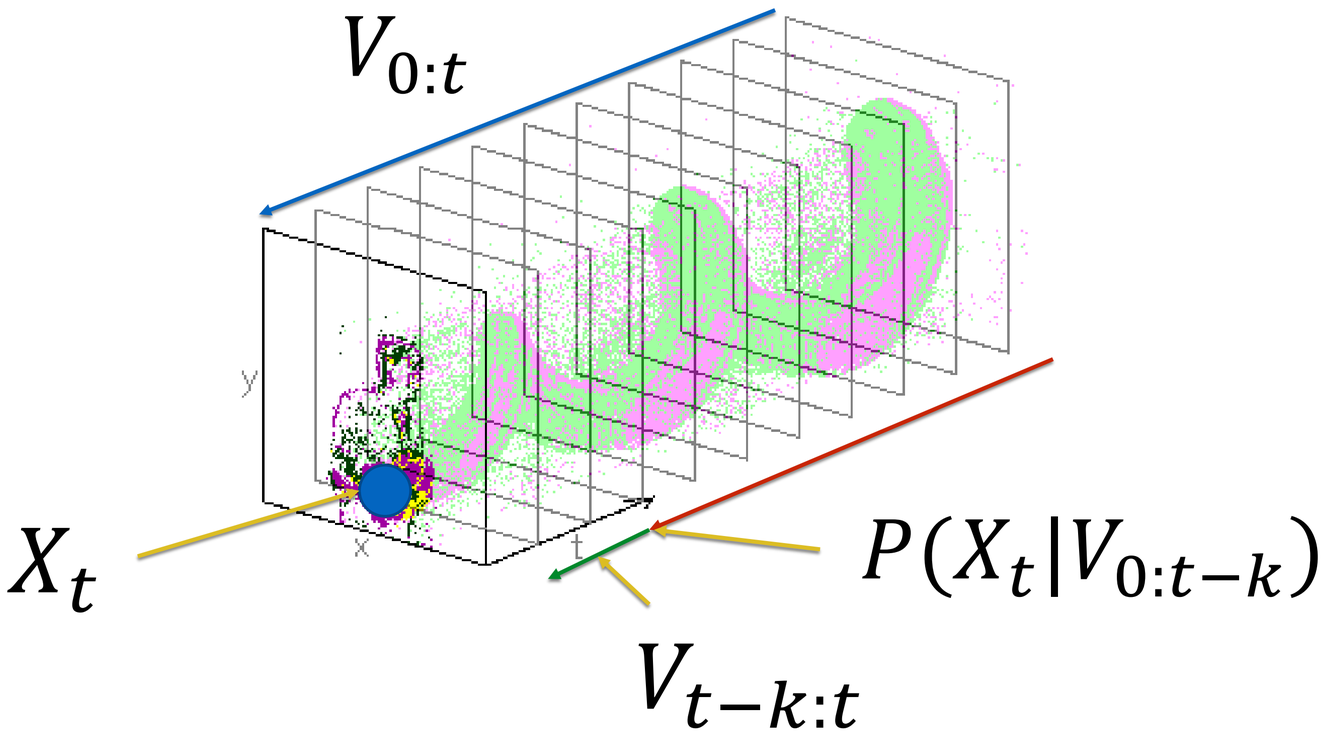
DETECTION RATE

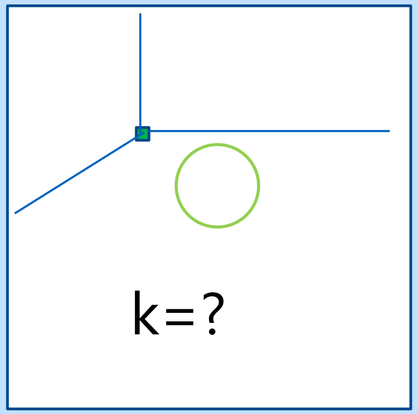


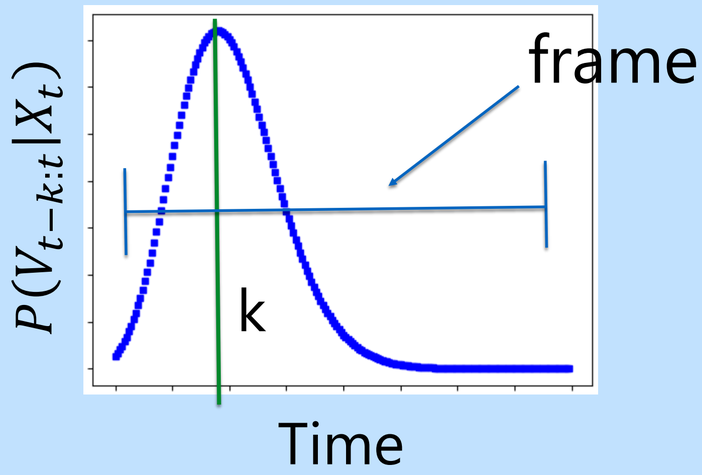


