Retinal Cell Identification from Compressed Signals

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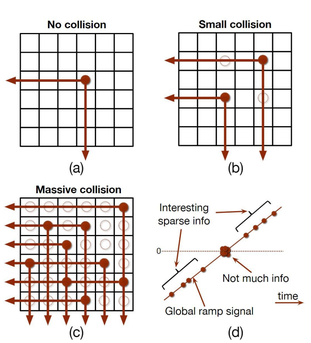
MOTIVATION

Brain-machine interfaces

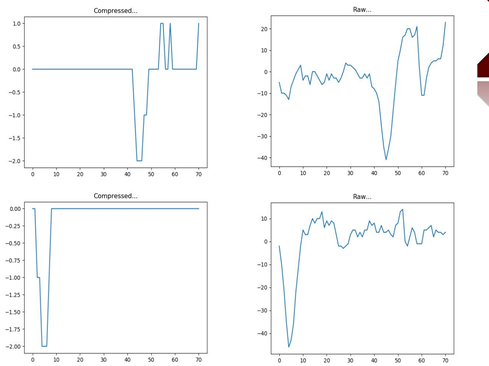
- Challenges
  - Current designs are bottlenecked by power constraints [1]
  - Can compress signals to reduce power, but degrades cell classification accuracy
- Spike reconstruction using deep neural networks
  - Allow for compression of signal at the implant
  - Offloads processing to an external devices
  - Reduces power and bandwidth requirements for data transmission
  - Can we reconstruct the compressed signal without any loss of information?
- End-to-End Reconstruction System
  - Reconstruct raw waveforms from compressed version
  - Pass through analysis pipeline for cell classification

DATA

- The dataset consists of about 60 million examples of 71-sample inputs and outputs.
- These 60 million examples come from retinal response waveforms from a macaque monkey provided by Professor E.J. Chichilnisky at Stanford.
- A raw recording of 30 minutes from a 512-electrode array sampled at 20kHz is processed by a state-of-the-art neurology data processing tool called Vision to provide the timestamps for each spike in the recording.
- The raw signals are passed through a model that applies compression inherent in the sampling circuit to create the compressed form.
- Cell mosaic reconstruction (test set) require recordings over 6mins. Therefore, training set consists 38 million spikes, dev set consists 468k spikes. Test set contains 10 minutes worth of data (20 million spikes)

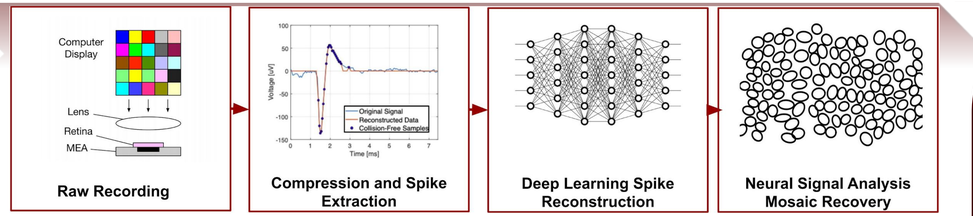


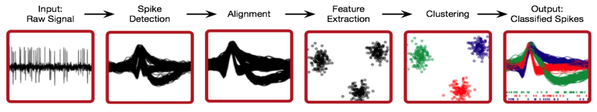
Compression scheme in sampling electrode array [1]



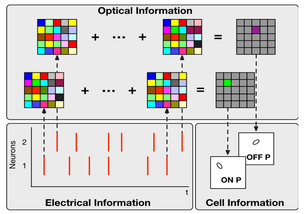
Dataset Preview: Two compressed waveforms and their corresponding raw waveforms.

