Selectivity to oriented patterns of different precisions

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Abstract

The selectivity of the visual system to oriented patterns is very well documented in a wide range of species, especially in mammals. In particular, neurons of the primary visual cortex are anatomically grouped by their preference to a given oriented visual stimulus. Interactions between such groups of neurons have been successfully modeled using recurrently-connected network of spiking neurons, so called "ring models". Nonetheless, this selectivity is most often studied with crystal-like patterns such as gratings. Here, we studied the ability of human observers to discriminate texture-like patterns for which we could quantitatively tune the precision of their oriented content and we propose a generic model to explain such results. The first contribution shows that the discrimination threshold as a function of the precision did not vary smoothly as would be expected, but more in a binary, "all or none" fashion. Our second contribution is to propose a novel model of orientation selectivity that is based on deep-learning techniques, which performance we evaluated in the same task. This model has human-like performance in term of accuracy and exhibits qualitatively similar psychophysical curves. One hypothesis that such a structure allows for the system to be robust to noise in its visual inputs.

Introduction

We investigated the performance of a novel computational model in comparison to humans in a orientation discrimination task. As a common frame of testing, we used **MotionClouds** [1] : random textures with natural-like stimulation, for which orientation θ and noise B_θ are controlled :

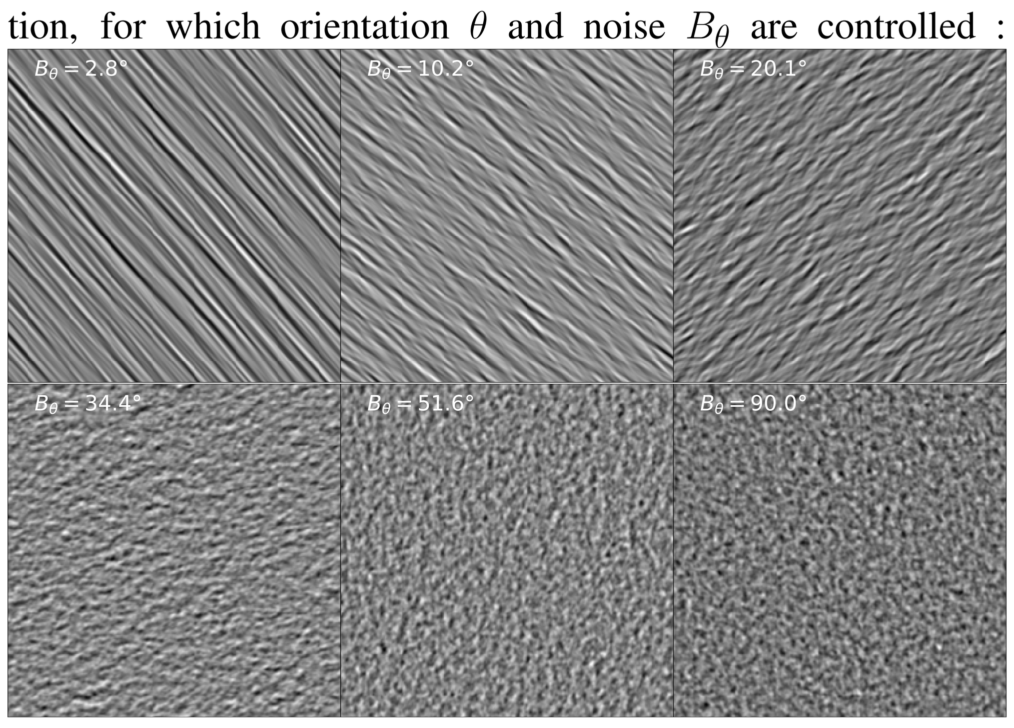


Figure 1: MotionClouds are oriented stimulus made of Von-Mises distributions. The bandwidth, B_θ controls the noise of the stimulus and θ controls its orientation. Can you guess the orientation for bandwidths of the lower row ?

Ring Model

Our model was trained on 3800 MotionClouds, with θ in 16 discrete classes $\in [0;\pi]$ and B_θ continuous $\in [1;15°]$. Accuracy was tested on 570 similar stimulus.

