

European Conference on Visual Perception
30/08/2017

A multi-stable gravitational approach to fixational eye movements

Kevin Parisot

A. Chauvin, A. Guérin-Dugué, R. Phlypo, S. Zozor



Grenoble



Agenda

- Context:
 - Experimental work on bi-stability
 - Observations of micro-pursuits
 - Current models of Fixational Eye Movements (FEM)
- Model description
- Perceptual multi-stability perspectives

Context

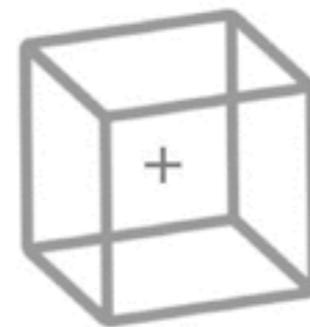
Motion on a Necker cube



FX



RW



LJ

Manipulate perceptual reversal dynamics of bi-stability (Necker cube) using retinal image motion:

FX: no stimulus motion (fixed)

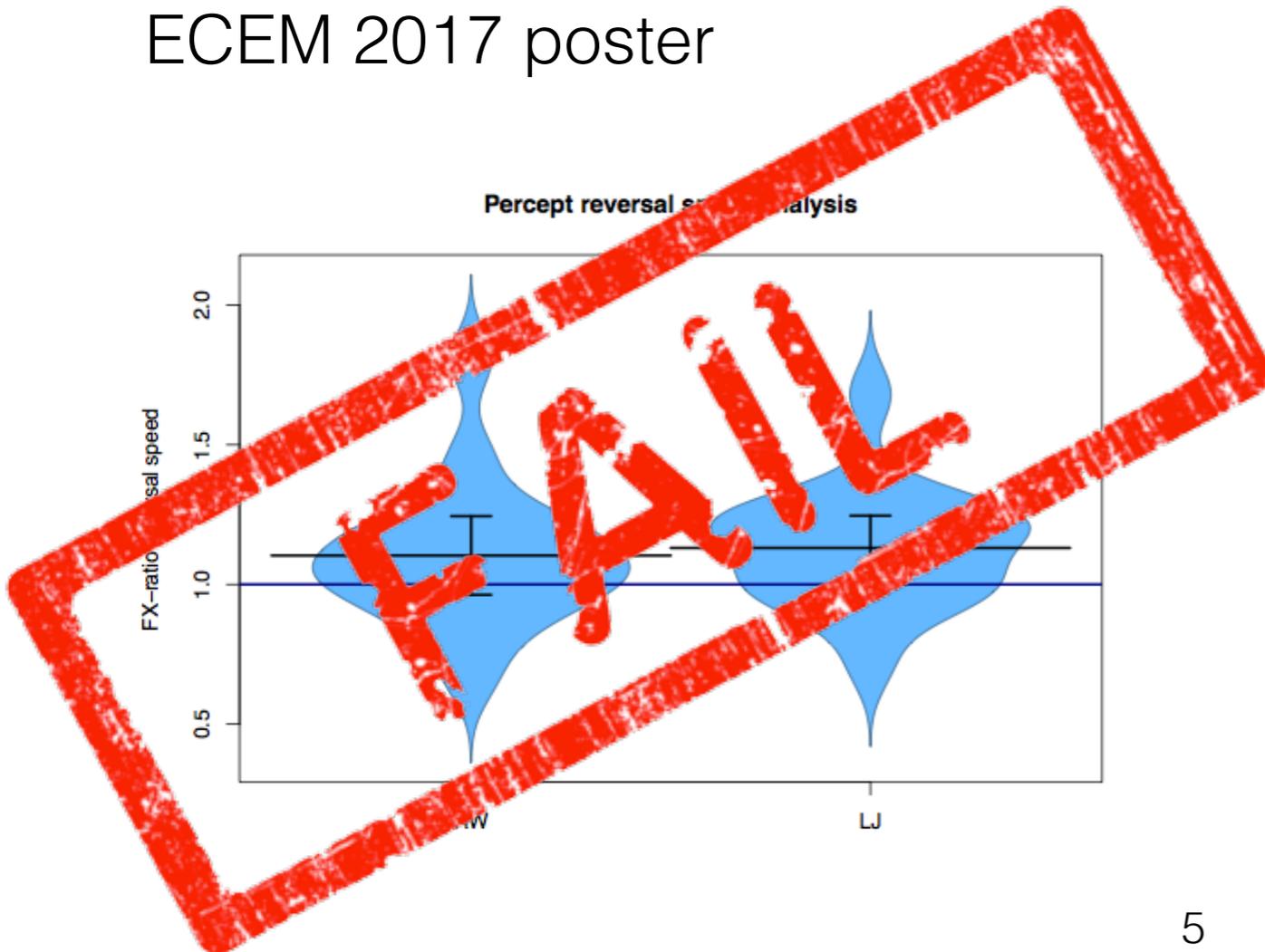
RW: unpredictable pseudo-random movement (random walk)

LJ: predictable smooth Lissajou trajectory

Experimental results

Perceptual dynamics results did not agree with hypotheses driven from bi-stability models

We investigated for a possible explanation in **ocular data**; ECEM 2017 poster



gipsa-lab
Laboratoire de Psychologie et Neurosciences
PERSYVAL-3

Motion on a Necker cube leads to micro-pursuit-like eye movements and affects the dynamics of bistability

Kevin Parisot, Alan Chauvin, Anne Guérin-Dugué, Ronald Phlypo, Steeve Zozor
kevin.parisot@gipsa-lab.fr, alan.chauvin@univ-grenoble-alpes.fr, anne.guerin@gipsa-lab.fr, ronald.phlypo@gipsa-lab.fr, steeve.zozor@gipsa-lab.fr

Objectives
Study the effects of adaptation and noise on perceptual reversal speed:

Theoretical models of bistable perception
Bistable perception: oscillation between different perceptual states under constant physical stimulus.
Models: Constant stimulation → neural adaptation → periodic suppression of alternative percept energy → adaptation drives the choice of percept.
Hypothesis: Predictable retinal image motion → counteract adaptation effect → observe lower reversal speed (cf. binocular rivalry results from Blake, Sobel & Gilroy, 2003).
Models: Visual processing noise → noise triggers percept reversal.
Hypothesis: Unpredictable retinal image motion → variance of visual information input → increase system noise → observe higher reversal speed.

