A dynamical neural model of motion integration

É. Tlapale[†], P. Kornprobst[†], G.S. Masson[‡]

† NeuroMathComp, INRIA Sophia Antipolis Méditerranée, France — ‡ DyVA, INCM, CNRS, France — Contact: Emilien.Tlapale@sophia.inria.fr

We propose a dynamical model of 2D motion integration where diffusion is modulated by luminance information. It incorporates feedforward, feedback, and inhibitive lateral connections and is inspired by the neural architecture and dynamics of motion processing cortical areas in the primate (V1, V2, and MT). The first aspect of our contribution is to propose a new anisotropic integration model, offering a competitive alternative to less parsimonious models based on a large set of cortical layers. A second aspect that is often ignored is that biological computation of global motion is highly dynamical. Our model can also explain several properties of MT neurons regarding the dynamics of selective motion integration, a fundamental property of object motion disambiguation and segmentation.

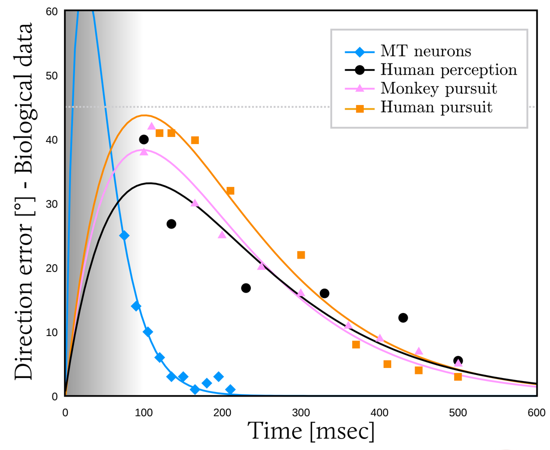
Goals

Integrate 2D motion

→ Reproduce perception

Berzhanskaya et al. (2007)

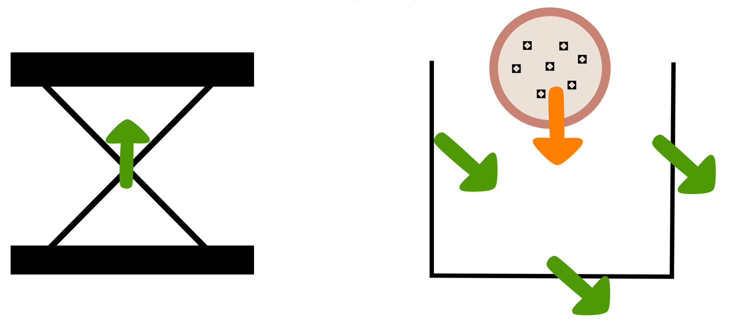
→ Reproduce dynamics



With a bio-inspired model

→ Cortical layers, feedback, . . .

Bayerl & Neumann (2004)



