Real-time seizure detection in iEEG using neuromorphic hardware

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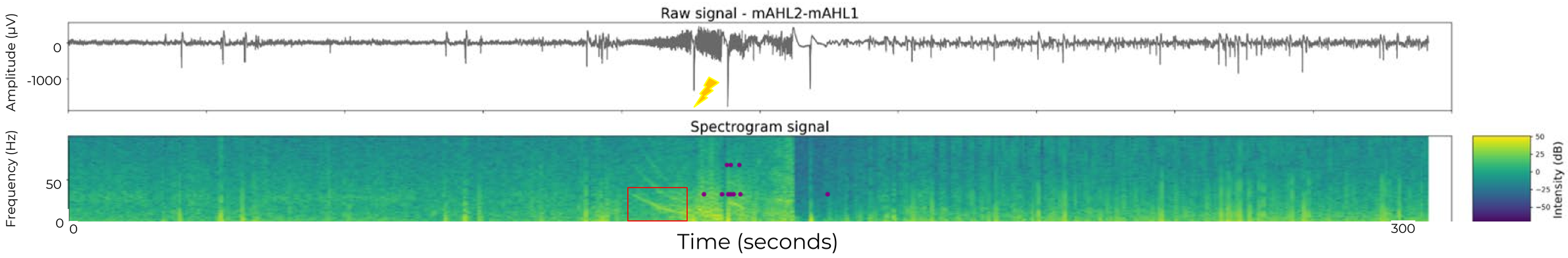
Introduction

- Traditional seizure monitoring (e.g. seizure diaries) is often inaccurate. There is a need for more precise, automated seizure detection systems.
- **Chirps** are time-frequency patterns initiating seizures [1].
- **Research goal:** To detect chirps in intracranial electroencephalography (iEEG) with neuromorphic hardware.

Methods

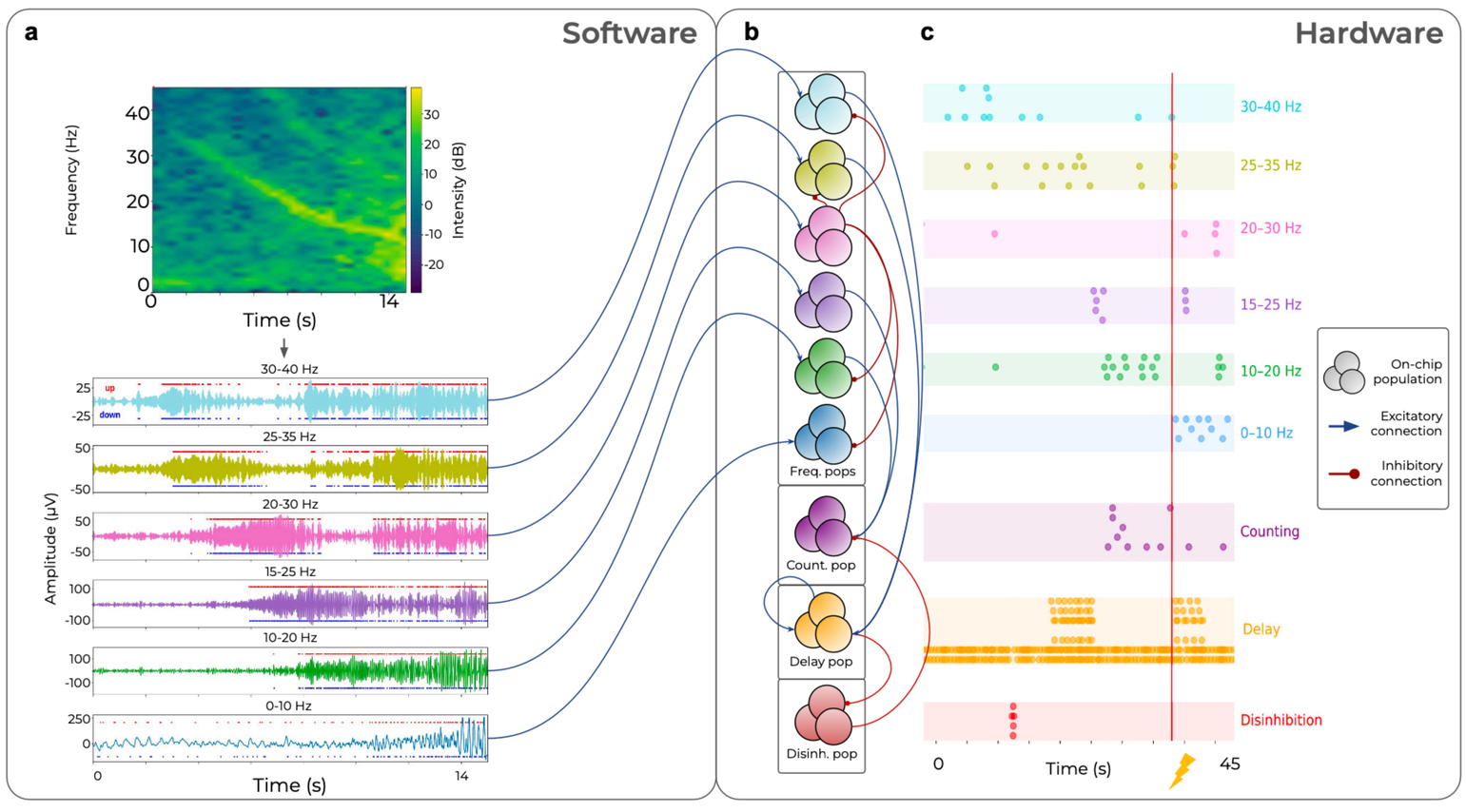
- We developed a spiking neural network (**SNN**) and implemented it on a mixed-signal analog/digital neuromorphic chip (**DYNAP-SE**).
- We build on previous detection of high-frequency oscillations with the same technology [2].
- Dataset: 7 patients, 492 hours of recording, 62 seizures.

