Simulating the cortical activity evoked by artificial retinal implants

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Introduction

Recent advances in neuroscience and microelectronics have opened up the possibility of partially restoring vision in blind patients using retinal prostheses. However, it only restores low-resolution vision, which may be explained by a poor understanding of how electrical stimulation activates the visual cortex. Our interest focuses on the modeling of retinal and cortical activities in the case of prosthetic stimulation, with the objective of comparing them to the activities evoked by visual stimuli.

General Context

Using retinal prostheses has a major disadvantage. The contact between the retina and the matrix of electrode is not perfect. Two diffusion effects are therefore observed.
In particular, Roux et al.[1] have shown, from experiments on rats, that the cortical activity obtained by optical imaging can be up to ten times higher during prosthetic stimulation compared to normal visual stimulation.

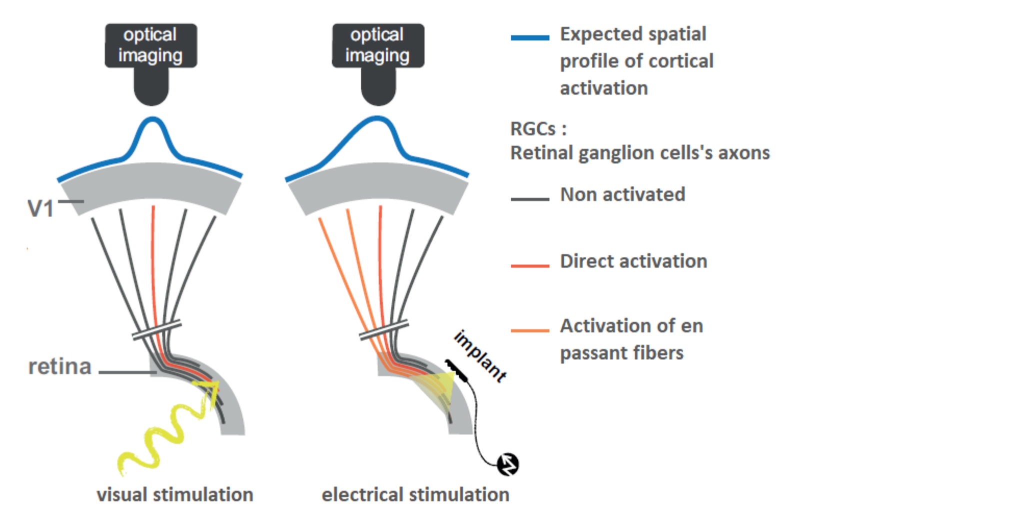

Figure A
Schematic view of the experimental setup with the camera and the visual pathway from the retina to V1 activated with normal visual stimuli (left) or with sub-retinal electrical stimulation using a MEA (right).
Source: Roux et al.[1]

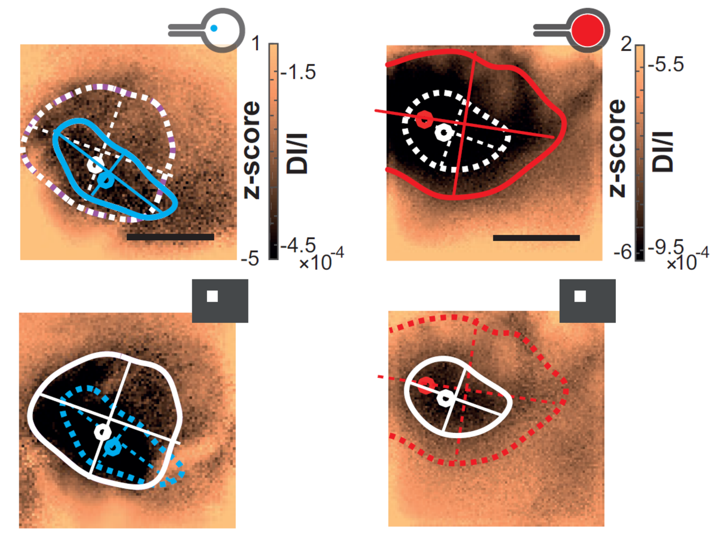

Figure B
Cortical activations generated in 2 animals by a single electrode (blue) and a whole multi-electrode array (red) stimulation (top maps) at a high current intensity (± 200 and 150 mA respectively) and their corresponding 20° visual stimulus (white, bottom maps).
Source: Roux et al.[1]

Roux et al.[1] developed a Matlab model in order to study the phenomenon of expansion of cortical activity between visual and prosthetic stimulation for one electrode. However, retinal prostheses integrate hundreds of electrodes and there is no study yet about the effect of the simultaneous activation of several electrodes reproducing the shape of an object.

