SILICON RETINA EVENT CAMERA HISTORY AND LIVE CAMERA DEMO

Keynote Speaker Tobi Delbruck

Sensors Group
https://sensors.ini.uzh.ch
at the Inst. of Neuroinformatics: www.ini.uzh.ch
UZH-ETH Zurich,

The continuing evolution of electronic vision is now becoming driven by the need for battery powered, always-on machine vision in future spectacles and robots. These systems must operate with uncontrolled high dynamic range lighting and have severe power-latency tradeoff constraints. Neuromorphic “silicon retina” event cameras electronically model spike-based output from biological eyes to increase dynamic range by using pixel-level gain control and their quick, activity-driven sparse output enables systems that have much better power-latency tradeoffs compared with frame cameras. This talk covers the history of silicon retina development starting from Fukushima and Mahowald and Mead’s earliest spatial retinas up to present-day industrial event camera developments. This will be followed by a live demo of our contemporary frame-event DAVIS camera that includes an IMU vestibular system capable of electronically stabilizing and deblurring the output even under dim lighting. Finally, it will be demonstrated how an activity-driven CNN with input from an event camera can beat humans at the game of rock-scissors-paper.
In the Wednesday event camera tutorial, I will teach (using a whiteboard), how these pixels are designed at the transistor level. These interesting circuit design techniques give the pixels quick responses even under low lighting, precise event threshold matching even with big transistor mismatch, and temperature-independent event threshold.

A SPIKING AUTO-ENCODER FOR INPUT RECONSTRUCTION AND DENOISING*

Presenter Mostafa Rahimi Azghadi[1#]
Ben Walters[1], Zhengyu Cai[2], Hamid Rahimian Kalatehbali[3], Amirali Amirsoleimani[3], Roman Genov[2], Jason Eshraghian[4]

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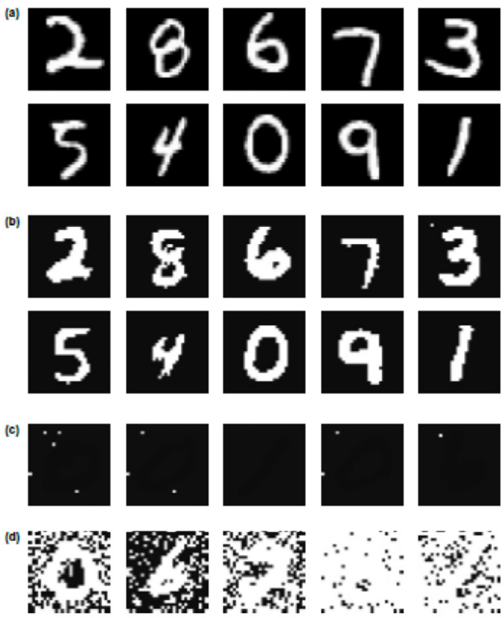
Auto-encoders can perform input reconstruction through an encoder-decoder structure. These networks can serve many purposes such as noise removal and anomaly detection, whilst being trained without the need for labelled data. Spiking auto-encoders can utilise asynchronous spikes to potentially improve power and simplify the required hardware. In this work, we propose an efficient spiking autoencoder with novel error-modulated STDP learning. Our autoencoder uses the Time To First Spike (TTFS) encoding scheme and needs to update all synaptic weights only once per input. Also, it needs only an average of 8 spikes in its hidden layer for reconstruction, leading to a very sparse and hence potentially power-efficient implementation. We demonstrate decent reconstruction ability for MNIST and the challenging Caltech Face/Motorbike datasets and achieve excellent noise removal from MNIST images.



Example image reconstructions for 10 MNIST digits. (a) A sample of inputs (one for each possible digit) that were presented to the network. (b) The network's attempted image reconstruction, corresponding to the input in (a) (with error-modulation and no homeostatic plasticity in the reconstruction layer.) (c) sample reconstructions for when the error-modulation factor and homeostasis is removed from the reconstruction layer. (d) Sample reconstructions for when homeostasis and error-modulation is introduced into the reconstruction layer.

*A similar version of this work has been submitted to ISCAS24 and is currently under review.

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INTEGRATED VISUAL ENVIRONMENT FOR DRAGONFLY PURSUIT ANALYSIS

Presenter Steven D. Wiederman[2]
Bernard Pailthorpe[1]

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Aerial predators, such as the dragonfly, can detect and pursue prey even when moving through complex, natural scenes. To achieve this, dragonflies must be able to distinguish desired prey items from potential distractors, including background clutter as well as distractor targets when hunting in swarms. Existing computational models of visual processing are derived from electrophysiological recordings from target-detecting neurons in the dragonfly brain. Until now, these models investigate open-loop responses to visual stimuli, not accounting for the complex changes in visual input during rapid, closed-loop pursuits.

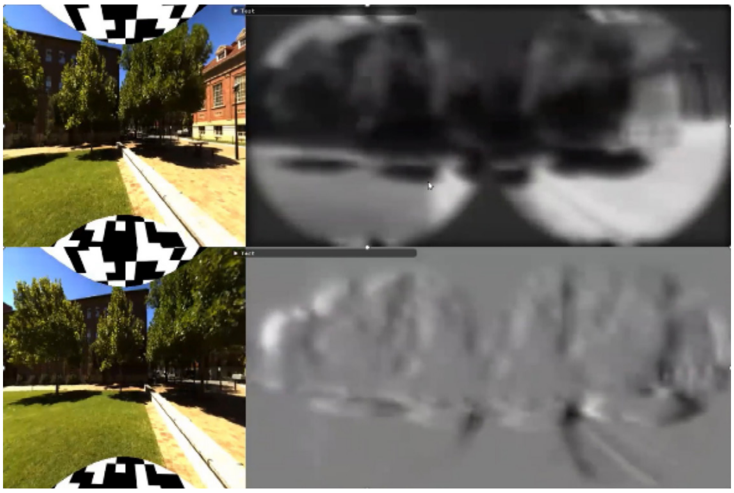

Figure 1: *Sample output of 3D modelling environment.*
Top: *Grayscale transform of 3D environment onto circular coordinates.*
Bottom: *Output of Large Monopolar Cells*

Here we have developed a full 3D virtual environment using OpenGL. This allows for construction of complex 3-dimensional scenes, with objects embedded at varying distances and speeds. We account for the spherical nature of insect eyes, mapping multiple 3D projections onto a 2D array of sensors (i.e., photoreceptors). These serve as the input for two dragonfly visual pathways, optic flow and target detection which are simulated using existing models [1][2]. The outputs of these pathways can then be used to drive desired changes in the dragonfly's position and orientation within the 3D environment to test predictions on the functionality and effectiveness of optic-flow corrections and target detection under hovering and pursuit conditions.

