Neurorobotics

Module 1: Background and Foundations

Lecture 3: Neuroscience. Case study: visual navigation in insects and mammals

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Inspiration

Optical flow is used by insects

- Bees estimate distances to surfaces using optical flow
- "Optic flow refers to the apparent motion across visual receptors due to moving objects or one's own movements"
- "Optical flow or optic flow is the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer and a scene"

Wikipedia

Image 40 of
Otte and Nagel's
Benchmark
Sequence

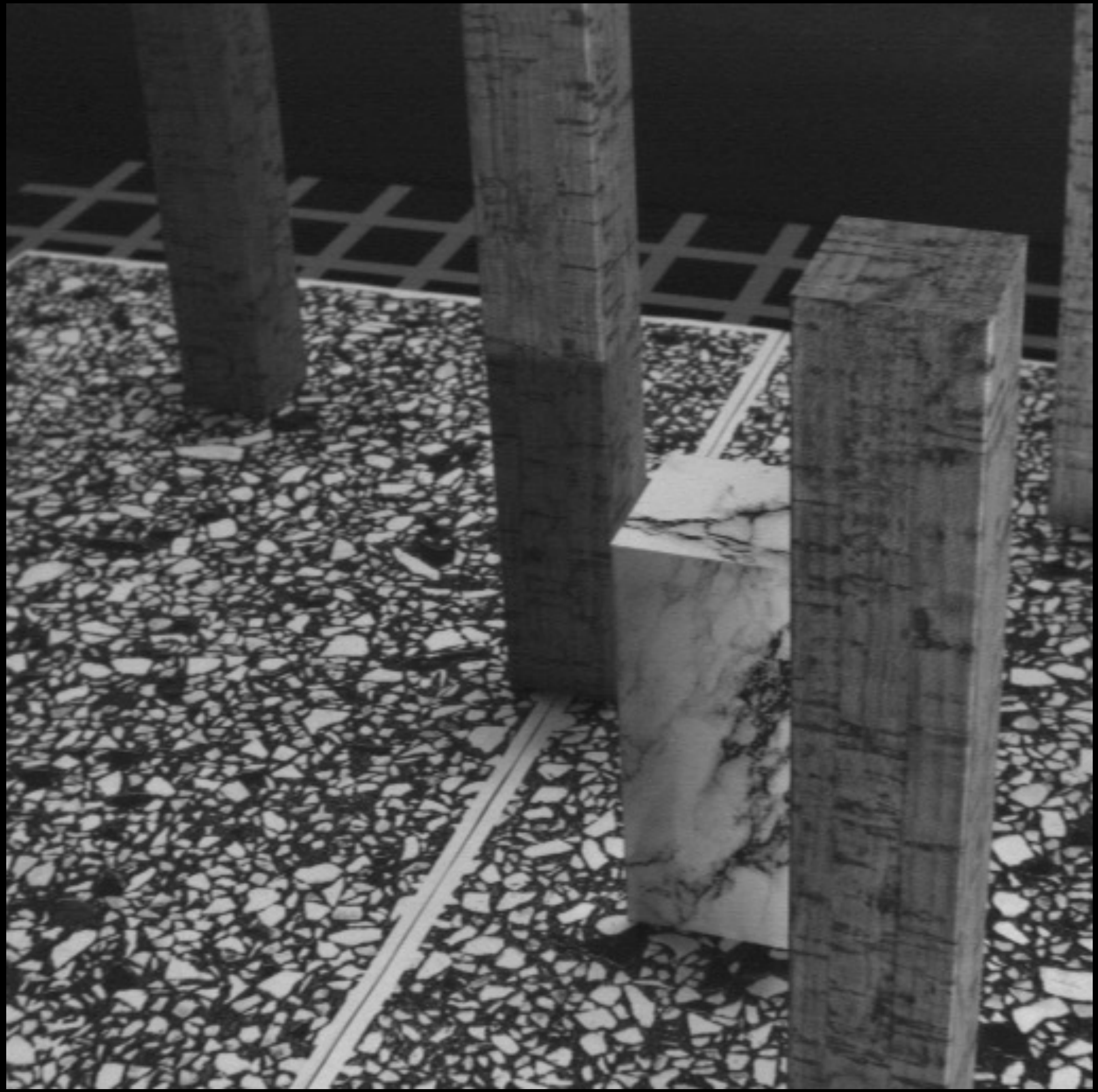
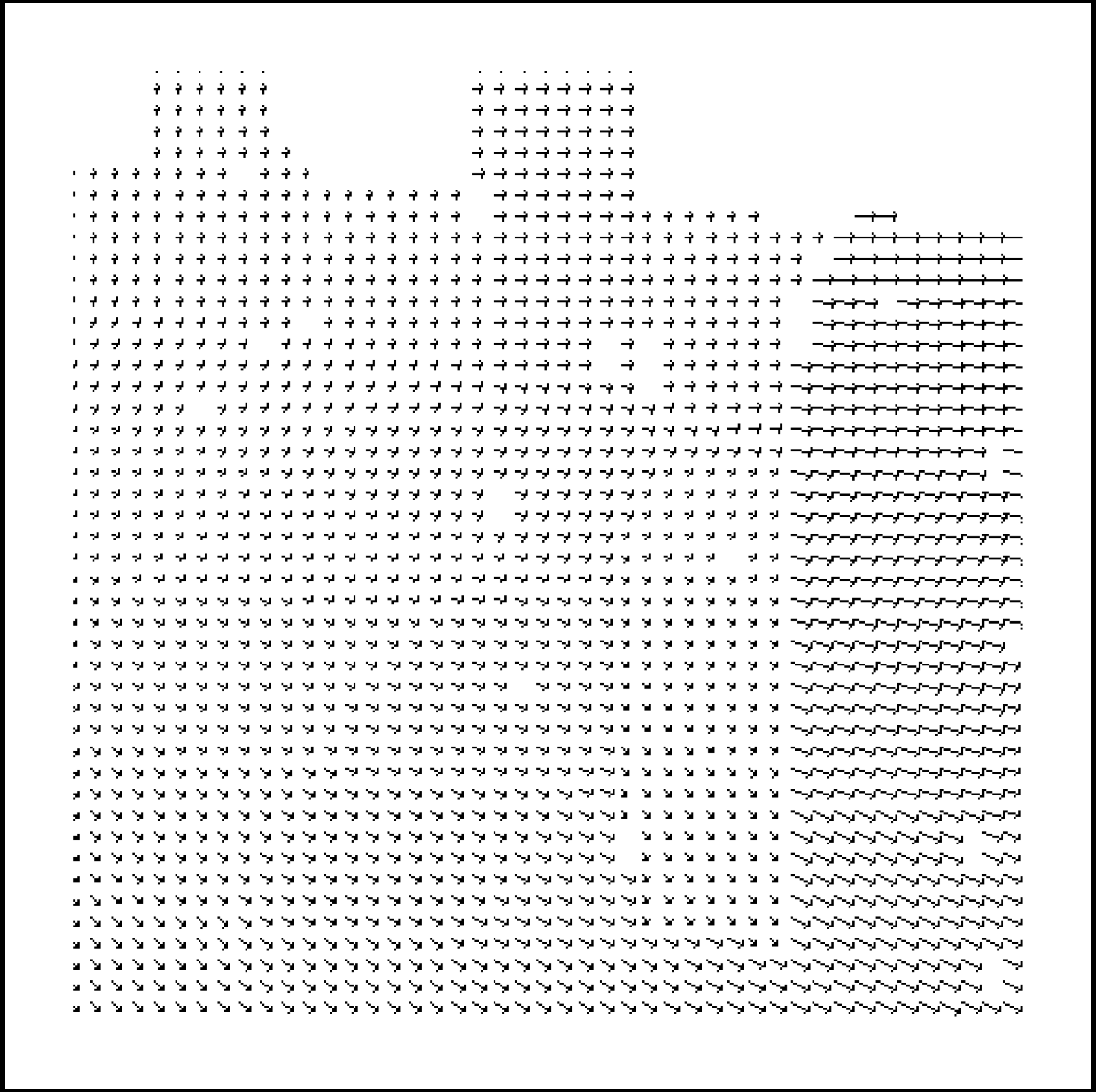