Model overview

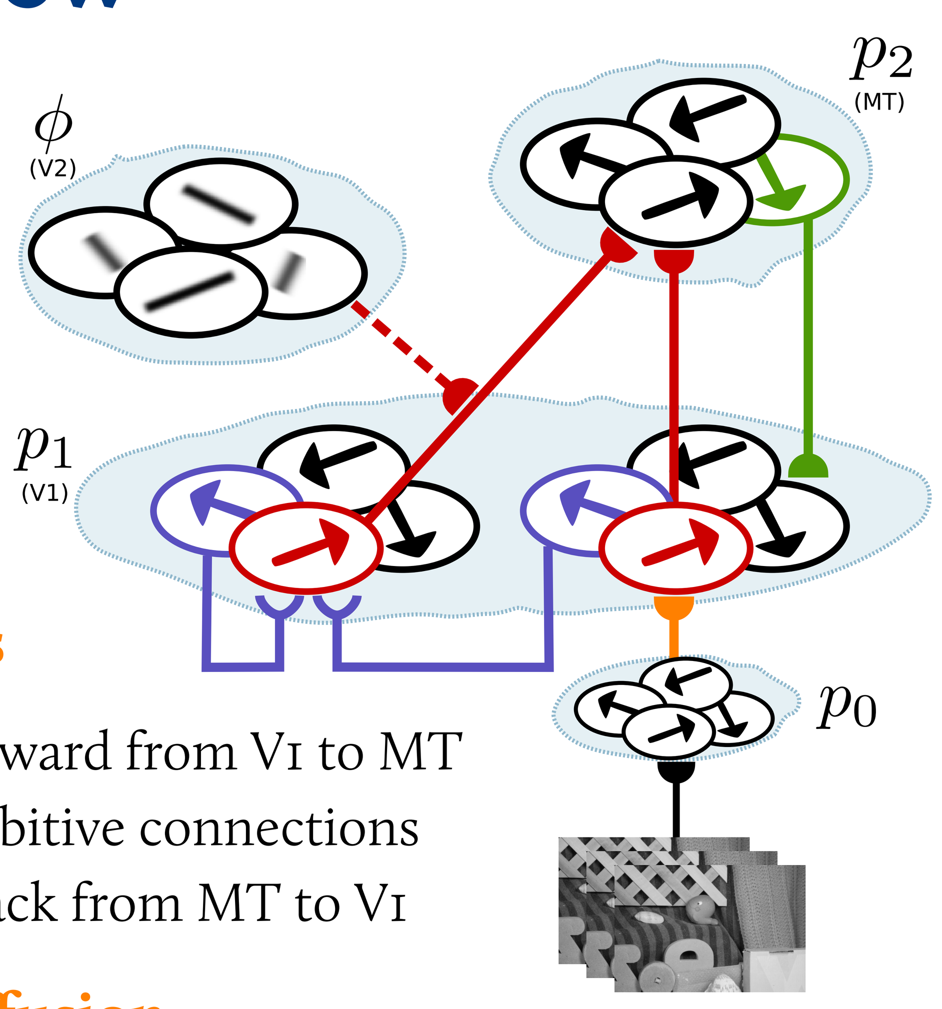
Cortical areas

→ Activity model

→ Retinotopic neurons

→ Distributed velocity

$p_i(t, x, v)$



Multiple interactions

→ Integration via feedforward from V1 to MT

→ Selection via local inhibitive connections

→ Propagation via feedback from MT to V1

Luminance-gated diffusion

→ Feedforward integration is anisotropic

→ Luminance (form) information modulates integration

Formalism

Neural fields

Wilson & Cowan (1972)

Feedforward integration

$$\frac{\partial p_2}{\partial t} = -\lambda_2 p_2 + S_2\left(-\lambda_2^l G_{\sigma_2^l} * \int_{\mathcal{V}} p_2(t,x,w)\mathrm{d}w + \lambda_2^f \int_\Omega K(t,x,y)p_1(t,x,y)\mathrm{d}y\right)$$

$$\frac{\partial p_1}{\partial t} = -\lambda_1 p_1 + S_1\left(-\lambda_1^l G_{\sigma_1^l} * \int_{\mathcal{V}} p_1(t,x,w)\mathrm{d}w + \lambda_1^f p_0 + \lambda^b p_0 p_2\right)$$

Decay

Lateral inhibition for selection

Yuille & Grzywack (1989)

Modulating feedback

Bayerl & Neumann (2004)

Sillito et al. (2006)

Luminance modulation

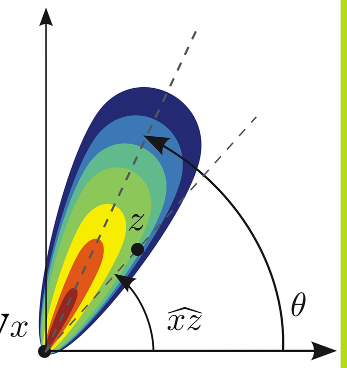
$$K(t,x,y) = G_{\sigma_2^f}(|x-y|)\phi(t,x,\widehat{xy})$$