We show that classic ESTMD (Elementary Small Target Motion Detector) models break down under a subset of pursuit conditions (when fixated targets generate no response) and that efference copies are necessary to overcome the presumed stabilization properties of EMD-based (elementary motion detector) control feedback loop. This modelling indicates that different target detection mechanisms likely underlie the distinct tasks of target acquisition (during hovering) and target tracking (during pursuit). Given electrophysiological experiments are currently performed from the constrained animal (open-loop), these closed-loop simulations provide important insight into the neuronal processing underlying these different visually guided behaviours.

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2. Bagheri ZM, Wiederman SD, Cazzolato BS, Grainger S & O'Carroll DC, 2017, Performance of an insect-inspired target tracker in natural conditions, Bioinspiration & Biomimetics., vol. 12, no. 2.

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NEUROMORPHIC SLAM:
MODELING THE HIPPOCAMPUS IN HARDWARE

Key Note Speaker Professor Ralph Etienne-Cummings

Zhaoqi Chen and Ralph Etienne-Cummings
Johns Hopkins University, Baltimore, MD 21218, USA

Navigation and localization are essential capabilities for animals and humans to survive in complex terrains. As they depart from their homes, they can plan a path through obstacles while advancing towards their targets and remember the path in order to return home. Interestingly, when exploring a new environment, animals can form a concept of the environment that couples spatial location with sensory stimuli to remember locations of, for example, food and danger. This behavior coincides with the scenario of autonomous robots navigating without a pre-charted map. In the robotics community, this problem is called Simultaneous Localization and Mapping (SLAM), and conceptualized as the computational problem of creating a map of an initially unknown environment and localizing the robot while exploring.

A neuromorphic SLAM system shows potential for more efficient hardware implementation of hippocampus cells than its traditional counterpart. We demonstrate a mixed-mode implementation for spatial encoding neurons including theta cells, vector cells and place cells. Together, they form a biologically plausible network that could reproduce the localization functionality of place cells. Experimental results validate the robustness of our model when suffering from variations of analog circuits, such as offsets and gain errors. Furthermore, we show how phase reset and position tracking can help map large spaces that are beyond the bounds of the error envelopes of individual spatial encoding cells. We provide a foundation for implementing dynamic neuromorphic SLAM systems and show how they can be used for navigating spaces with obstacles.

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TOWARDS A UNIFIED FRAMEWORK OF SPARSE CODING, PREDICTIVE CODING, AND DIVISIVE NORMALIZATION

Presenter Yanbo Lian[1#]

Anthony N. Burkitt[1,2]

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Sparse coding [1], predictive coding [2] and divisive normalization [3] are thought to be underlying principles of neural circuits across many regions of the brain, supported by much experimental evidence. However, the connection among these three principles is still poorly understood.

Sparse coding is a network-level model that finds an efficient representation of the sensory input using a linear combination of a set of basis vectors, which can learn receptive field of neurons in different brain areas such as the visual system, auditory system, and navigational system. The predictive structure of predictive coding provides an error-correction mechanism that is used to explain many brain phenomena, such as extra-classical receptive field properties in the visual cortex. Divisive normalization is a mathematical model that normalizes the response of individual model units by the division of the population response, which explains many experimental results.

In this study, we construct a two-layer model (a sparse predictive coding model) that implements sparse coding with the structure originating from predictive coding. Results show that a self-regulating function (the derivative of the sparsity function in original sparse coding) in the model can shape the nonlinearity of neural responses, which can display diverse nonlinearities generated by divisive normalization. We demonstrate that this model is equivalent to divisive normalization in a single-neuron scenario and the model can learn receptive fields of simple cells with the property of contrast saturation that is previously explained by divisive normalization (Figure 1).

This model has the ability to learn receptive fields as well as display diverse response nonlinearities, which provides a unified framework of different principles that may be able to explain other brain phenomena.

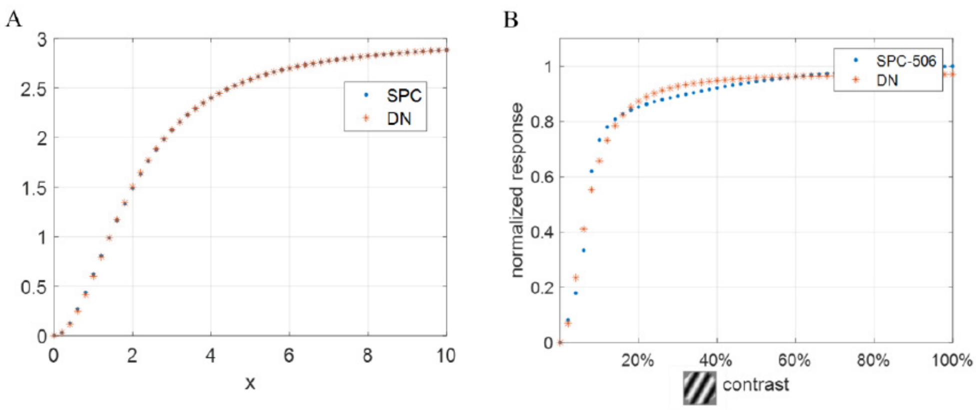

Figure 1. *(A) Sparse predictive coding (SPC) can be equivalent to divisive normalization (DN) in a single -neuron scenario. X-axis represents the input and Y-axis represents the model response. (B) Given natural images as the training input, SPC can learn simple cells with the property of response saturation that is previously explained by DN. Neuron #506 in the SPC model (SPC-506) shows one example model neuron that shows a nonlinear response curve with gradual saturation as the contrast of input sinusoidal grating increases.*