An event-driven particle filter

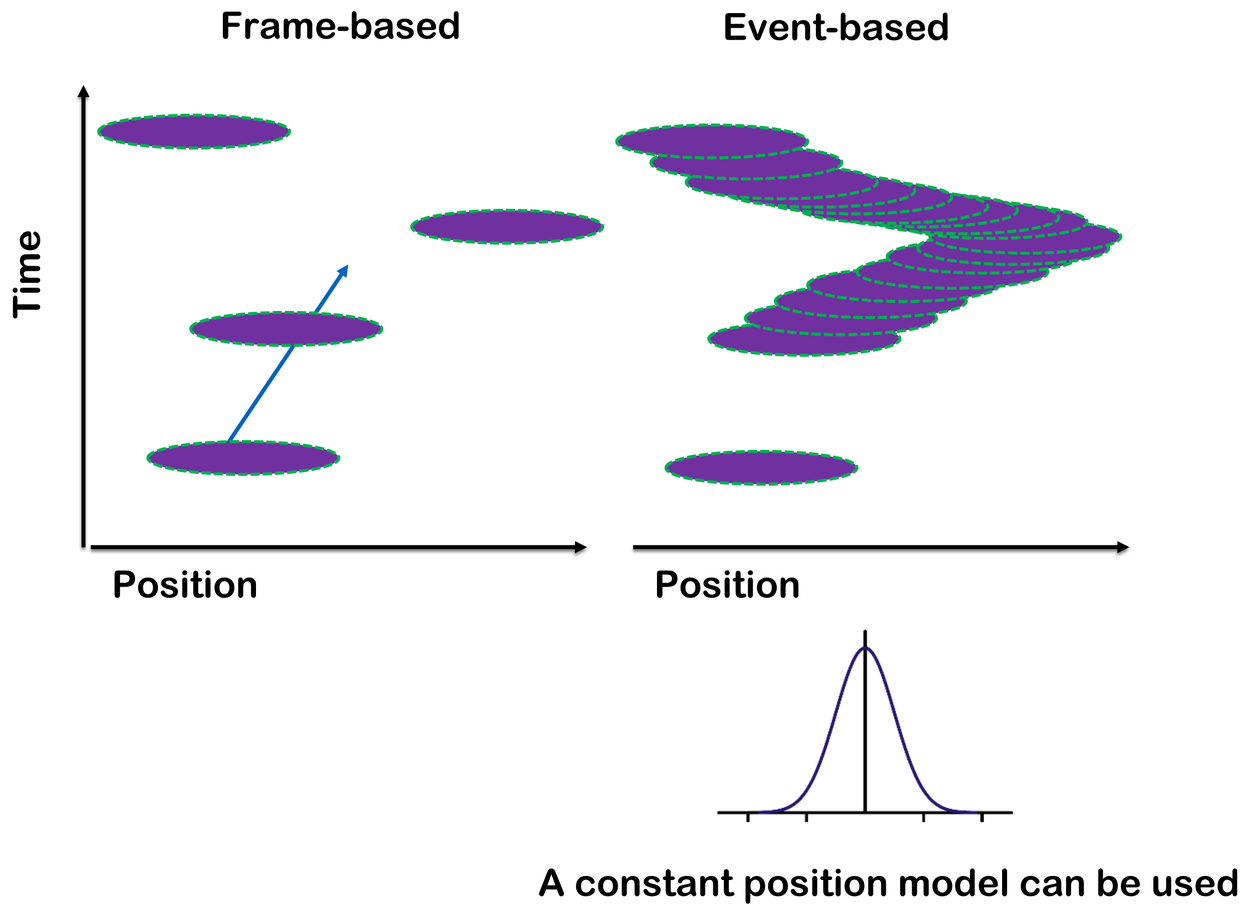
$$P(X_t|V_{0:t}) = \frac{P(V_{t-k:t}|X_t)P(X_t|V_{0:t-k})}{P(V_{t-k:t})}$$



