Technische Hochschule Nürnberg

SPICES Lab

Team NeurOHM

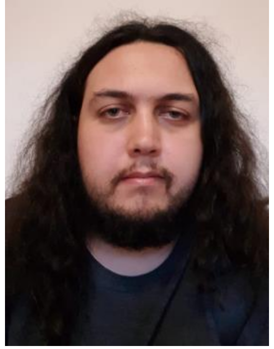
Project SPIDER

Spiking **P**erception and processing for **I**ntelligent **D**etection of p**E**destrians on urban **R**oads

Team

Ertan Halilov, Julian Main, David Weiss, Cristian Axenie

Team



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Project demo

Project report

Project datasets

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Outline

- Challenge goal
- Solution overview
- Solution development and life-cycle
- Sensing and algorithmics
- Performance evaluation
    - Accuracy
    - Deployment and power budget
    - BOM and costs
- Deliverables and datasets

Goal

"**Vision Zero**" as a street safety policy that strives for the elimination of traffic fatalities for all transportation modes.

McKee Road & Jackson Avenue, San Jose, California

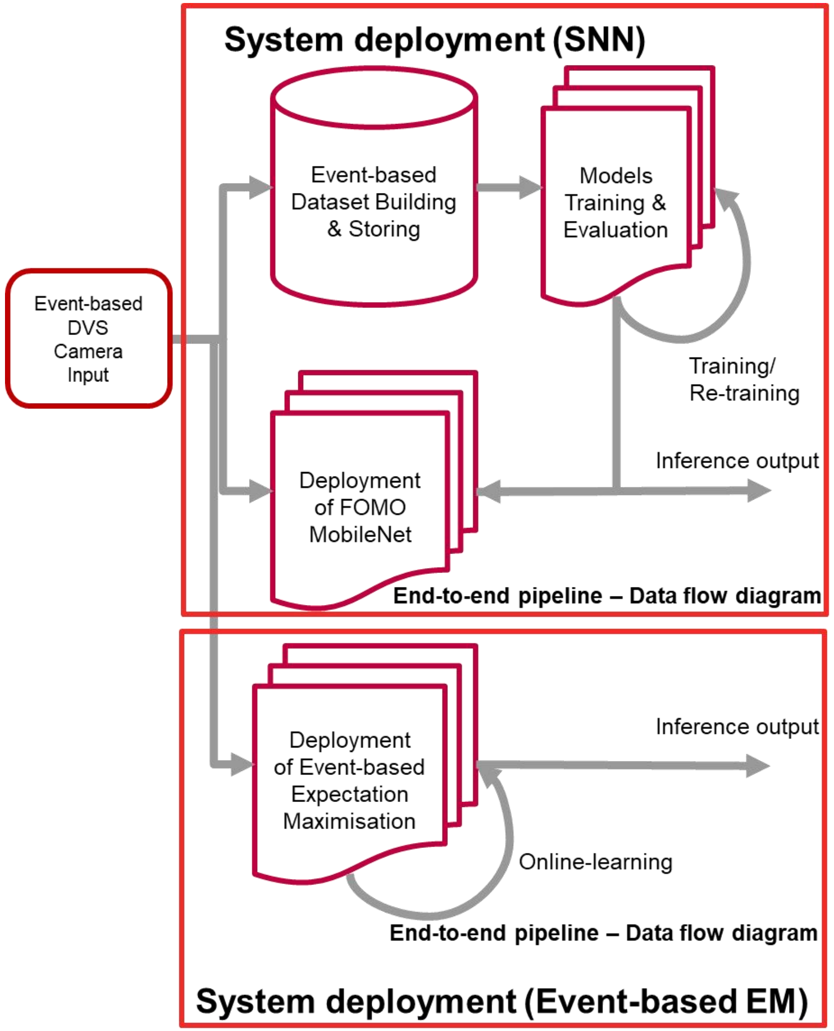
Tully Road & La Ragione Avenue, San Jose, California

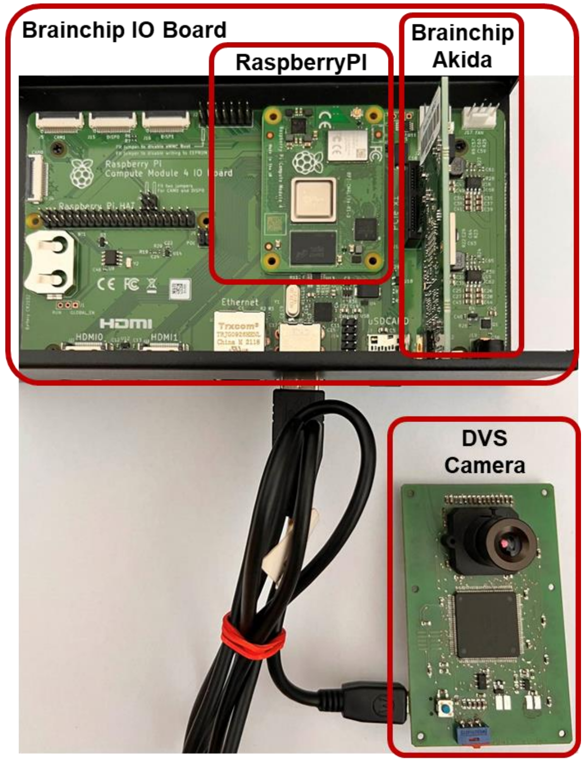
Cost effective and **accurate solutions** are needed to **detect pedestrians** during the **day** and especially at **nighttime** to implement safety measures. **Solutions** need to have a **very good energy footprint**, **robustness**, and a **budget** that allows scaling to city level.

CITY OF SAN JOSE
CAPITAL OF SILICON VALLEY

VZSJ
ASAP!