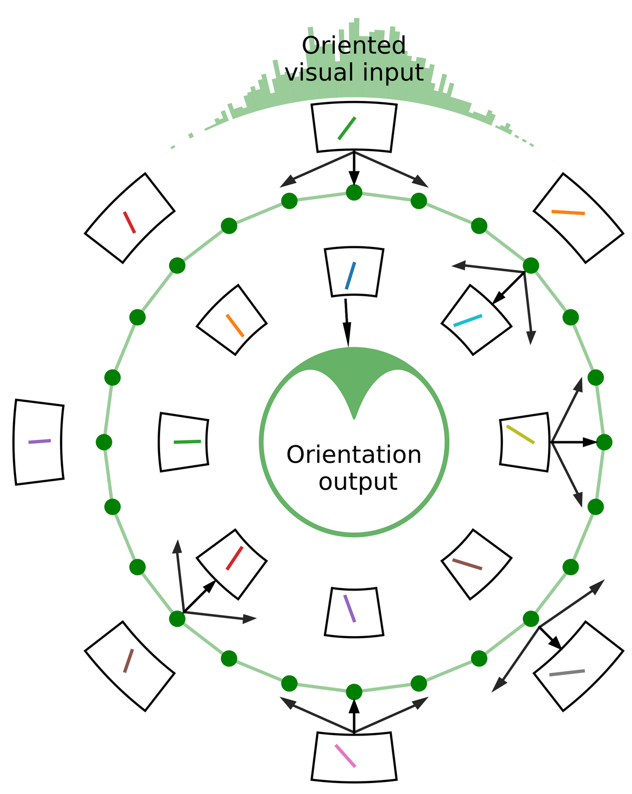


Figure 2: The Deep Recurrent Ring Model. Following [2], cortical columns are modeled by **convolutional neural networks** (outer and inner layer) and lateral connectivity is established using a **bidirectional LSTM network** (median layer) [3].

Psychophysics Data

2AFC Task

For our 2-Alternative Forced Choice task (2AFC), subjects were shown two different MotionClouds in quick succession. The first θ was always 90° (vertical) and the second was randomly chosen to produce a left/right shift. Subjects then had 1000 ms to **guess the direction of this shift**.

- For each human trial, B_θ was randomly chosen out of 7 possibilities and 150 trials were performed.
- For each model trial, B_θ was randomly chosen out of 15 possibilities and 600 trials were performed.

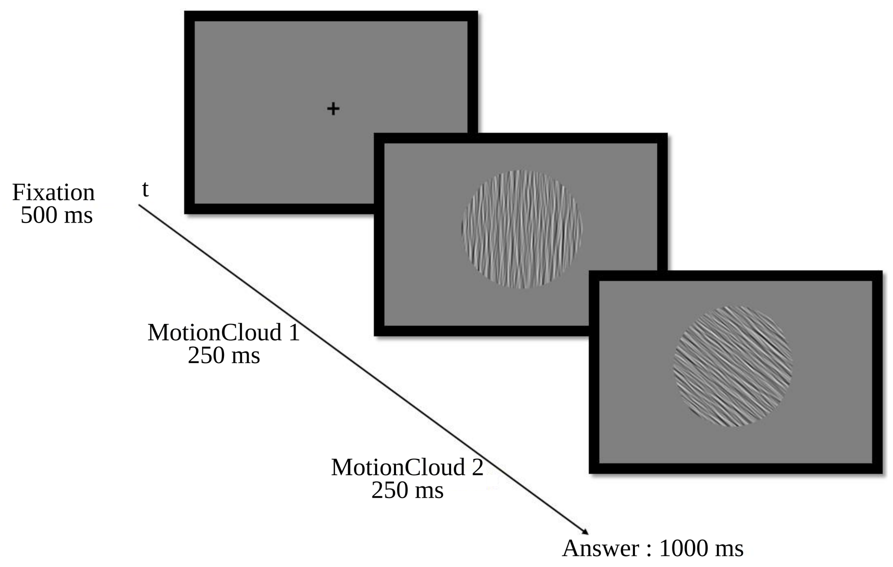


Figure 3: 2AFC task design. After a fixation time, subject were shown two stimulus before having to guess a shift, for a total of 2s per trial. n = 13.