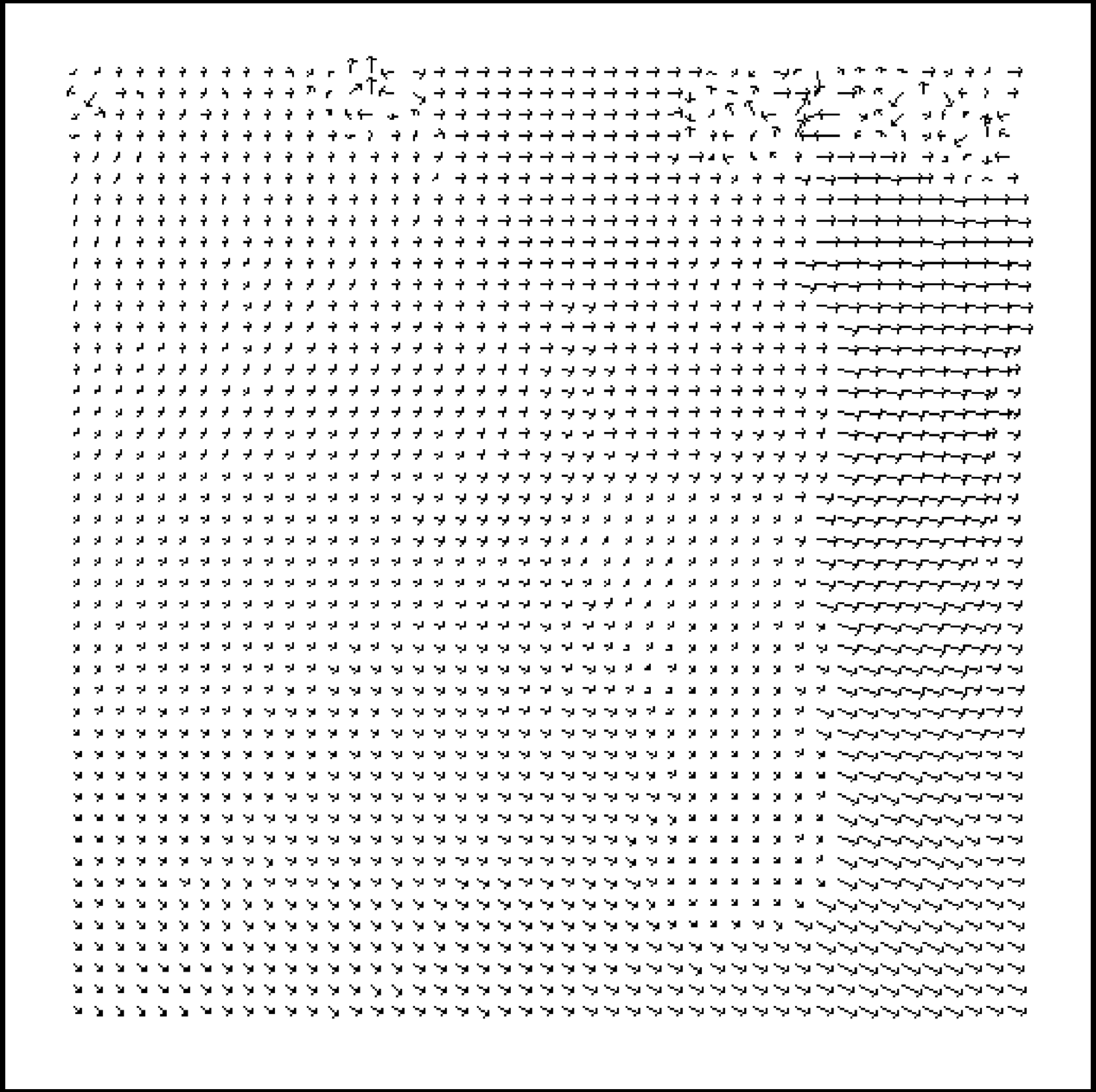
Image 41 of
Otte and Nagel's
Benchmark
Sequence