The goal is now to integrate and develop the model for a single electrode into a multi-electrode model. The Biovision team at Inria is currently designing a retina simulator, called Macular, aiming at reproducing the retina response to stimulation in normal (stimulation by light) and pathological conditions (electric stimulation by prostheses). Our objective is to compare the results from prosthetic simulation to normal vision.

Acknowledgements

We would like to thank our collaborators, Frédéric Chavane and Sébastien Roux from Institut des Neurosciences de la Timone, both for their significant help and their insightful suggestions.

The One-Electrode model

The model developed by Roux et al.[1] provides retinal and cortical activities for one electrode by taking into account two diffusions: the direct diffusion around the electrode and the diffusion due to the activation of axons so-called "en passant" (axons of distant retinal ganglion cells).

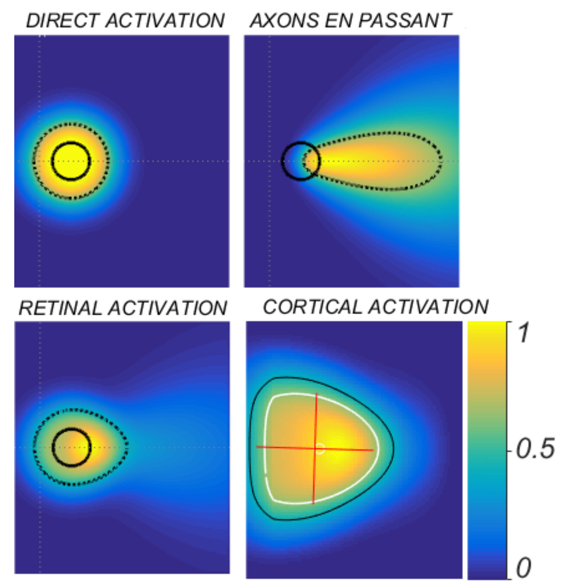

Figure C
Result for one electrode.

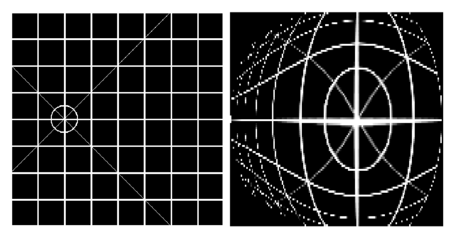

Figure D
Rat retinotopy based on the work of Gias et al.[5]