Experimental protocol
Task: stare at fixation cross (screen center) during a sequence of stimulus presentation (Necker cube - Fig. 2a) & report perceptual changes with keypad.
Participants: n = 26 (16 females and 10 males, M(age) = 28.35, SD(age) = 10.93, range = 20-71). 16 participants were analyzed after outliers & incoherent data removal.
Conditions:
FX: no stimulus motion (Fixed).
RW: pseudo-random movements (Random Walk).
LJ: smooth Lissajou trajectory.
Global sequence motion was matched between RW & LJ → 36 deg/sec.
Experimental design: 3 blocks of 15 sequences (pseudo-random shuffle) of 5-9 reversals.

Behavioral analysis
Percept reversal speeds (RS) calculated from measured phase times. As in Blake et al., (2003) RS [rev/min] was computed:
 $RS_{rev} = \frac{n_{rev} \times 60}{T_{seq}}$ where n_{rev} : number of reversals, T_{seq} : sequence total time.
Results:
RW will increase RS → not strong enough
LJ will decrease RS → opposite
LJ results differ from binocular rivalry (Blake, Sobel & Gilroy, 2003).

Eye-tracking analysis
Adaptation mitigation based on predictable motion of retinal image → excite new populations of neurons.
Warning: depends on participants' gaze stability on fixation cross.
Measures:
M1. Inertia: $I_s = \frac{1}{N_s} \sum_{i=1}^N (x_i^2 + y_i^2)$ where N_s : number of signal samples, (x_i, y_i) : spatial coordinates of signal s adjusted to different referential (e.g. center of screen, center of fixation, stimulus position, etc).
M2. Mutual information: $I(X;Y) = H(Y) - H(Y|X)$ where $H(Y)$: the marginal entropy and $H(Y|X)$: the conditional entropy under the assumptions of normal joint distribution and independence.
Fixational eye movements (FEM) displacement, mean sequence inertia (see M1) w.r.t. fixation event position (see Fig. 4a):
FX = RW
FX & RW < LJ
→ LJ condition generates more FEM displacement than FX & RW.
Micro-smooth pursuits? Gaze during LJ seemed to follow cube trajectory (see Fig. 4b).
Similarity between gaze in fixations & cube trajectory computed with mutual information (see M2 & Fig. 4c): LJ ≠ RW.
Retinal image displacement, mean fixation inertia (see M1) w.r.t. gaze position (see Fig. 4d):
FX = RW = LJ
RW & LJ: variance of stimulus sensitive group smaller than task focused group.
→ RW & LJ tend to affect control of retinal image motion in stimulus sensitive group.

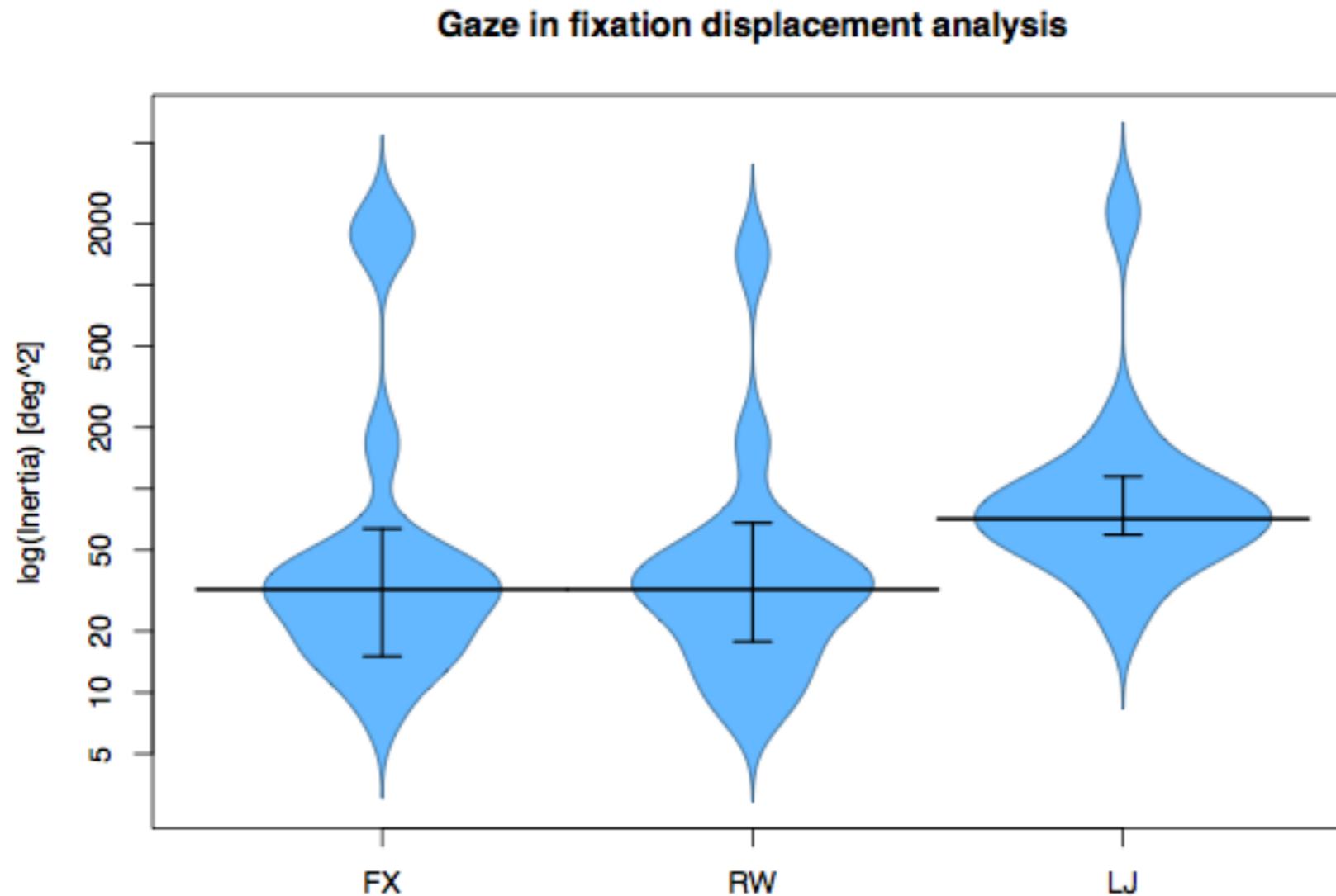
Conclusions
Stimulus motion leads to an increase in reversal speed as predicted by models but effect size is small.
Predictability of motion does not modulate noise and adaptation as expected. Retinal image shifts partially compensated by micro-smooth pursuits but does not suffice to explain behavioral results.
Experimental observations: Micro-movements of the eyes in the form of approximate smooth pursuits within fixation events detected → not studied in the context of multi-stability to our knowledge → development of a multi-stable gravitational attractor-based model of fixational eye movements (Parisot et al., ECVF 2017).