Solution overview



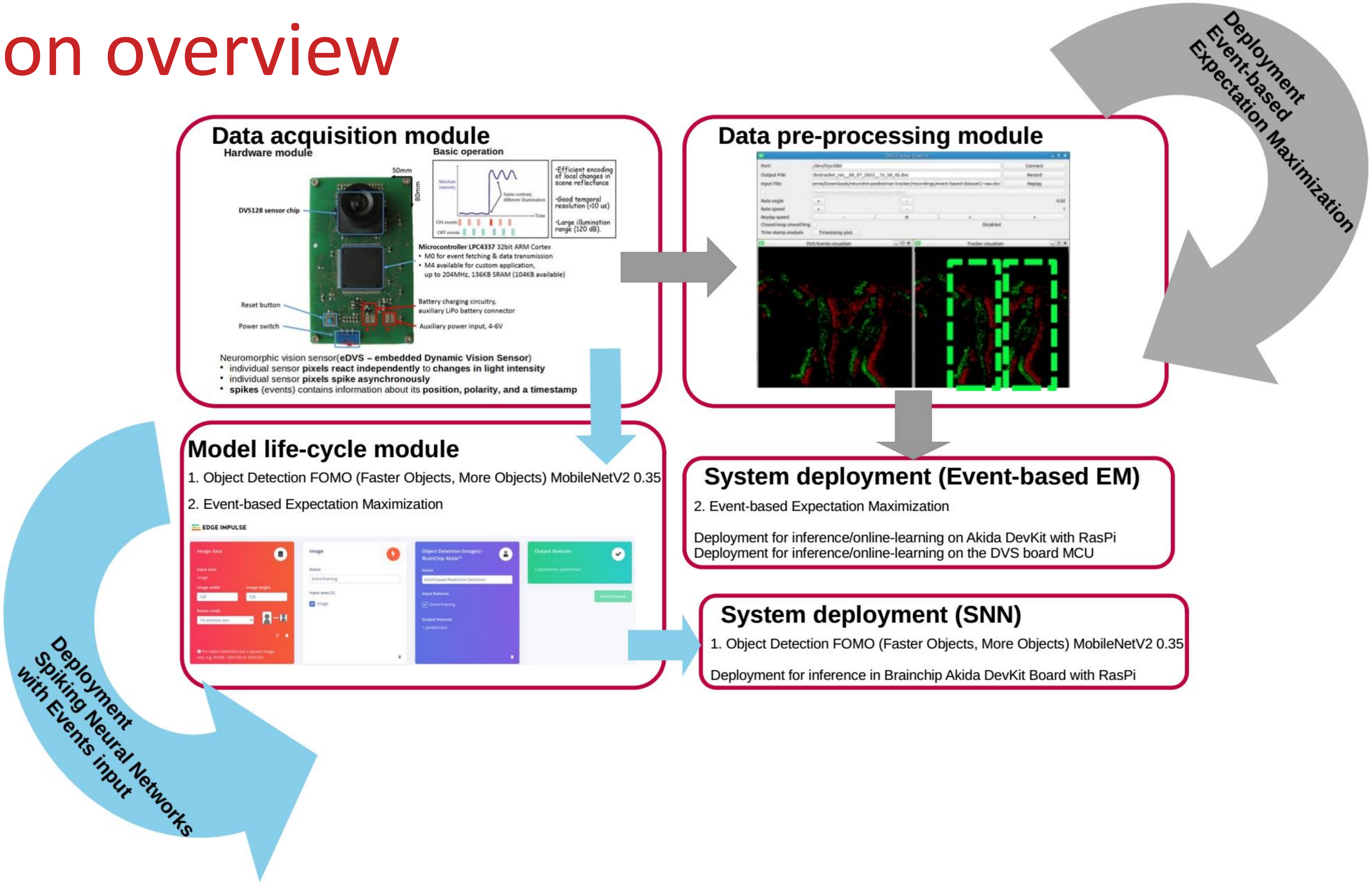


End-to-end pipeline – System hardware

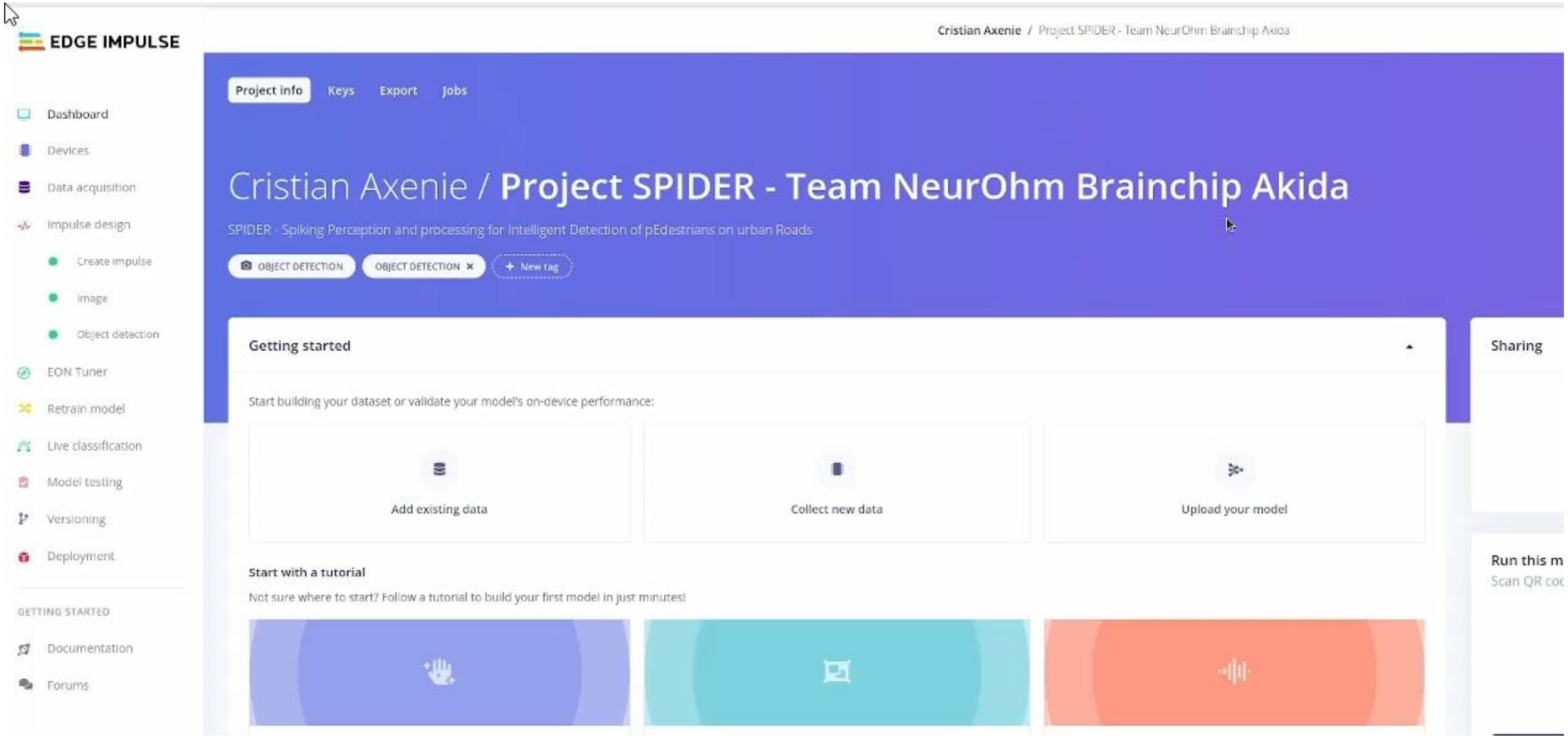
Thanks Brainchip Inc. !

