A super-resolution approach for receptive fields estimation of neuronal ensembles

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A super-resolution approach for receptive fields estimation of neuronal ensembles

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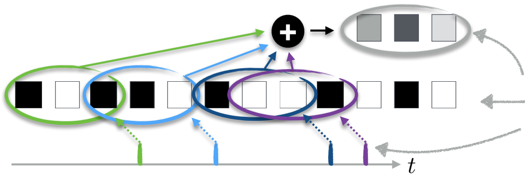
Spike Triggered Average (STA) with white noise (WN)

A classical technique to find receptive fields (RF)



Convergence: Error tends to zero as the spike count tends to infinity.

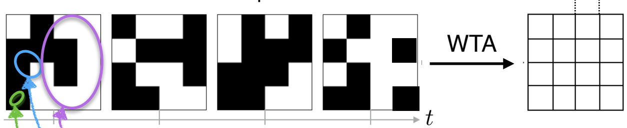
$$\mathcal{E}(STA, RF) = \sum_{x,y,t} (STA(x,y,t) - RF(x,y,t))^2 \approx \mathcal{N}(0,1)^2 \frac{\sigma^2}{n(T)}$$

Gaussian distribution
Variance of the stimulus
Spike count

Spatial resolution of the estimation

It is defined by the size of the blocks of the checkerboard stimulus.

How to set block size? A matter of compromise…



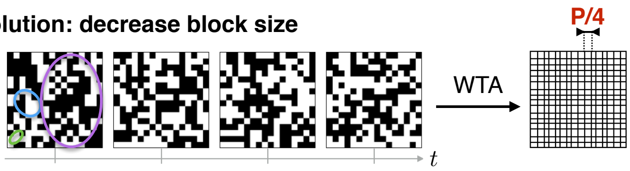
Averaging gray ⇒ low activity ⇒ slow convergence
Always "in between" ⇒ low activity ⇒ slow convergence
Always full field ⇒ strong activity… but no way to recover RF

Solutions exist for single cells but not for a whole population

Foldiak, Neurocomputing (2001)
Machens, Phys Rev Lett (2002)
MacKay, Neural Comput (1992)

How to increase the resolution of RF over the population?

Naive solution: decrease block size

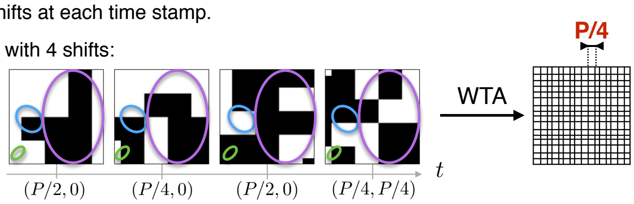


If the block size is considerably smaller than the RF, then the spike count will be low, resulting in very slow convergence speed, an impractical solution for experimentalists.

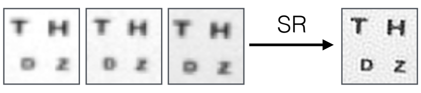
Proposed solution: Introducing shifted white noise (SWN)

We define SWN as a WN stimulus where blocks are randomly moved by discrete spatial shifts at each time stamp.

Example with 4 shifts:



Remark | *Analogy with super-resolution (SR) techniques in image processing*



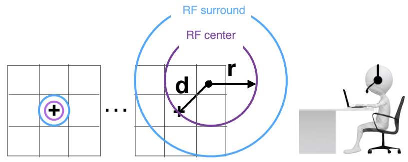
Using SWN$_{P,S}$ increases the STA resolution by a factor **S** without decreasing the block size, thus it is suitable for a large ensemble of neurons.

The STA obtained can still be theoretically related to RF in the context of LN models similarly to the classical white noise scenario.

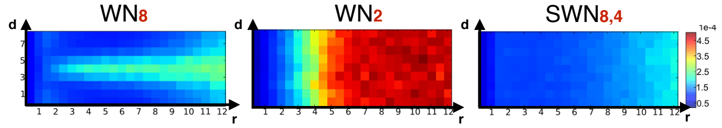
Simulation study

Population of LNP neurons

Spatial RFs: DOG
Temporal RFs: DOE
5 trials, 20000 images per trial
Display rate 30Hz



STA error as a function of the cell RF position and size:



Results

For a fixed block size, the STA spatial resolution is improved as a function of the number of possible shifts, leading to smaller estimation error.

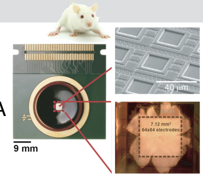
Targeting a given STA spatial resolution, shifting the stimulus increases the convergence speed.

(see COSYNE 2015 poster for more results)

Experimental study

Experimental protocol

Pan-retinal RGC responses from WT mice were recorded using the high-density large-scale CMOS-based APS MEA (Biocam, 3Brain GmbH, CH) featuring 4096 electrodes (42 µm spacing) arranged in a 64x64 configuration, covering an active area of 7.12 mm2.

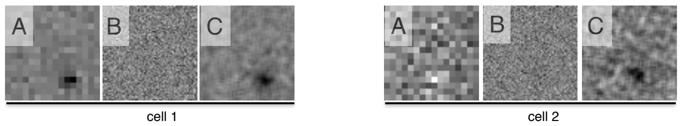


Berdondini et al., Lab On Chip (2009)

White Noise images (block size of 160µm, 40µm and 160µm with arbitrary shifts of 40µm) were presented for 15 min at 30Hz (P79) and 15 Hz (P76) using a custom built system based on a DLP video projector.

A: WN160
B: WN40
C: SWN160,40

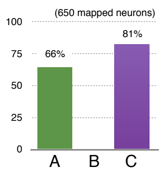
Comparison between RF estimations

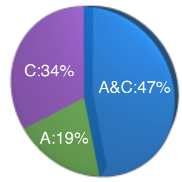


Statistical analysis over the population

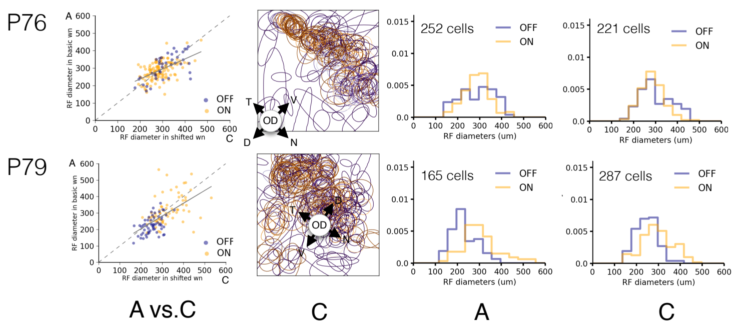
Most of RF are mapped by both stimuli (with highest resolution from SWN).

Differences are possibly coming from RF properties (e.g., size and position)





Distribution of RF sizes



WN and SWN give similar RF estimation. SWN allow to map more large RF.

This study presents for the first time a simple approach allowing quick and simultaneous extraction of receptive field profiles with great accuracy from hundreds to thousands of retinal ganglion cells. The method not only ensures strong responses because these stimuli are big (e.g. 160 µm), but it also provides receptive field measurements at super resolution thanks to the small shifts (40 µm) applied to the basic checkerboard stimuli.

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