References
Blake, R., Sobel, K. V., & Gilroy, L. A. (2003). Visual motion retards alternations between conflicting perceptual interpretations. *Neuron*, 39(5), 869-878.
Leopold, D. A., & Logothetis, N. K. (1999). Multistable phenomena: changing views in perception. *Trends in cognitive sciences*, 3(7), 254-264.
Kormmeier, J., & Bach, M. (2005). The Necker cube—an ambiguous figure disambiguated in early visual processing. *Vision research*, 45(8), 955-960.
Shapiro, A., Moreno-Bote, R., Rubin, N., & Rinzel, J. (2009). Balance between noise and adaptation in competition models of perceptual bistability. *Journal of computational neuroscience*, 27(1), 37-54.
Moreno-Bote, R., Knill, D. C., & Pouget, A. (2011). Bayesian sampling in visual perception. *Proceedings of the National Academy of Sciences*, 108(30), 12491-12496.

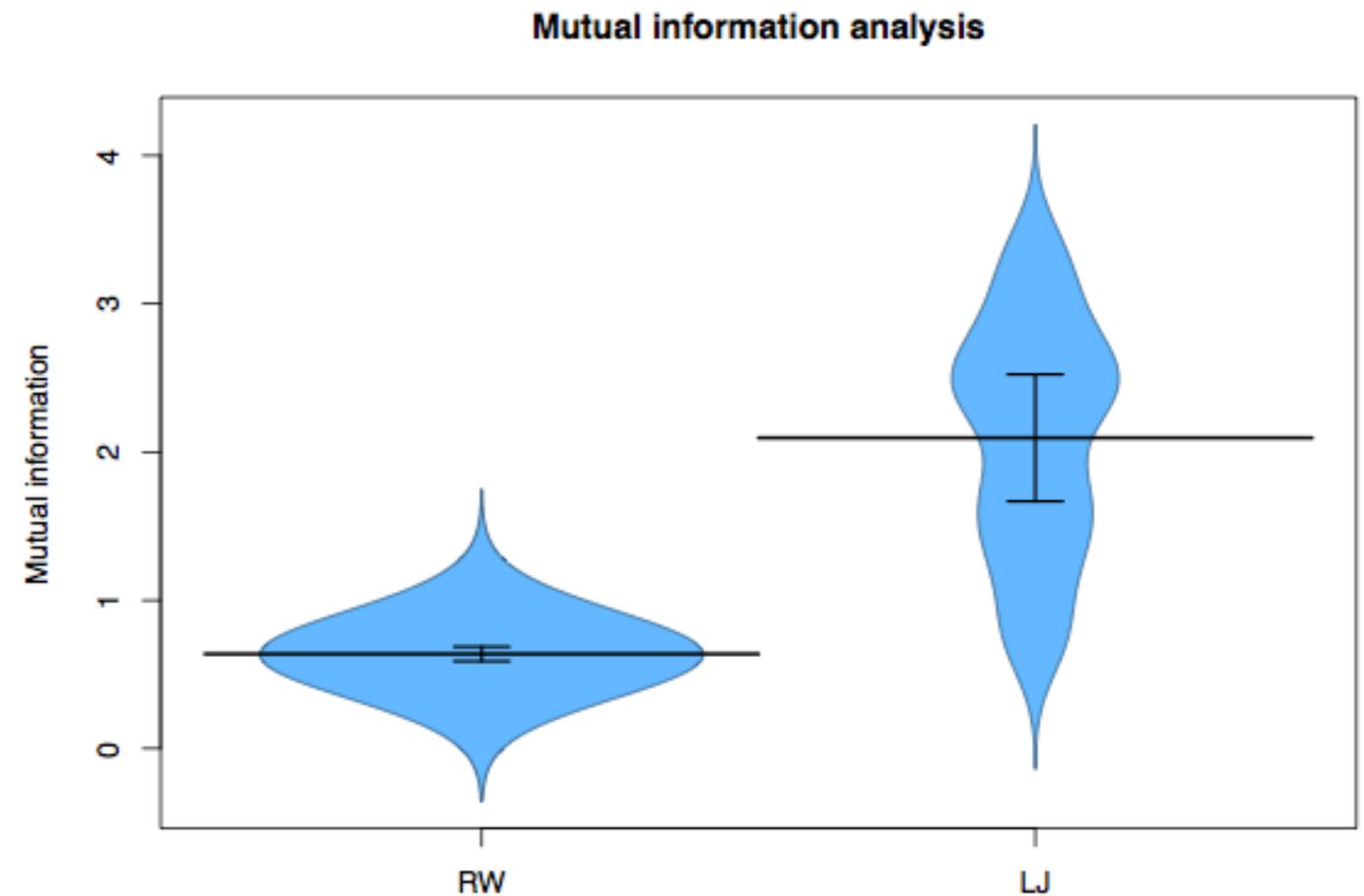
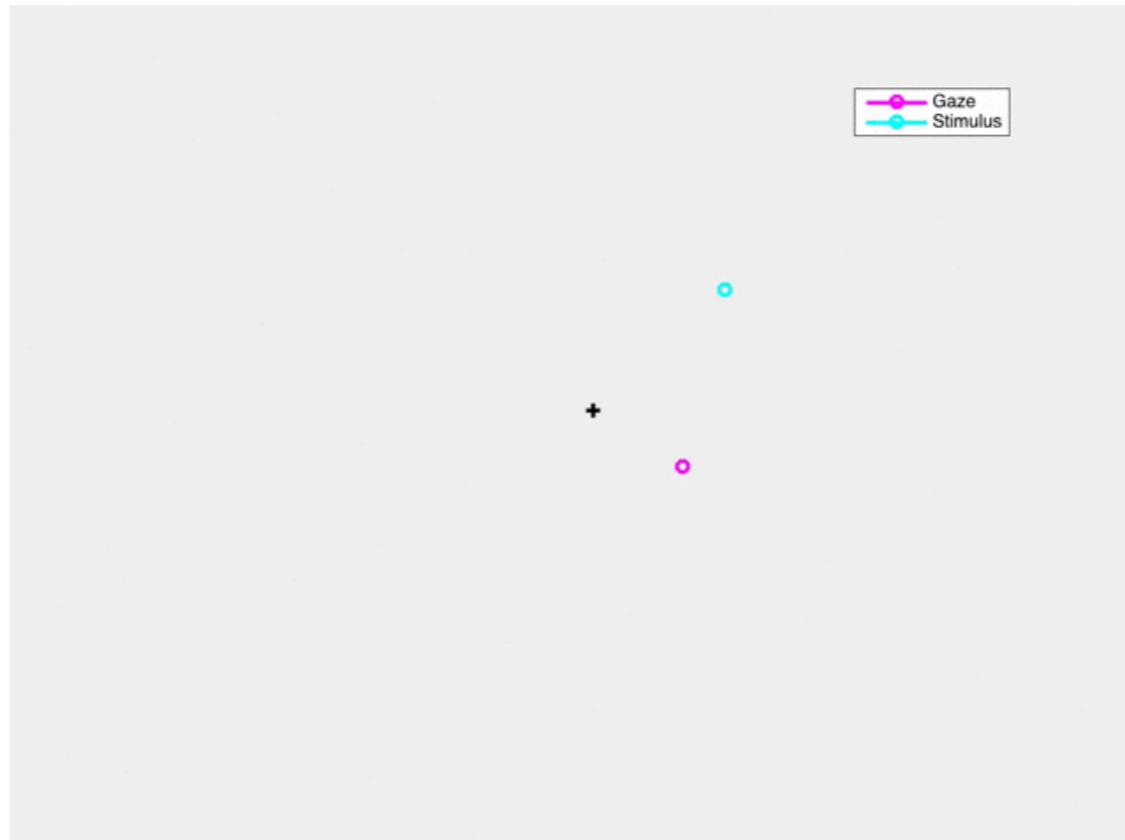
Fixational Eye Movements