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SwRI AND NEUROMORPHIC ENGINEERING

Keynote Speaker Dr Pete Roming

Director, Space Instruments & Payloads Department, Space Systems Division, Southwest Research Institute (SwRI)

Neuromorphic sensing technologies are viewed by the Southwest Research Institute (SwRI) as vital to the future of computing. Within the context of this statement, this talk aims to do three things:
Provide some background on the size, shape and research interests of SwRI overall,
Describe some of the space missions in which SwRI has been involved to illustrate where, in future missions, neuromorphic sensing technologies may be expected to be influential, and
Outline some of the steps under consideration by SwRI to strengthen the relationship with Western Sydney University and ICNS.
There will be an opportunity for questions and follow-on conversations.

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SEIZURE DETECTION WITH A BIOLOGICALLY PLAUSIBLE ALGORITHM: TOWARDS EDGE COMPUTING ENABLED ELECTROCEUTICALS

Poster Presenter Luis Fernando Herbozo Contreras[1], Zhaojing Huang[1], Leping Yu[1], Armin Nikpour[3,4], Omid Kavehei[1,2,#]

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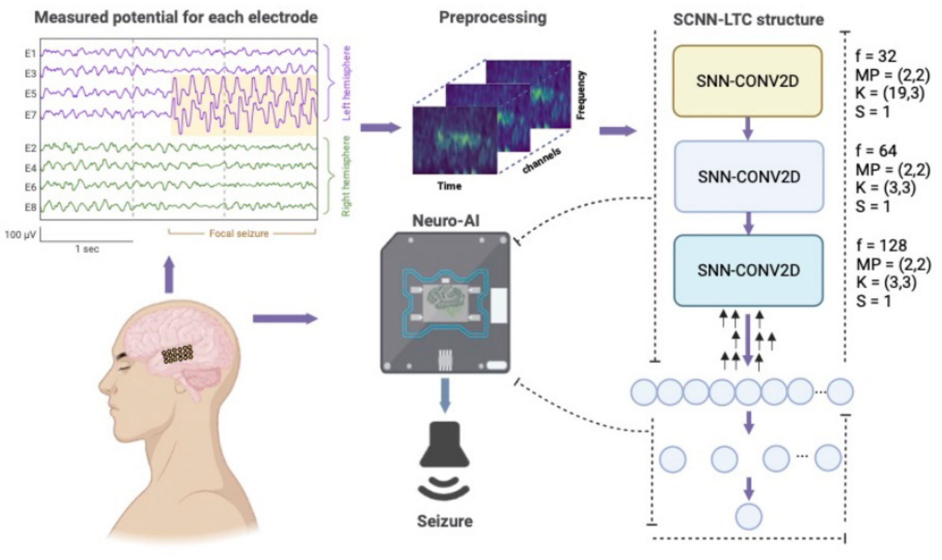
Approximately 1% of people worldwide suffer from epilepsy, which necessitates the use of dependable clinical EEG monitoring equipment for seizure identification. While conventional architectures and algorithms are unable to provide continuous on-device training with long-term recording due to excessive power consumption, artificial intelligence provides an alternative. A promising method for the next generation of closed-loop neuromodulation devices is neuromorphic computing. Leaky-and-Integrate Spiking Neural Networks, on the other hand, have a lower accuracy and don't present a dynamic time constant. For battery-constrained settings, our study investigates spiking neural networks with a Liquid-Time Constant and Forward Propagation through time (FPTT) [1]. Achieving an AUROC of 0.83 on the Royal Prince Alfred (RPA) Hospital dataset for data spanning 2011 to 2019, we evaluated the model's generalisation on 1,006 sessions (with 192 patients) from the RPA Hospital after training and validating it on the TUH Seizure Corpus data. When we lowered the model's memory requirement by 10 times and the number of hidden neurons by 80%, we examined the model's robustness. It still performed well, with an AUROC of 0.82, on par with a big SNN dynamic model. In light of these results, we examined our tiny model with an AUROC of 0.83 for 30 patients on the EPILEPSIAE Dataset. Especially our model showed outstanding result of 3.1 µJ/Inf (per inference) and a 25% firing rate during training, paving the way for future neuromorphic accurate neuromodulation devices.



[1] Yin, B., Corradi, F., & Bohté, S. M. (2023). Accurate online training of dynamical spiking neural networks through Forward Propagation Through Time. Nature Machine Intelligence, 1-10.

RESPONSE TO PHOTIC STIMULATION AS A MEASURE OF CORTICAL EXCITABILITY IN EPILEPSY PATIENTS

Poster Presenter Michaela Vranic-Peters[1#]
Patrick O'brien[2], Udaya Seneviratne[2],
Ashley Reynolds[1], Alan Lai[2], David Grayden[1], Mark Cook[1,2], Andre Peterson[2]