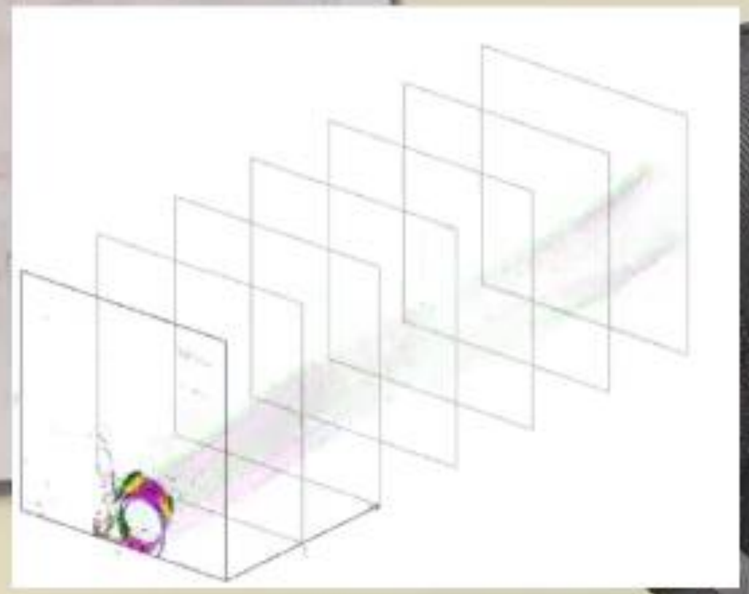


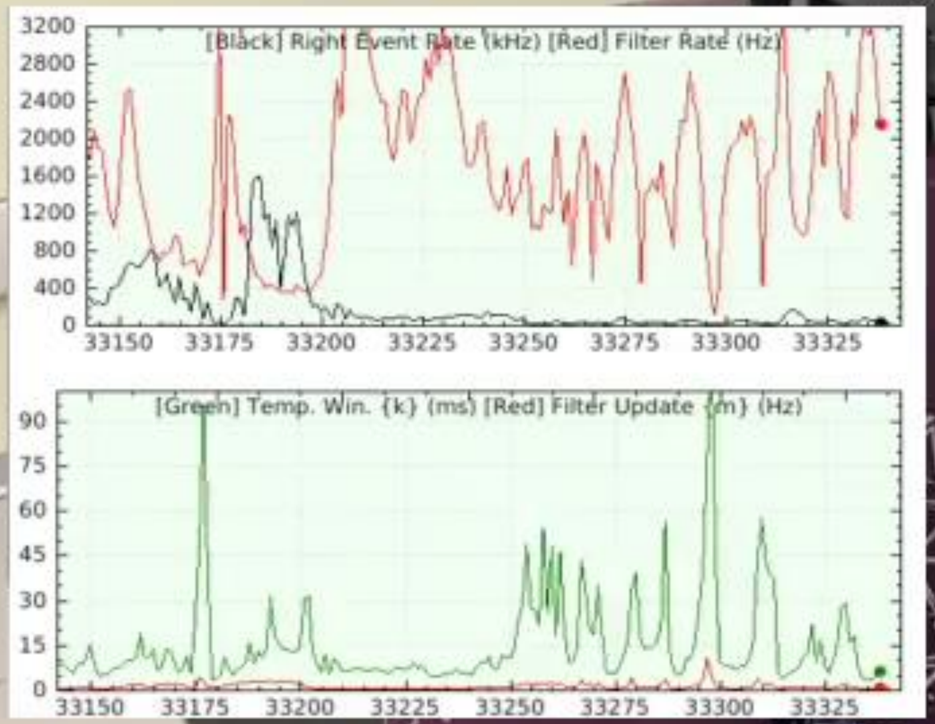


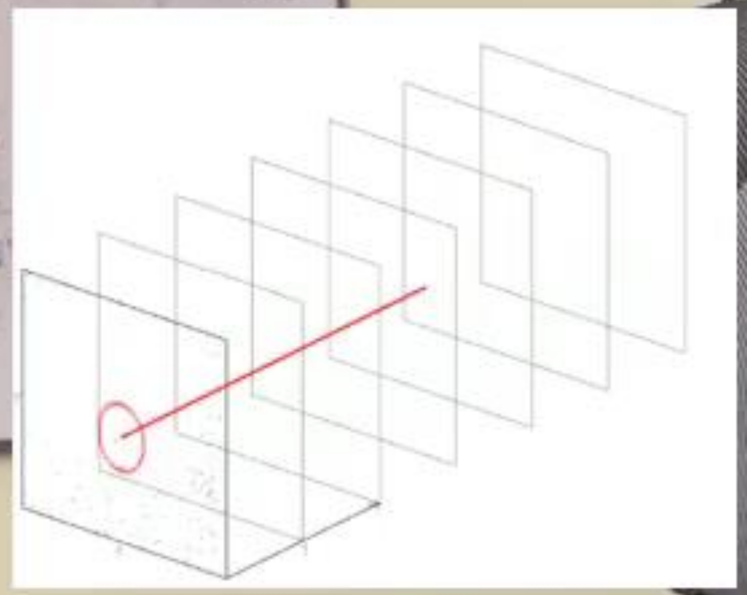
No motion model needed!



[1] A. Glover and C. Bartolozzi, "Robust Visual Tracking with a Freely-moving Event Camera," in *IEEE International Conference on Intelligent Robots and Systems*, 2017, pp. 3769–3776.

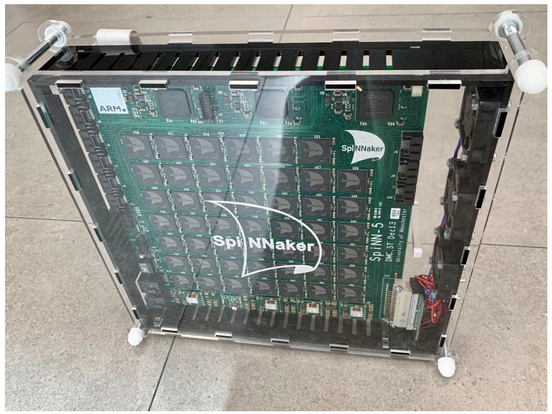



[Black] Right Event Rate (kHz) [Red] Filter Rate (Hz)
3200
2800
2400
2000
1600
1200
800
400
0
33150 33175 33200 33225 33250 33275 33300 33325
[Green] Temp. Win. (k) (ms) [Red] Filter Update (n) (Hz)
90
75
60
45
30
15
0
33150 33175 33200 33225 33250 33275 33300 33325

