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Neuromorphic Sensor Signal Processing Lab

Neuromorphic Sensing and Processing for Security and Defence

Dr Gaetano Di Caterina

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3rd May 2023

Outline

- The NSSP Lab
- NM, SNN and STDP
- NM applications for Security and Defence
- Conclusion

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Neuromorphic Sensor Signal Processing Lab

Neuromorphic Sensor Signal Processing (NSSP) Lab

Dr Gaetano Di Caterina, director

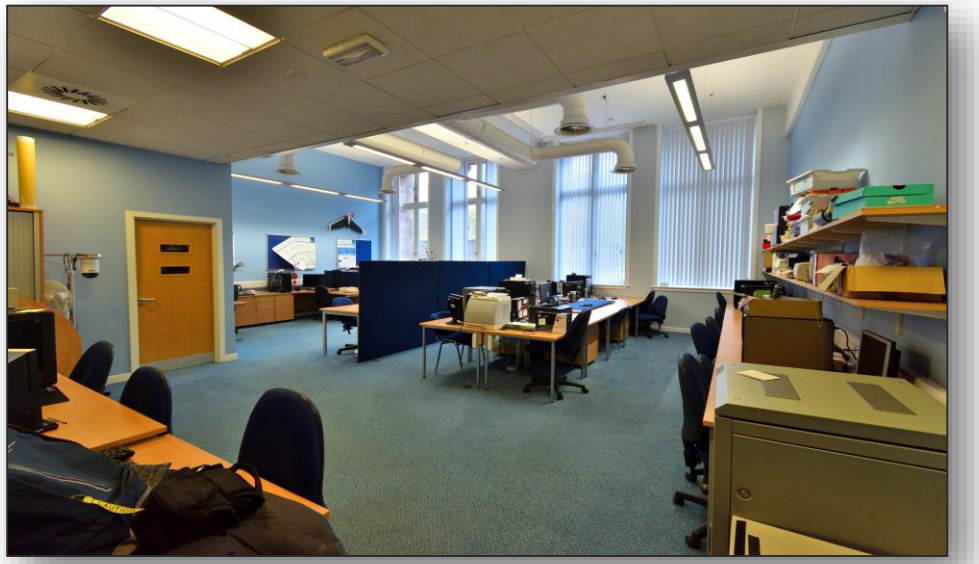
Senior Lecturer, Leonardo Lecturer

https://pureportal.strath.ac.uk/en/persons/gaetano-di-caterina

Dr Paul Kirkland, deputy

Research Fellow

https://pureportal.strath.ac.uk/en/persons/paul-kirkland



6 PhD students

- 2 PhDs funded by Leonardo UK
- 2 PhDs funded by US AFOSR/AFRL

RESEARCH TOPICS

Signal processing, image processing, video processing, biosignal processing, machine learning, deep learning, **neuromorphic engineering**, **spiking neural networks**, DSP and embedded systems.

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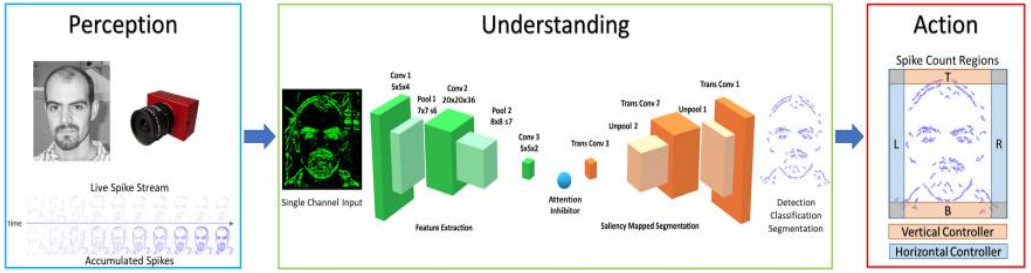
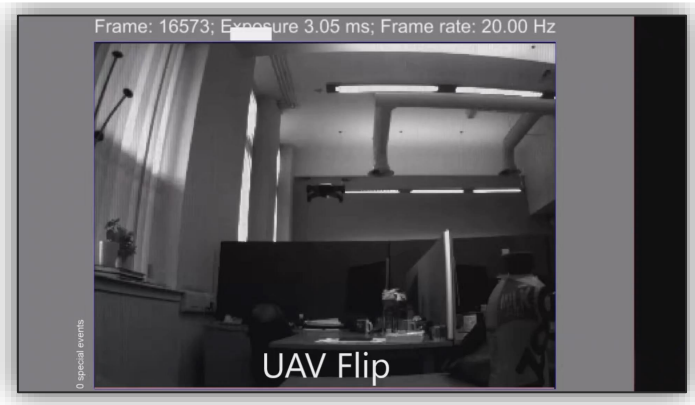
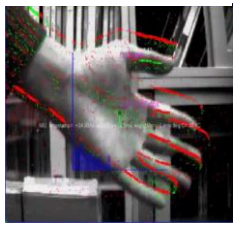
Research in the NSSP Lab

NEUROMORPHIC







➔ **Leonardo UK, DSTL, ESA, AFRL/AFOSR**

Imaging from Temporal Data via Spiking Convolutional Neural Networks

Paul Kirkland[1], Valentin Kapitany[2], Ashley Lyons[2], John Soraghan[1], Alex Turpin[2], Daniele Faccio[2], and Gaetano Di Caterina[1]

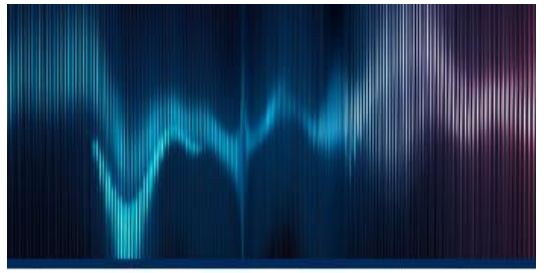
[1]Univ. of Strathclyde, Glasgow, UK
[2]Univ. of Glasgow, Glasgow, UK

Ultrafast Neuromorphic Photonic Image Processing with a VCSEL Neuron

Joshua Robertson*, Paul Kirkland, Juan Arturo Alanis, Matěj Hejda, Julián Bueno, Gaetano Di Caterina & Antonio Hurtado

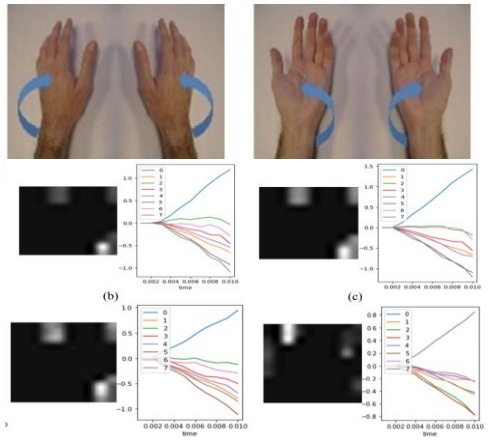
SIGNAL PROCESSING & DEEP LEARNING

Super resolution and turbulence removal

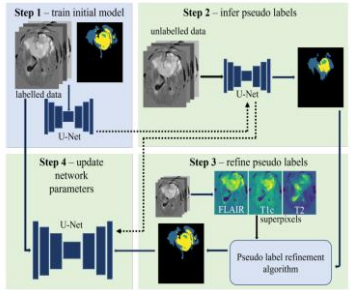


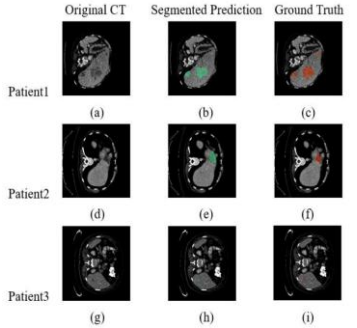
Smart Voice: A voice analysis app for sustainable health monitoring

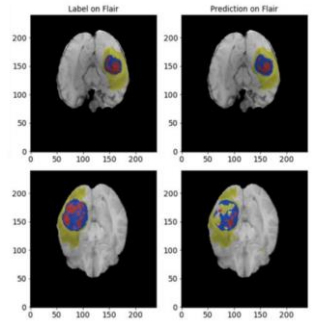
EMG analysis



Medical imaging segmentation





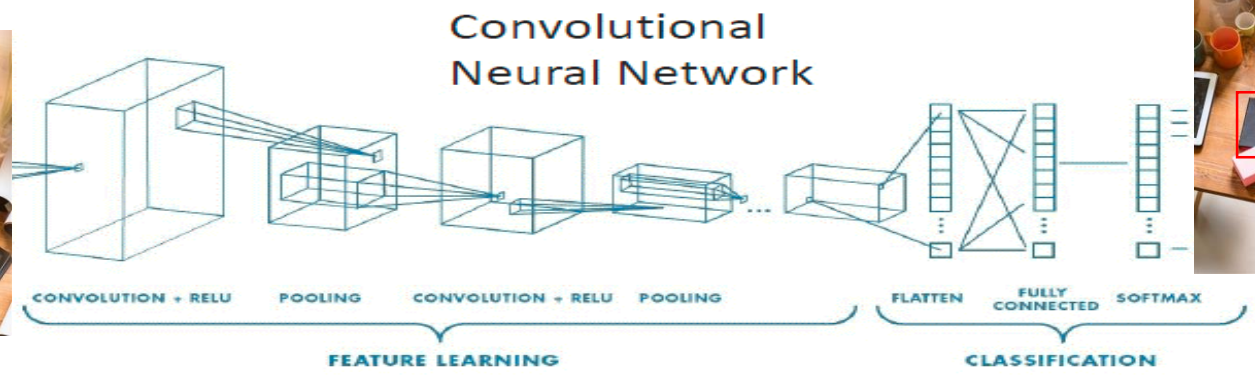


FROM SENSOR DEFINITION, TO ACTIONABLE INSIGHTS

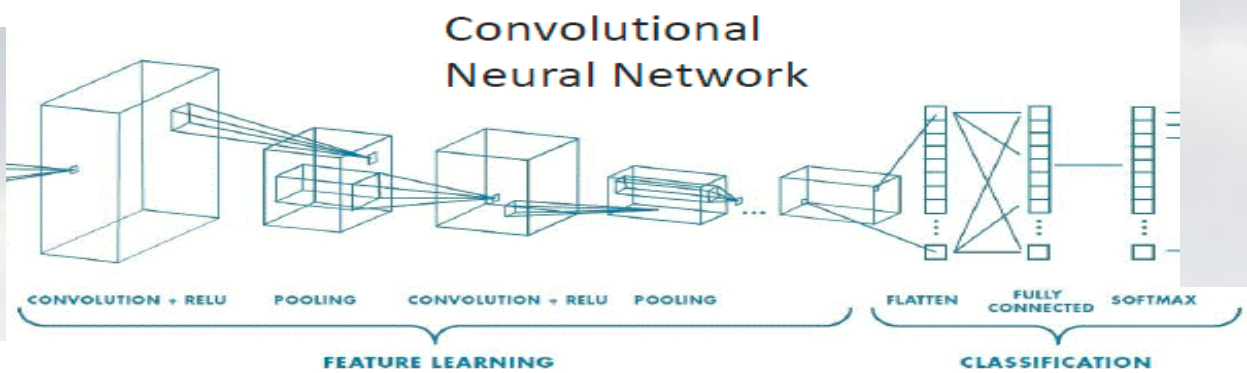
The **Centre for Signal & Image Processing, CeSIP**, is developing new algorithms, architectures, and applications to deliver actionable insights across five laboratories.

