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# A Retinotopic neural fields model of perceptual switching in 2D motion integration

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## Abstract

The underlying cortical dynamics that select one percept out of multiple competing possibilities are not fully understood. Switching behaviour for a classical psychophysics stimulus, the multistable barberpole, was successfully captured in a feature-only, one-layer model of MT with adaptation and noise. However, without a representation of space, only some very specific stimulus could be considered. Here we propose a model that takes into account the spatial domain in a two-layer configuration modelling V1 and MT cortical areas whilst incorporating both adaptation and noise.

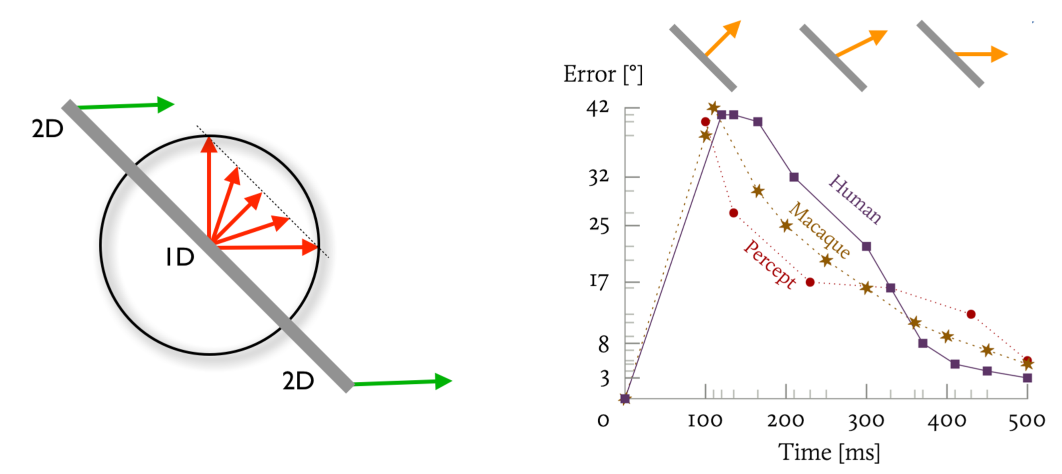
**Keywords: Motion Perception, Multistability, Neural fields, Dynamical systems, Competition, Bifurcation**

## Context and motivation

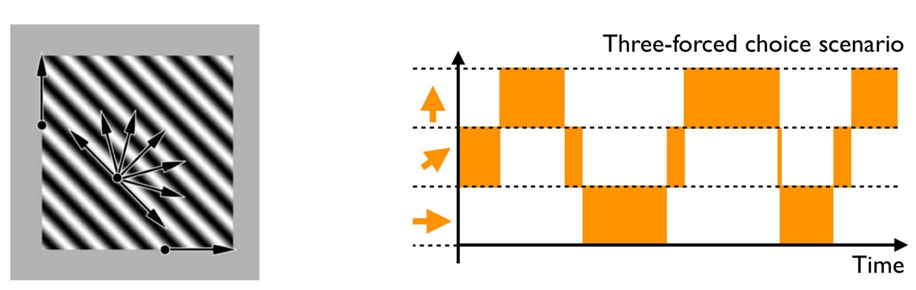
▶ Psychophysical observations on motion perception

- Motion perception results from a non-local integration process.


- Motion integration is a dynamical process (Masson, Rybarczyk, et al., Visual Neuroscience 2000).




- These dynamical process can have multiple solutions resulting in perceptual switching: Perceptual multistability is a phenomenon in which alternate interpretations of a fixed stimulus are perceived intermittently.




