Bio-inspired optic flow detection using neuromorphic hardware

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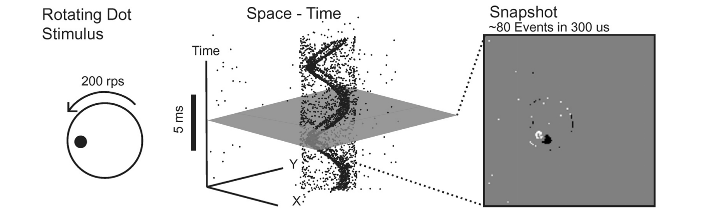
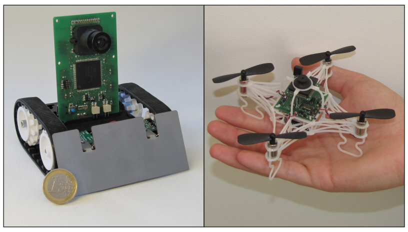
Dynamic Vision Sensor

The DVS[1] is an **event-based** vision sensor. Each of its pixels monitors its local brightness level $I(t)$ autonomously and **asynchronously emits events** when the brightness changes, i.e. $| d \log I(t) / dt |$ exceeds a certain threshold. The DVS is able to capture extremely **fast motion** with **high temporal precision** in diverse and **harsh lightning conditions**. The data stream it generates is sparse, containing only the changes and movements of a scene.



We have developed **eDVS**, an **embedded version** of the DVS technology. Its small form factor, low weight and **low power-consumption** enable using eDVS on **mobile robots**.

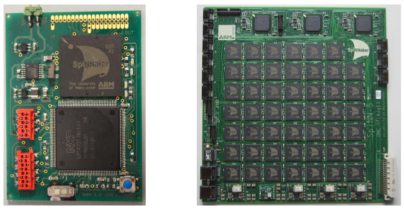


ultra-mobile robots, built at NST, featuring different versions of eDVS

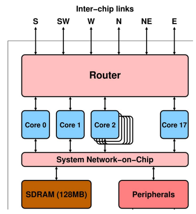
(1) Lichtsteiner, P., Posch, C., Delbruck, T.: *A 128x128 120db 15us latency asynchronous temporal contrast vision sensor*. IEEE Journal of Solid State Circuits (2007)

SpiNNaker

SpiNNaker[2] is a **massively parallel** computing system designed to **simulate large spiking neural networks**. A SpiNNaker system can comprise from 18 to 1.036.800 ARM9 computing cores that are interconnected by a **sophisticated routing** system. The routers are optimized to convey small data packets, which resemble **neural spikes** at high rates and low latency.

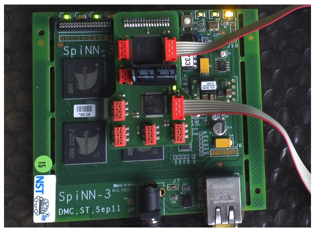


smallest (1 chip, 18 core) and largest (48 chip, 864 core) SpiNNaker board



schematic of a SpiNNaker chip

We have created an **interface board**[3] to flexibly connect **external devices** to SpiNNaker. The eDVS is a prime example: Events emitted by the DVS are directly translated to SpiNNaker packets.



SpiNNaker development board with mounted interface board

(2) Furber, S.B. , Galluppi, F., Temple, S., Plana, L.A.: *The SpiNNaker Project*, Proceedings of the IEEE (2014)
(3) Denk, C., Llobet-Blandino, F., Galluppi, F., Plana, L.A.. Furber, S., Conradt, J.: *Real-Time Interface Board for Closed-Loop Robotic Tasks on the SpiNNaker Neural Computing System*, ICANN (2013)

Project Description

We combine **neuromorphic hardware** – a DVS (dynamic vision sensor, 'silicon retina') and a SpiNNaker ('Spiking Neural Network Architecture') board – to create an artificial, spike-based version of the Hassenstein-**Reichardt motion detector**.

We demonstrate that the basic principle of Reichardt-style motion detection can naturally be extended from non-spiking to **spiking afferent neurons** – the DVS pixels.

Via our custom interface board these pixels become digital afferent neurons in a **neural network simulation** (the motion detector) running in **real-time** on a SpiNNaker board. Since our interface is bidirectional and the power consumption of the system is on the order of 1W, we could use the perceived optic flow to stabilize and control, e.g., a flying drone.