Image 42 of Otte and Nagel's Benchmark Sequence

Image 43 of
Otte and Nagel's
Benchmark
Sequence



Ground Truth optical flow field for Otte and Nagel's Benchmark Sequence



Computed optical flow field for Otte and Nagel's Benchmark Sequence

Inspiration

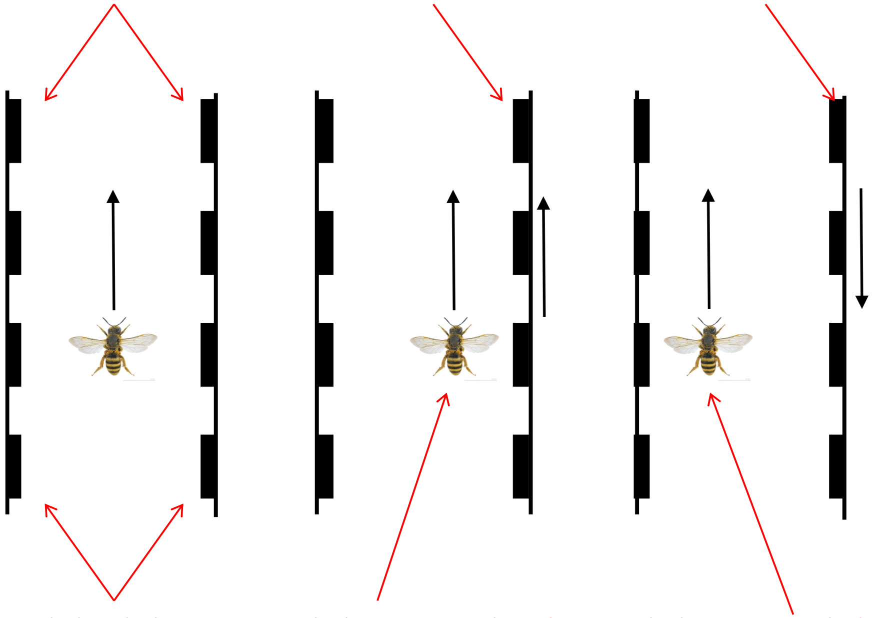
Optical flow is used by insects

- A centering response that balances the optic flow on either side of the honey bee allows it to fly safely through narrow spaces

- Balancing equation

$$turnRate = G\,\frac{(OF_{left} - OF_{right})}{(OF_{left} + OF_{right})}$$

This is somewhat misleading. It suggests optical flow is a scalar. However, optical flow is a field (or array) of vectors, each of which gives the magnitude and direction of apparent motion at that point. The book probably means the average magnitude of the optical flow on the left and right.

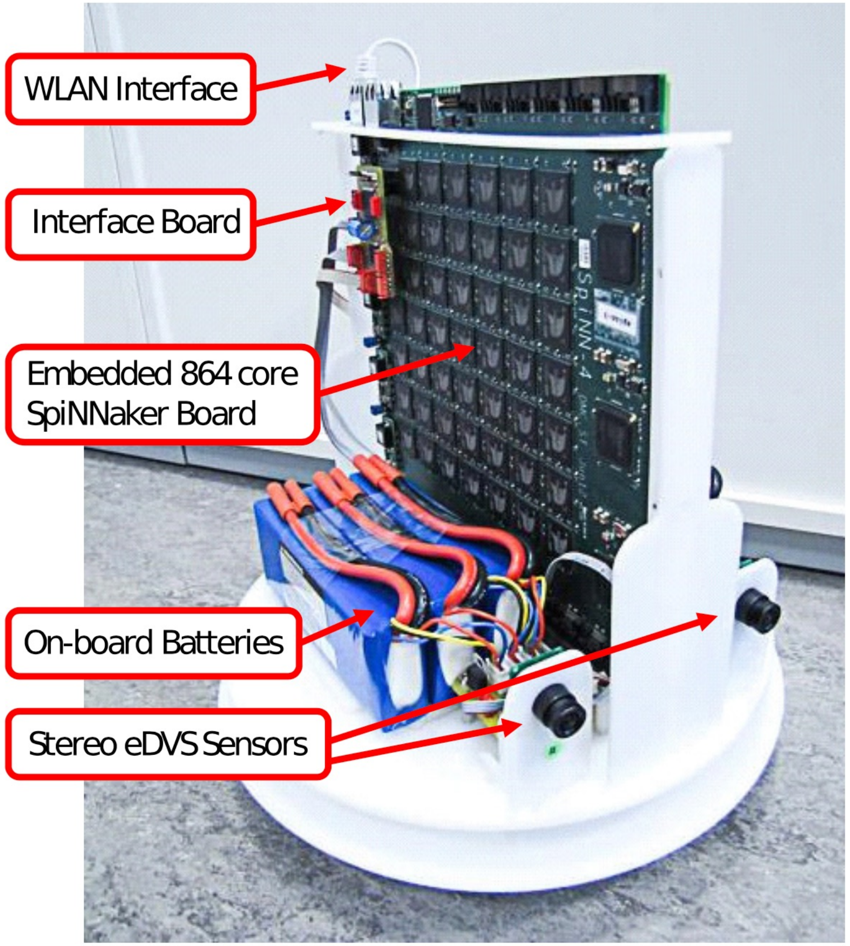


Why?
Because he magnitude of the optical flow decreases with distance

Trajectory Stabilization using Optic Flow from Event-Based Sensors

Case study based on (Galluppi et al, 2014)

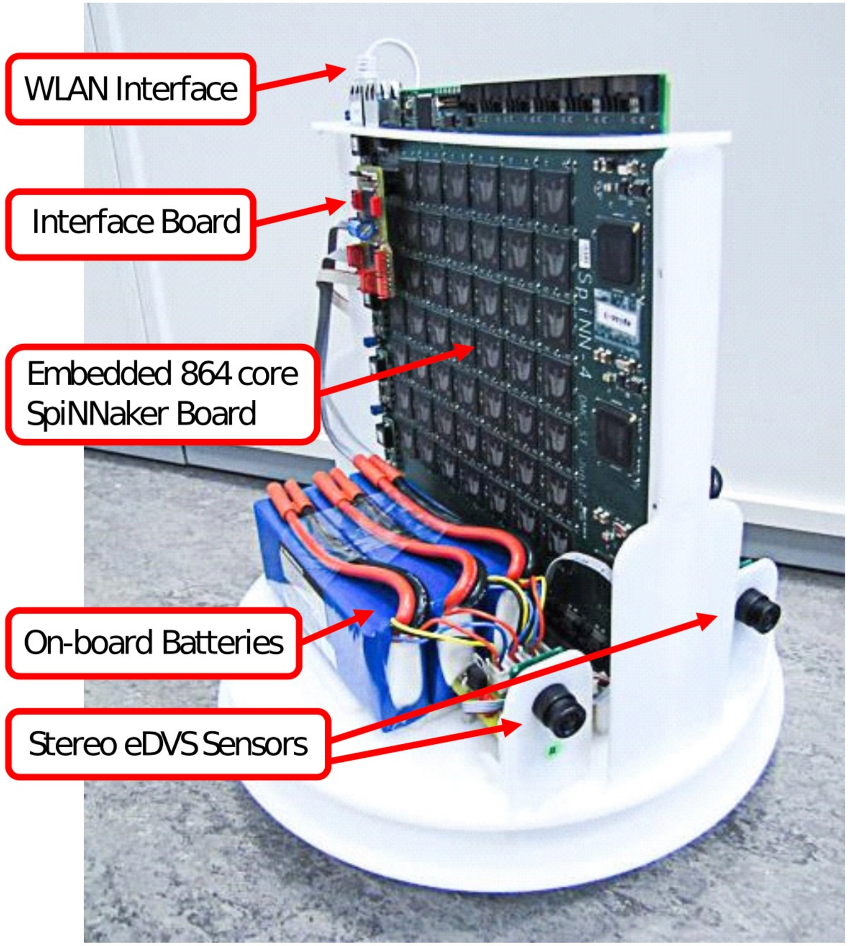
- Used a SpinNNaker neuromorphic processor
- Emulate spiking neurons
- Power reduction advantage:
  no computation between spikes
- Neurons operate in parallel:
  only need to be sampled when there is a spike