- Sensor Signal Processing and Security
- Broadband Multi-Sensor Processing
- Video and Hyperspectral Imaging
- Applied Space Technology
- Neuromorphic Sensor Signal Processing

A typical scenario…



Many objects to detect, so it makes sense to process the entire image.



We still need to process the entire image, even if quite clearly it is very sparse and there is only one object to detect.
➔ The CNN still has to go through each pixel in the image!!!

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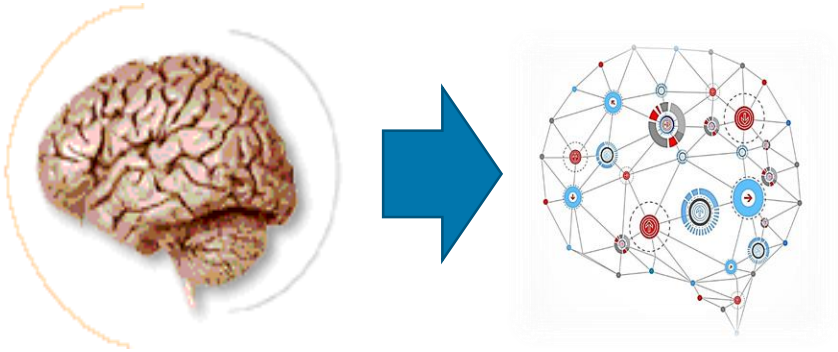
Neuromorphic Engineering

Mimicking in software and/or hardware of how the human nervous system works:

1. Sensing
2. Processing

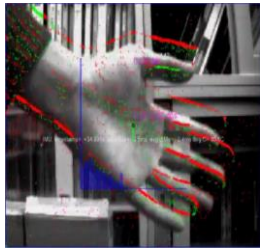


✓ **low SWaP profile**

✓ **ideal for on-board processing**

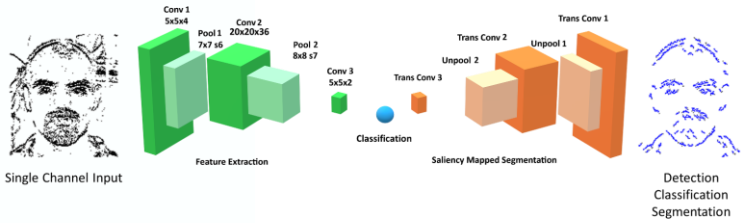
➢ New **sensors** and sensing approaches:

➔ *Event-based*

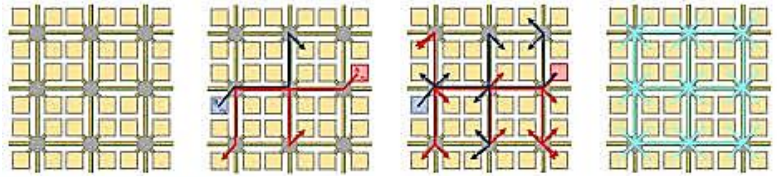


➢ New **algorithms**:

➔ *Spiking NN*



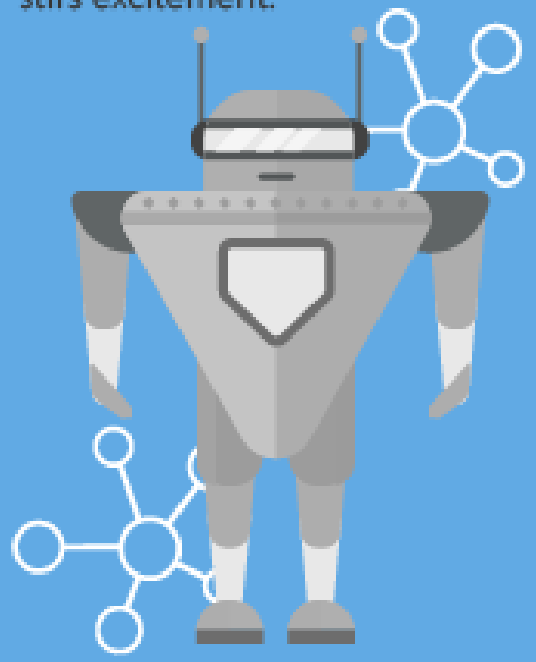
➢ New processing architectures and **processors**.



NEUROMORPHIC

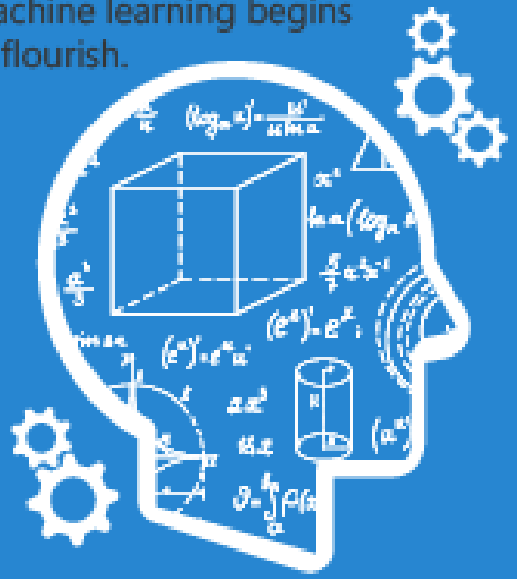
ARTIFICIAL INTELLIGENCE

Early artificial intelligence stirs excitement.



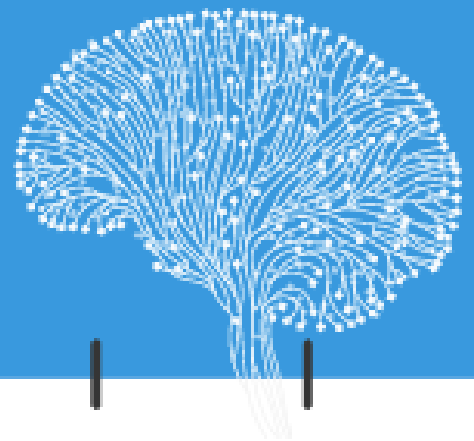
MACHINE LEARNING

Machine learning begins to flourish.



DEEP LEARNING

Deep learning breakthroughs drive AI boom.