Thanks Neurocomputing Lab, KTH Stockholm, Sweden !

Solution overview

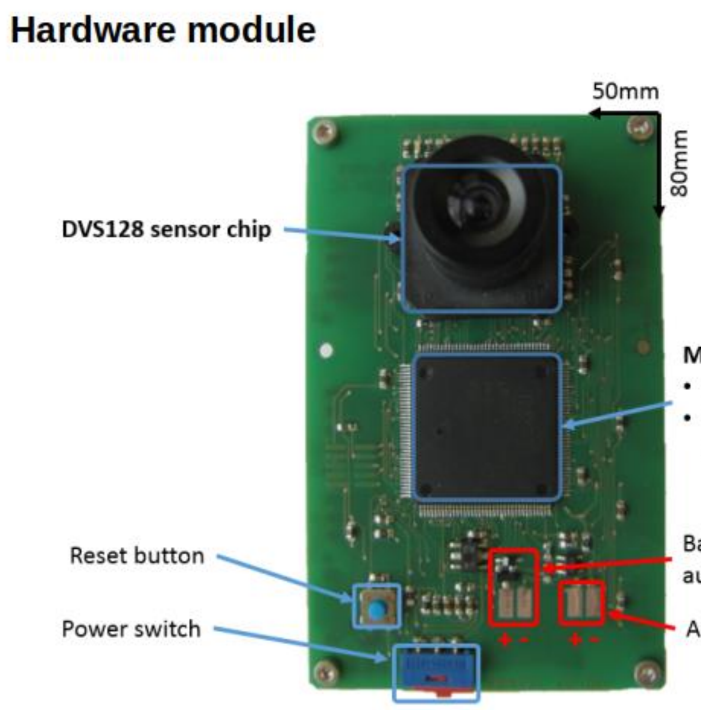


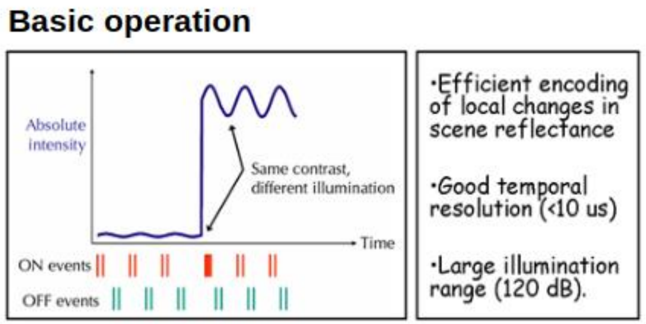
Solution development and life-cycle



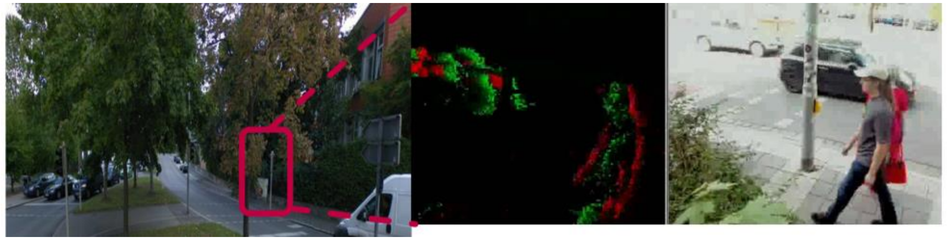
Approach

- Sensing



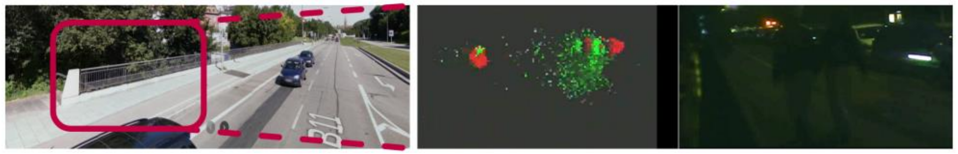


Neuromorphic vision sensor(**eDVS – embedded Dynamic Vision Sensor**)
- individual sensor **pixels react independently** to **changes in light intensity**
- individual sensor **pixels spike asynchronously**
- **spikes** (events) contains information about its **position, polarity, and a timestamp**



Dataset 1 sample – intersection (Nuremberg)

Dataset 2 sample – wide street (Nuremberg)



Dataset 3 sample – wide street at night (Munich)