Trajectory Stabilization using Optic Flow from Event-Based Sensors

Case study based on (Galluppi et al, 2014)

- Event-based vision sensors
- Embedded Dynamic Vision Sensor (eDVS) x 2
- Spike occurs when when a pixel value changes
- Rapid response and low power consumption



Trajectory Stabilization using Optic Flow from Event-Based Sensors

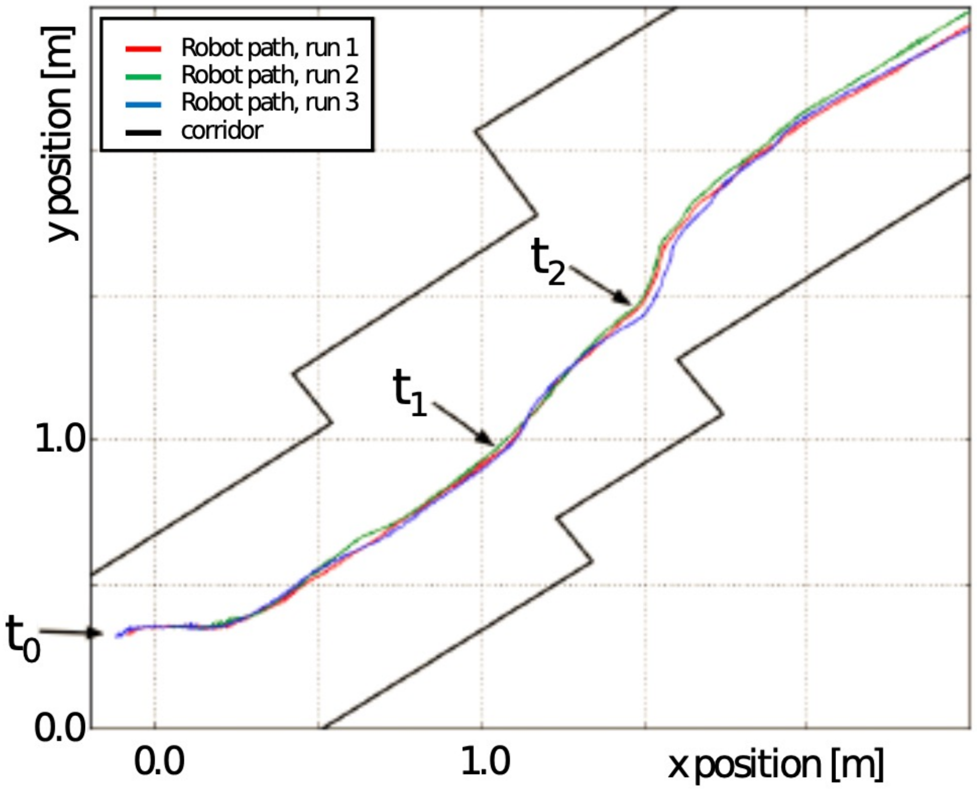
Case study based on (Galluppi et al, 2014)

- Traverse a corridor
- Black and white vertical stripes
- The contrast of the stripe make it easier to compute optical flow

Trajectory Stabilization using Optic Flow from Event-Based Sensors

Case study based on (Galluppi et al, 2014)

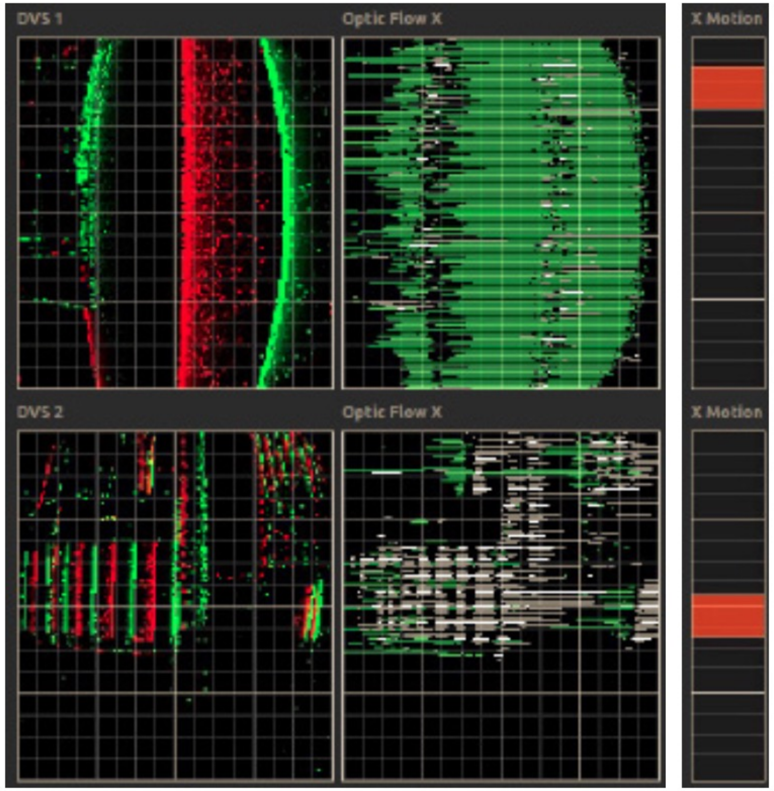
- Traverse a corridor
- Black and white vertical stripes
- The contrast of the stripe make it easier to compute optical flow
- Goal: keep in the middle of the corridor