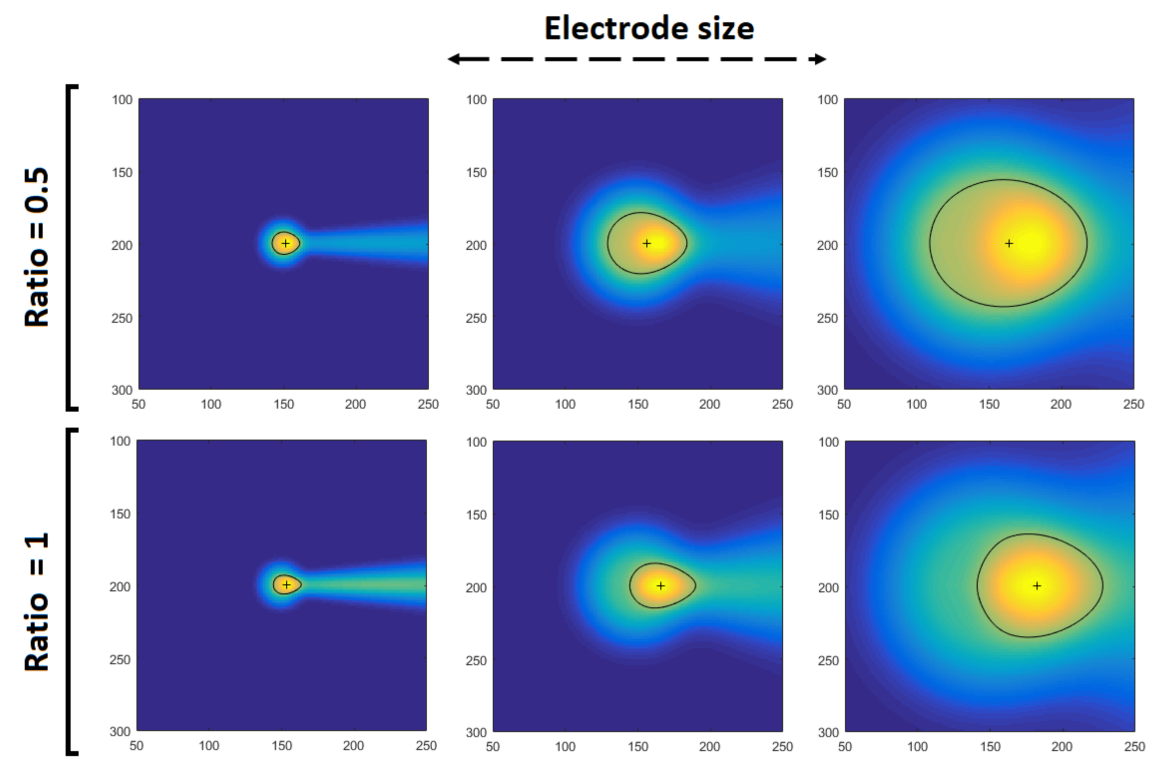

Figure E
Cortical activity depending on the size of the electrode and the ratio of contribution of axons en passant (in line, 0.5 and 1.0 respectively).

Descriptive Diagram

Main objective:

Virtual Retina[2] → **MACULAR** Retina simulator ← Prosthesis model
MACULAR Retina simulator → Comparison of retinal and cortical activities

Computational steps:

Video Image → Pre-processing[4] → Prosthesis model[3,4] → Retinal activity model[1] → Cortical activity model[1,5]

Conclusion & Future Perspective

- Based on the one-electrode model from Roux et al. [1], we developed a customizable model providing retinal and cortical activities for a multi electrode array.
- The arrangement of the electrodes needs to be adjusted to better match the design of the most recent prostheses, which will make it possible to compare simulation results and experimental results with greater accuracy.
- The model of information coding by the prosthesis must be added, as well as the preprocessing which has to be applied to the input image or video. This future work will be inspired from the work done in the theses of T.-K. Tran[3] and B. Durette[4].
- Among the perspectives offered by this internship, the study of a dynamic response is of central interest. In this static model we do not take into account any of the transient regimes resulting from variations in the signal received by the electrode. We can for example focus on the case where an electrode is activated by a pulse or step signal.

Results

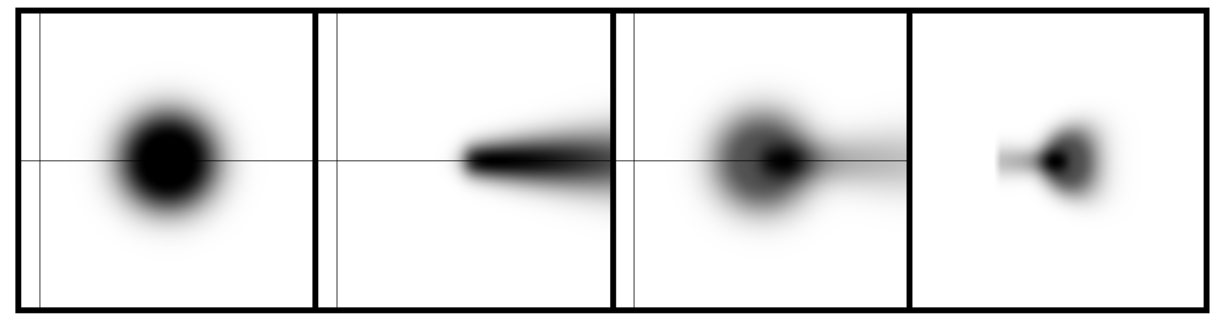

Figure F
Result for one electrode. The intersection of the lines represents the position of the blind spot.

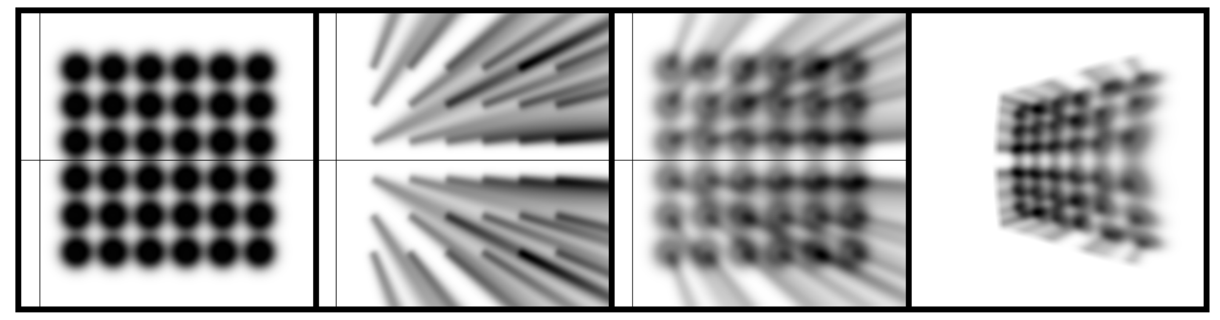

Figure G
Result obtained by simulating a 6x6 multi-electrodes network. For better visualization, the electrodes were spaced more apart than on a real prosthesis. In this case, the activations are superimposed due to the diffusion of current between the electrodes and the retina.