▶ About underlying neural mechanisms and cortical area MT

- Several cortical areas are involved in motion estimation
- MT is highly specialized for visual motion (Born and Bradley, 2005)
- MT has a rich set of interconnections with other regions, including feedbacks to V1 (Angelucci and Bulier, 2003)
- Cortical responses of MT have been linked specifically to the perception of motion (Britten, 2003)

▶ Modeling neural mechanisms of motion perception

- Building on the first linear/non-linear models (Chey et al. 1997; Simoncelli and Heeger 1998), several approaches added extensions to modulate the motion integration stages: feedback between hierarchi- cal layers (Grossberg et al. 2001; Bayerl and Neumann 2004), inclusion of input form cues (Berzhanskaya et al. 2007; Bayerl and Neumann 2007), luminance diffusion gating (Tlapale et al. 2010), or depth cues (Beck and Neumann 2010)
- Although these models reproduce the predominant percepts in a wide range of stimuli, in none of the articles describing them are multistable results depicted.

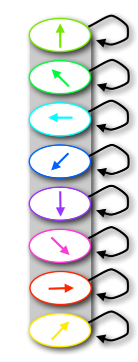
▶ About this work

- We work within the neural fields formalism: Neural fields are spatially structured neural networks which represent the spatial organization of cerebral cortex; the neural field approximation represents the mean firing rate of a neural population at the continuum limit (Bressloff, 2012)
- Neural fields equations have been successfully applied to the study of motion in, e.g., Giese (1998), Deco and Roland (2010) and Tlapale et al. (2010a)
- We aim to develop tractable models of manageable complexity that allows for a detailed study of the temporal dynamics of multistable motion perception using powerful tools from dynamical systems theory

## A neural field competition model to study multi stability

J. Rankin, A. I. Meso, et al., **Bifurcations study of a Neural fields Competition Model with an application to perceptual switching in Motion Integration**, Journal of Computational Neuroscience, 2013

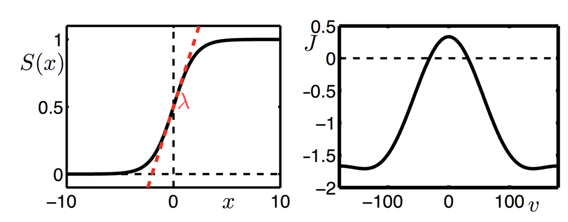
▶ Main features



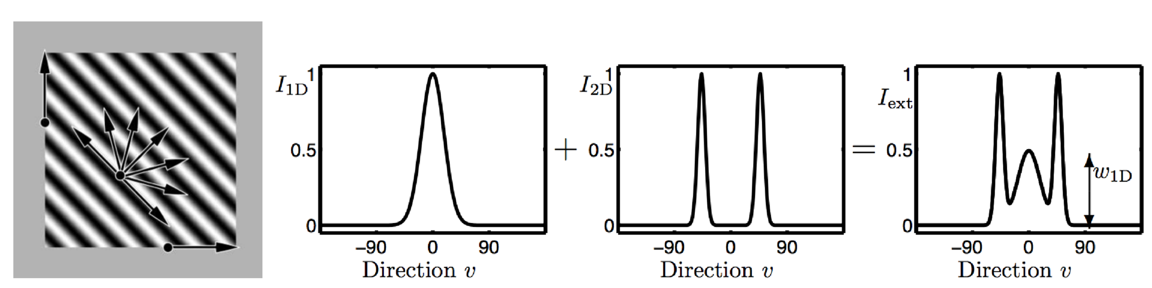
- One cortical area, feature only
- Continuous representation of MT activity across direction space ($p(t,v)$)
- An adaptation on the slow-time scale ($\alpha(t,v)$)
- Noise included in the model for comparison with psychophysics ($X(t,v)$, see paper)

▶ A slow-fast system

$$\frac{\partial p}{dt}(t,v) = -p(t,v) + S(\lambda[J(v) * p(t,v) - \alpha(t,v) + X(t,v) + k_I I(v)]),$$
$$\tau\frac{\partial \alpha}{dt}(t,v) = -\alpha(t,v) + p(t,v)$$