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Studying states and state transitions in the brain is challenging due to nonlinear, complex dynamics. In this research, we analyse the brain's response to non-invasive perturbations, which allow . Perturbation techniques offer a powerful method for studying complex dynamics by applying small inputs to a system, in this case via photic stimulation, and measuring its response. Sensitivity, or a greater response, to these perturbations can forewarn a state transition [1]. Therefore, biomarkers of the brain's perturbation response or 'cortical excitability' could be used to indicate seizure transitions. However, perturbing the brain often involves invasive intracranial surgeries or expensive equipment such as transcranial magnetic stimulation
(TMS) which is only accessible to a minority of patient groups, or animal model studies. Photic stimulation is a widely used diagnostic technique in epilepsy that can be used as a non-invasive perturbation paradigm to probe brain dynamics during routine electroencephalography (EEG) studies in humans. This involves changing the frequency of strobing light, which produces a photic driving response in the brain [2], and sometimes triggers a photo-paroxysmal response (PPR), which is an electrographic event that can be studied as a state transition to a seizure state. We investigate alterations in the response to these perturbations in patients with genetic generalised epilepsy (GGE), with (n=10) and without (n=10) PPR, and patients with psychogenic non-epileptic seizures (PNES; n=10), compared to resting controls (n=10). Metrics of EEG time-series data were evaluated as biomarkers of the perturbation response including variance, autocorrelation, and phase-based synchrony measures. Variance and autocorrelation demonstrated greater changes in epochs close to PPR transitions compared to earlier stimulation epochs, suggesting greater sensitivity to stimulation in the lead-up to the transition. Also, as expected, posterior channels demonstrated the greatest change in synchrony measures, possibly reflecting underlying PPR pathophysiologic mechanisms. We clearly demonstrate observable changes at a group level in cortical excitability in epilepsy patients as a response to perturbation in EEG data. Our work re-frames photic stimulation as a non-invasive perturbation paradigm capable of inducing measurable changes to brain dynamics.

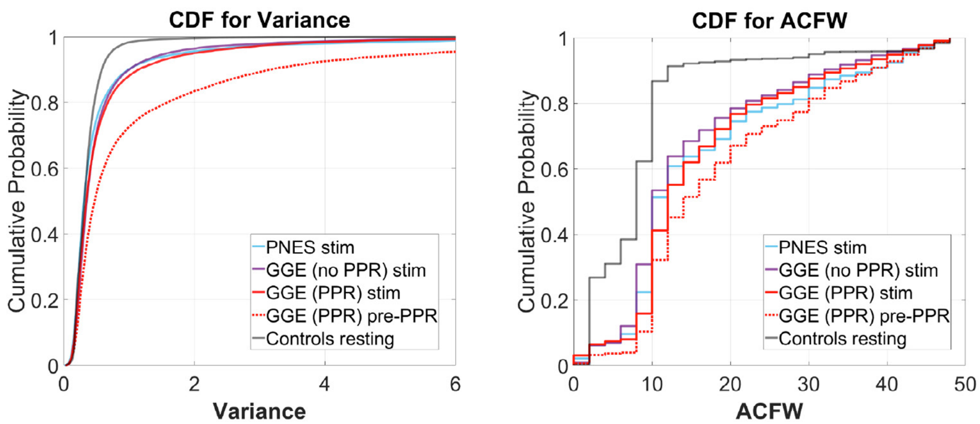

Figure. *(A) variance (left plots) and (B) autocorrelation function width (ACFW; right plots), where the x-axis is the values for each measure, and the y-axis is the probability of observing a corresponding x-value and all values less than it. Each coloured line represents a different group's distribution, pooled over all participants and channels for selected epochs (refer to legend). Right-shifted lines indicate distributions with larger proportions of high values. Observe how all groups show right-shifts compared to the control (grey) line. Also observe how, for the GGE (red) group, their distributions shift further to the right, in the epoch just before PPR (dotted red line labelled as 'pre-PPR'), compared to earlier stimulation epochs (solid red line labelled as 'GGE (PPR) stim').*

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2. Kalitzin, S., Parra, J., Velis, D. N., & Da Silva, F. L. (2002). Enhancement of phase clustering in the EEG/MEG gamma frequency band anticipates transitions to paroxysmal epileptiform activity in epileptic patients with known visual sensitivity. IEEE Transactions on Biomedical Engineering, 49(11), 1279-1286.

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IMPROVING THE SOUND QUALITY OF IMPLANTED MICROPHONES USING DEEP LEARNING ALGORITHMS

Poster Presenter Demi Gao[1#]
Adam Hersbach[2], Tim Brochier[2],
Zachary Smith[3], David B. Grayden[1]

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Commercially available cochlear implants use microphones outside of the body, typically located on the sound processor worn behind the ear. However, requiring an external unit restricts hearing in many situations, such as during sleep or showering. These limitations have driven the development of totally implantable cochlear implants, which require microphones implanted inside the body. The performance of implanted microphones is typically reduced compared to external microphones due to extraneous body noises and reduced microphone sensitivity [1]. Improving the performance of implanted microphones is a key aspect in ensuring totally implantable cochlear implants provide the best possible outcome for recipients.

In this study, we aim to maximise the performance of implantable microphones for cochlear implants using deep learning approaches. A deep neural network (DNN) was developed to process implanted microphone signals to better match those of external microphones, by reducing body noise and restoring suppressed high frequency content. The proposed DNN architecture was adapted from a speech enhancement generative adversarial network [2], consisting of a convolutional neural network with an encoder-decoder framework. Raw audio samples were used as input features to the speech enhancement process [2]. The proposed DNN was trained on synthetic implanted microphone recordings (created from the TIMIT corpus [3]) embedded in 11 types of body noise. The efficacy of the model was evaluated on a test set unseen by the network.