Spike-based implementation of a Hassenstein-Reichardt motion detector

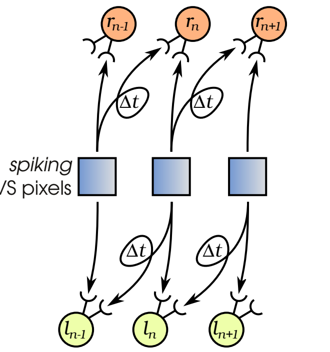
The Hassenstein-Reichardt motion detector is an intensity-based **spatiotemporal correlation** algorithm found in **natural vision** systems like the fly optic lobe[4] or the vertebrate retina[5]. Here, we demonstrate a **spike-based version**, the input of which are discrete events from a dynamic vision sensor (DVS). A **DVS pixel** generates an event in reaction to a local change in brightness. From these events our detection algorithm, implemented in **PyNN**, computes an **optic flow** map.

In the one-dimensional example sketched below, each photoreceptor (pixel) p_n projects to two motion-sensitive neurons. Those neurons, l_n and r_n, receive spikes not just from p_n, but also from the neighboring receptors (p_{n-1} -> r_n, p_{n+1} -> l_n).

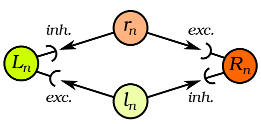
Those '**diagonal**' **connections**, however, **delay** the signal by a constant lag Δt. If a moving object stimulates neighboring cells in ascending (descending) order and with a temporal delay roughly matching Δt, it will generate spikes that arrive at r_n (l_n) at roughly the same time. r_n and l_n are tuned to **spike only if two action potentials coincide** in a time-window of width ~ Δt. Therefore, they spike in response to perceived rightwards (r_n) or leftwards (l_n) motion.

Flicker can, however, trick the cells: Both l_n and r_n spike simultaneously, when p_n spikes periodically, e.g. in response to light flickering at a period ~ Δt. A '**flicker filter**' subtracting the signals of l_n and r_n removes this effect.

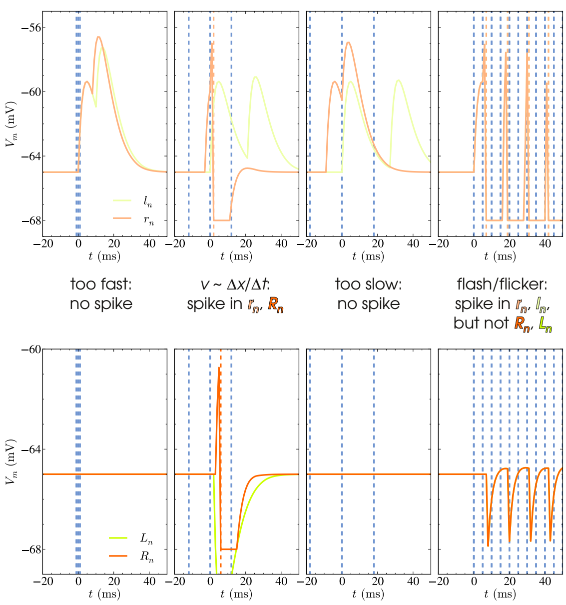
delay-based motion detector



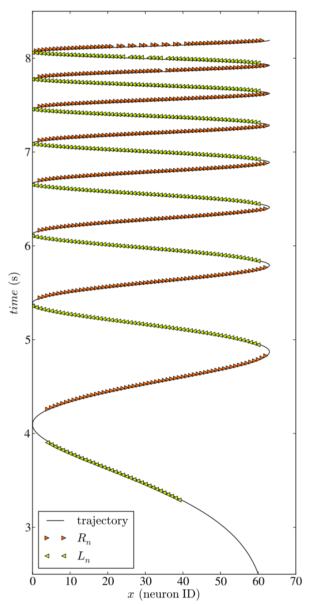
flicker filter



membrane potentials in response to different stimuli



spike response to oscillating object



(4) Maisak, M.S., et al.: *A directional tuning map of Drosophila elementary motion detectors*, Nature (2014)
(5) Kim, J.S., et al. : *Space-time wiring specificity supports direction selectivity in the retina*, Nature (2014)

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