▶ Description of the input

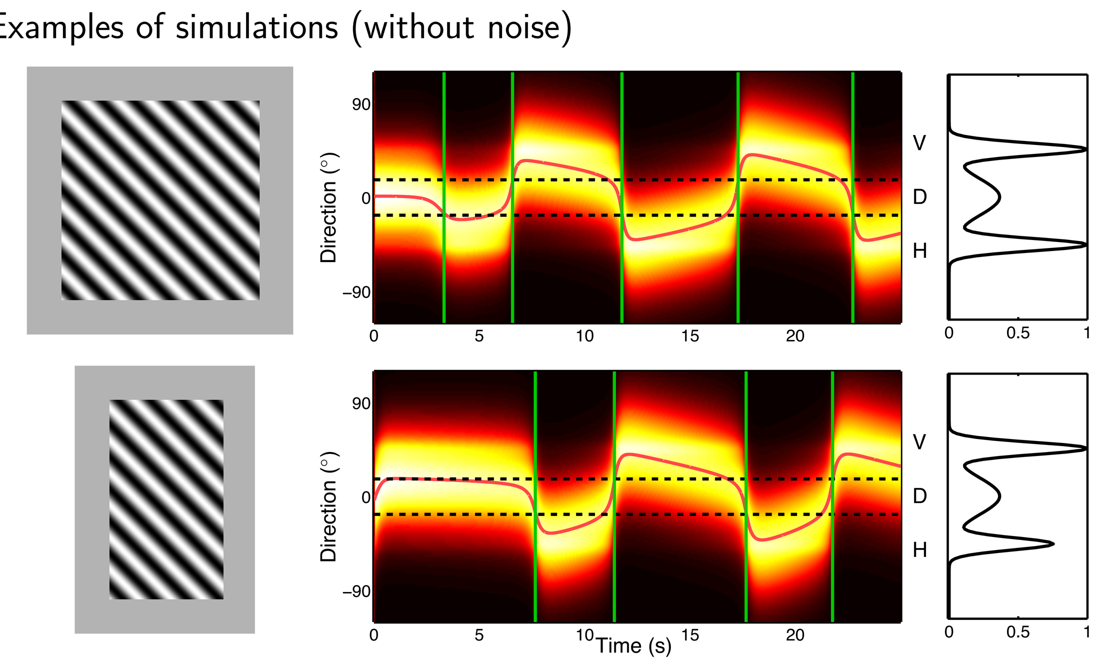



▶ Summary of results from Rankin, Meso et al. 2013

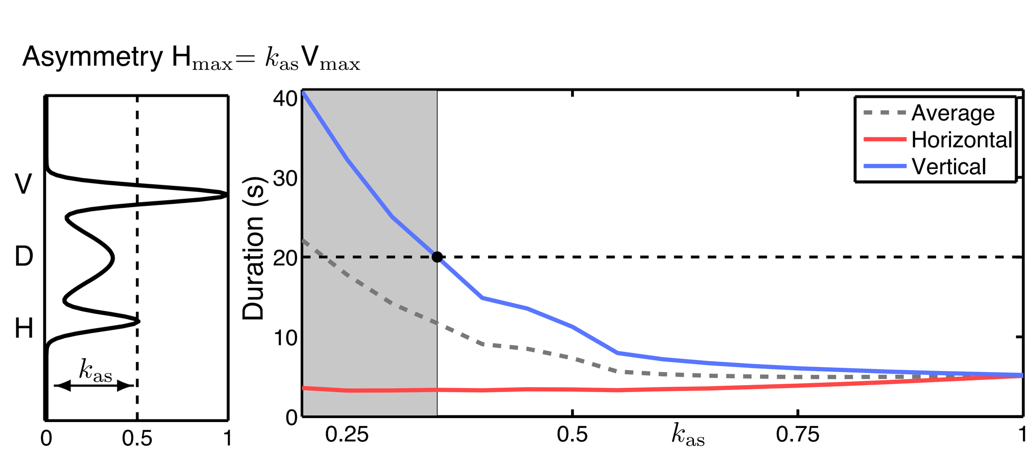
- We investigated multi stability w.r.t contrast alongside concurrent pyschophysics experiments
- Modeling results showed a shifting balance between adaptation and noise drives switching in different contrast regimes
- We provided predictions to test this hypothesis in psychophysics