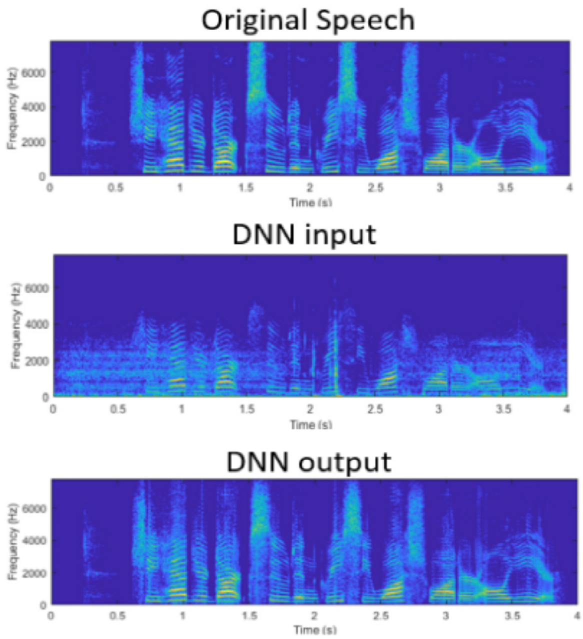

Figure 1. *Spectrograms of (a) original speech, (b) DNN input (synthetic implanted microphone signal), and (c) DNN output.*

Figure 1 shows example spectrograms of (a) 16 kHz original speech, (b) synthetic implanted microphone signal (DNN input), and (c) recovered speech using the trained DNN. Our results indicate that the trained DNN can achieve good restoration of high frequency content in the speech while reducing the level of body noise, which suggests that the proposed model may improve hearing and speech understanding of soft sounds and increase overall sound quality and comfort.

Our results provide insights into the design of sound processing that can alleviate existing issues of implanted microphones and provide implant users with sound quality that approaches currently used external microphones.

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TEMPORAL ALIGNMENT APPEARS TO BE CLOSELY RELATED TO TIGHT BALANCE IN BIOLOGICAL NEURAL NETWORKS

Poster Presenter Martin J. Spencer[1#]

Marko Ruslim[1], Yanbo Lian[1], Hamish Me in[1], Hinze Hogendoorn[2], Anthony N. Burkitt[1,3]

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[2]School of Psychology & Counselling, Queensland University of Technology, Brisbane, Australia
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Networks of neurons in the cortex are made up of both excitatory and inhibitory neurons. In addition to the bottom-up connections made from excitatory sensory inputs, there are lateral excitatory and inhibitory connections as well as top-down excitatory connections from higher regions (Figure 1A).
Individual neurons in the network are known to benefit from tight balance between excitatory and inhibitory inputs [1]. Additionally, it is hypothesized that top-down, lateral and bottom-up connections are in temporal alignment such that bottom-up sensory inputs are not integrated with outdated top-down and lateral predictions [2].
In a model of learning in the visual cortex, we quantitively balance and temporal alignment within a given neuron. It was found that a similar cross-correlation approach is appropriate for both quantities. In the case of balance, the measure compares the total excitatory input with the total inhibitory input (Figure 1B). In the case of temporal alignment, it compares differing sources of excitatory input (Figure 1C).

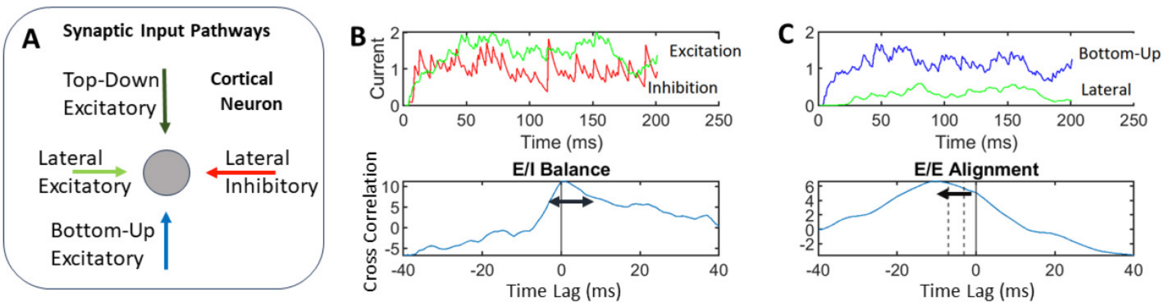

Figure 1: *Balance and temporal alignment in biological neural networks. (A) Network topology. (B) Top: Total input currents from excitatory and inhibitory pathways as a function of time, and Bottom: Cross-Correlation between the two traces. (C) Same as B, but cross-correlation is taken between bottom-up (un-delayed) and lateral (delayed) excitatory input. Dashed lines indicate the range of synaptic delays that are included in the lateral pathway. Model: 100 excitatory, 25 inhibitory Leaky-Integrate and Fire neurons with spiking On/Off cell input from moving visual stimuli. Spike-Timing Dependent plasticity rules use asymmetric Δw curves for bottom-up weights, and symmetric Δw curves for all other weights.*

This cross-correlation approach reveals a close conceptual relationship between tight balance and temporal alignment. The width of the peak in the cross-correlation curve gives the degree of balance (Figure 1B bottom), while the offset in the peak position gives the alignment (Figure 1C bottom). Given that excitatory input may come from more remote regions of the cortex than inhibition, temporal alignment is particularly relevant when comparing input from different excitatory pathways.

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ENCODING OF GAS IDENTITY AND CONCENTRATION USING ANALOG NEUROMORPHIC SENSORY FRONT-END

Poster Presenter Shavika Rastogi[1,2]
Nik Dennler[2,1], Michael Schmuker[2] and André van Schaik[3]

[1]International Centre for Neuromorphic Systems, Western Sydney University, Australia [2]Biocomputation Research Group, University of Hertfordshire, UK

Gas detection is crucial in different domains for the prevention of health hazards. It is equally important to detect the gas concentration for safety reasons, so that appropriate action can be taken within stipulated time. Therefore, there exists a demand for rapid concentration detection systems that can process gas sensor data quickly and efficiently. Spike-time encoding [1] is a technique which allows us to transmit the minimal amount of data, enabling quick decisions about gas identity and concentration at the processing end. Here we will introduce a simple analog circuit design inspired by the spiking output of mammalian olfactory bulb [2] and event-based vision sensors [3] for the detection of gas concentration from the data obtained from one of the Metal Oxide (MOX) gas sensors [4] of an electronic nose [5]. Similar to the mammalian olfactory bulb, the gas concentration is encoded in the time difference between the analog pulses of two separate pathways. We will further extend the circuit operation for an array of MOX sensors. The combined spiking output of all the sensors will allow us to detect gas identity along with its concentration. Encoding gas information in analog spike timings may lead to data and power efficient monitoring devices in future, which can be deployed in uncontrolled and turbulent environment.