Human vs Model performance

Accuracy for 2AFC task was best for $B_\theta < 28°$ and underwent a **rapid, full collapse** for $B_\theta > 51°$, both for humans and model runs. Model accuracy was slightly lower than humans' for all noise level.

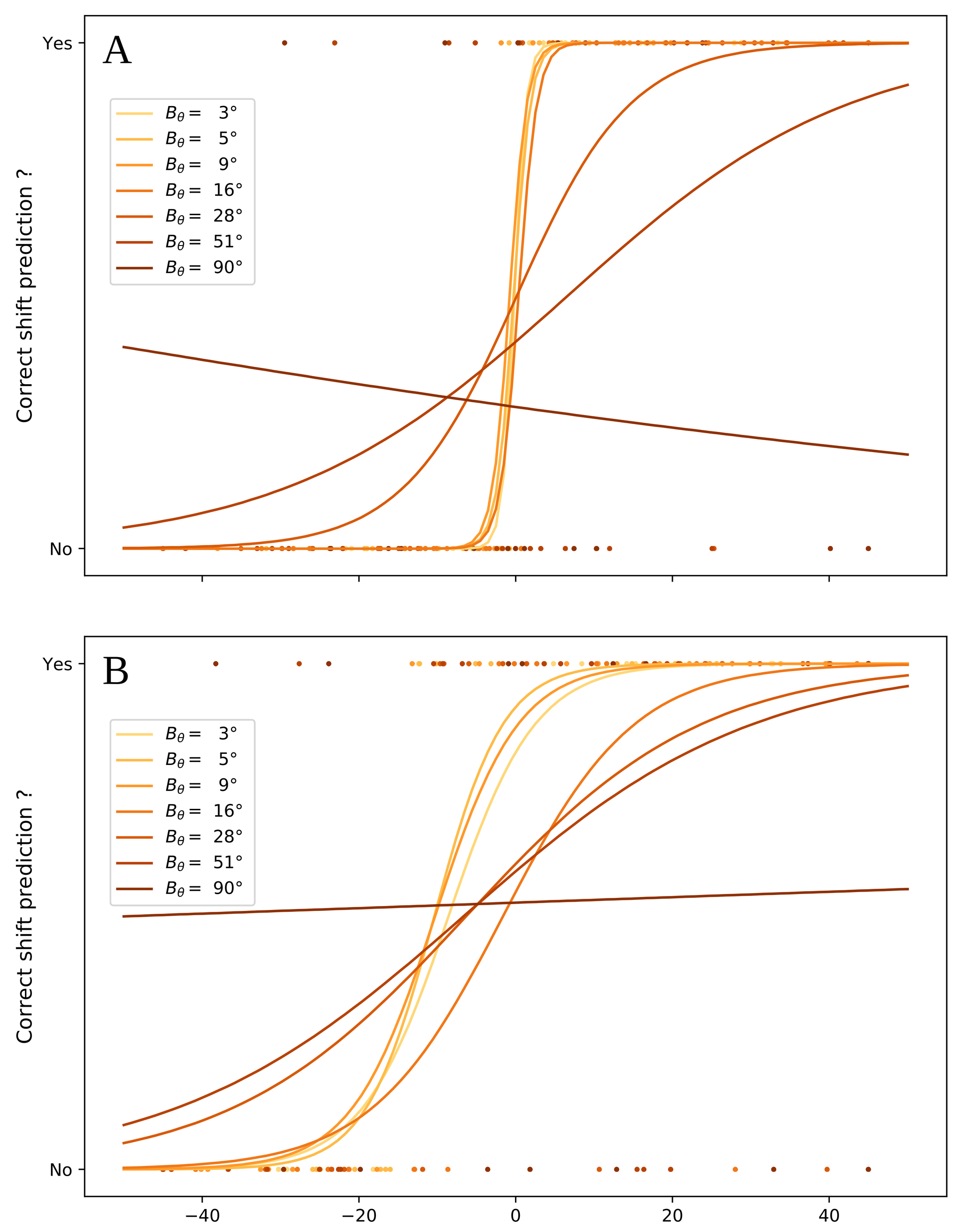


Figure 4: Logistic regressions for a randomly picked human subject (A) and Ring Model (B).