▶ Symmetric/Asymmetric aperture

- Examples of simulations (without noise)



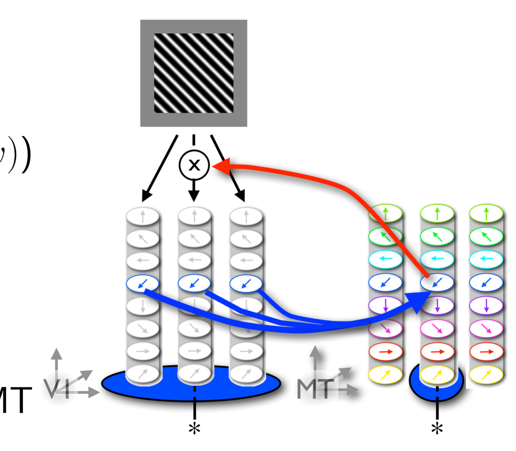

- Qualitative study without noise
  - A regime predicted in the simulations is not feasible for experimental study
  - How to select the aperture ratio to reflect the shape of the aperture?




## Extension: Two cortical retinotopic areas

▶ Main features

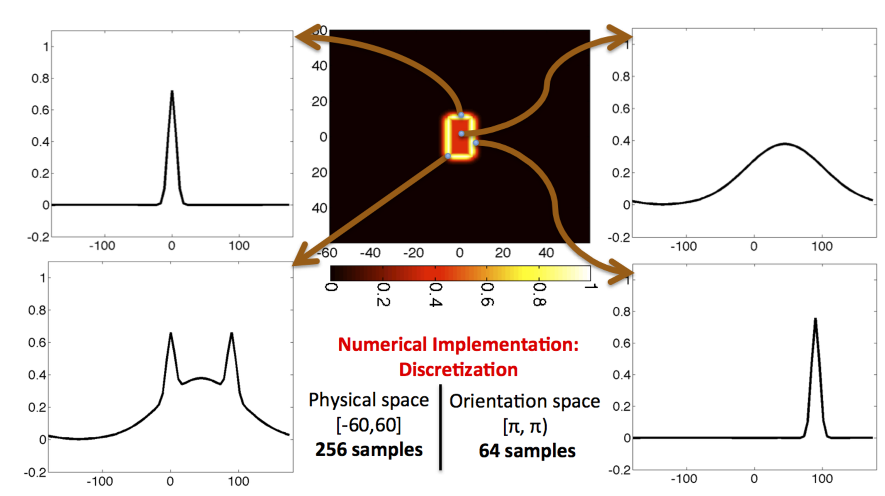
- Two cortical areas: V1 ($p_1(t,x,v)$) and MT ($p_1(t,x,v)$)
- Feedforward integration ($G$)
- Modulatory feedback ($\lambda_m$)
- Lateral connectivity ($J_1$ and $J_2$)
- Adaptation at the level of MT ($\alpha$(t,x,v))




▶ Mathematical description of the model

$$\frac{\partial p_1}{\partial t}(t,x,v) = -p_1(t,x,v) + S\left(J_1 * p_1(t,x,v) + p_0(t,x,v)(1+\lambda_m p_2(t,x,v))\right)$$
$$\frac{\partial p_2}{\partial t}(t,x,v) = -p_2(t,x,v) + S\left(G \overset{x}{*} p_1(t,x,v) + J_2 * p_2(t,x,v) - \alpha(x,t,v)\right)$$
$$\frac{\partial \alpha}{\partial t}(t,x,v) = \varepsilon\left(-\alpha(t,x,v) + p_2(t,x,v)\right)$$