Approach

- Sensing

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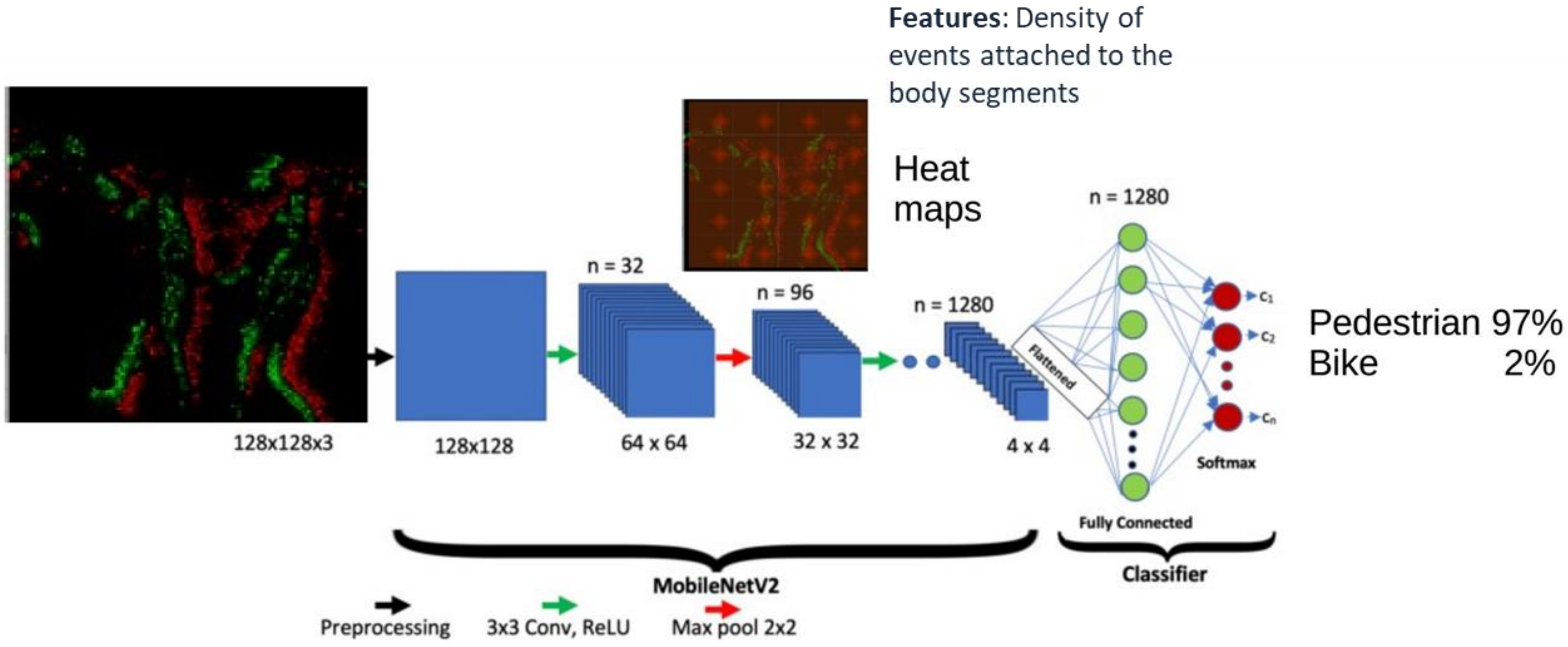
Approach

- Algorithmics – MobileNetv2 Conv Net, Spiking Neural Network (SNN)



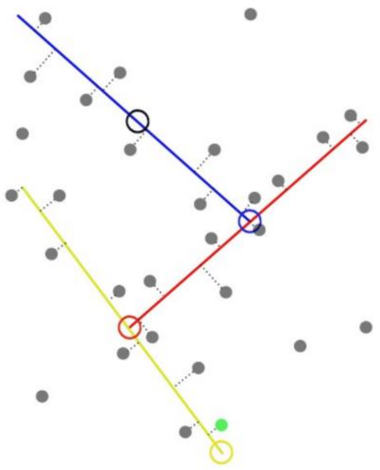
Demo - Spiking Neural Network (SNN)

```
rwxrwxrwx 6 ubuntu ubuntu     4096 Aug  6 14:43 neurohm-pedestrian-tracker-daq-module-code/
rwxrwxrwx 1 bcdev  bcdev  32457606 Aug  6 14:41 neurohm-pedestrian-tracker-daq-module-code.zip*
rwxrwxrwx 1 ubuntu ubuntu  1996048 Jun 27 17:52 spider-demo-event-based-dataset-video.avi*
rwxrwxrwx 1 bcdev  bcdev   4153564 Jun 27 17:52 spider-demo-event-based-dataset-video2.avi*
lrwxrwxr-x 3 bcdev  bcdev     4096 Aug  4 18:38 templates/
lrwxr-xr-x 2 ubuntu ubuntu     4096 Aug  1 13:15 tflite-model/
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm$ vim neurohm-event-based-pedestrian-detector.py
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm$ cd neurohm-pedestrian-tracker-daq-module-code/
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$ ll
otal 208
lrwxrwxrwx 6 ubuntu ubuntu   4096 Aug  6 14:43 ./
lrwxrwxr-x 7 bcdev  bcdev    4096 Aug  6 14:43 ../
rwxrwxrwx 1 ubuntu ubuntu   1614 Jun  6 09:10 CMakeLists.txt*
rwxrwxrwx 1 ubuntu ubuntu  13289 Aug  6 14:40 CMakeLists.txt.user*
rwxrwxrwx 1 ubuntu ubuntu  12258 Jun  6 09:09 CMakeLists.txt.user.7d0a13c.4.8-pre1*
rwxrwxrwx 1 ubuntu ubuntu  12347 Mar  1  2017 CMakeLists.txt.user.981edac*
rwxrwxrwx 1 ubuntu ubuntu  17226 May  2  2016 Makefile*
rwxrwxrwx 1 ubuntu ubuntu    244 Jun 29 14:23 README.md*
lrwxrwxr-x 4 ubuntu ubuntu   4096 Aug  7 15:17 build/
lrwxrwxrwx 2 ubuntu ubuntu   4096 Aug  6 10:44 lib/
rwxrwxrwx 1 ubuntu ubuntu 114156 Aug  6 14:39 logo.svg*
lrwxrwxrwx 2 ubuntu ubuntu   4096 Aug  2 17:38 recordings/
lrwxrwxrwx 3 ubuntu ubuntu   4096 Aug  7 15:17 src/
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$ cat README.md
 Neurotracker #

leuromorphic vision sensor (DVS) tracking system for pedestrian detection and tracking in urban scenarios. Using the event-based vision framework for detecting and tracking pedestrians, bikers, and other traffic
participants.
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code$ cd ..
venv_akida) ubuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm$ ll
otal 37868
lrwxrwxr-x 7 bcdev  bcdev     4096 Aug  6 14:43 ./
lrwxr-xr-x 3 bcdev  bcdev     4096 Aug  4 15:05 ../
rw-r--r-- 1 ubuntu ubuntu      458 Aug  1 13:15 CMakeLists.txt
rw-r--r-- 1 ubuntu ubuntu     1871 Aug  1 13:15 README.txt
lrwxr-xr-x 9 ubuntu ubuntu     4096 Aug  1 13:15 edge-impulse-sdk/
lrwxr-xr-x 2 ubuntu ubuntu     4096 Aug  1 13:15 model-parameters/
rw-r--r-- 1 ubuntu ubuntu   113875 Aug  1 13:15 neurohm-akida-fomo-event-based.fbz
rw-rw-r-- 1 ubuntu ubuntu     7828 Aug  7 15:34 neurohm-event-based-pedestrian-detector.py
lrwxrwxrwx 6 ubuntu ubuntu     4096 Aug  6 14:43 neurohm-pedestrian-tracker-daq-module-code/
rwxrwxrwx 1 bcdev  bcdev  32457606 Aug  6 14:41 neurohm-pedestrian-tracker-daq-module-code.zip*
rwxrwxrwx 1 ubuntu ubuntu  1996048 Jun 27 17:52 spider-demo-event-based-dataset-video.avi*
```