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5. D. Drix, N.Dennler and M.Schmuker, “Rapid recognition of olfactory scenes with a portable MOX sensor system using hotplate modulation”, 2022 International Symposium on Olfaction and Electronic Nose (ISOEN), pp. 1-4, 2022

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A MULTILAYER EVENT-DRIVEN FEATURE EXTRACTION ENGINE FOR PATTERN RECOGNITION TASKS

Poster Presenter Philip C Jose

Ying Xu, André van Schaik, Runchun Mark Wang

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Dynamic Vision Sensors (DVS) are developed by taking inspiration from the working principle of mammalian retinas that can detect changes in luminosity to produce a stream of events. This continuous stream of events from the sensor is used to extract a scene's complex spatiotemporal patterns or features with the aid of event-based (EB) feature extraction algorithms. Many of the variants of EB feature extraction algorithms with supervised and unsupervised learning mechanisms reported in the literature use time-surface (TS) computation to create a spatiotemporal event context (E_C) with a predefined radius around an incoming event from the sensor. Feature Extraction using Adaptive Selection Threshold (FEAST) is a novel EB feature extraction algorithm that uses such TS computation to extract the most common patterns or features in an event stream.

Even though the single-layered operation and hardware implementation of EB feature extraction algorithms are well understood in the literature, hardware architectures for multi-layer EB feature extractors are not well explored in the literature. To address this knowledge gap, we present a massively parallel and scalable hardware architecture for a multilayer implementations of the FEAST algorithm. The novelty of the design lies within the computing core, where the FEAST learning rule is split into two independent tasks and is executed in a time-multiplexed fashion with a minimum number of hardware resources. Moreover, each layer has its computing core, which supports runtime reconfiguration, where the user can configure the kernel size and the layer hyperparameters. Additionally, the EB computations are approximated with integer arithmetic, where TS and neuron weights are normalised to 8-bit integers. As a proof of concept, we have implemented a 10-layer FEAST network in Stratix 10 FPGA, where each layer has 64 neurons with configurable kernel sizes between 1x1 and 15x15.

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EVENT-DRIVEN REINFORCEMENT LEARNING WITH ODESA

Poster Presenter Yeshwanth Bethi[1]
Sérgio F. Chevtchenko [2], André van Schaik[1] and Saeed Afshar[1]

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We demonstrate the generalizability of the ODESA framework [1] by developing an event-based Reinforcement Learning (RL) network with delayed rewards. We introduce an ``Actor-Critic'' architecture, which is composed of an Actor network and a ``Critic neuron''. The Critic neuron evaluates the Actor's performance and provides intermediate rewards, thereby eliminating the need for episodic memory in the Actor network. We offer two variations of the Critic neuron for evaluating the Actor network: one using a Monte-Carlo approach, the other employing a Temporal Difference (TD) learning approach. We demonstrate the capacity of these architectures on a variety of Grid World environments, including the Morris water maze, which provides delayed terminal rewards to an agent. As with previous ODESA networks the architectures proposed in this work strictly adhere to event-based communication and locality. They do not require communication of continuous-valued information between the Actor and Critic, unlike other conventional Actor-Critic RL solutions that use TD-error to update both the Actor and Critic.

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HARDWARE ARCHITECTURES FOR NEURAL NETWORK INFERENCE ON EDGE

Poster Presenter Adithya Krishna[1,2], André van Schaik[2], Mahesh Mehendale[1] and Chetan Singh Thakur[1]

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Neural Network-based inference at the edge poses significant challenges due to the need for low-cost, low-power implementations that meet latency constraints. In this research, we try to address the challenges posed by NN inference at the edge by proposing architectures that are both Von-Neumann and non Von-neumann in nature and explore the trade-offs between the same. The Von-Neumann architectures are processing-centric in nature, with distinct memory and processing blocks. Employing the Von-Neumann framework, we propose two implementations: 1) RISC-V-based low-cost and compact CPU for low-precision binary/ternary neural networks using common subexpression elimination technique at compile time and packed SIMD custom instructions to improve the throughput and performance. 2) A generic and programmable neural network accelerator named RAMAN for edge computing applications [1]. RAMAN exploits sparsity in activations and weights to reduce storage, latency, memory access, and power. RAMAN employs Gustavson's dataflow to minimize the memory access and the overall data movement cost by locally reducing the partial sum with a processing element array and has a good output and input reuse. In addition, we perform hardware-aware network pruning at the compile time and activation pruning at the run-time to increase the sparsity of parameters and activations, respectively, and propose a method to reduce the peak activation memory by overlapping input and output activation memory spaces.

In the non-Von-Neumann framework, we propose an architecture that performs computation in SRAM memory (CIM) to significantly reduce latency and power consumption. The CIM architecture is designed based on the distributed arithmetic formulation for multiplier-less implementation of a neural network, wherein the existing SRAM architecture can be easily adapted to perform neural network computations.

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SPIKING BIO-INSPIRED SHALLOW NETWORK FOR OPTIMIZED EFFICIENCY, PERFORMANCE, ROBUSTNESS, AND ON-DEVICE EDGE LEARNING

Poster Presenter Zhaojing (Jim) Huang[1]
Wing Hang Leung[1], Leping Yu[1], Luis Fernando Herbozo Contreras[1], Ziyao Zhang[1], Jiashuo Cui[1], Nhan Duy Truong[1], Armin Nikpour[2], Omid Kavehei[1]

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Summary: This study evaluates the spiking ConvLSTM2D CfC (sCCfC) model's performance in detecting cardiac abnormalities, achieving an average F1 score of 0.82 and an average AUROC of 0.91. These results closely match those of the nonspiking ConvLSTM2D CfC (nsCCfC) model, a non-spiking model with a similar architecture, which achieves F1 and AUROC scores of 0.83 and 0.96, respectively [1]. Notably, the sCCfC model stands out for its remarkable energy efficiency, consuming only 4.68µJ per inference on a Loihi chip, in contrast to the nsCCfC model's consumption of 450µJ on a CPU. Furthermore, as a proof of concept, deploying the model on the Radxa Zero for fine-tuning leads to substantial performance improvements for the sCCfC model. After an initial 2-epoch training on a GPU, the F1 score improves from 0.46 to 0.56, and the AUROC increases from 0.65 to 0.73 with an additional 5 epochs of on-device fine-tuning. Moreover, the sCCfC model demonstrates robust generalization capabilities when faced with data from a new dataset, achieving an average F1 score of 0.71 and an average AUROC of 0.86.