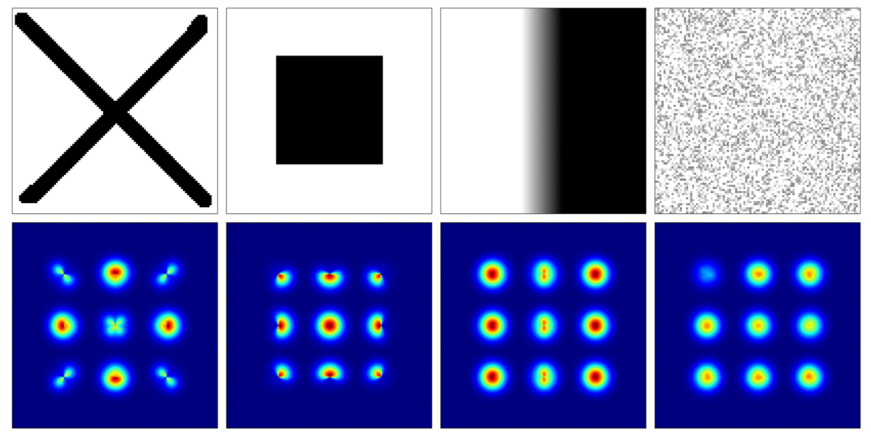
$$\phi(t,x,\theta) = \int_\Omega G_{\sigma_x}(x-z)G_{\sigma_\theta}(\theta - \widehat{xz})G_{\sigma_s}(I(t,x) - I(t,z))\mathrm{d}z$$

$\theta \in [0, 2\pi[$

Directional neighborhood

Luminance similarity





→ Simple luminance gating

(no explicit junction detectors)

Weiss (1998)

Sajda & Baeck (2005)

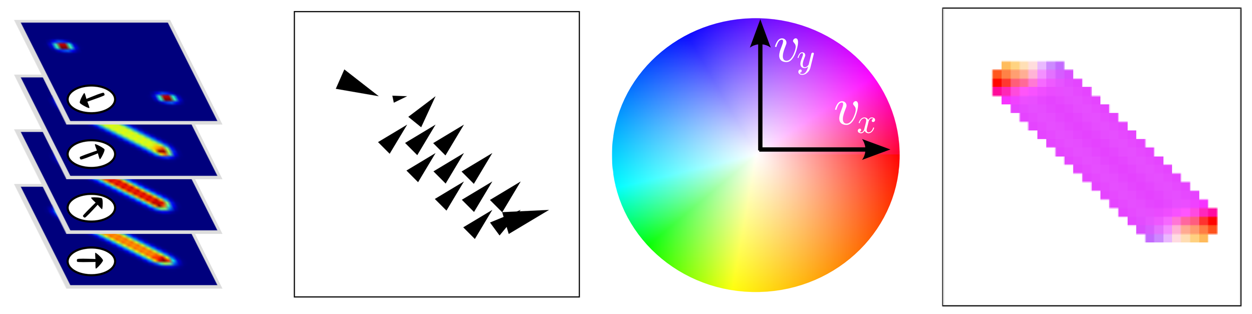
Bayerl & Neumann (2007)

→ Higher contrast ➡ wider integration

Pack et al. (2005)