Investigation of Fixational Eye Movements (FEM) displacement

Predictable condition (LJ) had higher gaze motion w.r.t. center of fixation than other conditions



Micro-pursuit eye movements



Observation of **small amplitude smooth pursuit-like fixational eye movements** ($FEM < 1^\circ$):

Mutual information used as a measure of similarity between Gaze and Stimulus

Only observed once before: Martins, A. J., Kowler, E., & Palmer, C. (1985).

JOSA

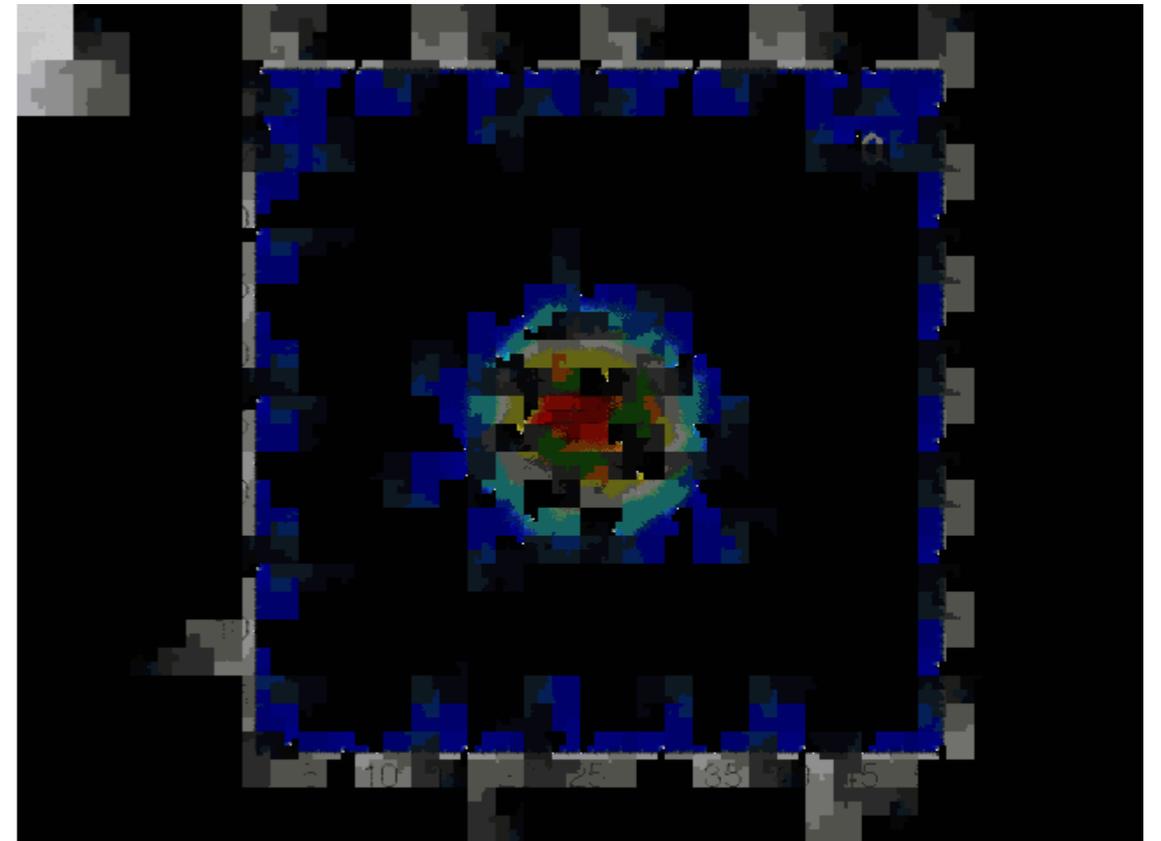
Fixational Eye Movements models

Compatibility with micro-pursuit eye movements?

