From variational to spiking network image segmentation techniques

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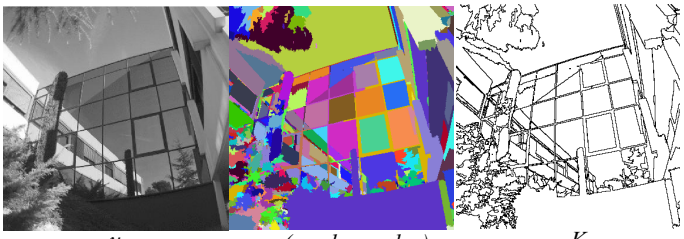
We consider a discrete approximation of the Mumford Shah functional, yielding a dynamical system grid and explore the different possibilities to link it to a grid of neurons, considering the neuron oscillation phase, the membrane voltage or a more complex neuron state, depending on the neuron model (from integrate and fire to Hodgkin-Huxley) and encoding . From this theoretical study and the related numerical experiment an original biologically inspired segmentation network emerges from our study. See also Sarti, Citti:03

Mumford, Shah 89

The Mumford-Shah segmentation paradigm

$$\inf_{u,K} F(u,K) = \int_{\Omega-K} (u-u_0)^2 dx + \alpha \int_{\Omega-K} |\nabla u|^2 dx + \beta \int_K d\sigma$$

Two unknowns — *Attach term* — *Smoothing term* — *Length of edges*



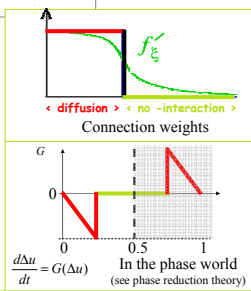
u_0 — u (random color) — K

Chambolle, Dal-Masso: 99

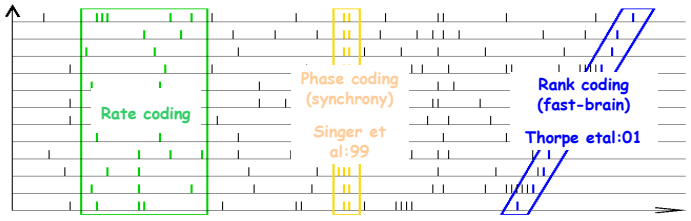
The Chambolle discretization scheme

$$\frac{du_x}{dt} = \sum_\xi \frac{1}{h^2} f'_\xi\left(\frac{(u_x - u_{x+h\xi})^2}{h}\right)(u_{x+h\xi} - u_x)\phi(\xi) + \dots$$

- Connections are excitatory, symmetric, depend on local gradient and nonlinear (threshold)
- Biological plausibility? Think about local gap junctions and high conductance states



Spike coding: where is the information ?



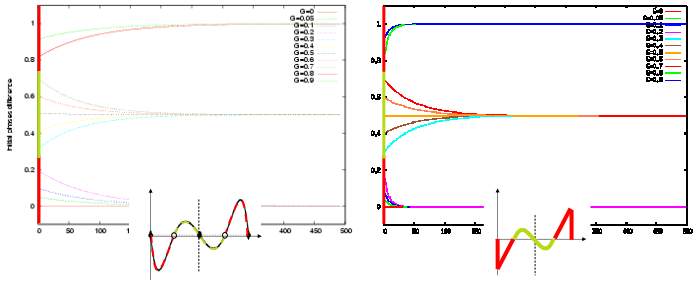
- In vivo segmentation is related to synchrony
- Integrate and Fire neurons detect synchrony

Neuenschwander 99
Castelo, Branco 00

Test with 2 neurons

Mutual inhibition with delay

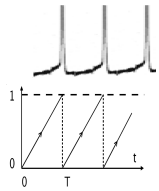
X-axis= time
Y-axis= initial phases difference



Phase reduction theory

Brown:04, Kopell, Ermentrou et al: 01

- Let us define hyperbolic orbits, assuming small local interactions
- Result: We have the following 1D dynamic reduction



$$\frac{dV_x}{dt} = g(V_x) + D(V)$$

D correspond to couplings

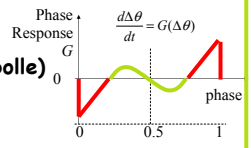
$$\frac{d\theta_x}{dt} = \omega + z(\theta_x)D(V(\theta))$$

Back to the potential allows to understand the effective couplings

Depends on neuron model

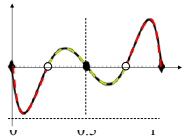
One defines this term following Chambolle model for example

- A "good" phase response will
  - Synchronise similar phases (as in Chambolle)
  - Desynchronise non-similar NEW



Case of two neurons with mutual inhibition

Lewis, Rinzel: 03



- Study of the dynamics
  - Mutual inhibition
  - Exponential synapses
  - Investigate the role of delays NEW
  - Leaky IF neuron

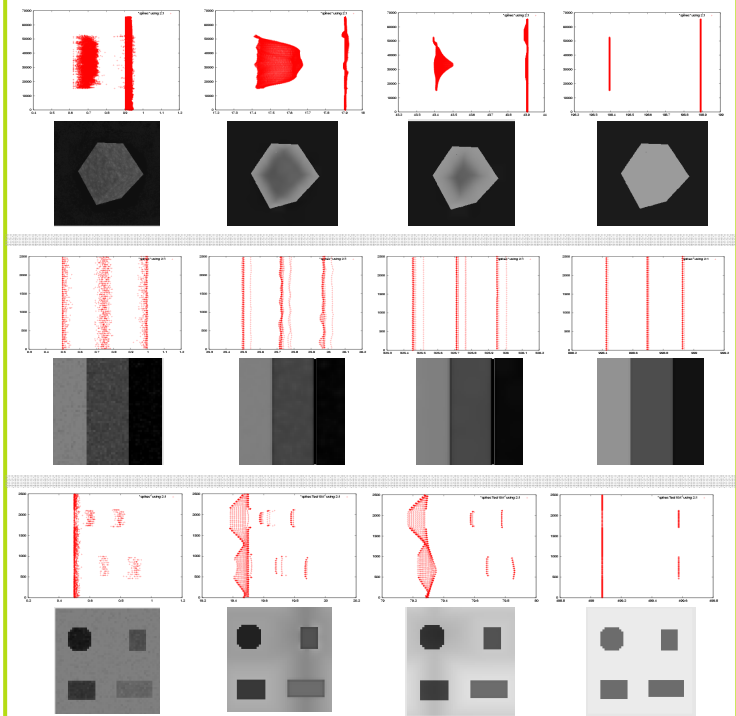
- Our analytical solution allows event-based simulation
- From two to N neurons: a closed-form beyond numerical results ?

Test in a network

NEW

Grid with local delayed mutual inhibition

- Attraction inside of the each region and repulsion among them



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