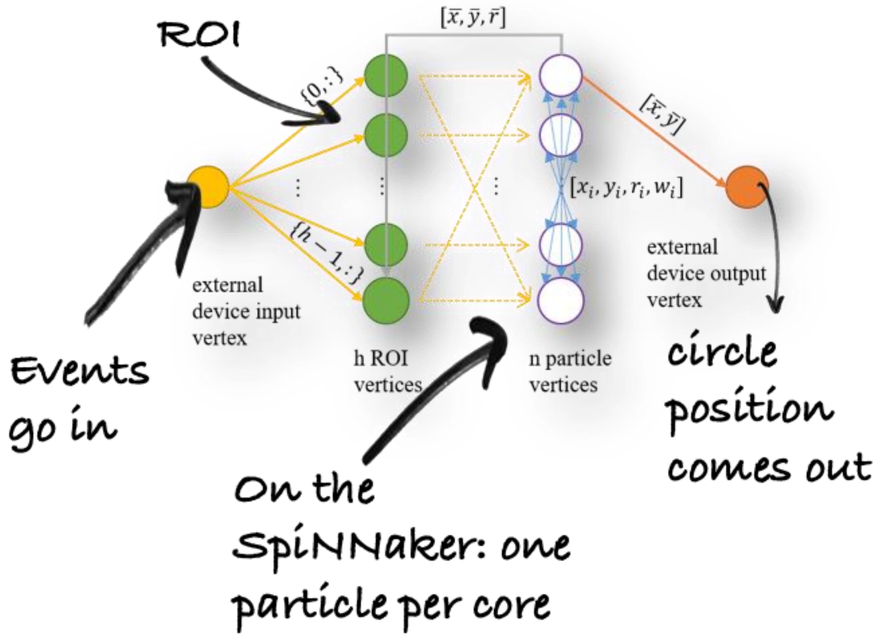


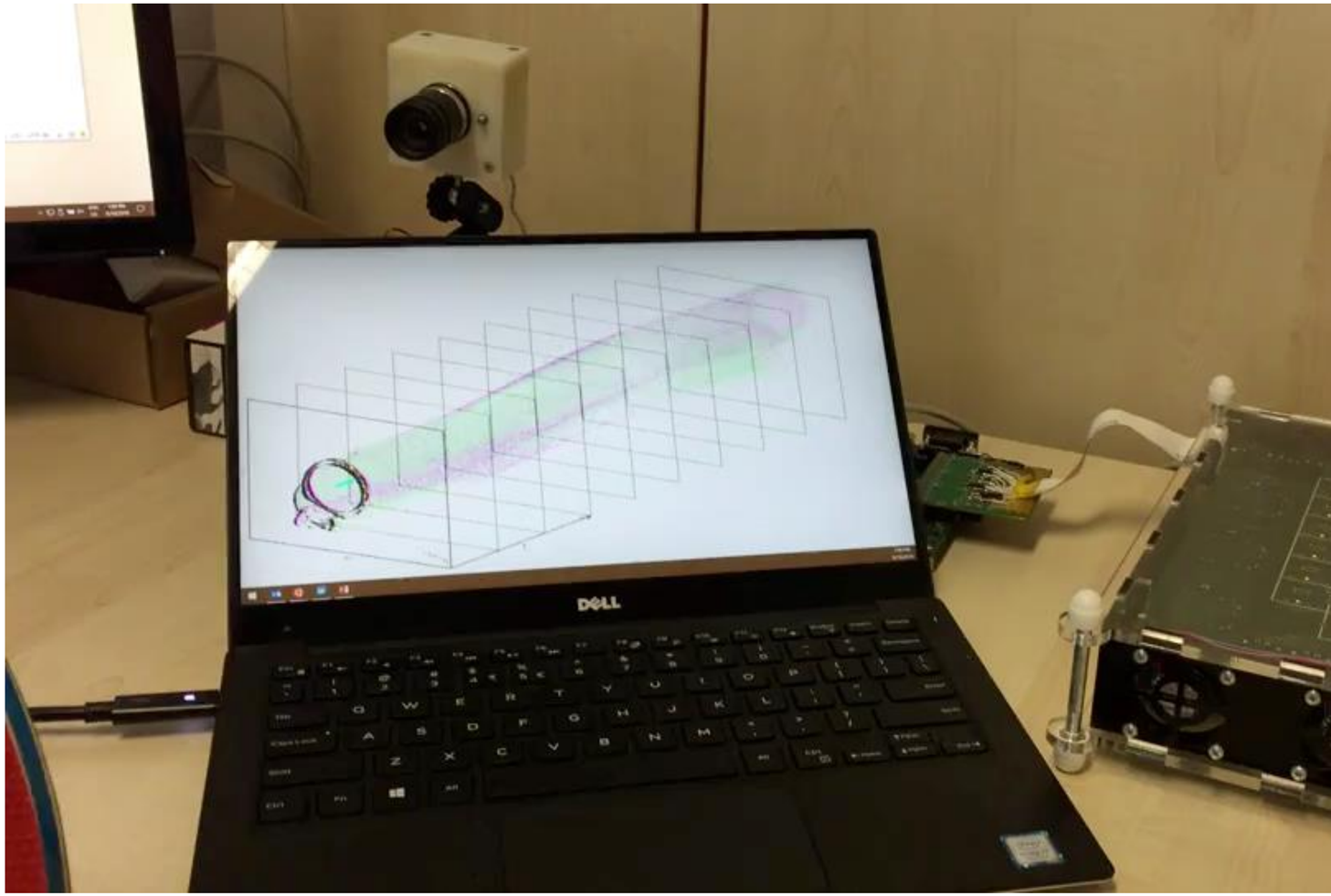

[Black] Left Event Rate (kHz) [Red] Filter Rate (Hz)
3200
2800
2400
2000
1600
1200
800
400
0
48275
48300
48325
48350
48375
48400
48425
48450
[Green] Temp. Win. (k) (ms) [Red] Filter Update (m) (Hz)
90
75
60
45
30
15
0
48275
48300
48325
48350
48375
48400
48425
48450