Current generative model:

- Integration of micro-saccades, small amplitude saccades, and other FEM
- Use of **potential fields**

To our knowledge, no model can account for micro-pursuit eye movements!



Engbert, R., Mergenthaler, K., Sinn, P., & Pikovsky, A. (2011). *PNAS*

Sinn, P., & Engbert, R. (2016). *Vision research*

Model Description

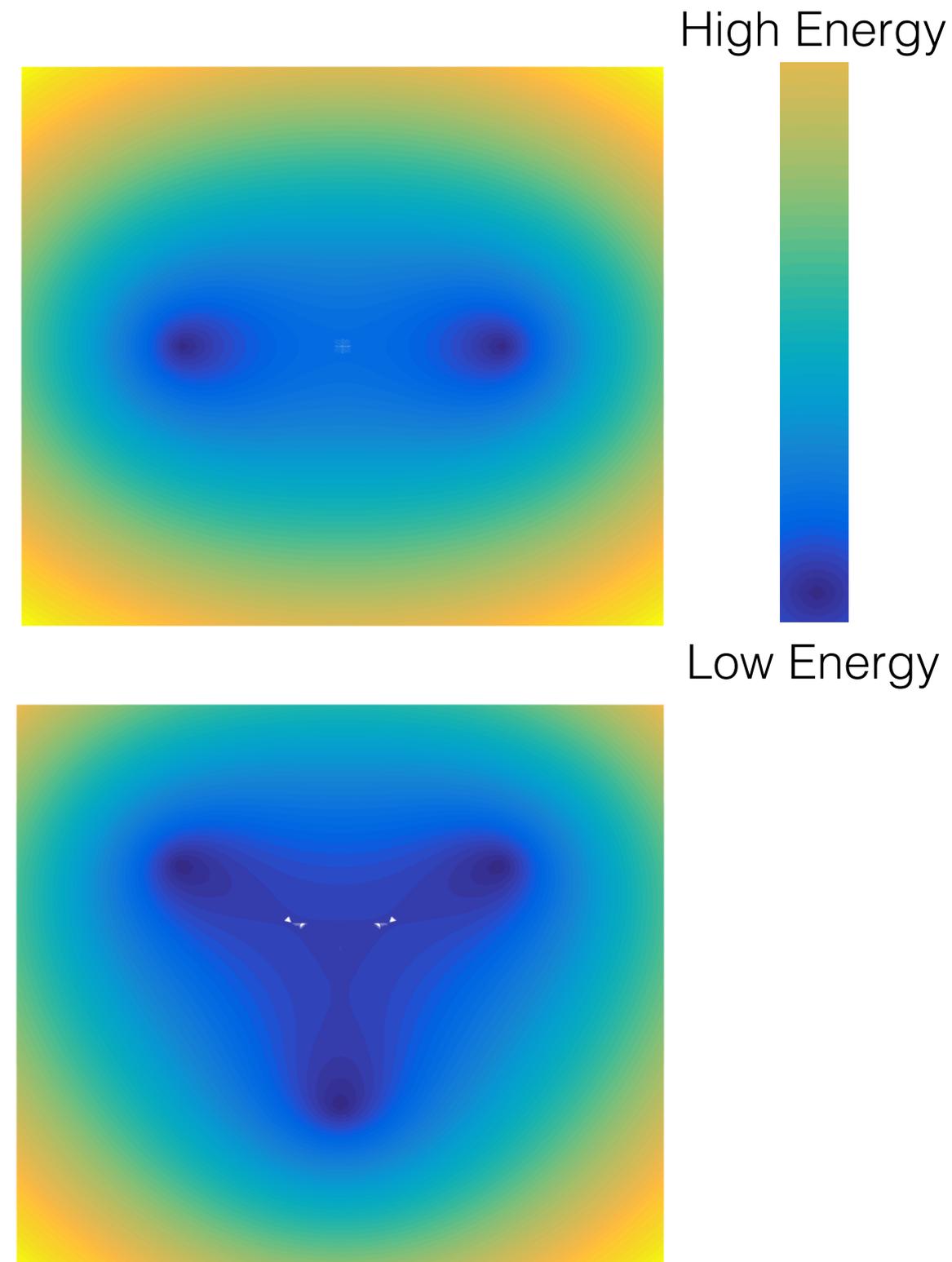
GraFEM: Gravitational potential Fixational Eye Movements model

Map of visual field

Gravitational energy **potential field (V)** can generate multiple **attractors**

Attractor **parameters**:

- position (x,y coordinates)
- depth (energy)
- slope

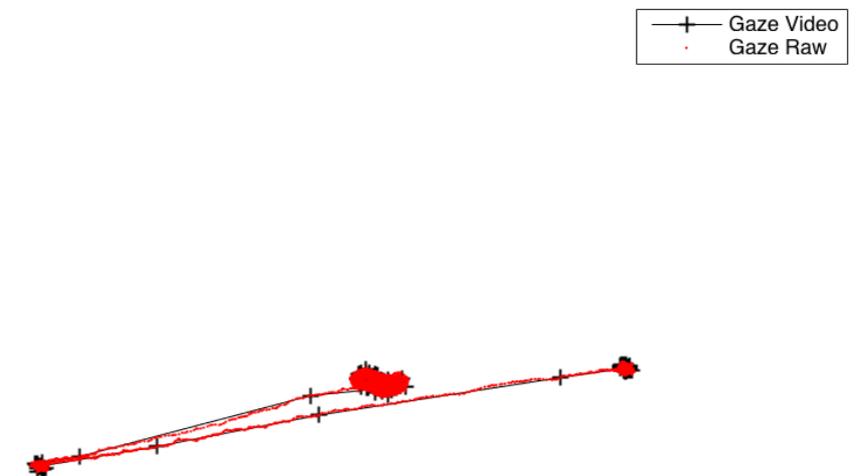
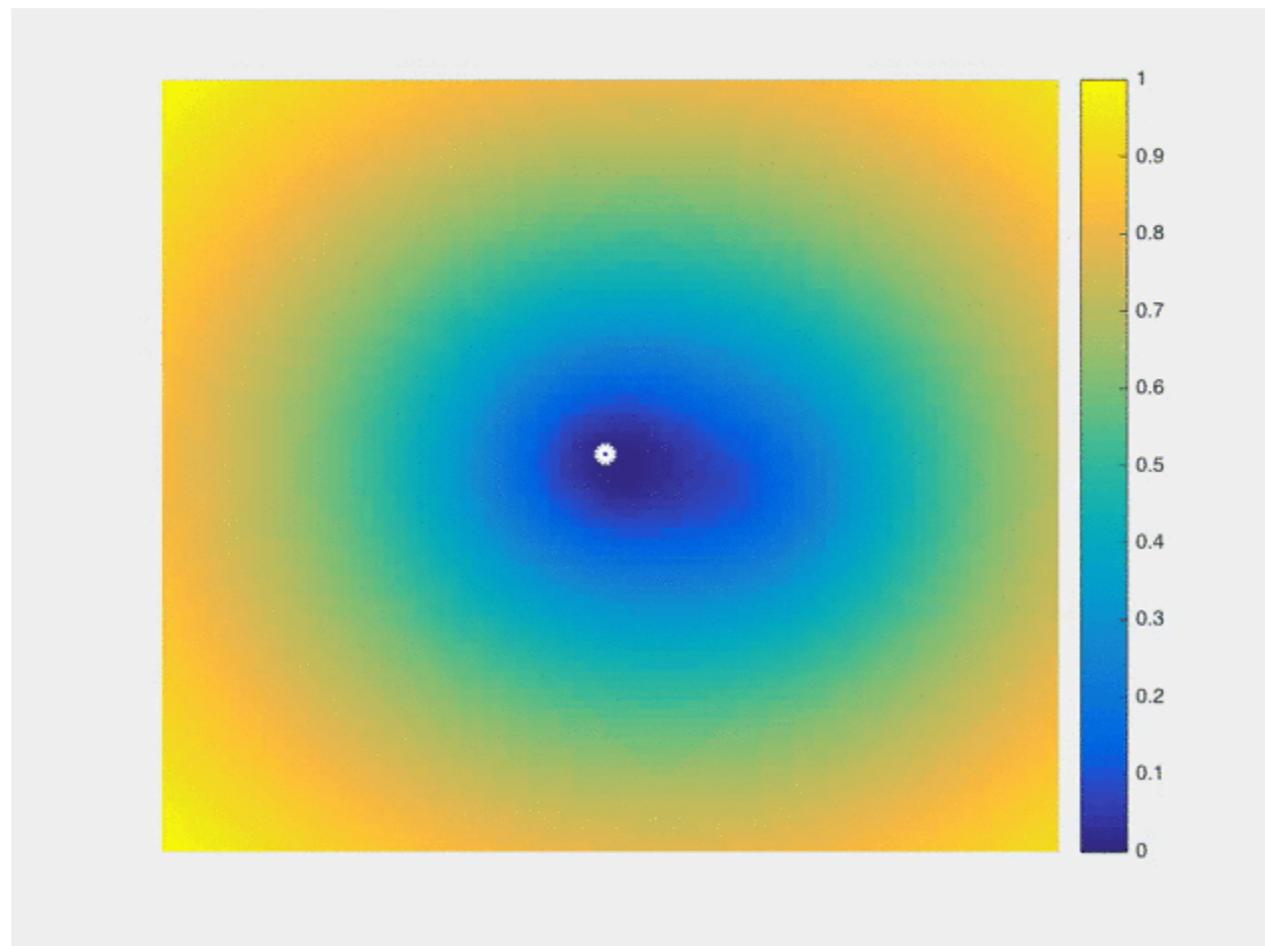


Gaze: a particle in the energy potential

Gaze-dynamic: **particule (p)** in the **potential field** and with added **noise**

$$\vec{p}(t) = -\nabla V(\vec{p}, t) + \xi(t)$$

Result:

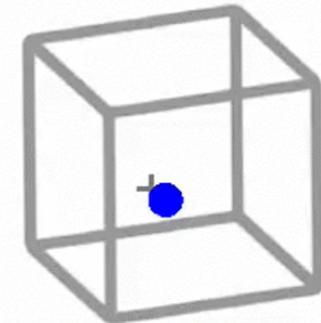
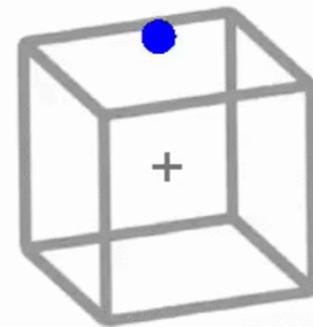
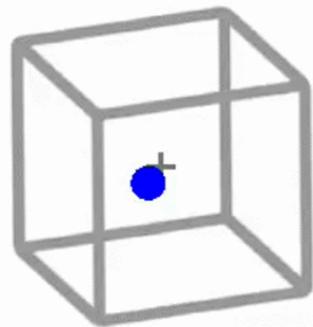
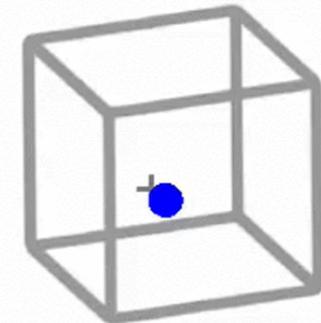
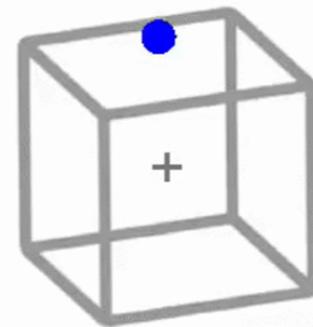
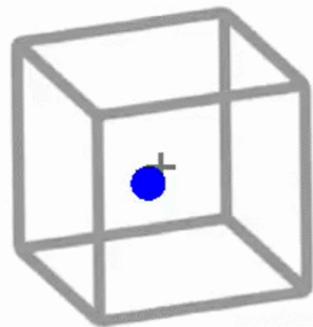