F1 scores

We subsequently compared F1 scores, whose distribution is consistent with our previous interpretation that our model is relevant in approximating human performance in this task. Furthermore, subjects had a 'all or none' F1 score variation with a variable B_θ threshold.

The role of lateral connectivity of the primary visual cortex was also investigated using the model. **LSTM was deactivated**, leaving the cortical columns without any lateral information, causing a threefold lower F1 score for $B_\theta > 40°$.

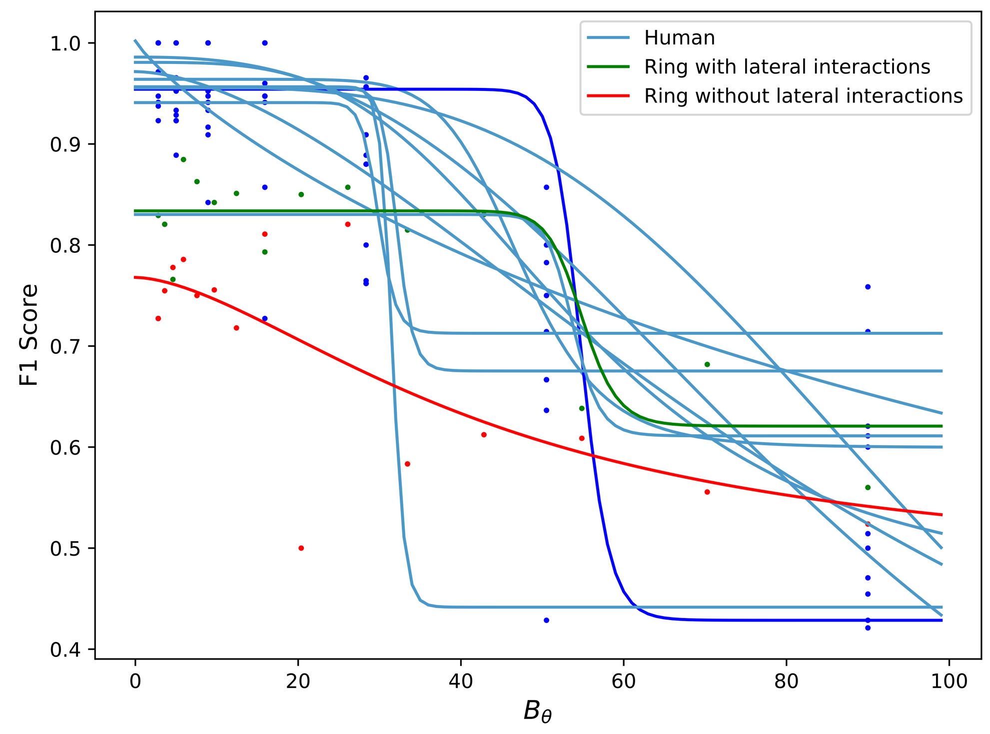


Figure 5: Quadratic logistic regressions for the same randomly picked human subject as Figure 4(A) (dark blue), other human subjects, Ring Model and a Ring Model with an inactive lateral connectivity.

Conclusions

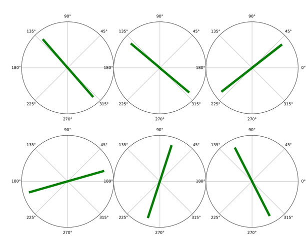
The visual cortex is canonically described as a group of cortical columns organized in a hierarchical network, whose entry level consists of oriented stimulus in the visual field [4].

In this network, the role of lateral connectivity between columns selective to different orientation has often been theorized to be an inhibitor network for neighbouring columns [5] or a support for contour integration [6].

Here, using a new deep-learning model, we showed that orientation discrimination of the primary visual cortex varies in an 'all or none' fashion past a certain threshold. Suppressing the lateral connectivity of this model resulted in a tremendous F1 loss only for higher B_θ, hence our hypothesis that this lateral connectivity could also increase the robustness of the primary visual cortex to noisy inputs.

Additional resources

Polar plots of the MotionClouds shown in the Introduction section.



The model and data are open-source. You can either flash the code or go to www.github.com/hugoladret/InternshipM1 to get them.

References

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