ARCHITECTURE

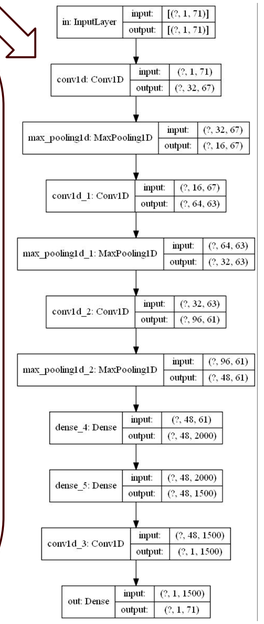




- Spikes are detected using state-of-the-art neural signal analysis algorithm - Vision.
- 1D convolutional neural network
  - Layers: Convolution, Maxpool, Dense
  - Loss Function: Mean Squared Error
  - Optimizer: ADAM
  - Hyperparameters
    - Learning rate α: 0.002
    - Momentum β_1: 0.85
    - RMS β_2 : 0.999
    - Batch size: 512
- Different types of retina neural cells as well as the mosaic of cells are recovered using Vision based on their response to light stimulus.



Mosaic Recovery Process (figure provided by Prof. E.J Chichilnisky)



RESULTS

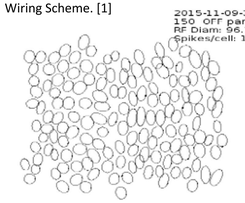
- Mean squared error (MSE) is chosen for loss function as well as result evaluation metric:

$$MSE(\hat{y}, y) = \frac{1}{71}\sum_{i=1}^{71}(y(i) - \hat{y}(i))^2$$

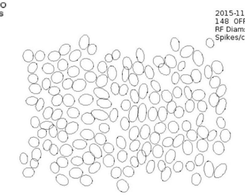
	12 bit	10 bit	8 bit	
Conventional	0	5.8	27.9	← No Compression
1 wire	23.5	32.5	42.1	← Baseline
	74x	198x	559x	
2 wire	18.7	2[illegible]	[illegible]	This Work 24
	31x	8[illegible]	16x 228x	
4 wire	13.8	22.4	32.5	
	13x	35x	96x	
8 wire	7.9	16.1	28.2	
	6x	15x	42x	

MSE and Compression Rate VS Bit Resolution and Wiring Scheme. [1]

- Train MSE (38M) = 23.99
- Dev MSE (468k) = 24.88
- Cell recovery rate ultimately evaluates our network performance.



150 OFF Parasol Cells Mosaic from Raw Data



147 Cells Mosaic from Reconstructed Data

Table 1: Neural Signal Analysis Result

Mosaic Recovery	ON Parasol	ON Midget	OFF Parasol
Ground Truth / [cells]	116	202	150
Baseline /[cells]	96 (83%)	Not reported	121 (81%)
This Work	114 (98.27%)	195 (96.50%)	147 (98%)

DISCUSSION

- Audio processing was the closest analog to our problem, but those approaches could not be directly applied
  - Spectrograms are typically computed using 25ms windows and 10ms stride for applications in audio, but each of our cropped spikes is only 3.55ms long
- The final model does not predict any noise in the zero-valued segments of the compressed signal
  - Suggests that the oscillations we see in the raw waveform in these regions are stochastic in nature
  - Naturally provides a regularizing effect that helps prevent overfitting
- This work achieves a MSE of 24 and cell recovery rate of over 98%, which has lower MSE than the 8-bit, 1 wire configuration MSE of 42.1, and higher cell recovery rate than the 81% before reconstruction.
  - At the same MSE and cell recovery rate as a 10-bit, 4 wire configuration, an extra 16x compression is achieved

FUTURE SCOPE

- Try combining current network with spectrogram
- Add residual connections to network.
- Find the smallest network that can achieve comparable results
- Train on entire array at once: 512 x 71 dimension of input

REFERENCES

[1] D.G. Muratore, et al. “A Data-Compressive Wired-OR Readout for Massively Parallel Neural Recording,” *2019 IEEE International Symposium on Circuits and Systems (ISCAS)*, 2019, doi:10.1109/iscas.2019.8702387.