Trajectory Stabilization using Optic Flow from Event-Based Sensors

Data at time t_2

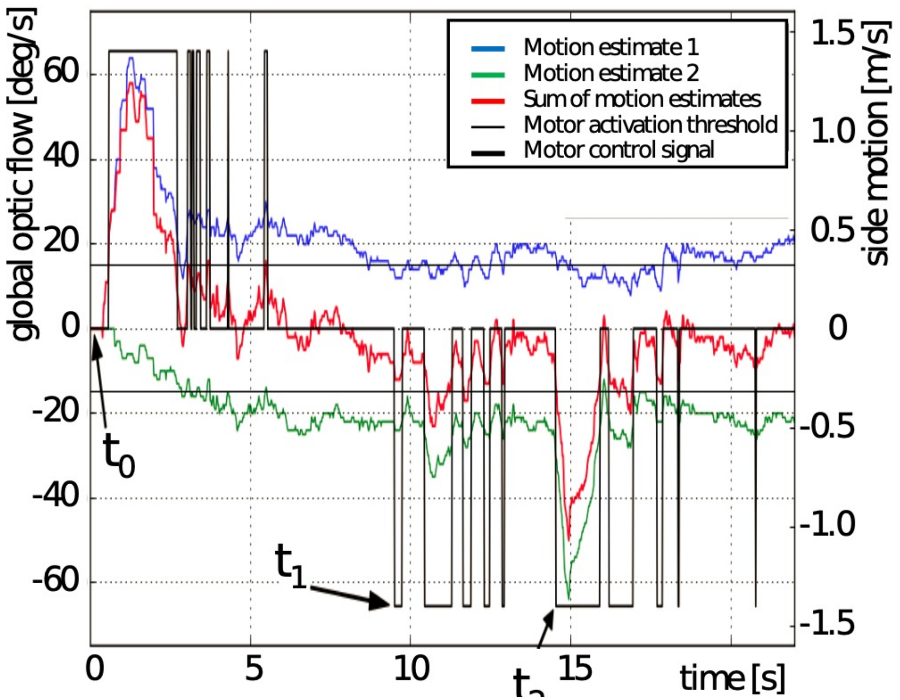
- Left: DVS sensor data: right and left (DVS 1 and DVS 2)
  - Red and green indicate visual events
  - i.e., change in intensity from white to black and vice versa
- Middle: Optic Flow X (horizontal)
  - Green and white indicate different polarities (direction?)
- Right: lateral motion motor command



Trajectory Stabilization using Optic Flow from Event-Based Sensors

Computation and control

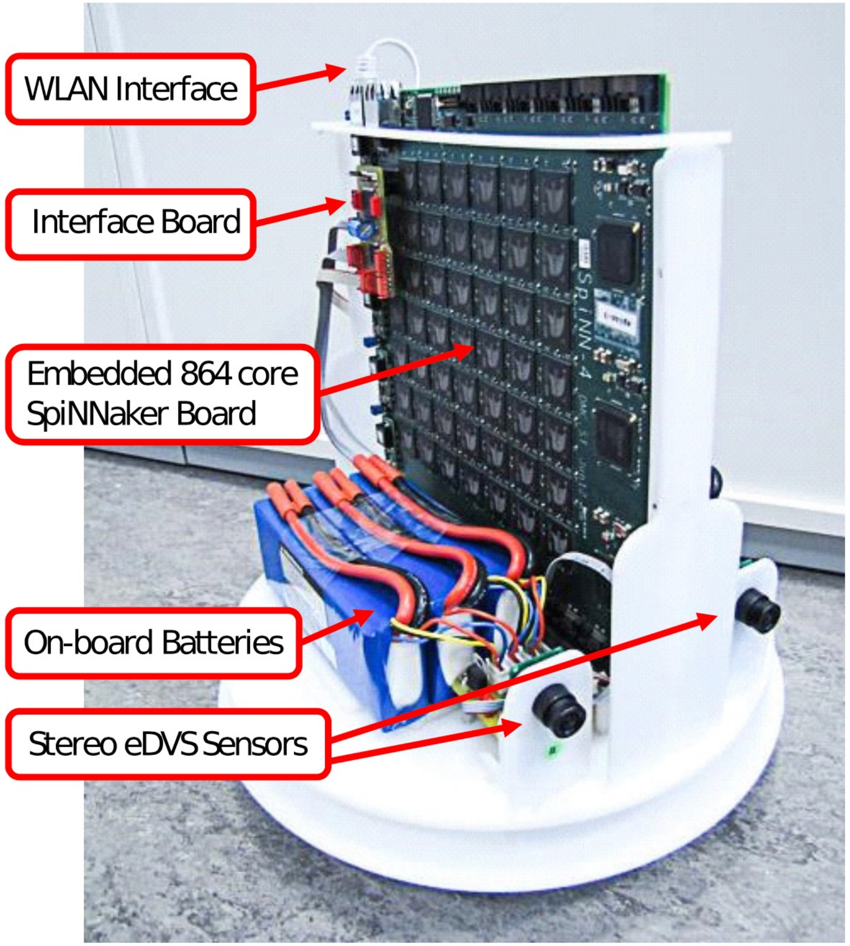
- Global optic flow: right, left, sum (average)
- Motor control activated if sum exceeds a threshold
- Move to right at t_0
- Move to left at t_1
- Move to left at t_2