Approach

- Algorithmics – Event-based Expectation Maximization (EM)



Event membership allocation

Adding a prediction model

- $\dot{\theta} = \frac{\Delta\theta}{\Delta t}$ (for each body segment)
- Future centers:

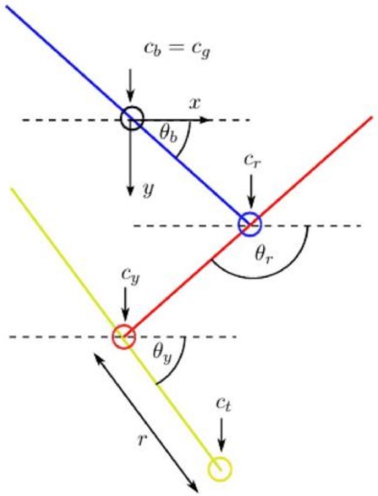
$$c_b(t+T) = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$c_r(t+T) = c_r(t) + T \begin{bmatrix} -\dot{\theta}_b \sin(\theta_b) \\ \dot{\theta}_b \cos(\theta_b) \end{bmatrix}$$

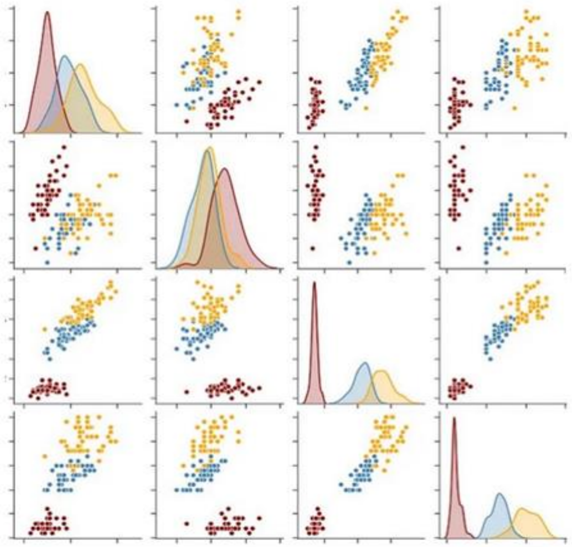
$$c_y(t+T) = c_y(t) + T \begin{bmatrix} -\dot{\theta}_b \sin(\theta_b) - \dot{\theta}_r \sin(\theta_r) \\ \dot{\theta}_b \cos(\theta_b) + \dot{\theta}_r \cos(\theta_r) \end{bmatrix}$$

- Future angles:

$\theta(t+T) = \theta(t) + T\dot{\theta}$ (for each body segment)



Embedding physics in the Expectation Maximization



Likelihoods estimation

Demo - Event-based Expectation Maximization (EM)

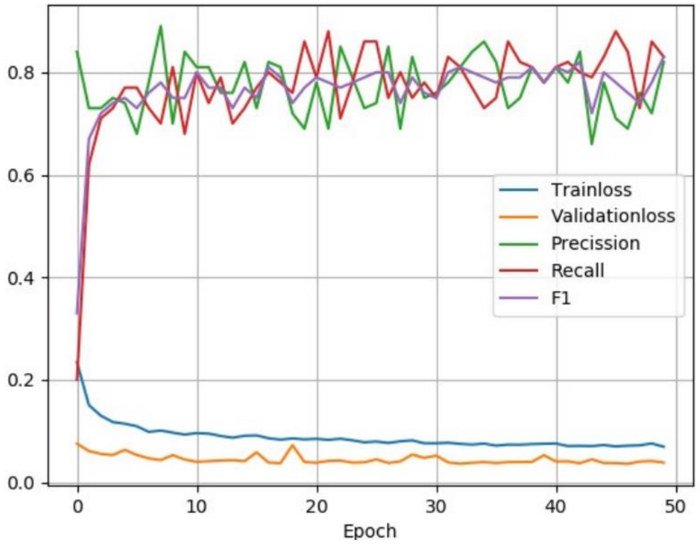
```
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$ ll
:otal 7988
lrwxrwxr-x 4 ubuntu ubuntu    4096 Aug  7 15:48 ./
lrwxrwxrwx 6 ubuntu ubuntu    4096 Aug  6 14:43 [illegible]/
 rw-rw-r-- 1 ubuntu ubuntu   14786 Aug  6 14:44 CMakeCache.txt
lrwxrwxr-x 6 ubuntu ubuntu    4096 Aug  7 16:02 CMakeFiles/
 rw-rw-r-- 1 ubuntu ubuntu   18716 Aug  6 14:44 Makefile
 rw-rw-r-- 1 ubuntu ubuntu    1611 Aug  6 14:44 cmake_install.cmake
 rw-rw-r-- 1 ubuntu ubuntu   20405 Aug  6 14:44 compile_commands.json
 rwxrwxr-x 1 ubuntu ubuntu 8099224 Aug  7 15:48 dvstracker*
lrwxrwxr-x 4 ubuntu ubuntu    4096 Aug  7 15:46 dvstracker_autogen/
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$ make
  6%] Automatic MOC for target dvstracker
  6%] Built target dvstracker_autogen
 100%] Built target dvstracker
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$
ıbuntu@ubuntu:/home/bcdev/venv_akida/bin/neurohm/neurohm-pedestrian-tracker-daq-module-code/build$ ./dvstracker
```

