Team
NeuroMathComp

2004 Route des Lucioles
06902 Sophia Antipolis
France

http://www-sop.inria.fr/neuromathcomp

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

N V Kartheek Medathati[1] - James Rankin[1] - Pierre Kornprobst[1] - Guillaume S. Masson[2]
(1) Inria, Team Neuromathcomp, France – (2) Institut des Neurosciences de la Timone, Team InVibe, France

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 adaptation to drive switches.

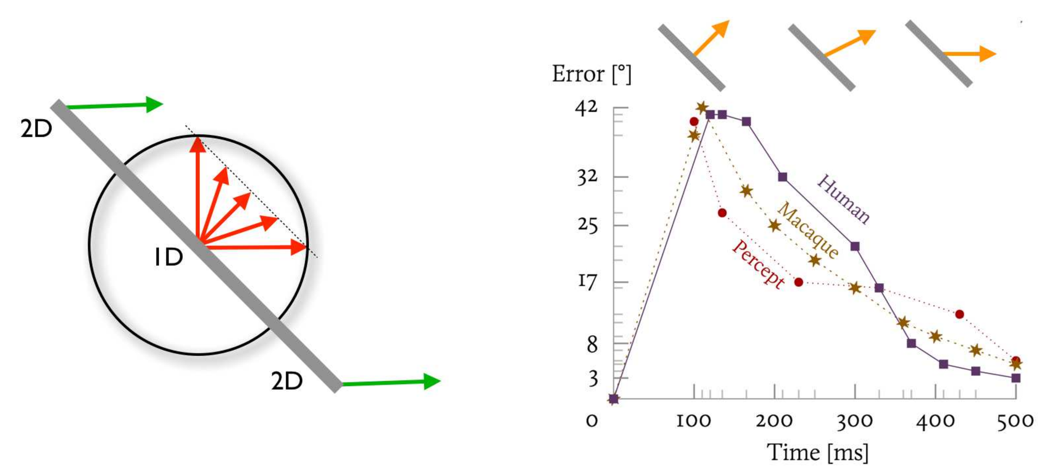
Keywords: Motion Perception, Multistability, Neural fields, Dynamical systems, Competition, Bifurcation

Context and motivation

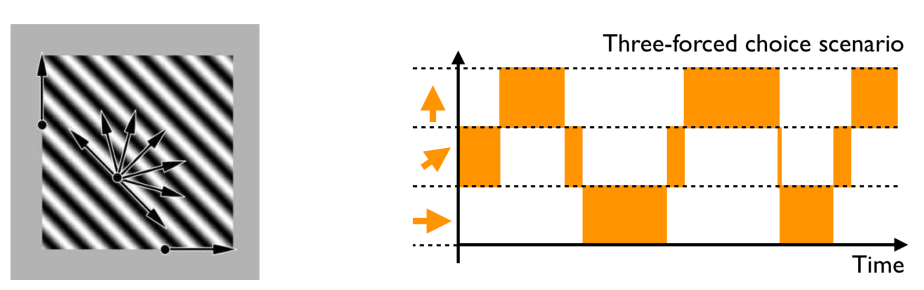
▶ Psychophysical observations on motion perception

- 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 hierarchical 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

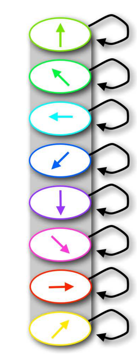
▶ About this work

- 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 allow 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