Trajectory Stabilization using Optic Flow from Event-Based Sensors

Neuromorphic hardware

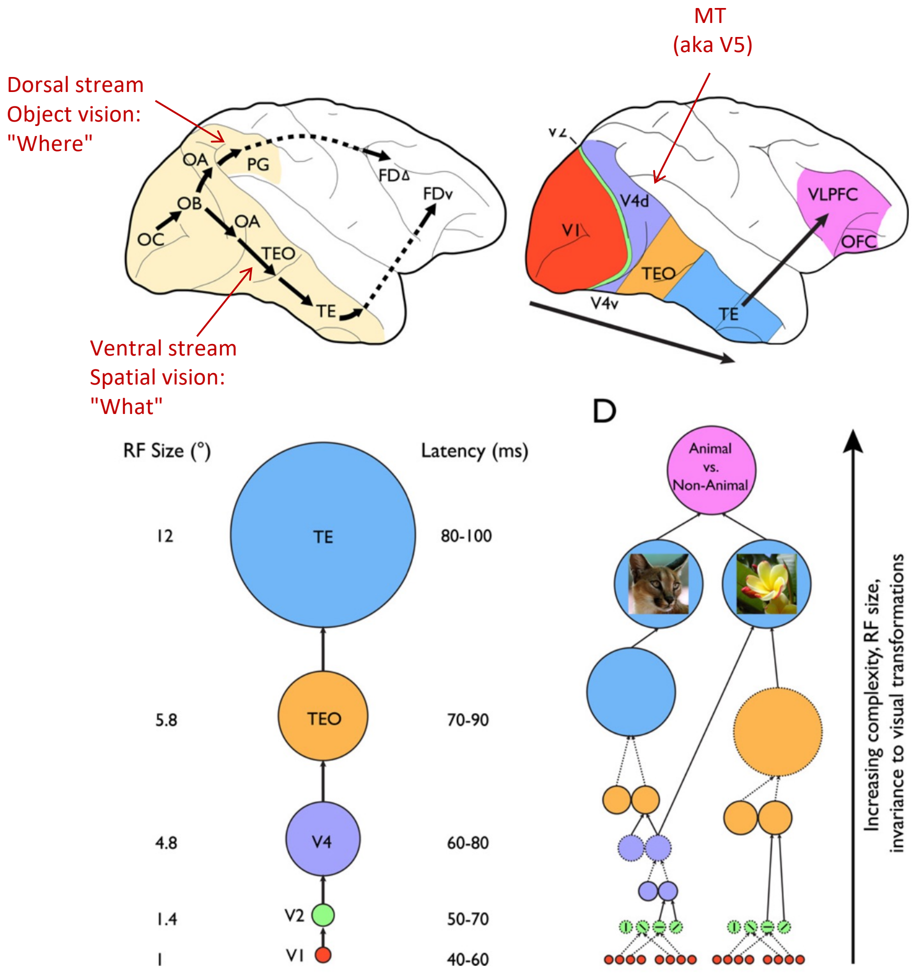
- Small size
- Low weight
- Low power
- Event-driven, massively parallel, distributed processing of information
- Ideal for autonomous robots where there are limited power resources and limited connectivity



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

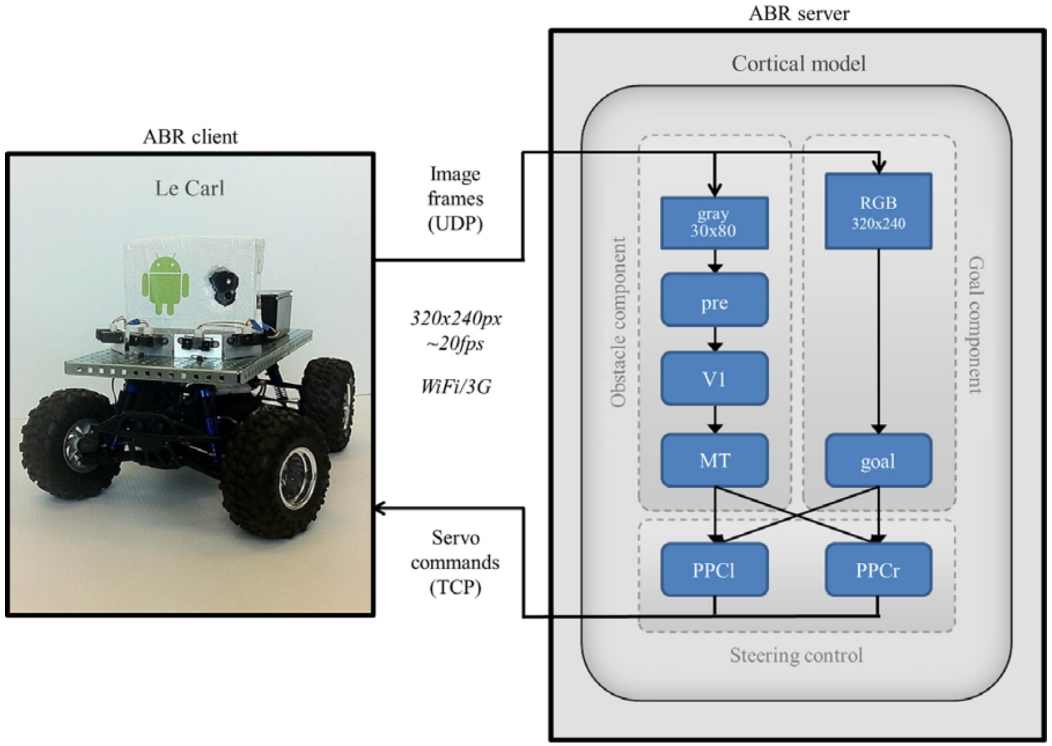
- Dorsal stream of the visual cortex processes motion
- Neurons in middle temporal cortical area (MT) respond to the speed and direction of visual object motion or self-motion



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

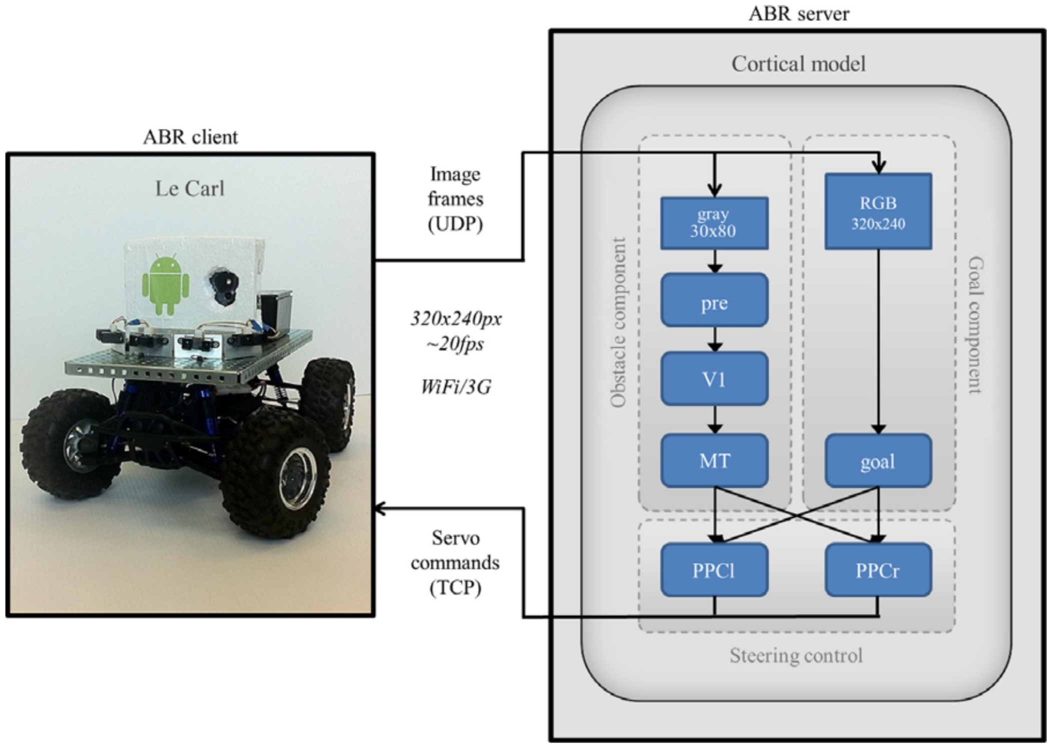
- Android Based Robot
- ABR client
- ABR server