Performance

- Spiking Neural Network

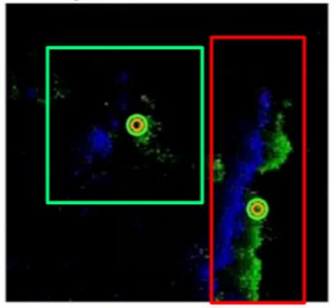
Quantitative evaluation

	BACKGROUND	BICYCLIST	PEDESTRIAN
BACKGROUND	99.7%	0.1%	0.2%
BICYCLIST	12.1%	87.9%	0%
PEDESTRIAN	6.2%	0%	93.8%
F1 SCORE	1.00	0.62	0.77

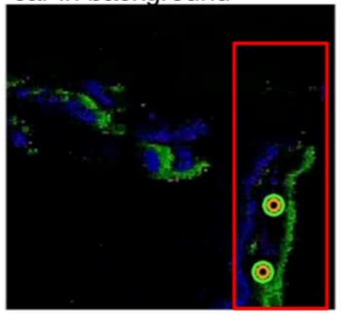


Qualitative evaluation

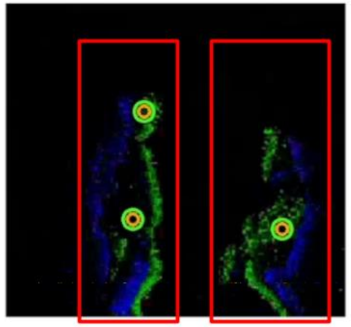
Detection: 1 pedestrian and 1 bicyclist



Detection: 1 pedestrian and car in background



Detection: 2 pedestrians

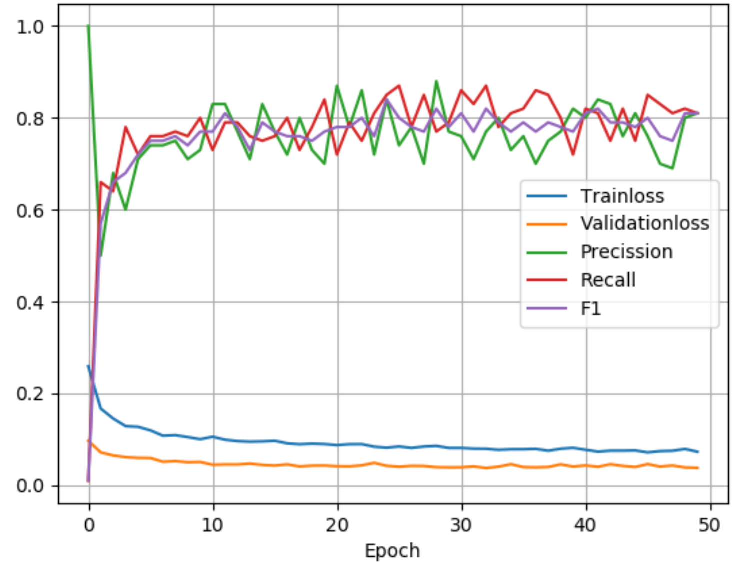


Performance

- Event-based Expectation Maximization

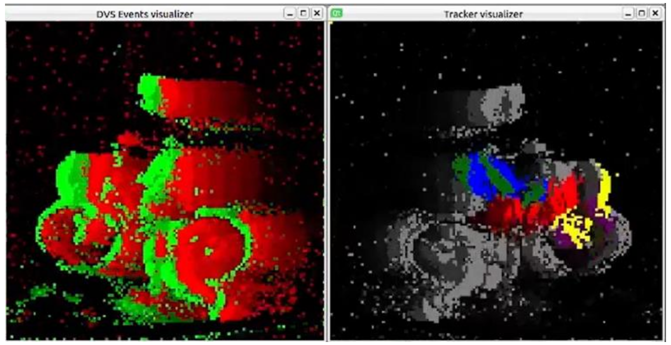
Quantitative evaluation

	BACKGROUND	BICYCLIST	PEDESTRIAN
BACKGROUND	99.9%	0.0%	0.0%
BICYCLIST	15.2%	84.8%	0%
PEDESTRIAN	16.8%	0%	83.2%
F1 SCORE	1.00	0.73	0.86

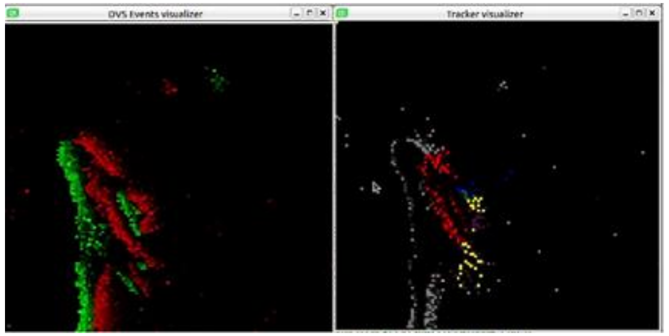


Qualitative evaluation

Bicyclist detection



Pedestrian detection



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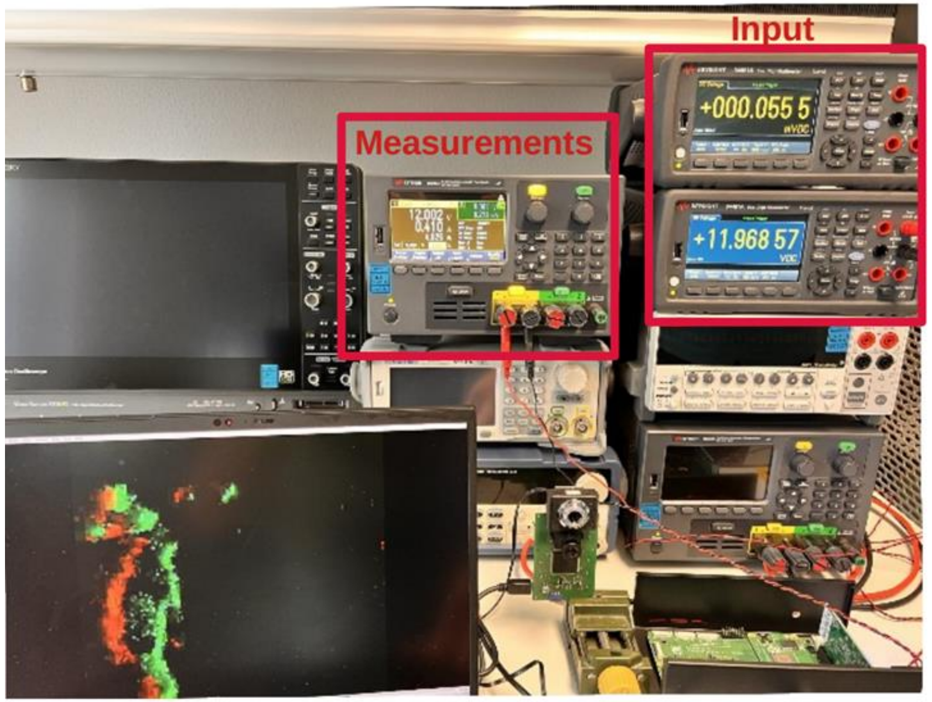
Deployment evaluation

