Algorithms for Identifying and Avoiding Axon-Bundle Activation in Epi-Retinal Prosthesis

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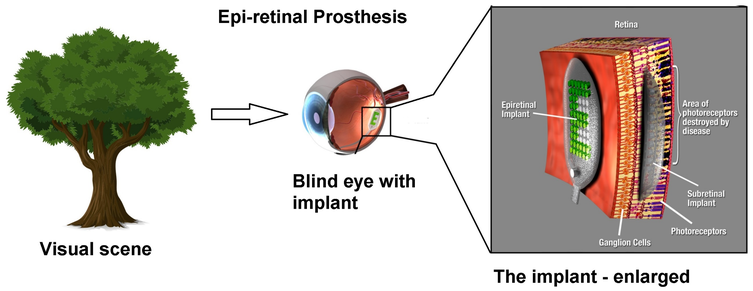
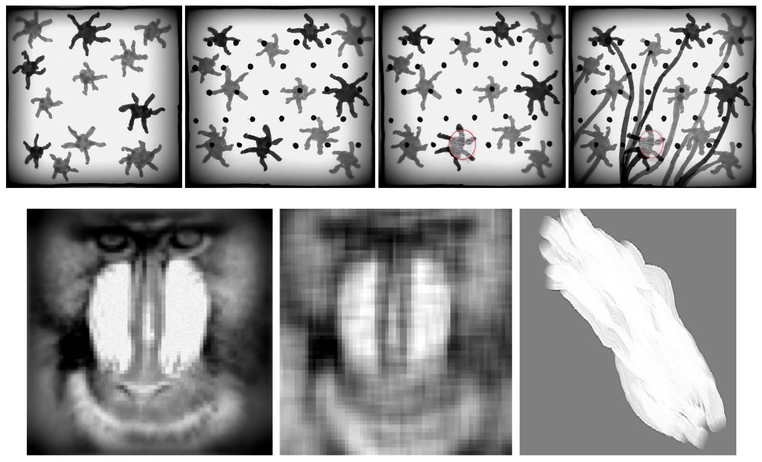
What is (Epi) Retinal Prosthesis?

Retinal prosthesis systems are designed to restore vision to people blinded by incurable photoreceptor degeneration. It stimulates the Retinal Ganglion Cells (RGCs) electrically to transmit artificial visual signals to the brain.



The problem: Axon-bundle activation

Axons from all the RGCs lie between the electrodes and the RGC layer forming axon bundles. Instead of activating a cell (soma), the prosthesis ends up stimulating entire bundles leading to **arc-shaped percepts**.



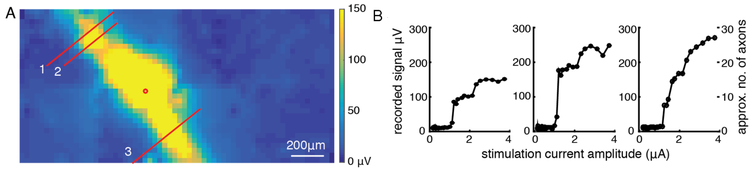
Prosthesis-in-lab

Isolated macaque monkey retina and custom **512**-electrode array system for stimulation and recording are used.

For each stimulation electrode, the current is ramped up in steps until the axon bundle is activated - "threshold".

Features of Identification

- Bidirectional Propagation:
- Signal Growth and Spread:



Motivation for automation

Speed, scalability, accuracy - humans make mistakes!

Acknowledgements

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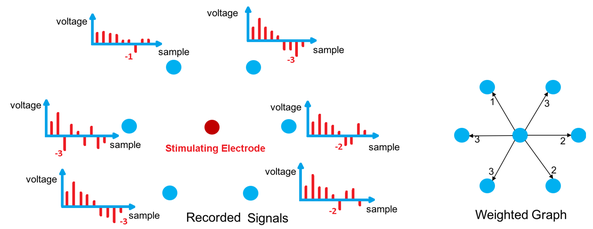
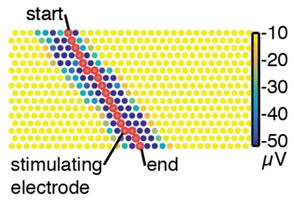
Graph Abstraction

The magnitude of the minimum voltage of recorded waveforms after stimulation at each electrode is used to build a complete, weighted graph on the electrodes.