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

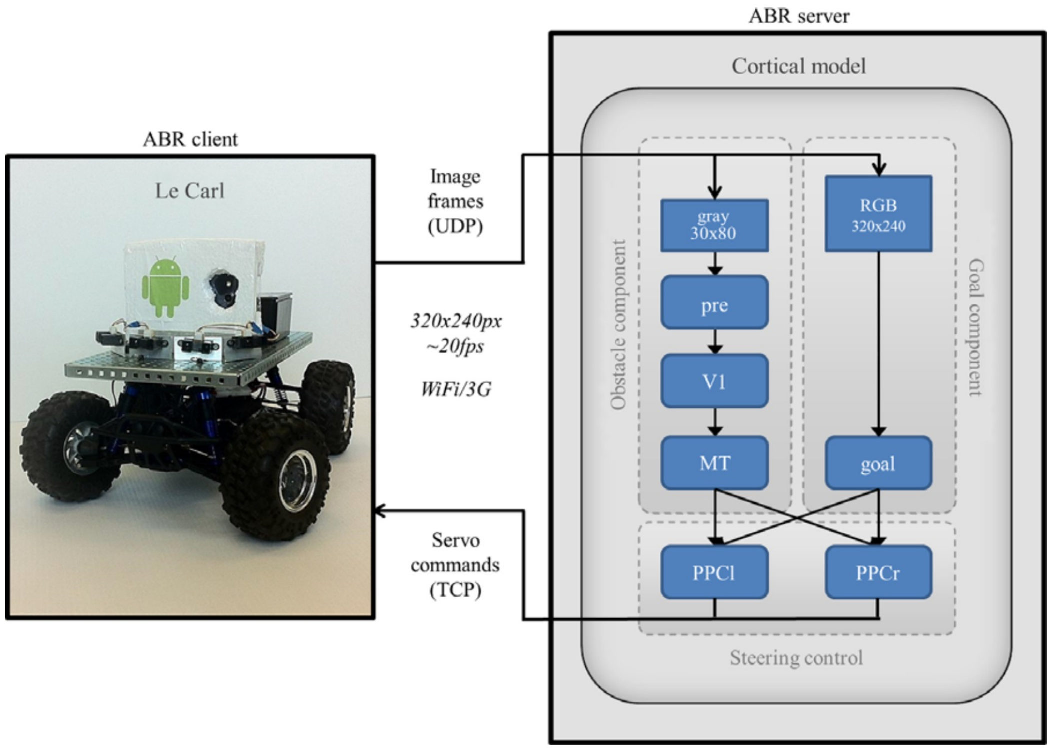
- ABR client
  - sends 320 x 240 pixel images
  - 20 frames per second (fps)
  - to the ABR server



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

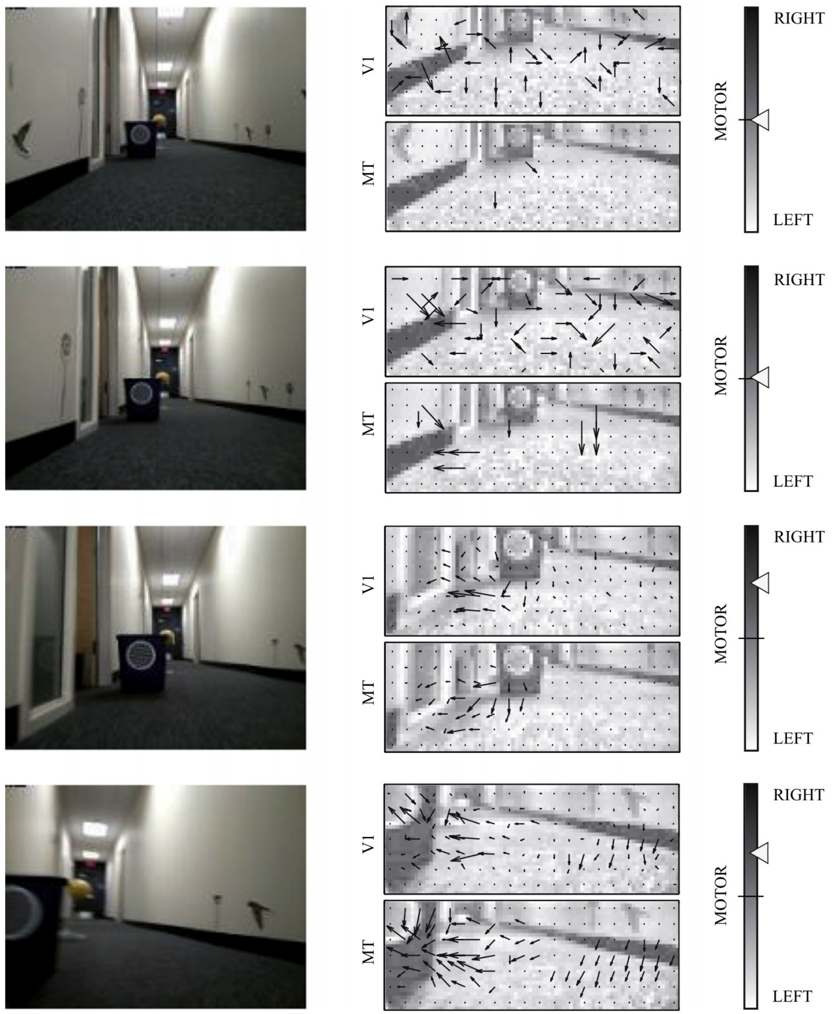
- ABR server
  - Computer equipped with a GPU
  - Simulates a spiking neural network model
  - 40,000 spiking neurons
  - 1.7 million synapses
  - Handles images at frame rate (20 Hz)