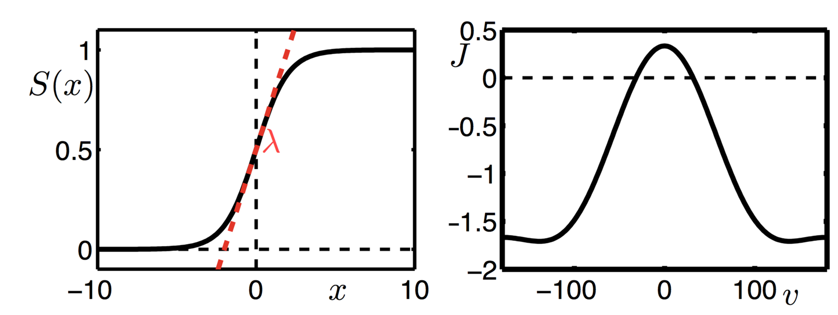
▶ Main features



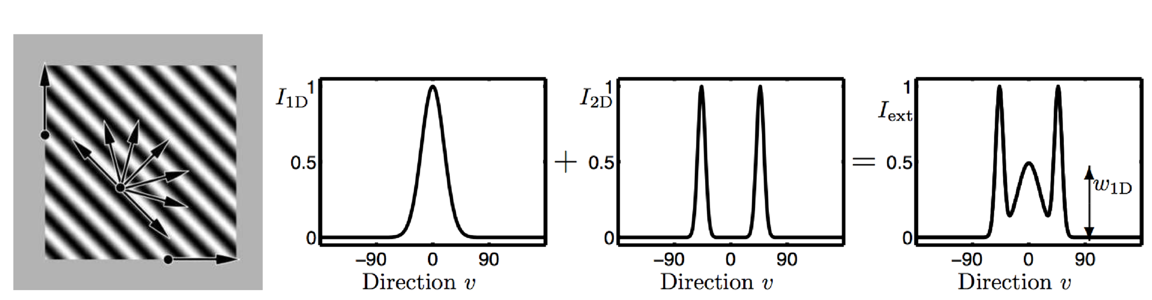
- One cortical area, feature only
- Continuous representation of MT activity across direction space ($p(t, v)$)
- An adaptation on the slow-time scale ($\alpha(t, v)$)
- Noise included in the model for comparison with psychophysics ($X(t, v)$, see paper)