1950's 1960's 1970's 1980's 1990's 2000's 2010's

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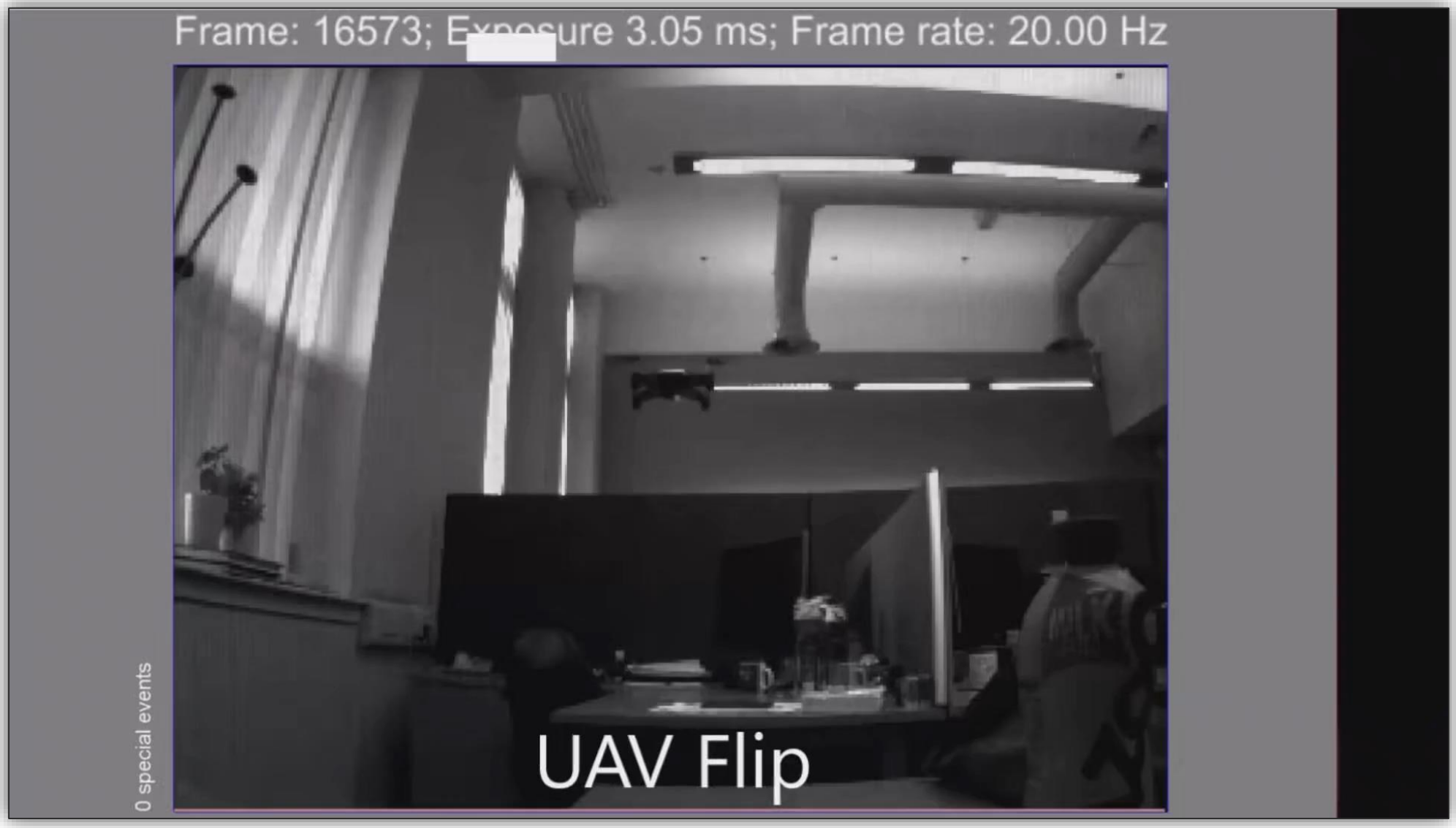
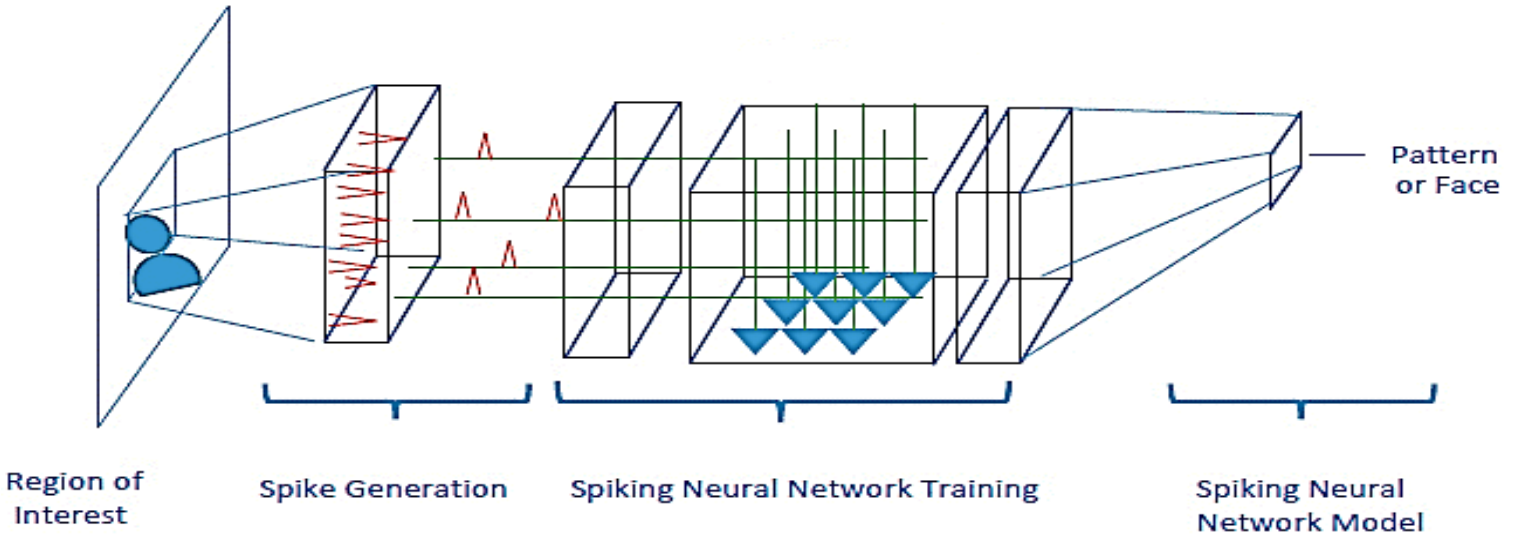
NM sensors exploit sparsity of change



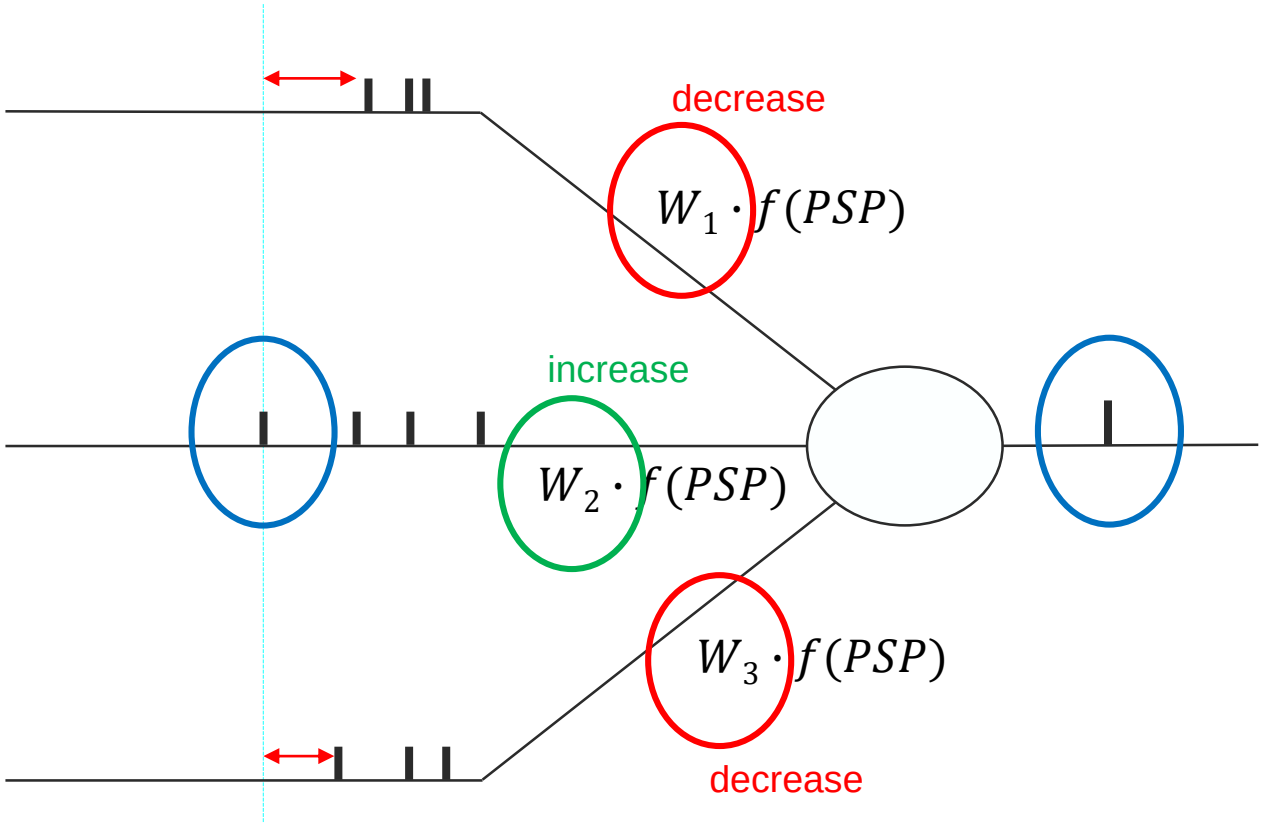
Spiking Neural Networks (SNN)

- Inspired by information processing in biology
- Sparse and asynchronous binary signals, i.e. spike or no spike
- Favourable properties:
  - ✓ **event-driven asynchronous processing**
  - ✓ **fast inference / low latency**
  - ✓ **low power consumption**



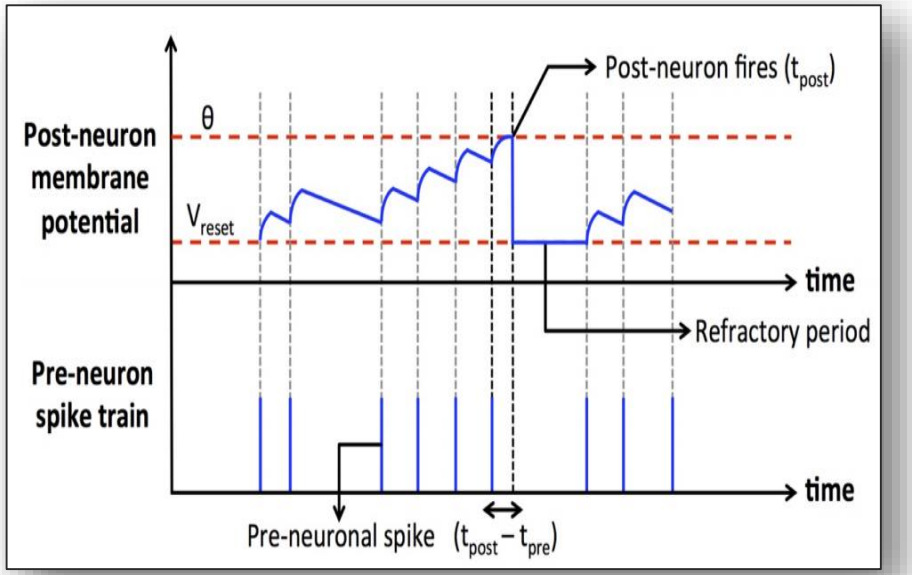
Spike Time Dependent Plasticity (STDP)

In biology it has been seen that the timing between an input spike and an output spike can induce persistent synaptic modifications:



- ✓ **Unsupervised learning**
- ✓ **Feedforward**

https://arxiv.org/pdf/1703.03854.pdf



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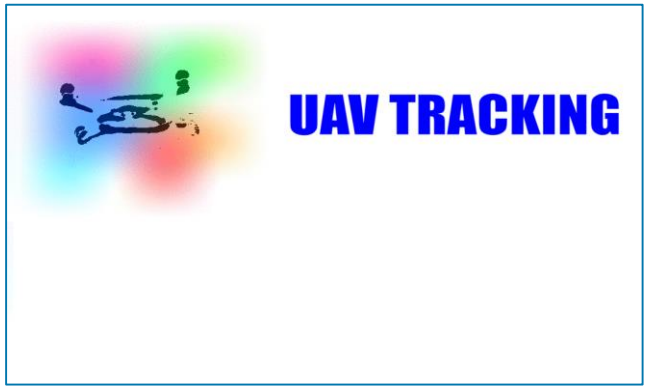
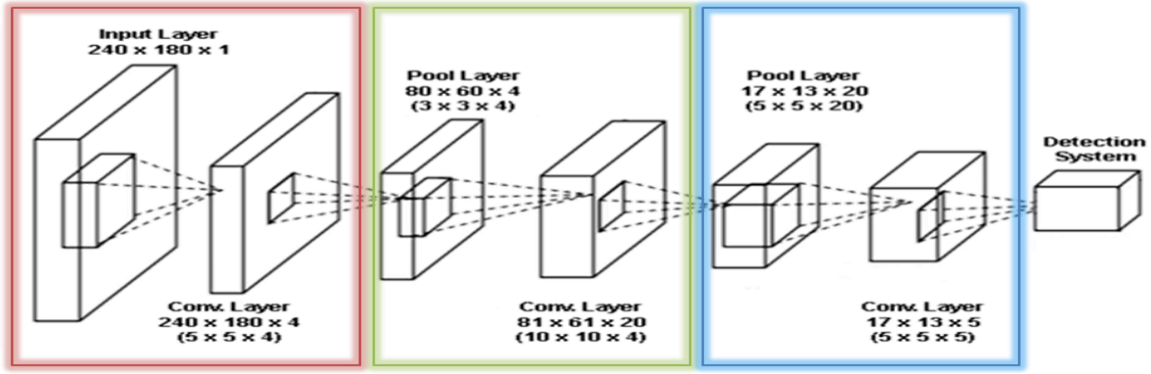
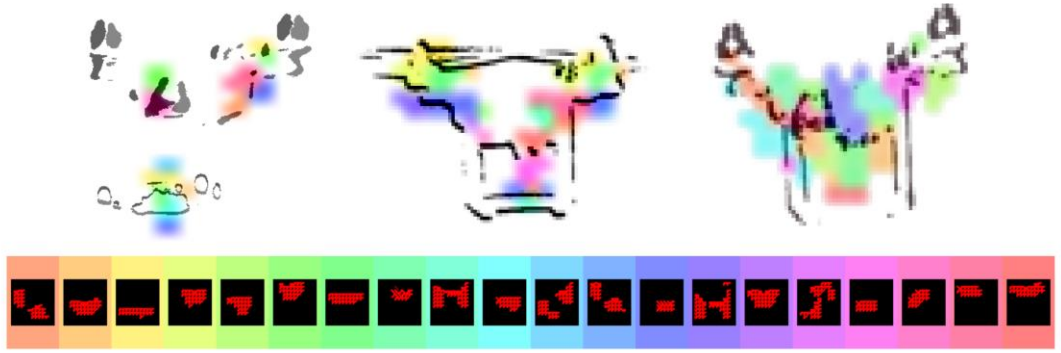
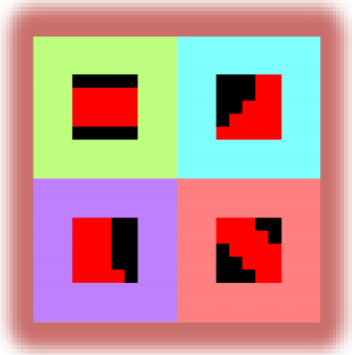
Spatial feature detection

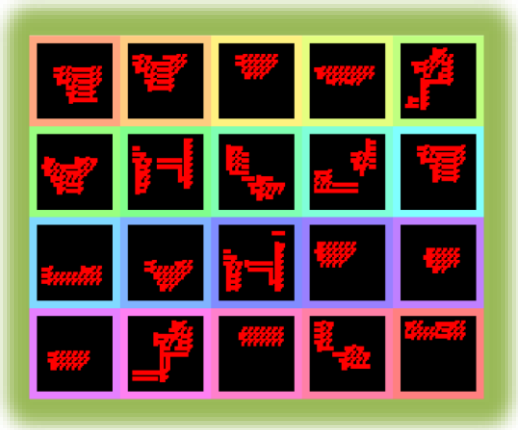
Our initial work had shown that event-based sensing and Spiking Neural Networks (SNN) could perform efficient target identification for drones and other UAVs.

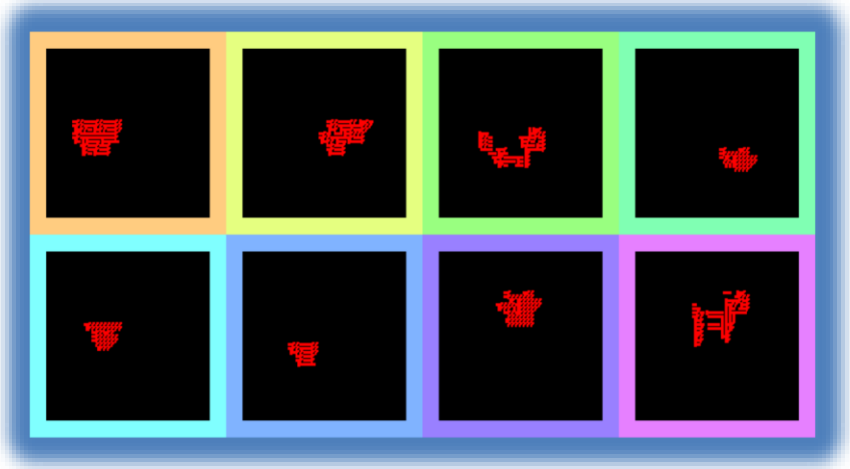












https://doi.org/10.1007/978-3-030-30487-4_56

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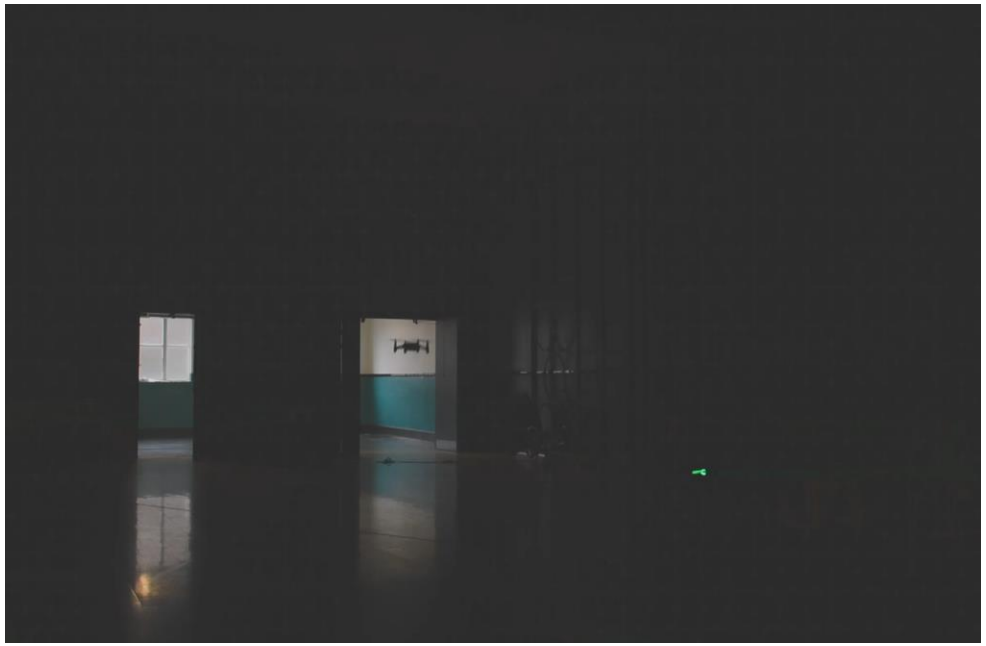
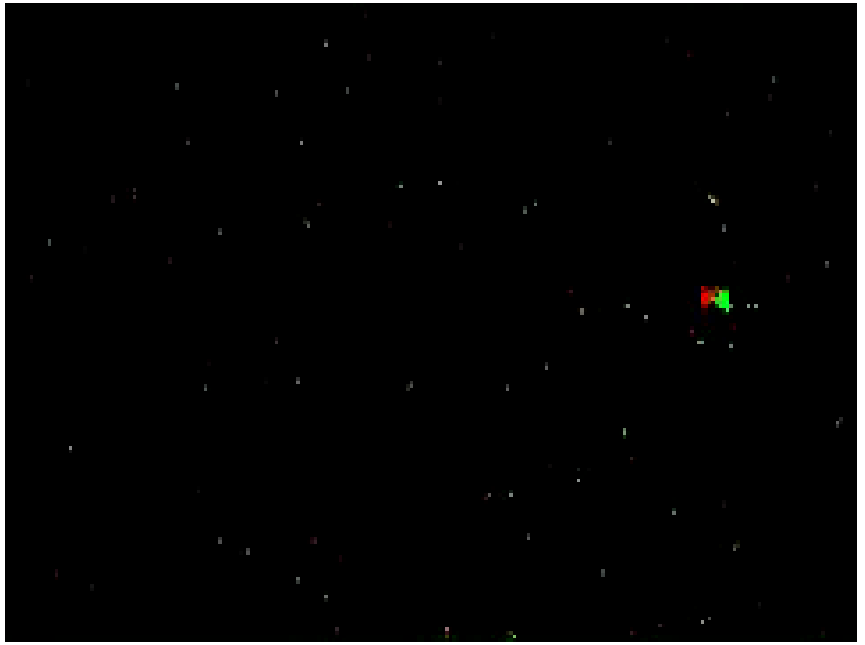
Spatial feature detection

High dynamic range

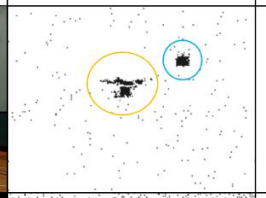
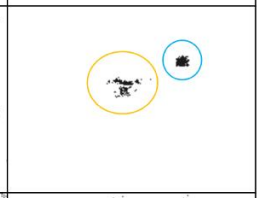
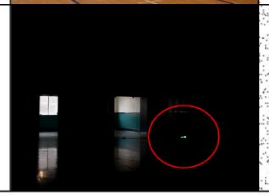
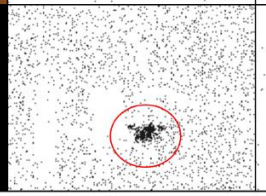
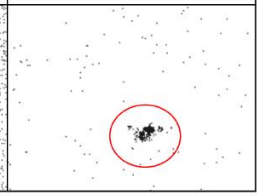
DSLR



Inivation DVS240



Variable time integration

	Visual Band	Raw DVS	Filtered DVS
Indoor Well Lit Scene			
Indoor Poorly Lit Scene			

Time (*ms*)	10	30	50	100	200
Fast Moving Scene (UAV Collision)					
Slow Moving Scene (UAV Stationary)					