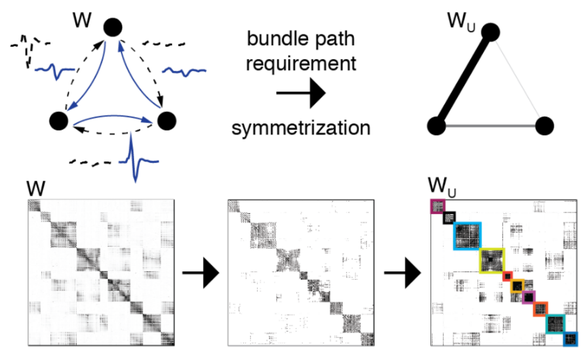
Graph Traversal

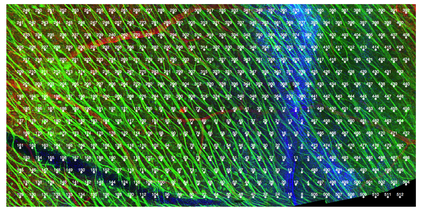
After the graph has been created, a minimum-cost path across the array is determined using the A-star pathfinding algorithm. This path will be used to prune the partitions.



Graph Partitioning

Using the adjacency matrix of the graph that was created, spectral clustering is used to partition the set of electrodes into distinct partite-sets. Each of these partite-sets corresponds to a certain spatial region within which the bundle detection algorithm will test for bidirectional propagation.

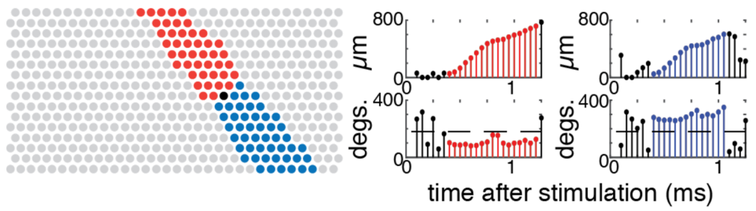



Tubulin image of the axon bundles in the retina


Graph partitioning result

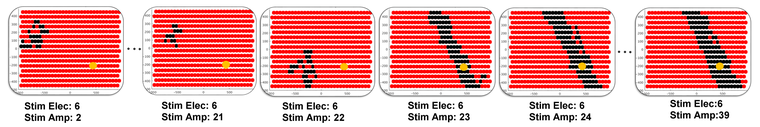
Bidirectional Propagation

In each of the partite-sets, a weighted center of mass can be computed at each time sample. The algorithm tracks this movement across time to identify bi-directional propagation.



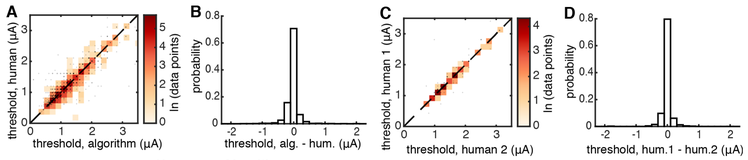
Cluster Extraction

The graph abstraction idea is implemented, not just for the highest amplitudes but for every amplitude for a given stimulating electrode. These are then partitioned by their magnitude to give a set of representative clusters, which are distinguishable as above the threshold and below.



Results

The automated analysis produced bundle thresholds similar to the human. This was tested across four retinas in the periphery. In many cases, the algorithm was more sensitive, and detected bundle activation events when the human was not able to discern them using manual inspection.



Human vs Algorithm correlation: 0.94

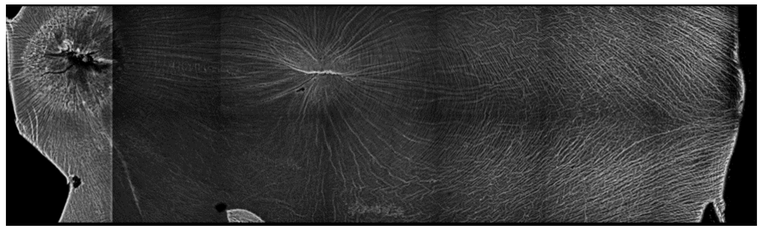
Human 1 vs Human 2 correlation: 0.97

Summary

- Unwanted axon bundle activation can be identified by an automated method.
- Avoid large distortions produced by axon activation in current clinical devices.
- May be possible to reproduce a portion of neural code in an epiretinal prosthesis.
- Remain below threshold for bundles, while activating cells.

Future Work

There is a region in the central retina called raphae which is avoided by peripheral axon bundles. With its low axon density, this may represent the ideal target location for a high-resolution epiretinal prosthesis.



Movies

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