- Power consumption analysis

Measurement setup
Camera pointing to a screen with recorded traffic data

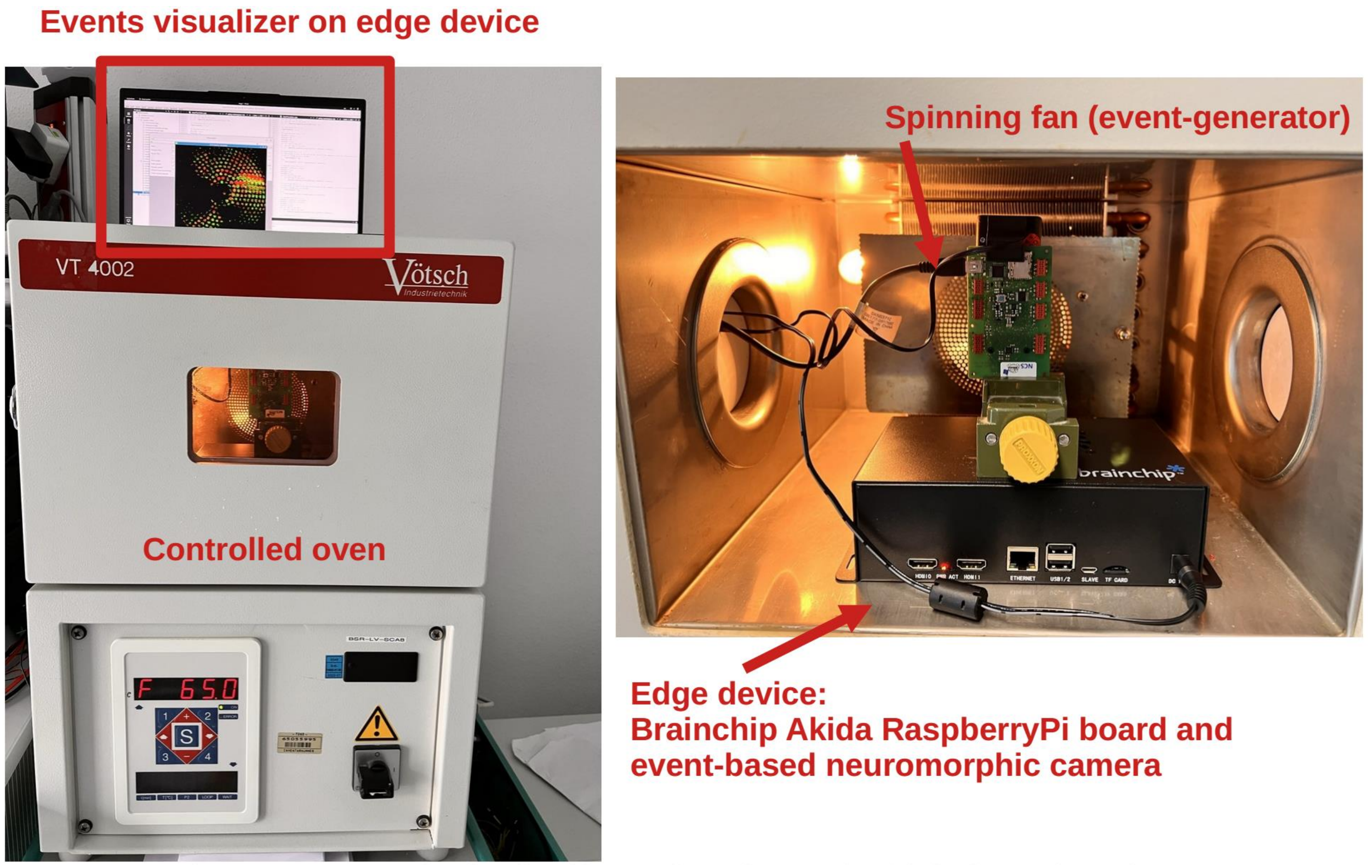


Deployment
RaspberryPi Event-based Expectation Maximization

Deployment
Akida Spiking Neural Networks in Event data

Deployment evaluation

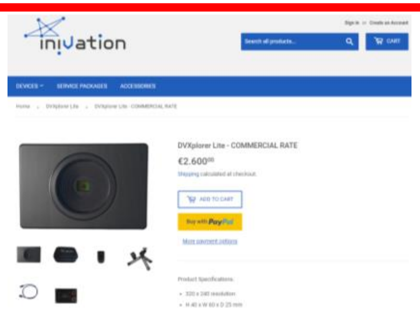
- Weatherization and operational analysis



Complete BOM and costs

Bill of Materials (BOM) Single unit & suggested price for large quantities		
Component	**Price**	**Notes**
Raspberry PI Compute Module 4 IO Board with RPI CM4Lite	50 $	Price pro unit sold independently from the Brainschip Akida PCIexpress board (see below). https://www.reichelt.de/de/de/raspberry-pi-compute-modul-4-io-board-rpi-cm4-io-board-p290556.html
Brainchip Akida AKD1000 PCIexpress Board	499 $	Price pro unit sold independently from the IO board/carried board. https://shop.brainchipinc.com/products/akida%E2%84%A2-development-kit-pcie-board
IniVation Dynamic Vision Sensor	2500 $	Price per unit, with up to 50 $ if large quantities purchased. https://shop.inivation.com/collections/dvxplorer-lite-1/products/dvxplorer-lite-commercial-rate
USB to miniUSB cable	1 $ (1m long USB cable) – 26 $ (5m long USB cable with signal amplifier)	Length of the cable depends on the gantry layout, we have tried with 1m long USB cable and also with signal amplification 5m long USB cable. https://www.conrad.de/de/p/delock-usb-kabel-usb-3-2-gen1-usb-3-0-usb-3-1-gen1-usb-a-stecker-usb-a-buchse-5-00-m-rot-schwarz-vergoldete-steckkontakte-ul-zertifiziert-82755-649883.html
Total	**3076 $**	Price per unit. When more units are bought a total price of approx. **226 $** for a price per unit **100 $ for Akida Chip**, **50 $ for RaspberryPI boards**, **50 $ for DVS camera**, and long **USB cable 26 $**.