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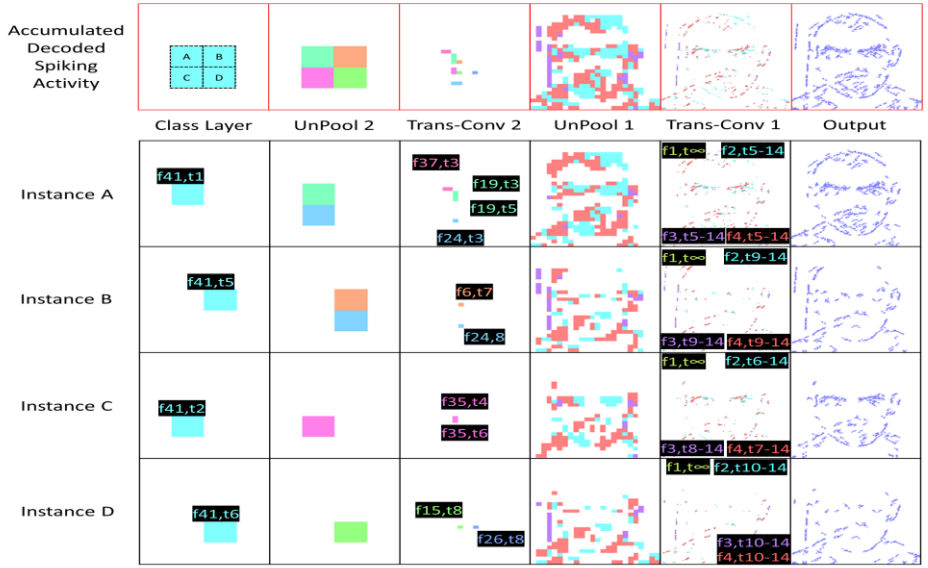
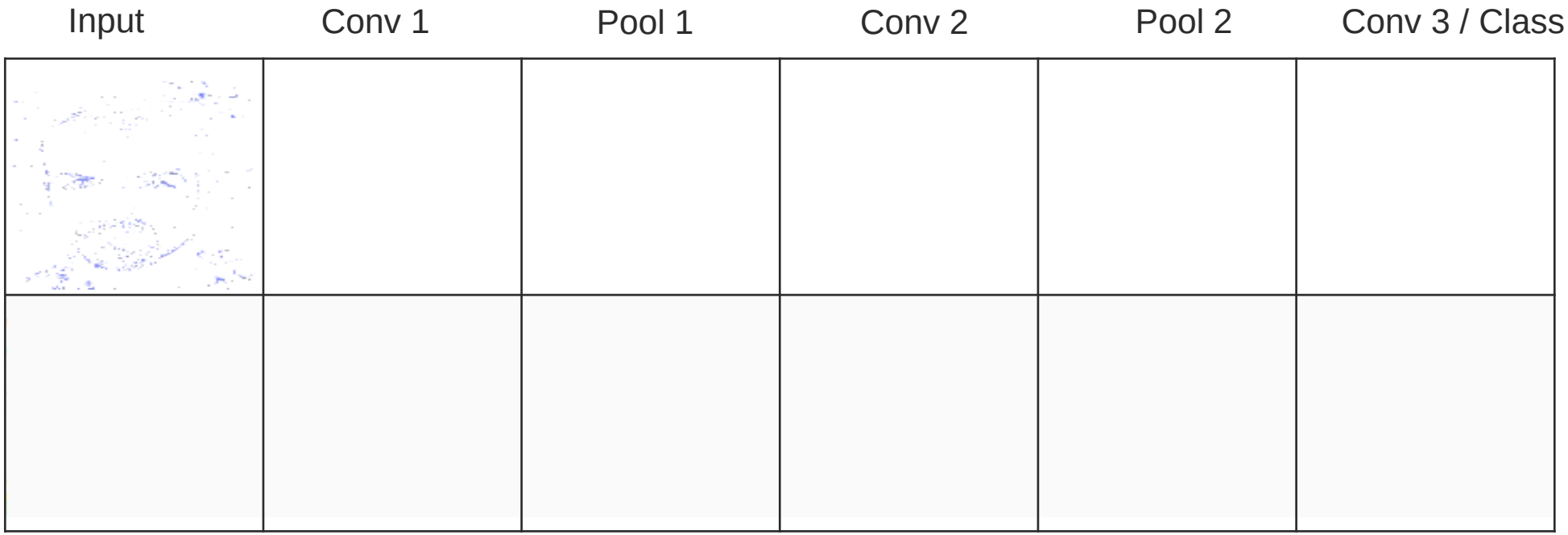
Instance Segmentation

Ability to label each instance's features throughout the encoder-decoder network, allowing to identify individual objects.





https://doi.org/10.1109/TC.2022.3191968

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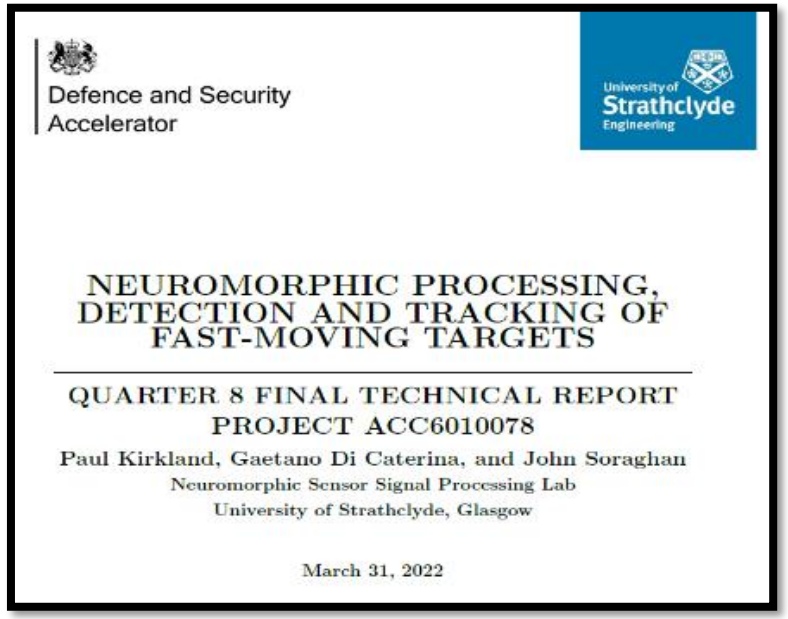
Detection and tracking of fast-moving targets

- Spatially unresolvable targets
- Very fast targets ➔ *motion blur*
- Very slow targets ➔ *noisy time accumulation*
- Targets have characteristic spatial-temporal motion patterns



Defence and Security Accelerator

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NEUROMORPHIC PROCESSING, DETECTION AND TRACKING OF FAST-MOVING TARGETS

QUARTER 8 FINAL TECHNICAL REPORT
PROJECT ACC6010078

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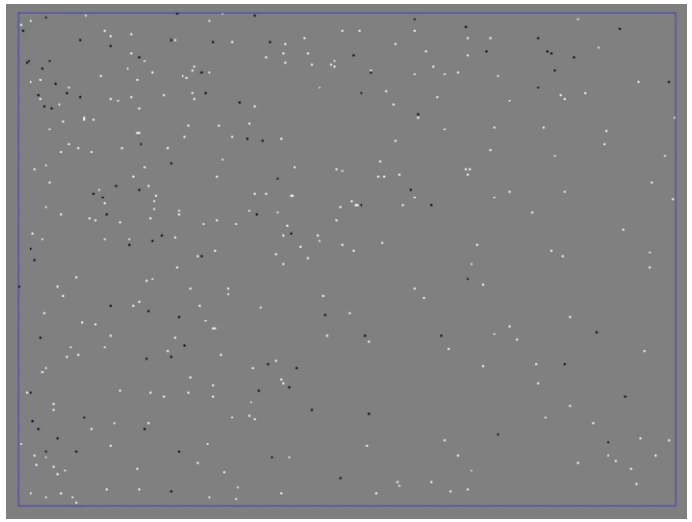
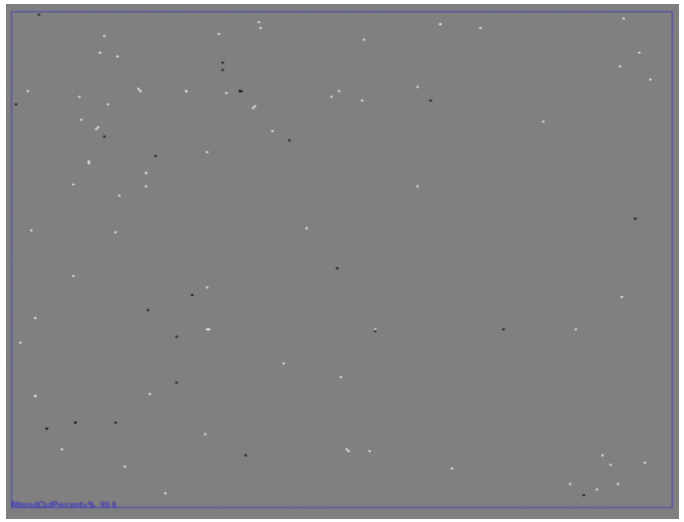
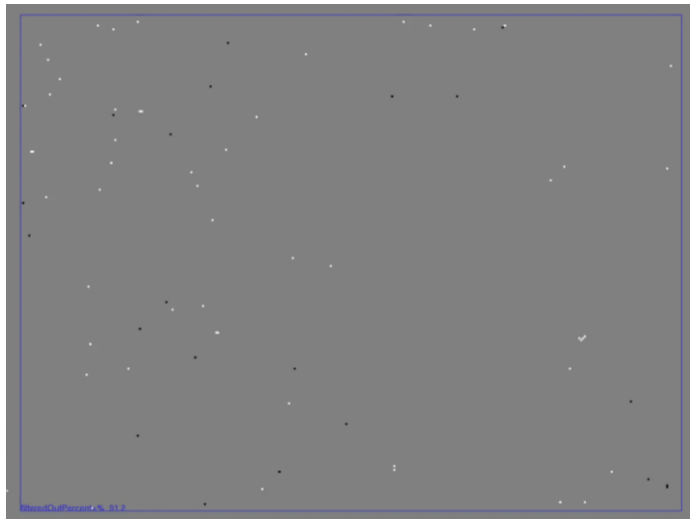
University of Strathclyde, Glasgow

