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Shifting stimulus for faster receptive fields estimation of ensembles of neurons

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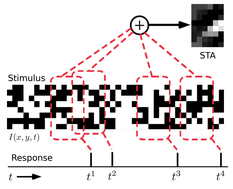
SPIKE TRIGGERED AVERAGE (STA)

The STA is a widely used receptive field (RF) estimator.
If the stimulus is white noise, the estimation error tends to zero as the spike count tends to infinity.
The speed of convergence depends on the variance of the stimulus and the number of spikes.



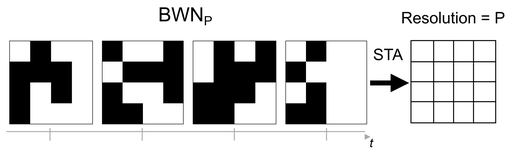
$$\text{Error}(STA, RF) = \sum_{x=0}^{X}\sum_{y=0}^{Y}\sum_{z=0}^{Z}(STA(x,y,z) - RF(x,y,z))^2$$

$$\text{Error}(STA, RF) \sim Z^2 \frac{\sigma^2}{n(T)}$$

Conclusion: For a good estimation, the STA resolution should be fine. To increase the speed of convergence the stimulus variance should be low or the spike count should be high.

STANDARD STIMULUS

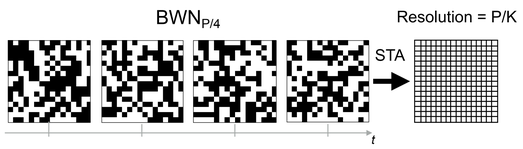
Black and white checkerboards images of block size P:



But... If the block size is too large, the resolution is coarse. The STA might miss RFs or estimate them roughly. Thus, the estimation error might be very high.

INCREASING THE RESOLUTION

Naive solution: decrease the block size (here K = 4 times)

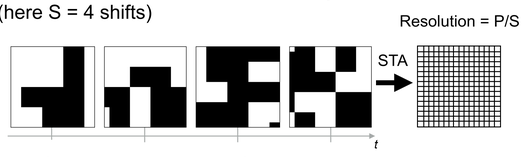


But... If the block size is too small, the spike count might be too low. Therefore the speed of convergence might very slow which can be impractical in an experimental setup.

Problem: How can we define a good stimulus resolution for a neural ensemble?

PROPOSED SOLUTION

Checkerboard stimulus where blocks are randomly shifted in discrete steps at each time stamp (here S = 4 shifts)

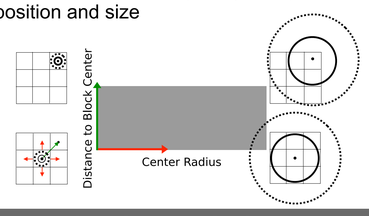


Conclusion: The $SWN_{P/S}$ increases the STA resolution without decreasing the block size, thus it is suitable for a large ensemble of neurons.

SIMULATION PROTOCOL

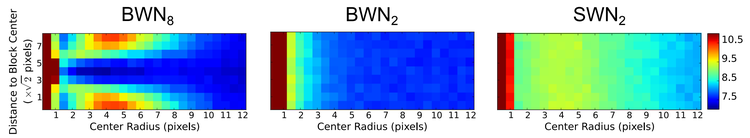
Experimental setup:
- 5 trials, 20000 images per trial, display rate 30Hz
- 3 sets of stimuli: BWN_8, BWN_2, SWN_2 (P=8 and S=4)

Neural Ensemble Model:
- Linear-Nonlinear Poisson (LNP) neurons
- Spatial RFs: Difference-of-Gaussians (DOG); Temporal RFs: 2 phases function
- DOG varying in position and size

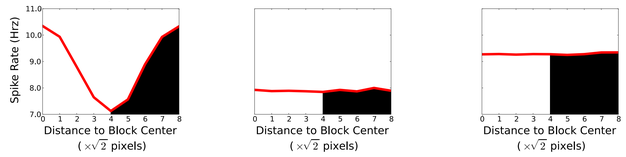


RESULTS: AVERAGE SPIKE RATE

Neuron's spike rate as a function of RF position and size:



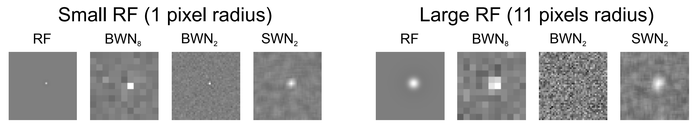
For a radius of 5 pixels:



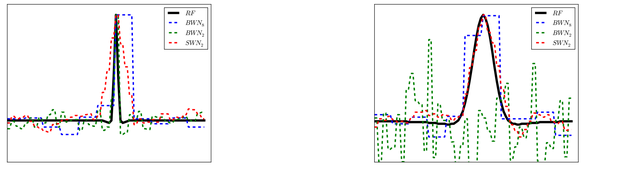
Conclusion: Under the BWN_2 and SWN_2 the neuron's spike rate is independent on the RFs position, on the contrary BWN_8's spike rate is dependent on the position. In general, SWN_2 leads the highest spike rate and BWN_2 to the lowest one.

RESULTS: SPIKE TRIGGERED AVERAGE

Spatial RF:



Profile on the x-axis:

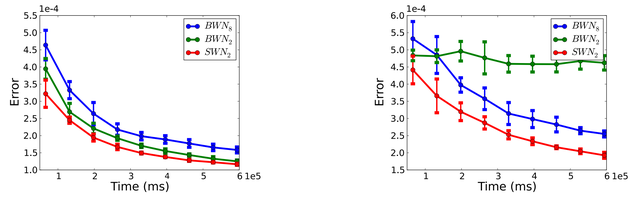


Conclusion: for a small RF the STA is better under SWN_2 than BWN_8. For a large RF the SWN_2 is clearly the best.

RESULTS: CONVERGENCE SPEED

Small RF Large RF

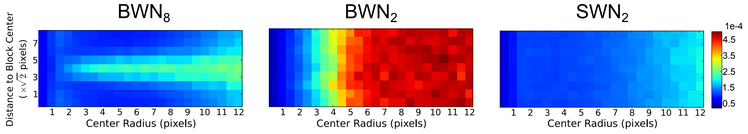
STA error as a function of time:



Conclusion: For small RFs, given that the neuron's spike rate is similar under the three stimuli, the speed of convergence is similar. In contrary, for large RFs, the neuron's spike rate under BWN_2 stimulation is low, therefore the speed of convergence as well. In both cases, the SWN_2 converges as fast as BWN_8.

RESUTS: ESTIMATION ERROR

STA error as a function of the DOG position and size:



Conclusion: In general, the STA error is smaller under the SWN_2 than both BWN_8 and BWN_2. Furthermore, under the SWN_2 the error does not depend on the position, but it depends sightly on the RF size.

CONCLUSIONS

The shifted stimulus has the following properties:
1) 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.
2) Targeting a given STA spatial resolution, shifting the stimulus increases the convergence speed.
This means that, for a fixed stimulation time, this method allows a global improvement in the estimation RFs independently of their characteristics. Thus, this shifted stumulus method is suitable to fastly and accurately estimate the RFs of large neural ensembles.

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