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Differentiable learning of image encodings for cortical visual neuroprosthetics through bio/phenomenologically-aware phosphene modeling

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Introduction: The development of high-channel count intracortical neuroprostheses for the blind[1], alongside recent demonstrations of these systems in human patients[2], establishes the possibility of restoring a rudimentary form of vision. Alongside these developments, the interdisciplinary field of neurotechnology is met with a wide array of challenges. Among these is the task of creating meaningful visual representations constrained by a limited implant resolution and safety and hardware constraints.

In order to gain insight on phosphene vision (i.e. creating artificial light percepts by electrically stimulation of the brain), simulated prosthetic vision grants researchers the ability to generate and test scientific hypothesis allowing for the optimization of computer image algorithms that are designed/trained to generate useful visual representations for the users [3], [4]. Here, we demonstrate how we can learn to create meaningful image representations using cortical phosphene representations in a biologically plausible way. In order to do that, we integrate decades of research evidence on modeling the effects of electrical stimulation on cortical tissue, coupled with electrophysiology and psychophysics data, into a novel, phenomenologically realistic differentiable artificial vision simulation pipeline.

Material, Methods and Results: An integrative model of phosphene perception, accounting for a wide array of psychophysical and neuroscientific evidence such as cortical magnification, current spread, phosphene thresholds, the relationship between electrical stimulation parameters and phosphene brightness, size, and temporal dynamics - including phosphene fading effects- is developed. Implemented in Pytorch, this model of phosphene perception, linked to computer vision algorithms based on Deep Neural Networks, allows for differentiable end-to-end learning of phosphene-based image representations on a broad diversity of conditions. These include realistic safety stimulation constraints, dynamic encoding of video data, and encoding of naturalistic images, in real time on a single GPU.

Discussion: While the neurophysiology and psychophysics of phosphene vision regarding cortical neural implants is still on its developmental beginning, an integrative pipeline able to create biologically and phenomenologically realistic cortical simulated prosthetic vision is a Prerequisite for the creation of when creating useful visual representations. Our simulations show highly correlated predictions with respect to the empirical psychophysics literature. In addition, the differentiable nature of our proposed modelling and optimization approach allows for deep learning-based end-to-end optimization of phosphene-based visual representations tailored to realistic physical and safety constrains.

Significance: A machine learning-compatible, realistic model of cortical phosphene perceptions enables neuroscientists, neuroengineers and clinicians to narrow the gap between prosthetic vision research and clinical applications.

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