March 31, 2022







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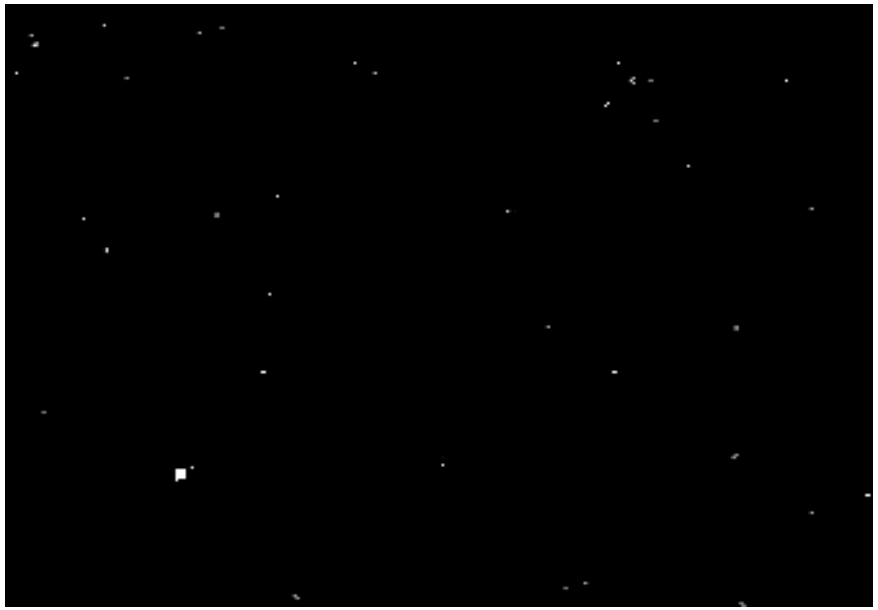
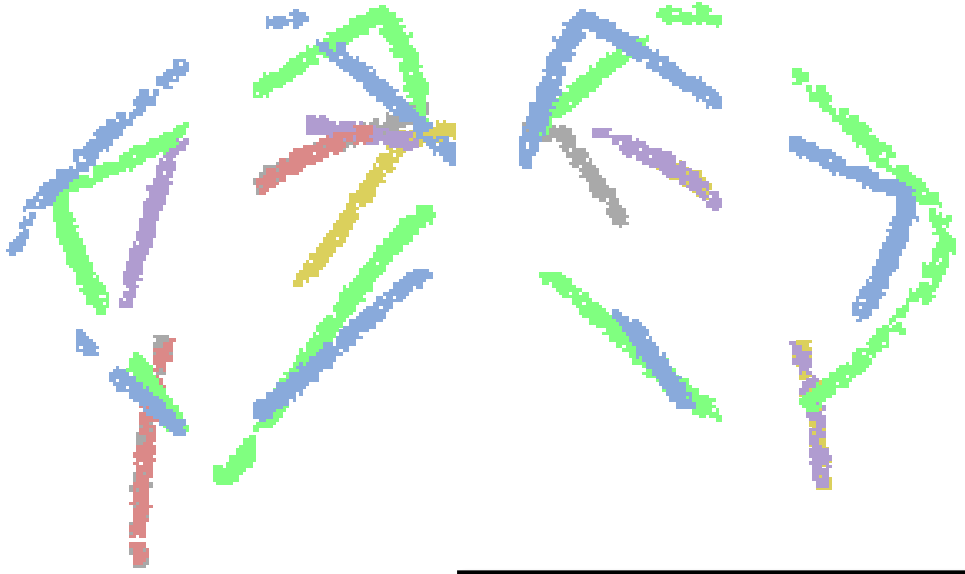
Detection and tracking of fast-moving targets





https://doi.org/10.1109/SSPD54131.2022.9896217

Movement classification and segmentation using event-based sensing and spiking neural networks

Movement Classification and Segmentation Using Event-Based Sensing and Spiking Neural Networks

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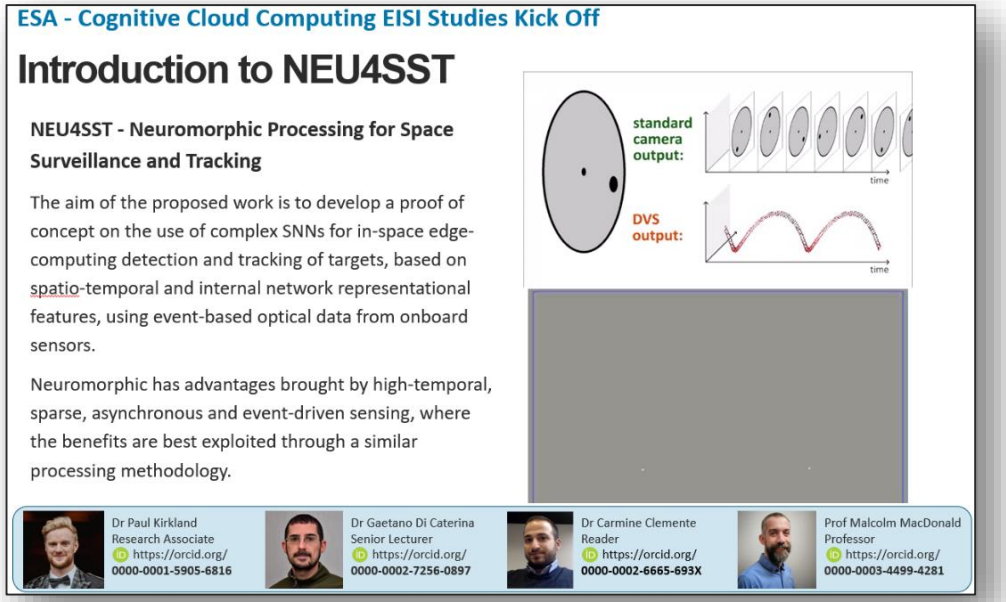
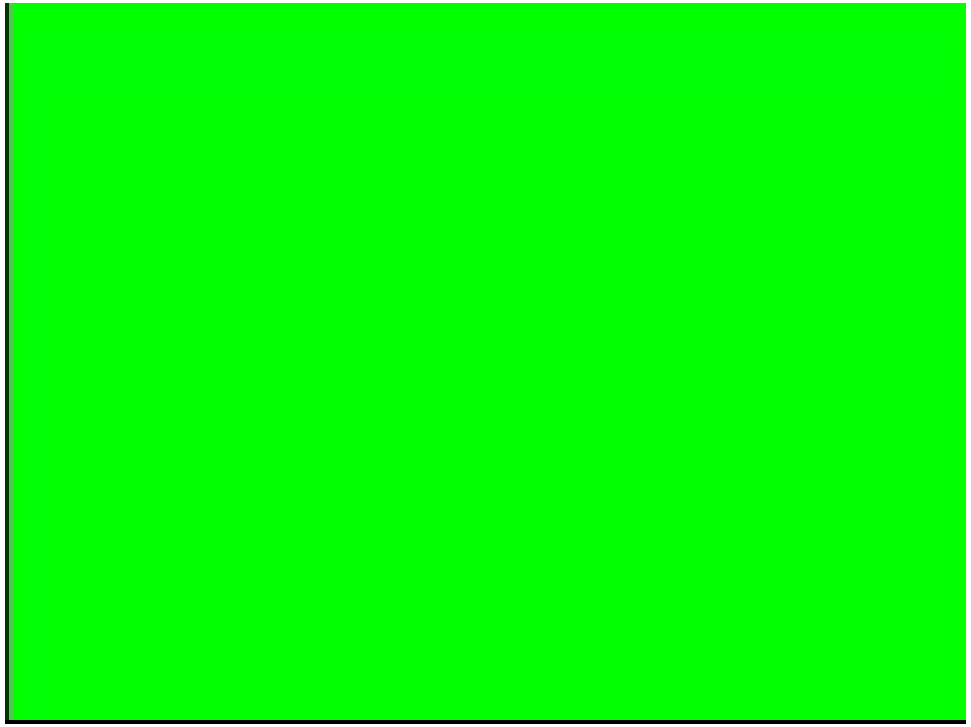
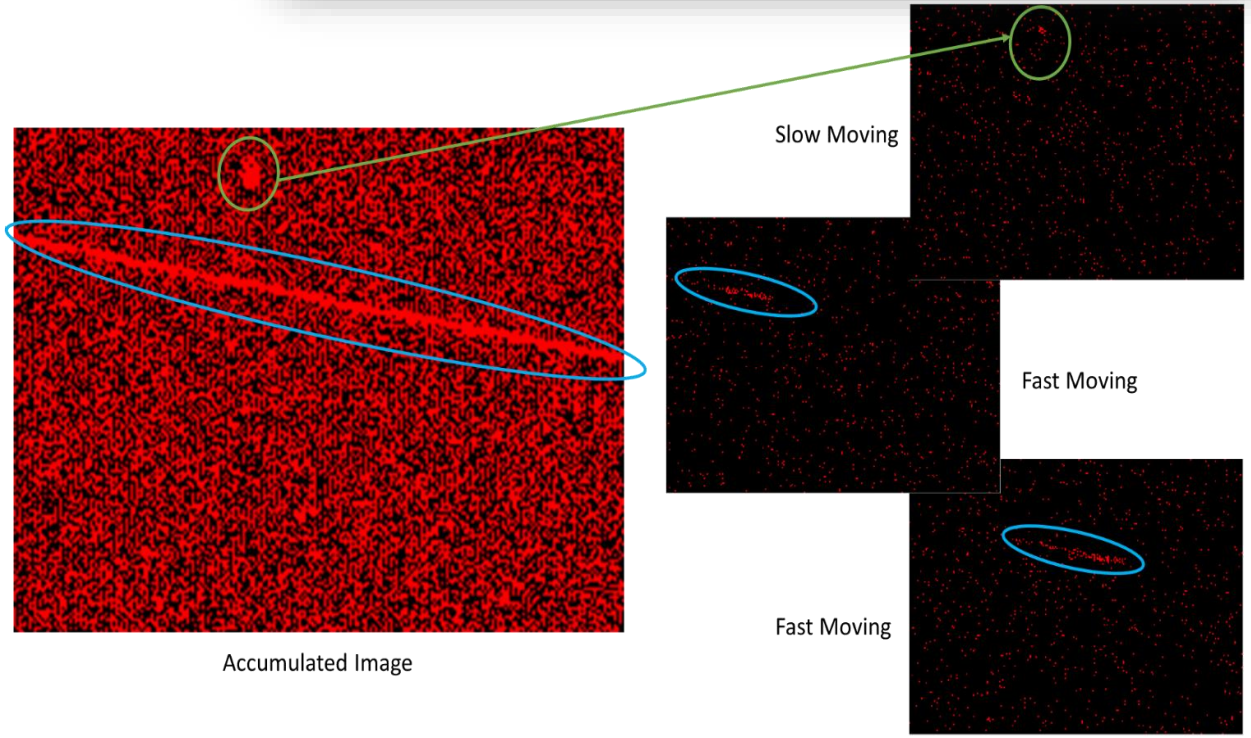
Space situational awareness