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

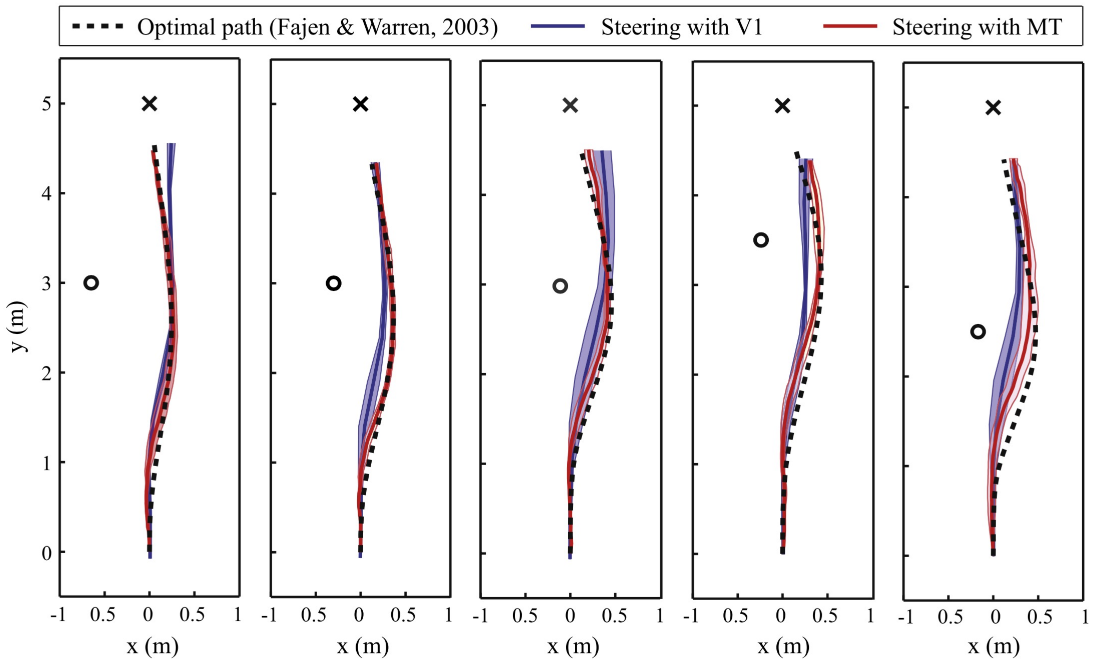
- Four frames of the image sequence
- Optical flow derived from V1 processing
- Optical flow derived from MT processing
- Motor command based on balancing optical flow in left and right regions of the image



Cortical Neural Network Model for Visually Guided Robot Navigation

Case study based on (Beyeler et al., 2015)

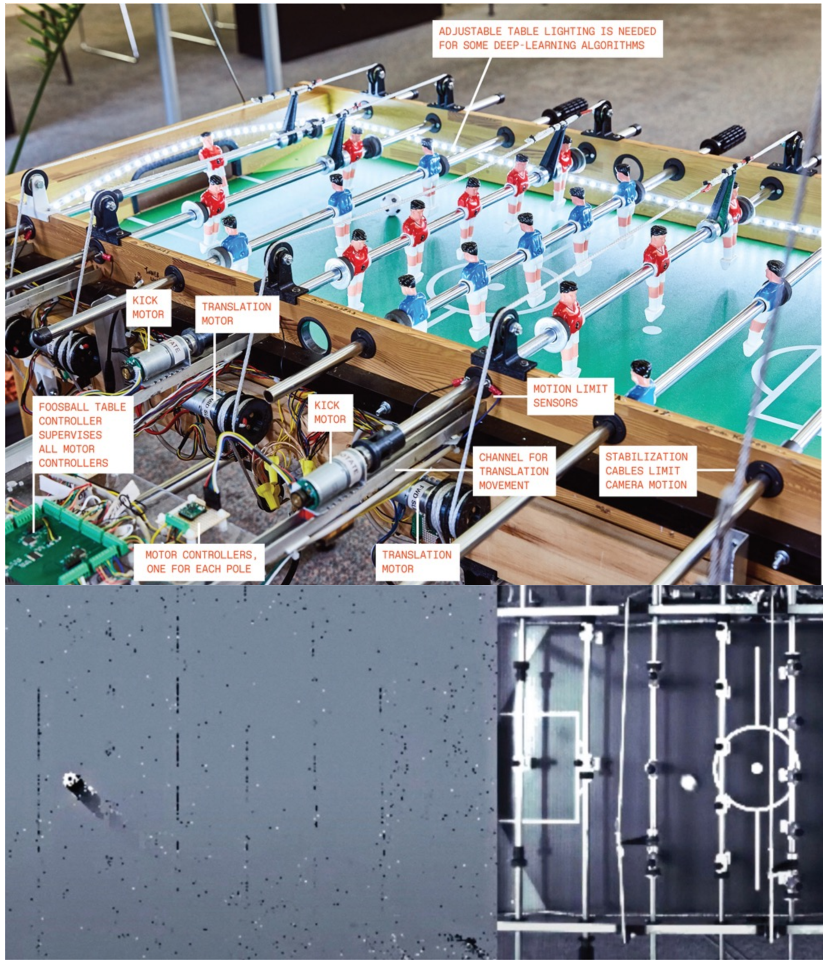
- Five experiments
- Navigating around a single object (recycle bin)
- Towards a goal (yellow foam ball)
- Using steering commands based on V1 and MT
- Better performance of MT
  - Possibly due to summing and pooling of V1 signals in MT



Neuromorphic Control of a Foosball Table

Additional case study based on (Cohen, 2022)

- Motors to rotate rods
- Motors to slide rods
- Neuromorphic motor controllers
- Event-based cameras
- See the article in Spectrum for the details



Reading

Hwu, T. and Krichmar, J. (2022). Neurorobotics: Connecting the Brain, Body and Environment, MIT Press.

Chapter 2, Sections 2.5 - 2.6, pp. 34-42

Cohen, G. (2022). "Goal!!! Why We Built a Neuromorphic Robot to Play Foosball", IEEE Spectrum, March.

https://read.nxtbook.com/ieee/spectrum/spectrum_na_march_2022/gooaall_why_we_built_a_neurom.html

References

Galluppi, F., Denk, C., Meiner, M.C., Stewart, T.C., Plana, L.A., Eliasmith, C., Furber, S., and Conradt, J. (2014). Event-based neural computing on an autonomous mobile platform, Proceeding of IEEE International Conference on Robotics and Automation (ICRA).

Beyeler, M., Oros, N., Dutt, N., and Krichmar, J.L. (2015). A GPU-accelerated cortical neural network model for visually guided robot navigation. Neural Networks 72, 75-87.