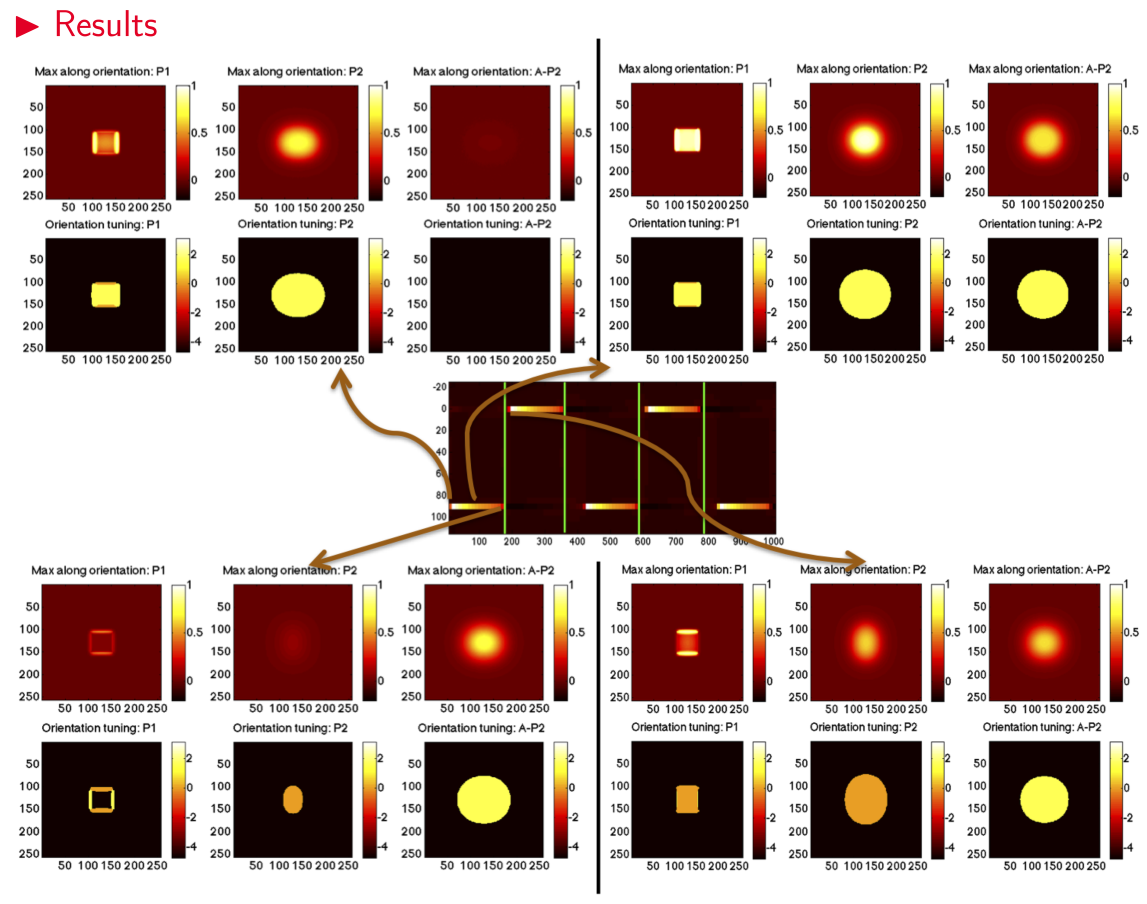
▶ Description of the input




▶ Numerical implementation

- After discretization, the dimensionality of $p_i(t,x,v)$ and $\alpha(t,x,v)$ at any time time $t_j$ is $256 \times 256 \times 64$
- The simulations are performed with help of GPUs using CUDA.

▶ Results



Videos are available

## Conclusion

- Our feature only model has been previously used to study multistable switching for a symmetric aperture
- It can also capture asymmetry but it is ignoring the detail of the spatial interaction
- We proposed a retinotopic model that includes recurrent multi layer interactions that solve motion integration and captures multi stable behavior
- The retinotopic model allows us to investigate other stimuli
- We need bifurcation analysis to investigate selectivity properties of different kernels (e.g., subtractive inhibition, DOG)

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