Source:
https://www.proshop.nl/Smart-Home/Samsung-SmartThings-Vision/2786571



Source:
https://shop.inivation.com/collections/dvxplorer-lite-1

Best price ~226$

Worst price ~3000$

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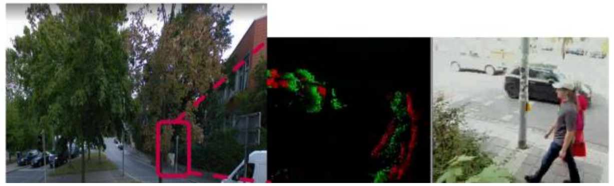
Deliverables

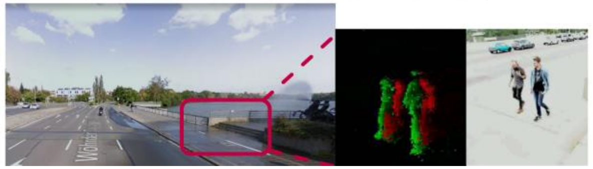
Project demo *Project report* *Project datasets*

- **Datasets** release

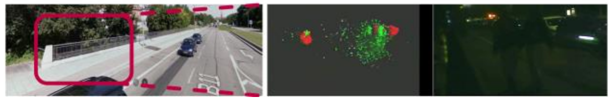
Dataset location 1
- 4 lanes (4 per direction) wide street
- Location: https://goo.gl/maps/JaYGwaTaBHj5H6SL9
- 50 kmh (urban) speed limit
- Near university campus with Pedestrians (people walking), Bicyclists (people biking, scooting, rolling, etc.)
- Ideal Operating Environment



Dataset location 2
- 8 lanes (4 per direction) wide street
- Location: https://goo.gl/maps/jar6AjysZiM2LP5S7
- 50 kmh (urban) speed limit
- Near main train stations of the city and a location with Pedestrians (people walking/running/jogging), Bicyclists (people biking, scooting, rolling, etc.)

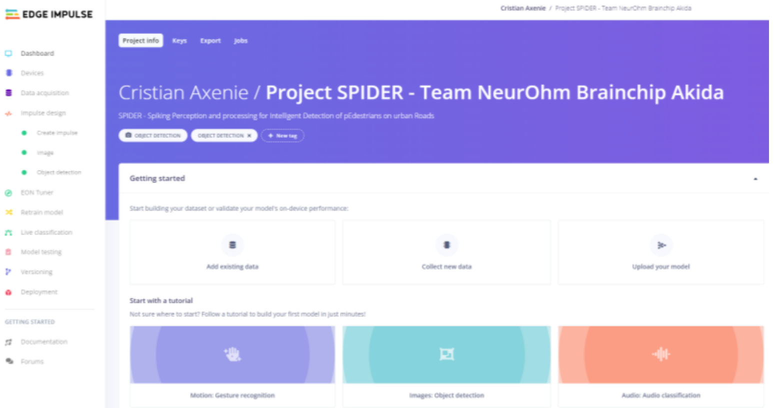


Dataset location 3
- 6 lanes (3 per direction) wide street on bridge
- Location: https://goo.gl/maps/SEEsmpgmLPcD8fG7A
- 50 kmh (urban) speed limit
- Near ring street of Munich and a location with Pedestrians (people walking/running/jogging), Bicyclists (people biking, scooting, rolling, etc.)
- Night time data acquisition

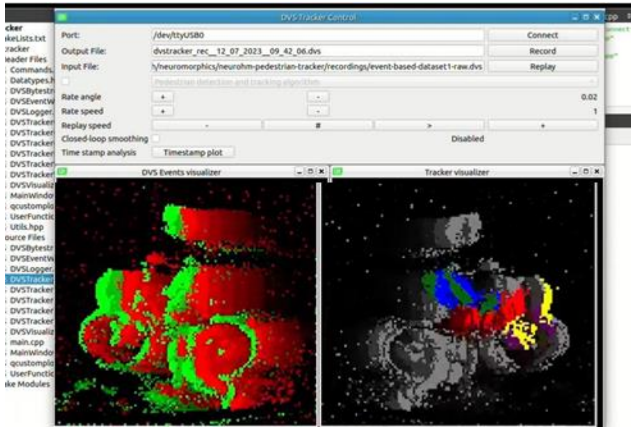


- **Code** release

Model life-cycle and data analysis



Accurate TinyML algorithms



- **Solution** release

Minimal energy footprint

Deployment
Akida Spiking Neural Networks in Event data

Deployment
RaspberryPi Event-based Expectation Maximization

Feasible deployment

Project demo | Project report | Project datasets

Wrap-up

Project SPIDER is a **TinyML solution** for supporting **VisionZero pedestrian detection**

- uses **low-power neuromorphic sensing** and **processing**
  - *the Brainchip Akida system with a DVS event camera consumes between **4W and 7W** when processing camera data on-site (with SNN or EM, respectively). Conventional real-time vision processing systems (data centers) require specialized GPUs operating at around **400W** per high-speed camera. The neuromorphic design enables at least a **100-fold power reduction**; per expected 100 million devices, this continuously saves 40GW,*

  given 100 × 10^6units × (400 W - 4 W) = 39.6 GW.
- employs **only local processing** (at the **edge**)
  - *on-site pre-processing reduces transmitted data from about **30MB/s** in conventional systems to **300B/s**,*

  *a **10,000-fold data rate reduction**, 25 bytes per object (8 for time, 16 for coordinates, 1 for class), 10-12 objects are detected per second: 25×12 = 300B.*
- provides **good accuracy** for **robust visual detection** under varying conditions