FEM simulations

Fixation

Micro-saccade

Micro-pursuit



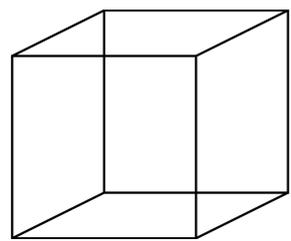
Can you differentiate the lines with simulation or data?

Perceptual multi- stability perspectives

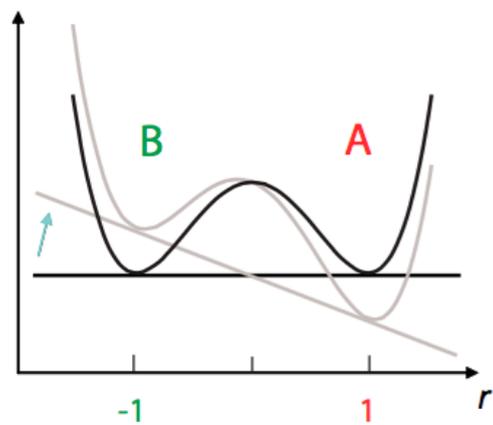
GraFEM: a multi-stable model?

GraFEM → **multi-stable** model with **spatial attractors**

Multi-stable models → predict perceptual dynamics and behavior for ambiguous figures (e.g. bi-stability) where **attractors are perceptual states**