▶ 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

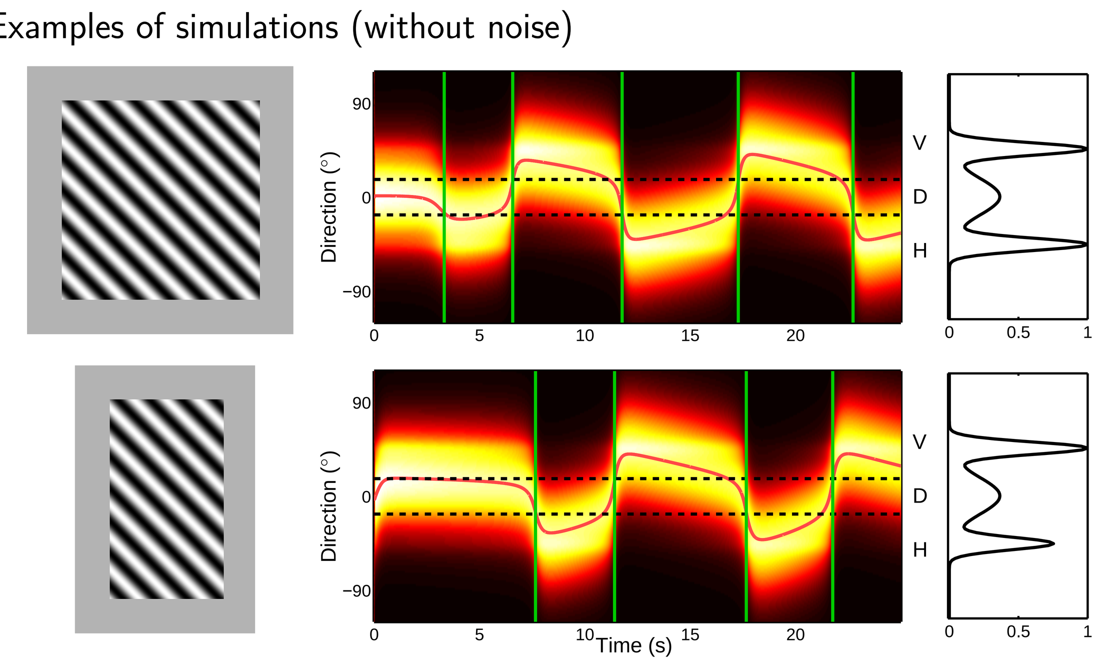


▶ Summary of results from Rankin, Meso et al. 2013

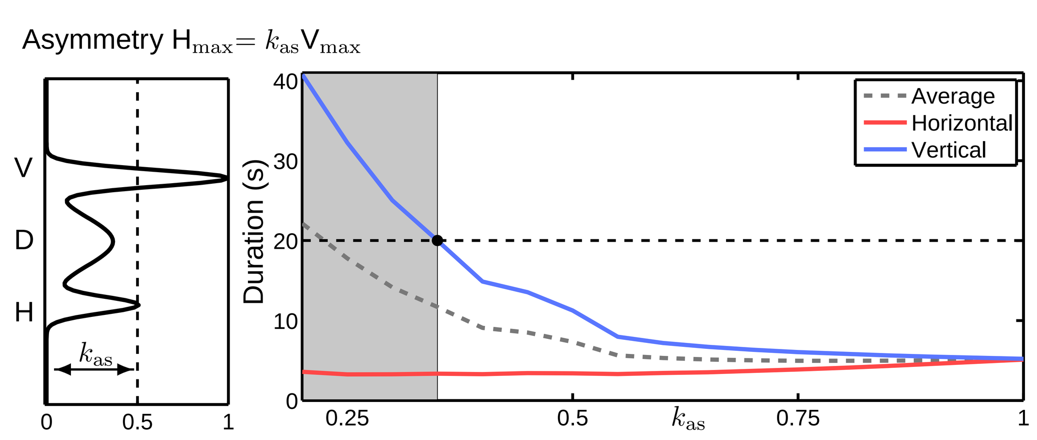
- We investigated multistability w.r.t contrast alongside concurrent pyschophysics experiments
- Modeling results showed a shifting balance between adaptation and noise drives switching in different contrast regimes
- We provided predictions to test this hypothesis in psychophysics

▶ Symmetric/Asymmetric aperture

- Examples of simulations (without noise)



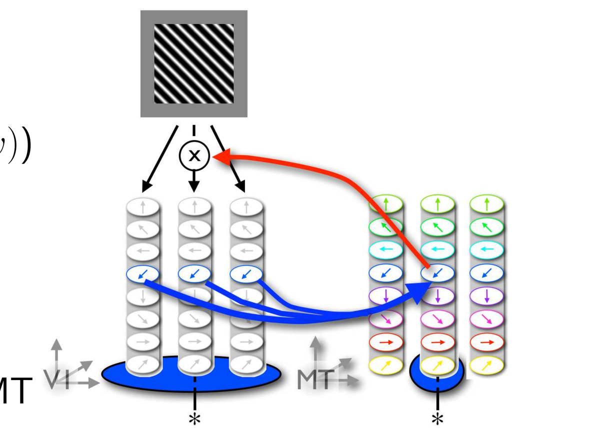
- Qualitative study without noise
  - A regime predicted in the simulations is not feasible for experimental study
  - How to select the aperture ratio to reflect the shape of the aperture?



Extension: Two cortical retinotopic areas

▶ Main features

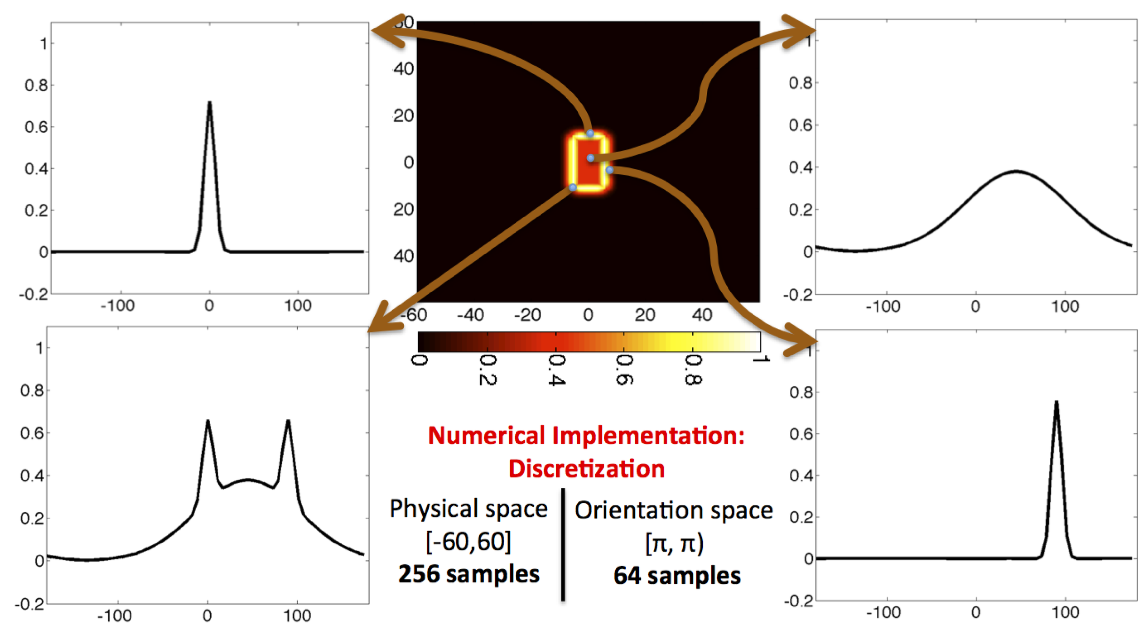
- Two cortical areas: V1 ($p_1(t, x, v)$) and MT ($p_2(t, x, v)$)
- Feedforward integration (G)
- Modulatory feedback (λ_m)
- Lateral connectivity (J_1 and J_2)
- Adaptation at the level of MT (α(t,x,v))