- Funded by European Space Agency
- Paper accepted for IGARSS2023

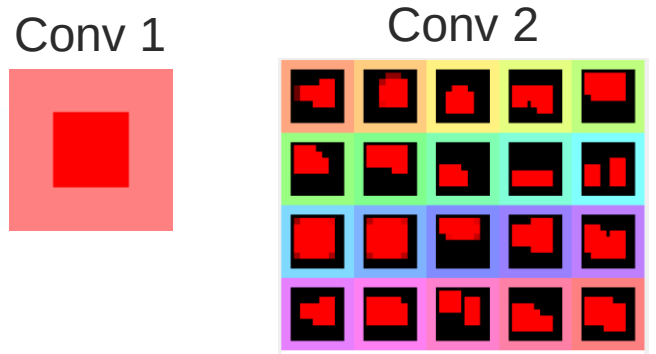




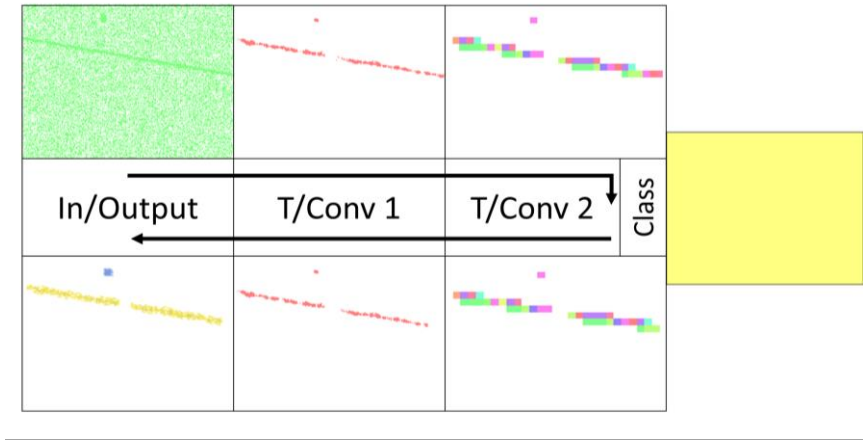


https://www.westernsydney.edu.au/icns/reproducible_research/publication_support_materials/space_imaging

Space situational awareness



- Leaky IF neurons
  - ✓ Leakage helps with background noise filtering
- Heterogeneous neurons
  - ✓ Each neuron has a continually adaptive threshold
  - ✓ Different temporal dynamics within the leak factor



Accumulated

Event-Based

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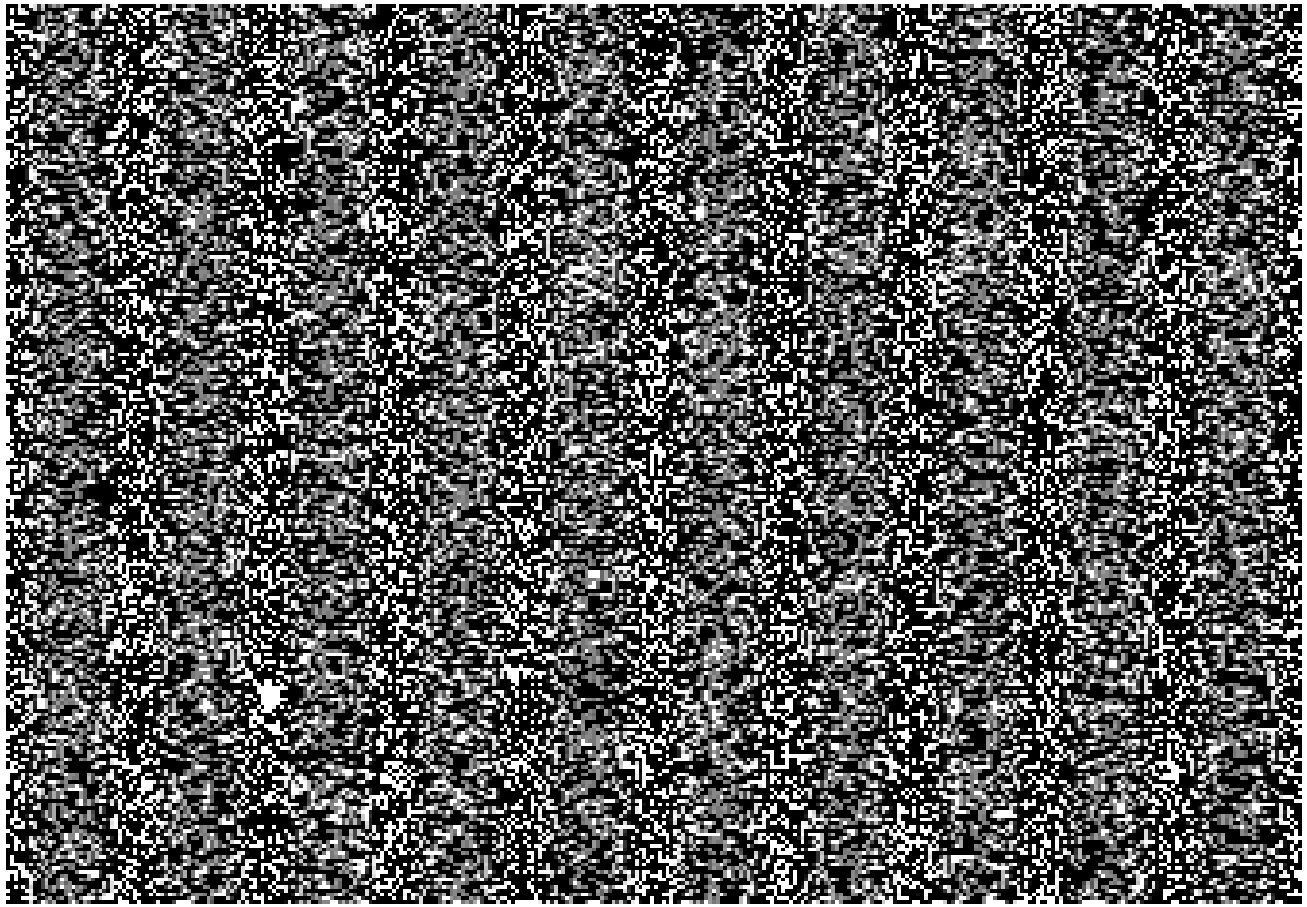
Neuromorphic Sensor Signal Processing Lab

Track before detect

Current 2-year DASA project, started in March 2023.

Detection and tracking of very small/faint targets, in very low SNR scenarios:



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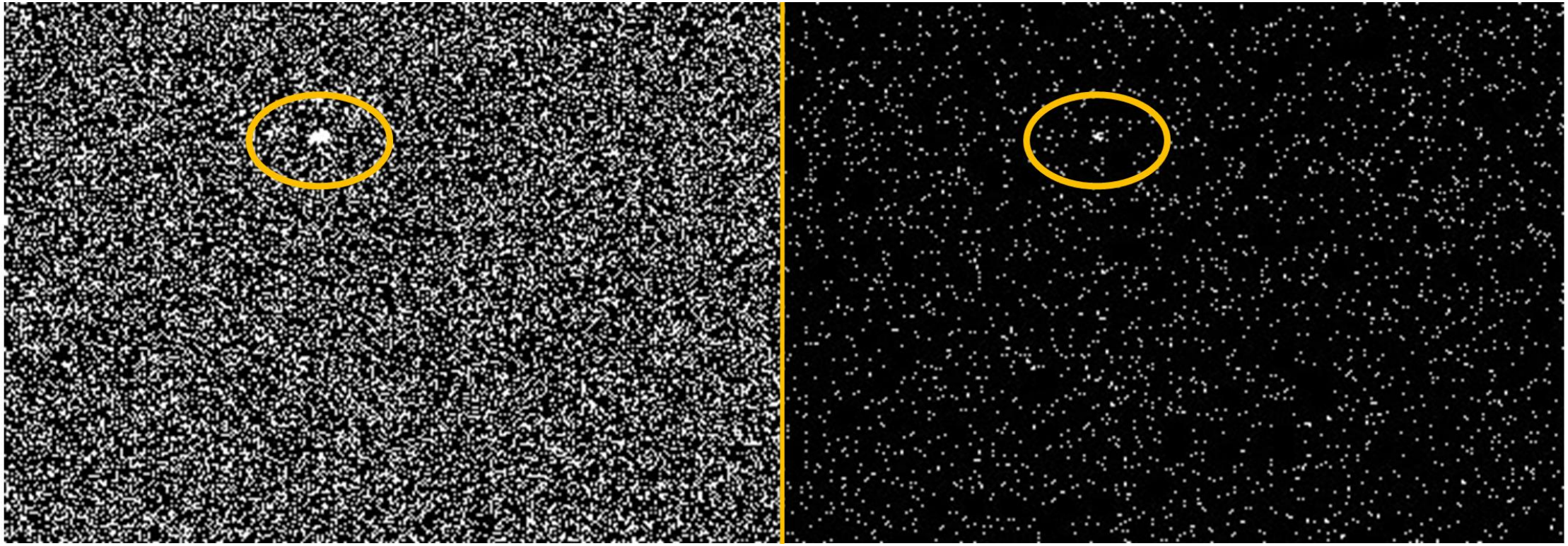
Track before detect

Current 2-year DASA project, started in March 2023.