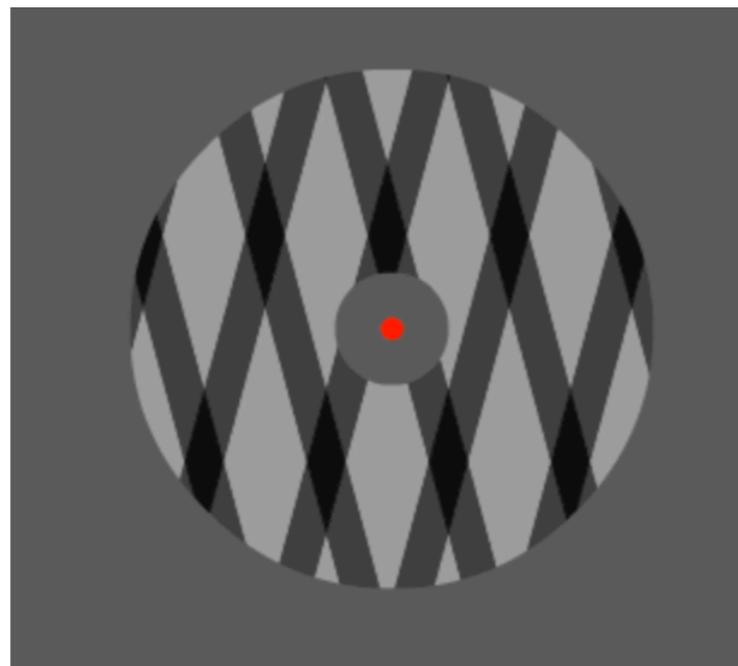


Necker cube

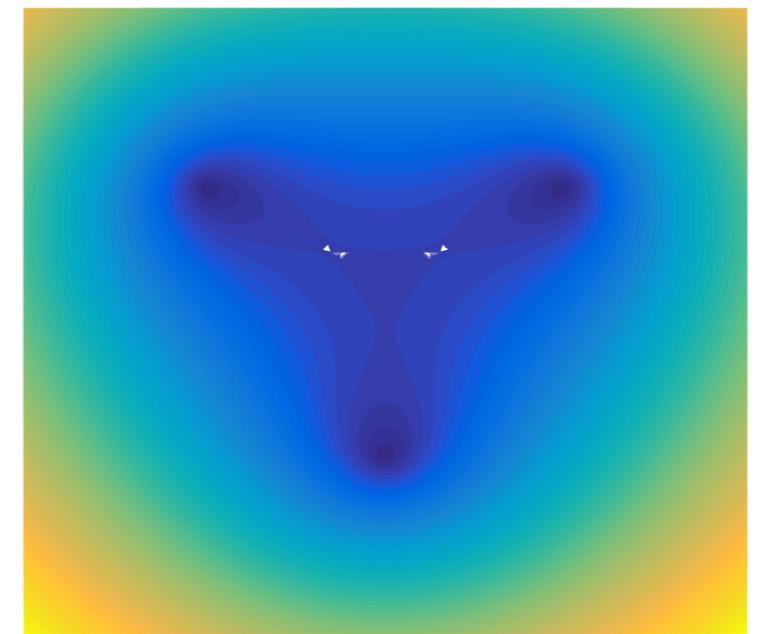


Bi-stability

⋮



Tri-stability



Moreno-Bote, R., Rinzel, J., & Rubin, N. (2007). *Journal of neurophysiology*

Moreno-Bote, R., Knill, D. C., & Pouget, A. (2011). *PNAS*

Huguet, G., Rinzel, J., & Hupé, J. M. (2014). *Journal of vision*

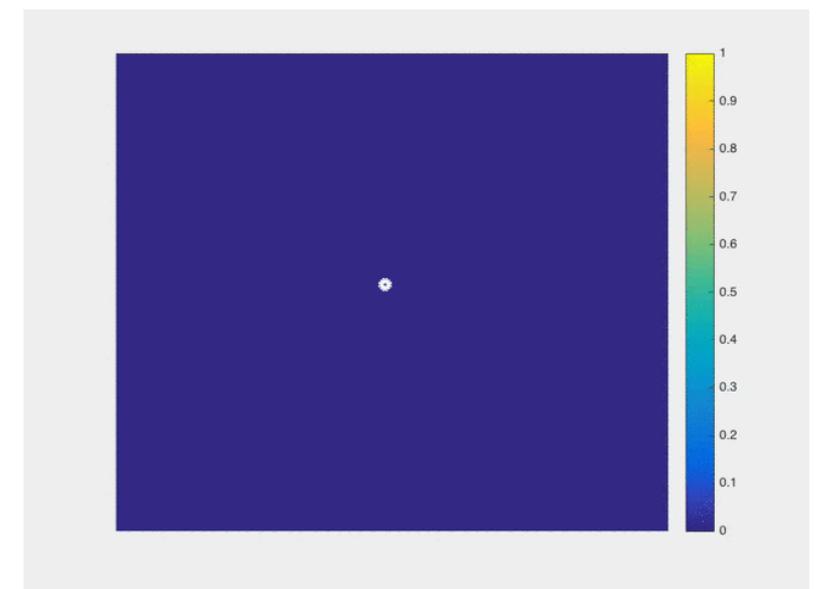
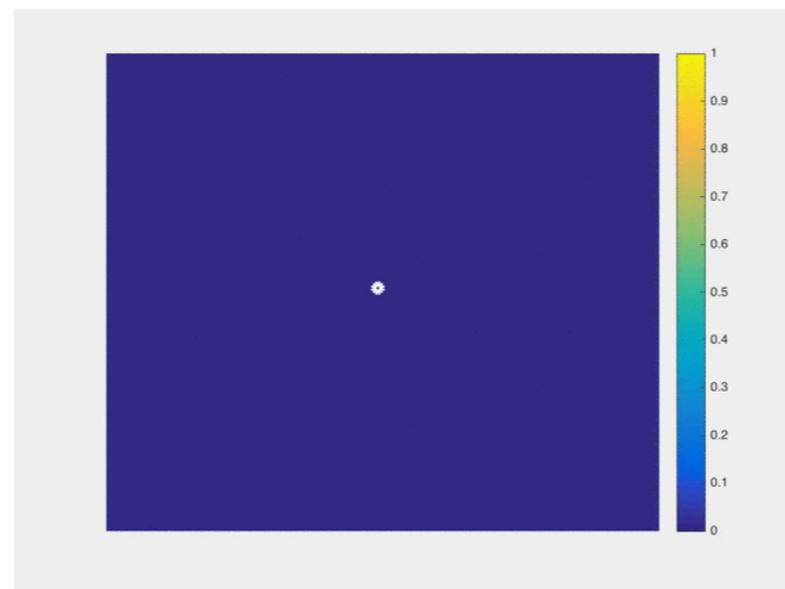
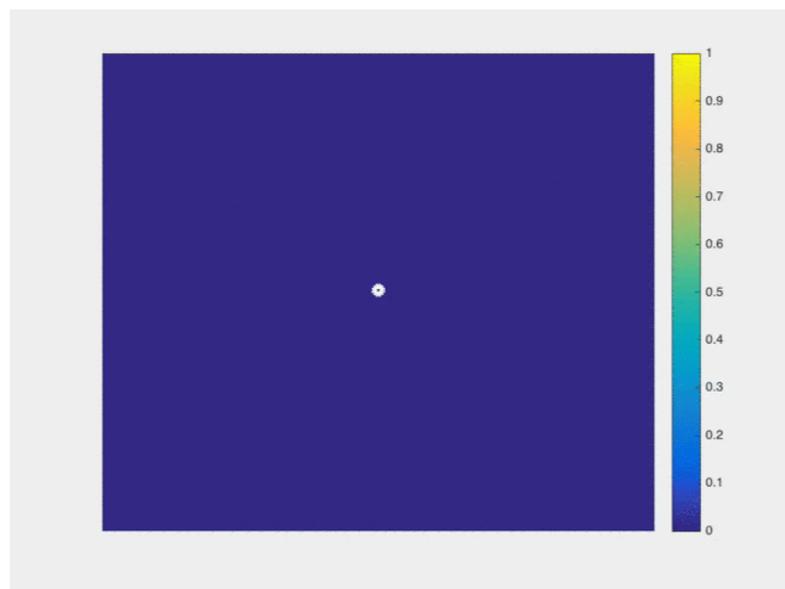
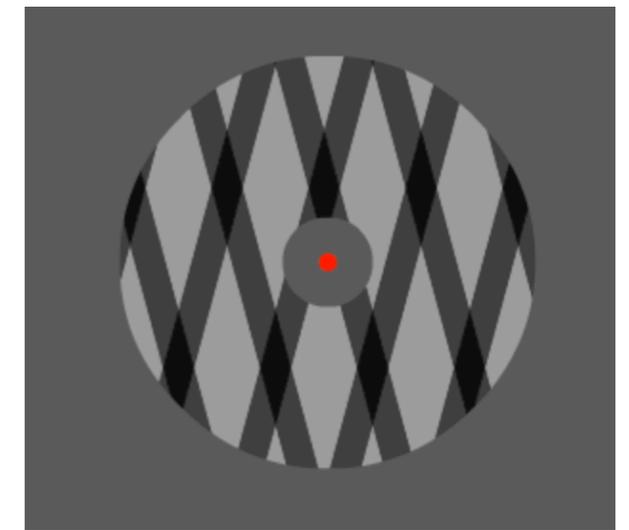
http://www.cerco.ups-tlse.fr/~hupe/plaid_demo/demo_plaids.html

Perspectives

Integration of both spaces to investigate interactions between eye movements & visual perception

Moving plaids: first naïve approach

Eye movement **predictions** on perception?



Take home message

- Observations of **micro-pursuits** FEM: only observation since Martins, Kowler, & Palmer, (1985). *JOSA*
- Description of **GraFEM**: an FEM generative model that can be extended to **all eye movements**
- GraFEM is multi-stable w.r.t. spatial attractors
- Development of links between eye-movement and perceptual models



GraFEM