▶ Mathematical description of the model

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

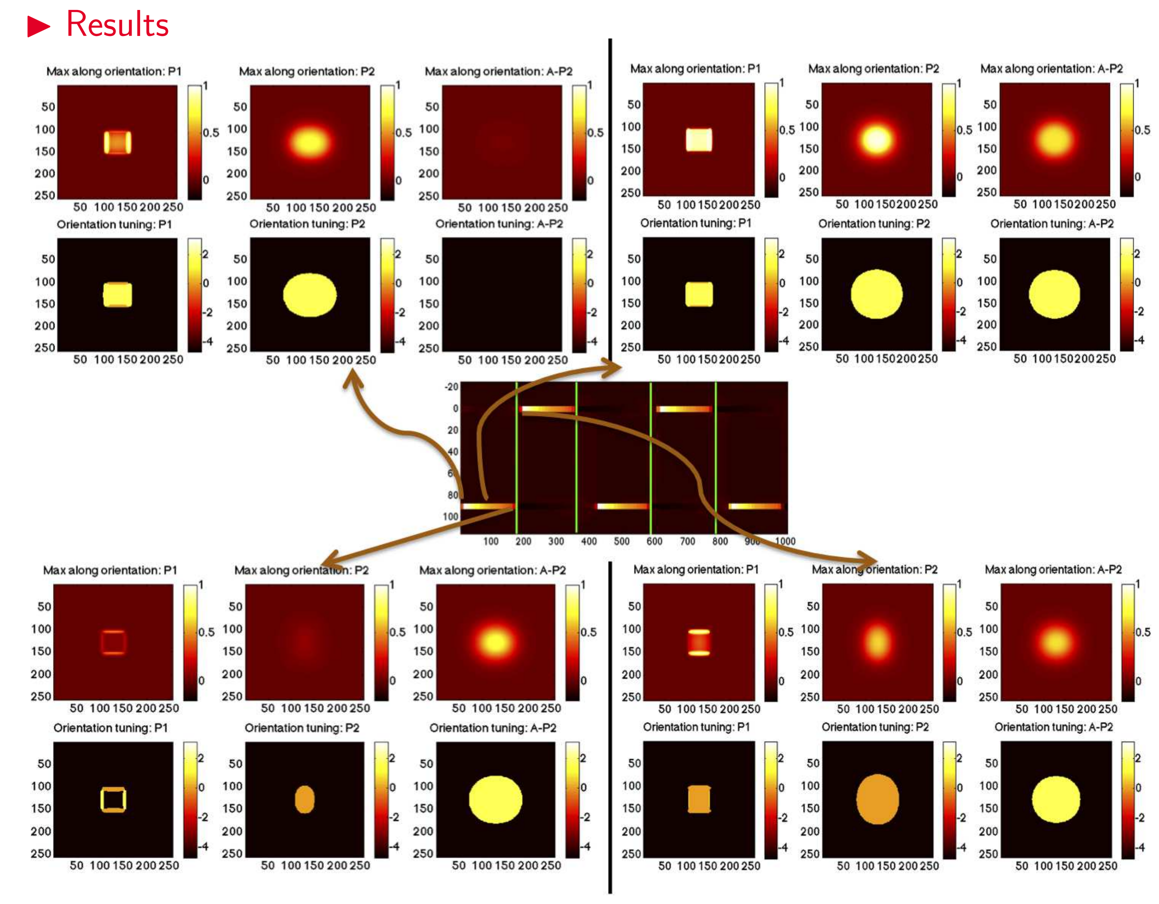
▶ Description of the input



▶ Numerical implementation

- After discretization, the dimensionality of $p_i(t, x, v)$ and $\alpha(t, x, v)$ at any time 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 solves motion integration and captures multistable behavior
- The retinotopic model allows us to investigate other stimuli
- We will use bifurcation analysis to investigate selectivity properties of different kernels (e.g., subtractive inhibition, DOG)

This work was partially supported by the
EC IP project FP7-ICT-2011-8 no. 318723 (MatheMACS)

N V Kartheek Medathati
kartheek.medathati@inria.fr
http://www-sop.inria.fr/members/Kartheek.Medathati