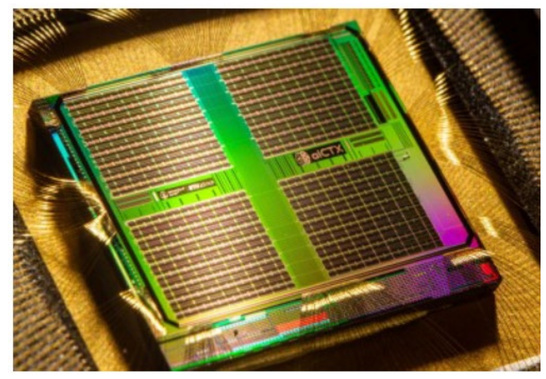
1. Chirp patterns in iEEG initiate a seizure



A) Raw iEEG data from the seizure onset channel.
B) Spectrogram shows a chirp pattern that initiates the seizure onset. Chirp count activation in violet.

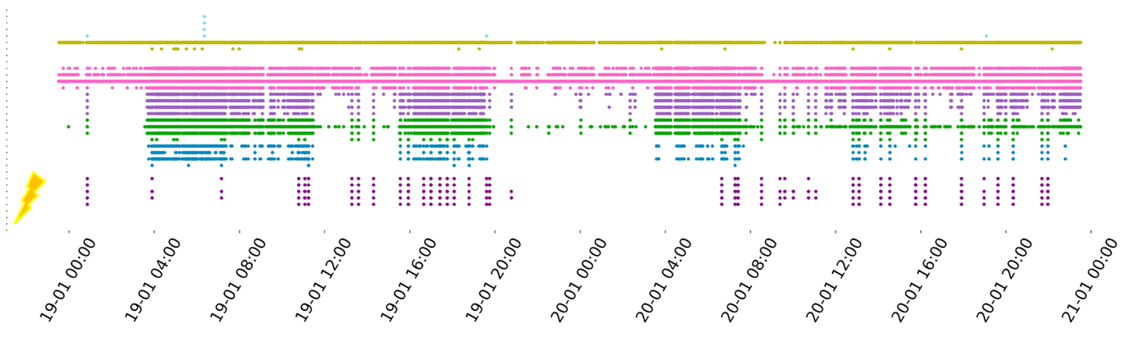
2. SNN pipeline to detect chirps in iEEG using DYNAP-SE





A) iEEG filtered into frequency bands and encoded into events (ADM).
B) **SNN (DYNAP-SE)**: Each population inhibits all but next lower frequency. Disinhibition blocks counting pop if highs are inactive.
C) The second and third lowest frequency SNN populations connect to the chirp count population, **detecting the chirp/seizure**.

3. Hardware SNN detects chirps in iEEG



Correct detection of 4 consecutive seizures. SNN output for Patient 6 in neuronal populations corresponding to the 6 frequency bands and the chirp counting during 4 h of continuous iEEG recording. The 4 chirp detections (vertical violet bars) co-occur with the annotated seizures (vertical red lines), indicating correct detection (true positives TP).

1. Di Giacomo, … Gnatkovsky. Ictal fast activity chirps as markers of the epileptogenic zone. Epilepsia 2024
2. Costa, … Indiveri, Sarnthein. Robust compression and detection of epileptiform patterns in ECoG using a real-time spiking neural network hardware framework. Nature Communications 2024

4. Sensitivity and FAR for 7 patients

Patient	Duration (h)	Processing overhead	Consumption (µW)	Seizures annotated	TP	FN	FP	Sensitivity CI (%)	FAR (day^{-1})
1	53	2.6%	3.4	4	4	0	1	100 [51 100]	.45
2	61	5.0%	55	4	3	1	2	75 [30 95]	.79
3	85	3.4%	4.2	2	2	0	4	100 [34 100]	1.1
4	66	3.1%	3.5	14	13	1	3	93 [69 99]	1.1
5	55	2.6%	3.5	3	3	0	3	100 [44 100]	1.3
6	93	2.0%	2.7	32	28	4	39	88 [72 95]	10
7	79	6.5%	65	3	3	0	58	100 [44 100]	18
Sum	492			62	56	6	110	90 [81 96]	

Conclusions

- We detected 56/62 (90%) seizures in pre-recorded iEEG data
- False Alarm Rate <1.3 day^{-1} in 5/7 patients.
- Low power consumption (< 65 µW)
- Detecting chirps in iEEG identifies seizures in real-time.