Model Architecture: This study primarily focuses on the sCCfC model, which represents an advancement of the nsCCfC model, as described in Huang et al. [1]. The architectural layout of the sCCfC model is visually presented in Fig. 1. When energy consumption is estimated, the sCCfC model demonstrates a remarkable advantage when compared to the nsCCfC model. Through simulations conducted using the KerasSpiking package in Python, the sCCfC model consumes only 4.68 µJ/inf (per inference) when executed on a Loihi chip. In contrast, the nsCCfC model consumes a substantial 450 µJ/inf when executed on a CPU, which is almost 100× greater.

Performance of the Models: This data comprises two distinct datasets: the Telehealth Network Minas Gerais (TNMG) subset and the China Physiological Signal Challenge 2018 (CPSC) dataset. The TNMG subset was employed for training and validation purposes, encompassing six different types of abnormalities and consisting of 21,000 data points. Meanwhile, the CPSC dataset was utilised to assess the model's generalization, featuring eight distinct abnormalities observed among 6,877 individuals. It is worth noting that while the CPSC dataset includes eight abnormalities, four of them overlap with those present in the TNMG subset, which is used for generalization testing. A comprehensive summary of the models' average performance and their generalization outcomes can be found in Table 1.

Model Deployments: Following an initial GPU training phase spanning only 2 epochs, the sCCfC model underwent a device-based fine-tuning process. This demonstration aimed to showcase the potential for on-device training to personalize the model. The model's energy efficiency, primarily derived from its Spiking Neural Network (SNN) architecture, is a critical factor for its practicality in battery-operated medical devices. Despite the absence of a dedicated neuromorphic chip, the model was successfully deployed on a Radxa Zero, a Single-Board Computer (SBC), serving as a substitute to evaluate its performance. The F1 score improved from 0.46 to 0.56, and the AUROC increased from 0.65 to 0.73 after 5 additional epochs of on-device fine-tuning, demonstrating the proof of concept.

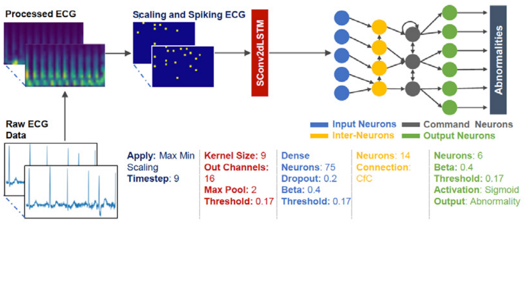

Figure 1: *The model features a Spiking SConv2dLSTM layer for processing spiking STFT ECG data, extracting key features linked to 75 LIF neurons as the NCP network's input. These neurons are interconnected via CfC arrangements, with a final sigmoid activation on the LIF neurons.*

Model	P	R	F1	AUROC
Model Validation				
sCCfC	83.0%	80.7%	81.8%	90.6%
nsCCfC	85.9%	80.6%	82.8%	96.3%
Model Generalization				
sCCfC	75.1%	69.98%	71.1%	85.9%
nsCCfC	75.5%	73.9%	72.1%	91.3%

Table 1: *Average model validation and generalization results (P: Precision, R: Recall) Model P R F1*

[1] Zhaojing Huang, Luis Fernando Herbozo Con-treras, Wing Hang Leung, Leping Yu, Nhan Duy Truong, Armin Nikpour, and Omid Kavehei. Efficient edge-ai models for robust ECG abnormality detection on resource-constrained hardware. medRxiv, pages 2023–08, 2023.

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CRITICAL SLOWING DOWN IN EPILEPSY: INSIGHTS FROM NEURAL MASS MODELS

Poster Presenter Parvin Zarei Eskikand[1#],
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Epilepsy is a complex neurological disorder that often exhibits critical slowing down as a precursor to seizures [1]. In this study, intracranial EEG data obtained from a rat model of epilepsy induced with tetanus toxin was used, which evokes spontaneous seizures over a span of approximately six weeks after injection into the hippocampus. Background intracranial EEG recordings and responses to periodic electrical stimulation [2] were analyzed, with the key objective to evaluate whether computational neural models can facilitate use of critical slowing down as a biomarker for seizure forecasting.
This study incorporated a neural mass model of a cortical column encompassing layers 2/3, 4, and 5 [3], each of which have excitatory and inhibitory neural populations. Using an Unscented Kalman Filter, the model's connectivity weights were optimized to match background EEG data recorded from six rats. Subsequently, we simulated the administration of electrical stimulation to the neuronal populations at each layer to monitor the neural responses, with a particular focus on the recovery time—defined as the duration for the membrane potential to return to its baseline.

Our results show that, for four rats, the recovery times during the 5 min window preceding seizures are notably longer compared to 1 hour prior to seizures. Moreover, an analysis of EEG data recorded in response to electrical stimulation underscore this observation, confirming the longer recovery times during the 5-minute preictal phase in the same four rats.

One rat exhibited longer recovery times within 1 hour before seizures, mirroring the modelling results. The data-driven model aligns with these findings in five of the six rats, underscoring the valuable role of computational models in enhancing our comprehension of intricate neurological conditions, such as epilepsy. The results of analysis of EEG data for one rat contradicted the modelling results.