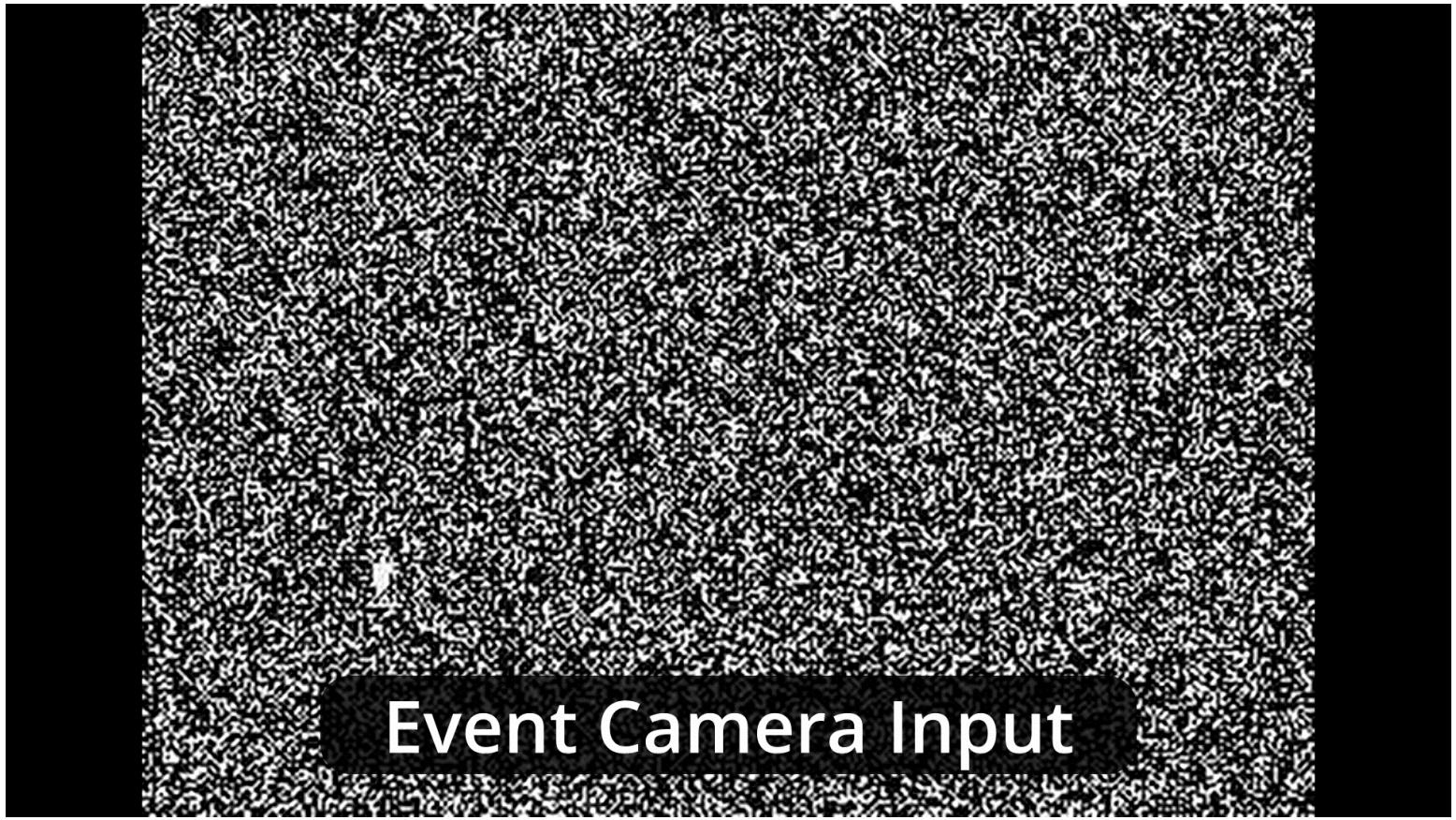
Time integration for better signature detection exacerbates noise.



Track before detect

Current 2-year DASA project, started in March 2023.

The aim of this work is to formally apply SNN-based processing to this problem.



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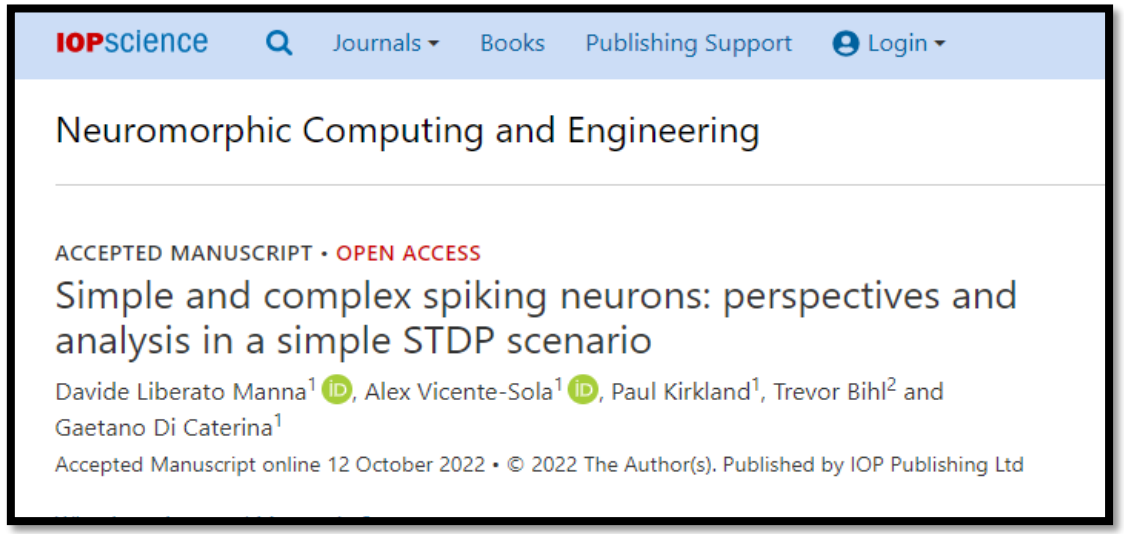
Latest articles from NSSP Lab



Investigation of spiking neuron models

https://doi.org/10.1088/2634-4386/ac999b

SNNs with BP-based training

https://doi.org/10.1088/2634-4386/ac8bef

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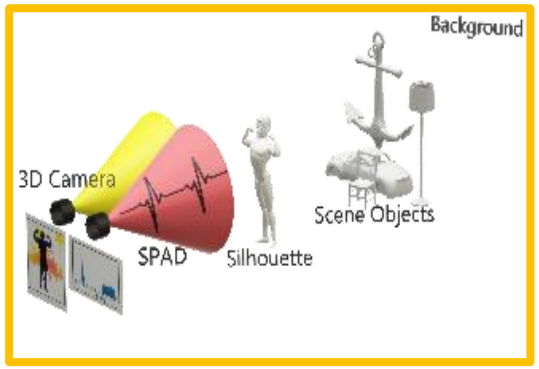
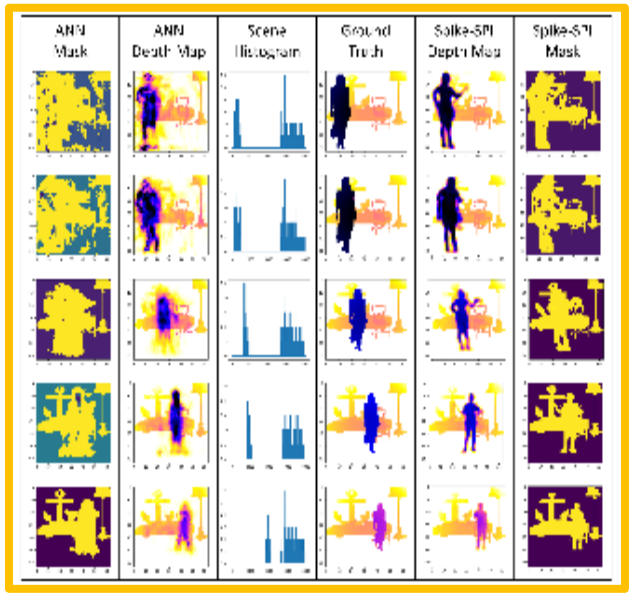
NM in other contexts

Imaging from Temporal Data via Spiking Convolutional Neural Networks

Paul Kirkland[1], Valentin Kapitany[2], Ashley Lyons[2], John Soraghan[1], Alex Turpin[2], Daniele Faccio[2], and Gaetano Di Caterina[1]

[1]Univ. of Strathclyde, Glasgow, UK
[2]Univ. of Glasgow, Glasgow, UK





https://doi.org/10.1117/12.2573484

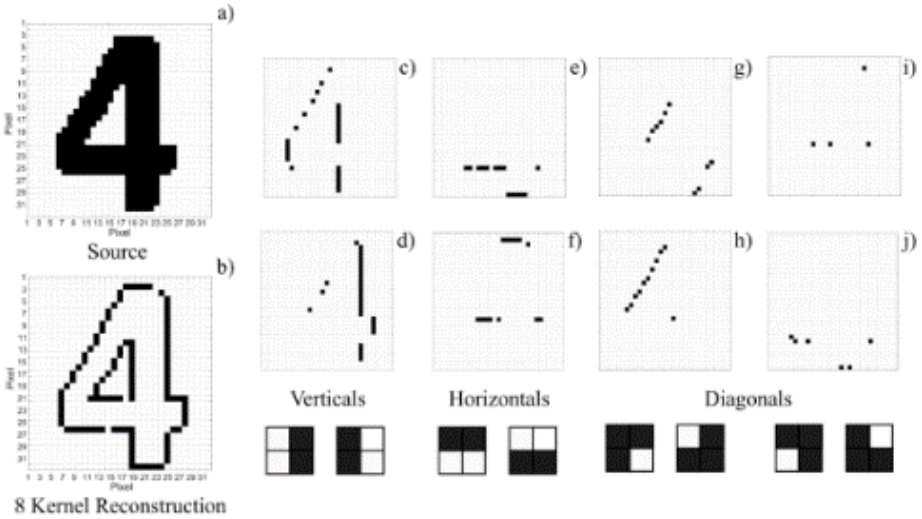
Article | Open Access | Published: 22 March 2022

Ultrafast neuromorphic photonic image processing with a VCSEL neuron

Joshua Robertson, Paul Kirkland, Juan Arturo Alanis, Matěj Hejda, Julián Bueno, Gaetano Di Caterina & Antonio Hurtado

Scientific Reports 12, Article number: 4874 (2022) | Cite this article

1397 Accesses | 1 Altmetric | Metrics



https://doi.org/10.1038/s41598-022-08703-1

Other links and activities

- Leonardo Lectureship
- 2 new PhDs part-funded by Leonardo

- Member of the Intel INRC

- Links with Waterloo Uni/ABR, Syracuse University, Ohio University, UCL

- Invited talk "Neuromorphic processing and event-based sensing" at NATO 48th SET Panel Business Meeting (28th Oct 2021)

- Part of NATO SET-ET-131 on event-based cameras

- Two papers presented at 10th NATO Military Sensing Symposium, Apr 2023

Conclusion

- NM represents a paradigm shift in sensing and processing.
- In NM, information is encoded in the time and frequency of spikes.
- NM comprises algorithms (SNNs), sensors (event-based) and processors.
- NM can provide:
  - Reduced SWaP profile and computational complexity
  - Asynchronous and low latency processing
- However, beware that NM is not the solution to any problem!
- Other/novel NM sensors???

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Thank you for your attention.

Any questions?

https://www.strath.ac.uk