Particle Filter on SpiNNaker



- 865 ARM cores
- Asynchronous
- Parallel





Problems to be solved for a pervasively neural processing

- Spiking models:
  - Stereo disparity with a SNN
  - Head pose estimation with Head-direction networks
- Neural algorithms
  - Scalable and flexible
  - Accessible hardware
  - Integration with common robot middle-ware (ROS/YARP)

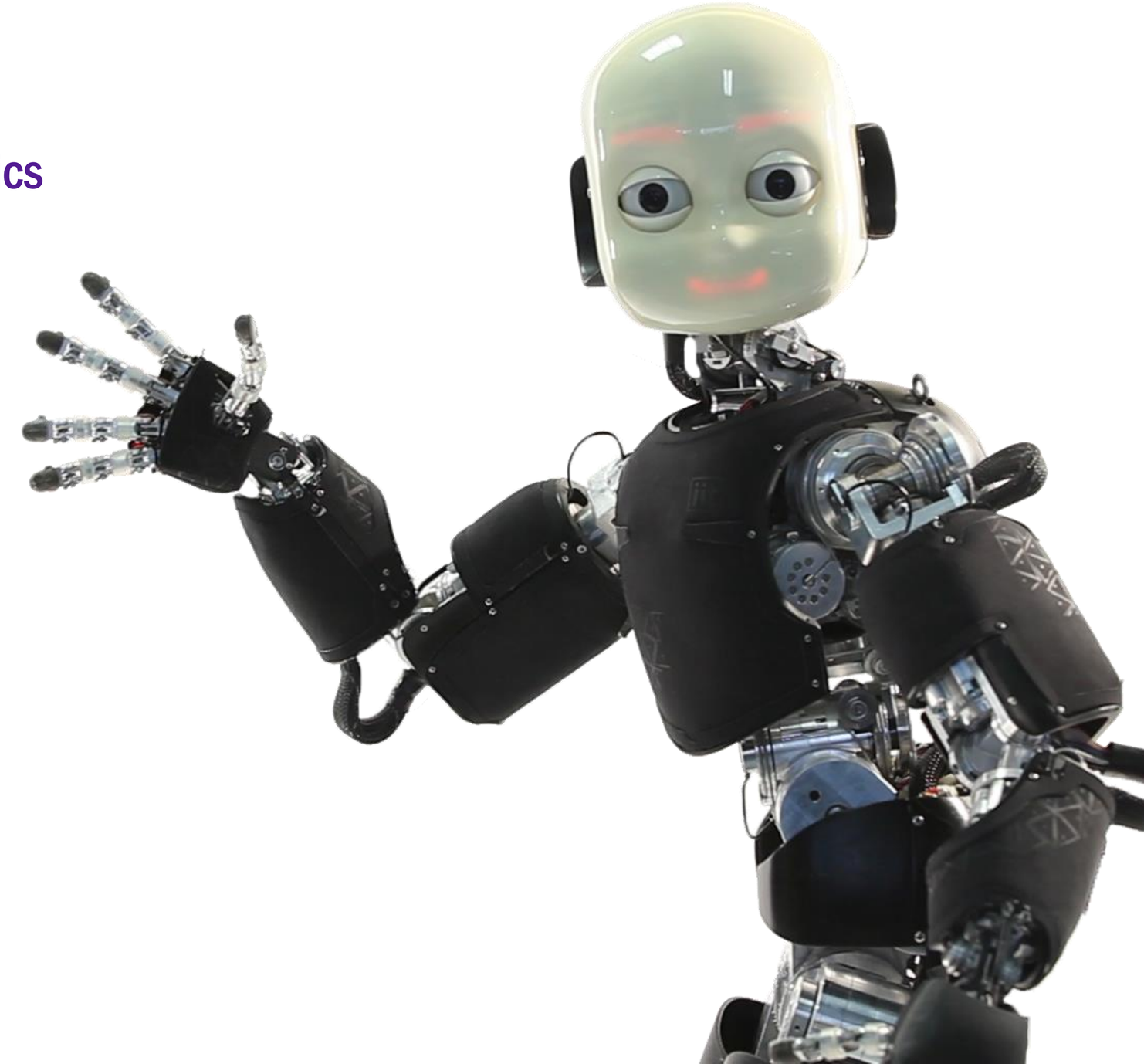
IIT - Event-driven Perception for Robotics

Chiara Bartolozzi (adapted slides)

Valentina Vasco

University of Manchester (SpiNNaker)

Alan Stokes



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