In addition to these findings, a detailed analysis of parameter testing was conducted for short and long seizures, revealing a statistically significant difference in the means of the parameters for short and long seizures, thus indicating distinct distributions for these two seizure types. This insight may greatly assist in the study of factors involved in seizure initiation, with the potential to identify strategies to either halt seizures or reduce their frequency.

Acknowledgment: This work was funded by the Australian Government, under the Australian Research Council's Training Centre in Cognitive Computing for Medical Technologies.

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A METHOD FOR TRACKING THE FORMATION AND CHANGE OF PLACE FIELDS OVER SHORT TIMESCALES

Poster Presenter Kathrine Clarke[1]
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During sessions where an animal traverses an environment, the firing of hippocampal place cells is usually assumed to have a static relationship with position, but there is much evidence to suggest slow changes as animals experience an environment [1]. Additionally, many place cells take time to recall spatial firing relationships in familiar environments and to establish them in novel ones. Accurate tracking of whether a cells firing is modulated by position, and how that relationship to position changes over time, can provide information on mechanisms behind the formation, and update of memories with experience. Additionally, comparison of place field dynamics with those of transgenic Alzheimer model mice could provide insight into which mechanisms are disrupted by the Alzheimer disease progression.

Detecting changes in place fields over a short time necessarily requires estimation of place field statistics using shorter sections of the recording, which often yields a low number of spikes. As such it is important to ensure that there is enough evidence to avoid overfitting. To derive reliable information about the dynamics of learning in place fields, care needs to be taken in the filtering of which cells are classified as place fields, especially when combining statistics between cells of varying spatial dependence. With larger datasets becoming more prevalent, it is important to develop methods that automatically handle large variability in both noise levels and firing rates, as well as cells with weak or intermittent spatial dependence. In this study, we devise a method for analysis of place fields that can accommodate changes in the place cell encoding over time, where care is taken in the calculation of confidence intervals on both the shape and position estimates. Recording sessions are broken down into shorter segments, where the stationarity assumption is deemed appropriate, and various place field statistics, including position, size and skew are calculated. A bootstrapping method accounting for the sequential sampling of position allows for statistically rigorous significance testing and calculation of confidence intervals for derived place field statistics. This allows us to observe place field changes on a short time scale, while ensuring that the necessarily small spike counts involved in such short sequences does not result in statistics dominated by noise. Place fields detected over short time segments are then registered together to provide whole trial tracking of place fields. Using this method, place cells can be differentiated from non-place cells in a way that doesn't exclude cells where place fields change quickly.

Additionally, cells that exhibit spatial firing properties for only a subset of the recording can be identified and analysed. Validation of this method is performed on surrogate place field data, generated from models of non-stationary place fields. The method is shown to effectively track place fields for cells with a range of firing rates and rates of change in position and shape. The method is then applied to 2 photon imaging of mouse CA1 cells during repeated traversals of a circular track, demonstrating its effectiveness at detecting and tracking place field like firing in real data.
This method will allow a systematic and statistically validated description of the rate of formation of place fields, and the extent to which place cells shift through experience. This can then be compared with used to test neural models of plasticity mechanisms potentially underlying these changes.

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REMOVING CARDIAC ARTIFACTS FROM ENDOVASCULAR INTERFACE DATA

Poster Presenter Suleman Rasheed[1,2,3#]
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The current industry standard of implantable deep brain stimulation (DBS) [1] and endovascular brain-computer interface (BCI) devices [2] implants the complementary electronics (i.e. pulse generator and telemetry unit) in the chest. While this has been proven to be safe and effective, it introduces large cardiac artifacts in the recorded signal. An alternative is to miniaturize electronics and place them somewhere more electrically benign or use a completely percutaneous system, which both have implications for scalability and have not yet proven to be safe.

This work compares existing cardiac artifact removal algorithms and proposes time and frequency selective methods that utilize the characteristics of cardiac artifacts to improve existing standard algorithms. In the time-domain, these artifacts occur every 700-800 ms, and in the frequency-domain, they only occur in lower frequencies (<40 Hz). In time selective methods, the correction is applied only where QRS regions (130ms around R peaks) occur and in frequency selective methods, the correction is applied only up to 40 Hz and higher spectral activity is left untouched. Following standard artifact removal algorithms were considered: bipolar subtraction, linear regression, common average referencing (CAR), amplitude-matched common average referencing (AMCAR), independent component analysis (ICA) and artifact subspace reconstruction (ASR).

Figure 1 shows results for classification of eye movement direction from endovascular EEG for a visually guided saccade task. The dataset contains 200 eye movement (saccade) trials and 200 rest trials. The horizontal line shows performance without removing artifacts, and we can see that standard algorithms do not outperform this baseline substantially.

However, the time selective and time-frequency selective methods always outperform the original methods, which suggests that applying corrections in only artifact regions (QRS regions) results in better performance compared to standard methods that apply correction on whole duration of timeseries.

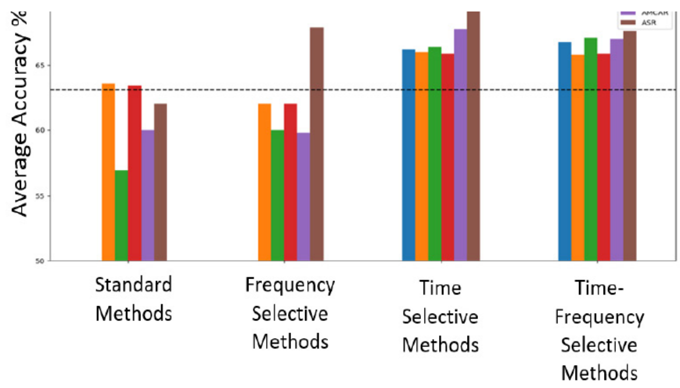

Figure 1. *Performance Comparison of Cardiac Artifact Removal Methods*

This work was funded by Australian Research Council's Training Centre in Cognitive Computing for Medical Technologies (ICI7020-0030).
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