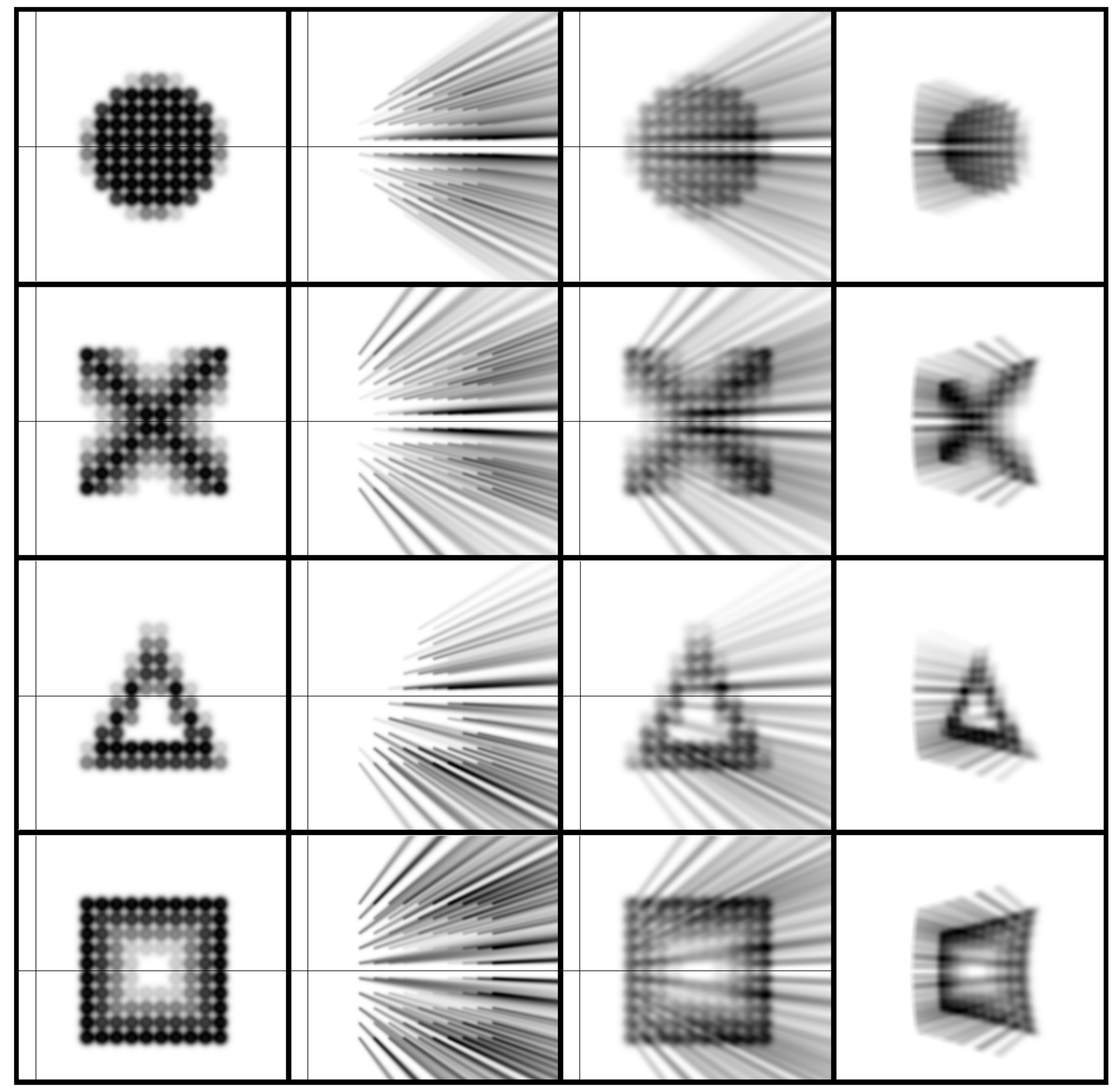

Figure H
Results obtained by simulating a 10x10 multi-electrodes network. The test forms were simulated using intensity levels between 0 and 1.

References

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