Defining read-out

Color-coded results



→ Simplify multi-dimensional data

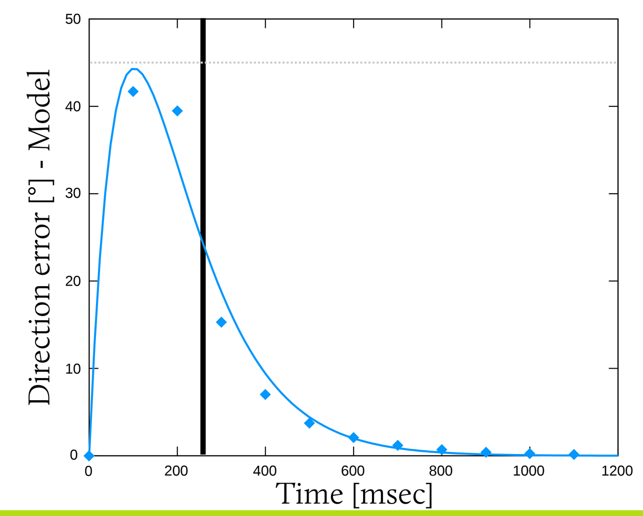
Biological read-outs

→ Fetch simpler quantitative values

→ Allows comparison with biology

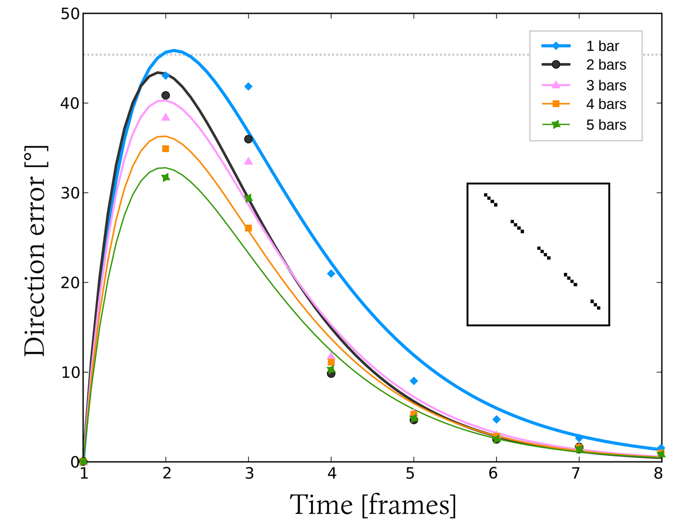
$$m_i(t,x) = \frac{\sum_{v\in\mathcal{V}} p_i(t,x,v)v}{\sum_{v\in\mathcal{V}} p_i(t,x,v)}$$

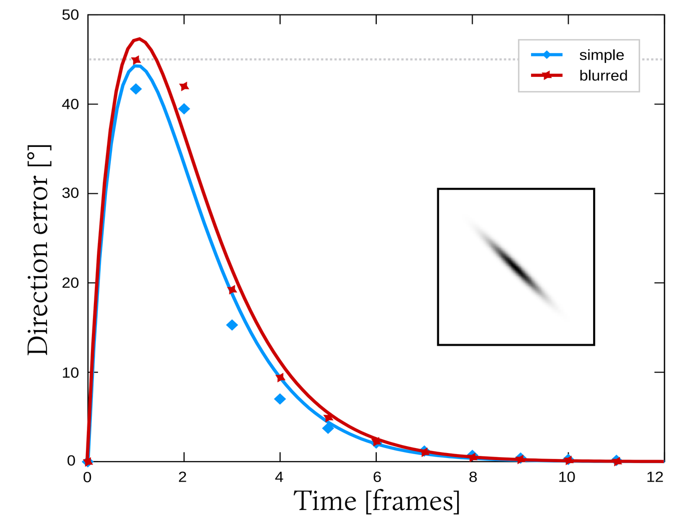
$$\frac{\mathrm{d}w}{\mathrm{d}t} = \lambda\left(\sum_{x\in\Omega} m_2(t,x) - w(t)\right)$$



Results

2D cues effects on dynamics



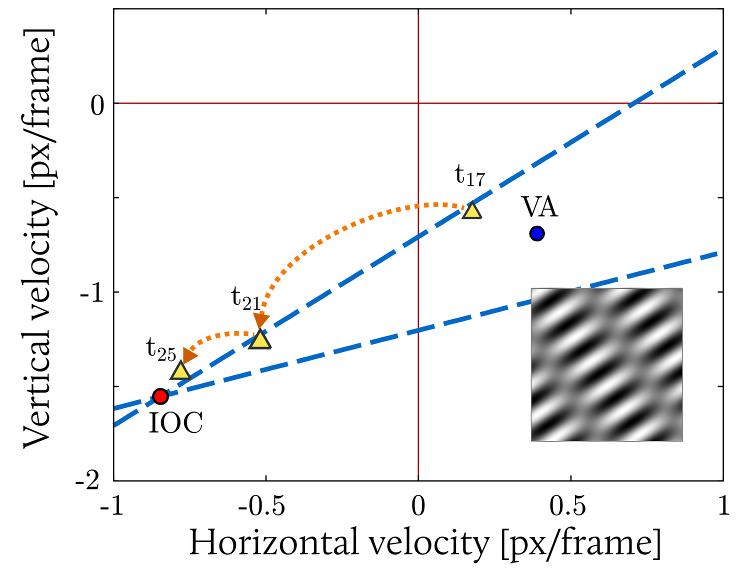


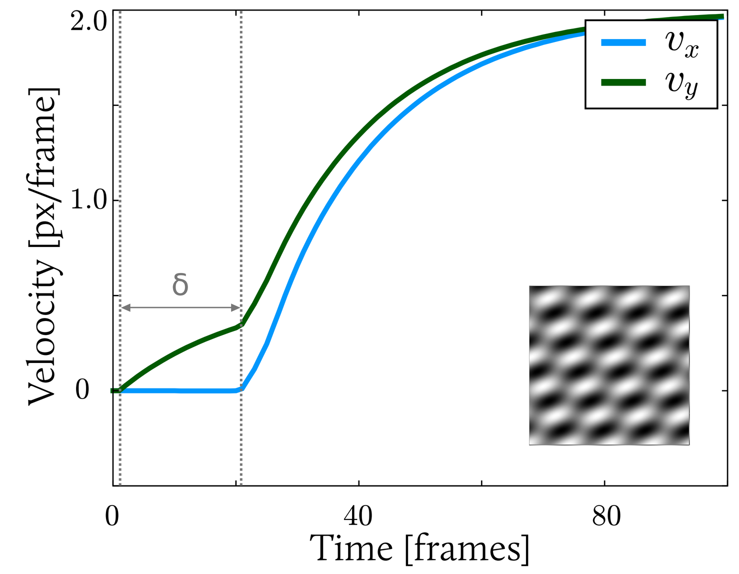
→ Increasing 2D information fasten the dynamics

Lorenceau et al. (1993)

→ Increasing 2D information fasten the dynamics

Plaids dynamics





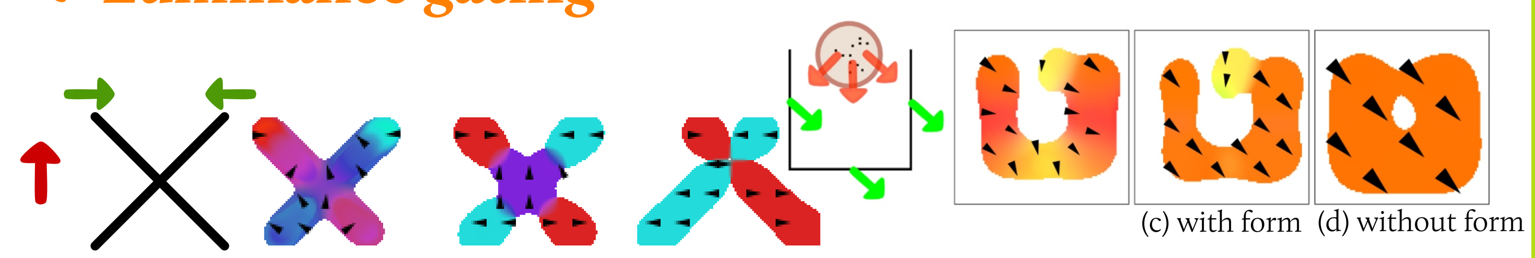
→ Global motion moves towards IOC

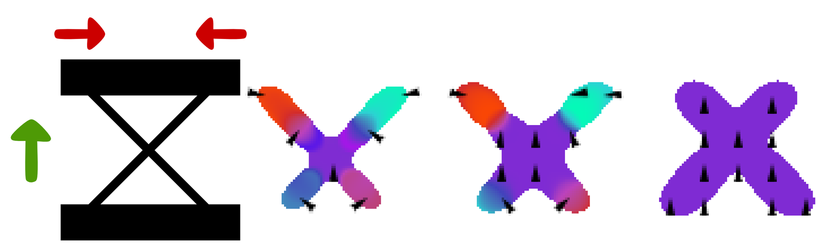
Bowns (1996)

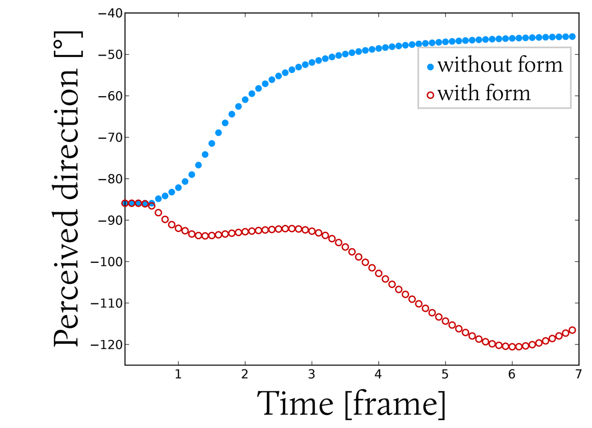
→ Vertical shift is delayed

Masson & Castet (2002)

Luminance gating







→ Extrinsic junction detection

→ Object discrimination

Huang et al. (2007)

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