Morphogenetic "neuron flocking":

Dynamic self-organization of neural activity into mental shapes

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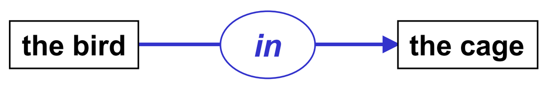
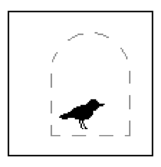
THE CASE FOR "MENTAL SHAPES (IMAGERY)" FROM THE COGNITIVE PERSPECTIVE

"Abstract" representations should not mandate "symbolic"
→ **"analogic" formats preserving the underlying combinatorial complexity are critical!**

- *traditional logical atomism (set theory): "things" are individuated symbols and "relations" are links connecting these symbols*



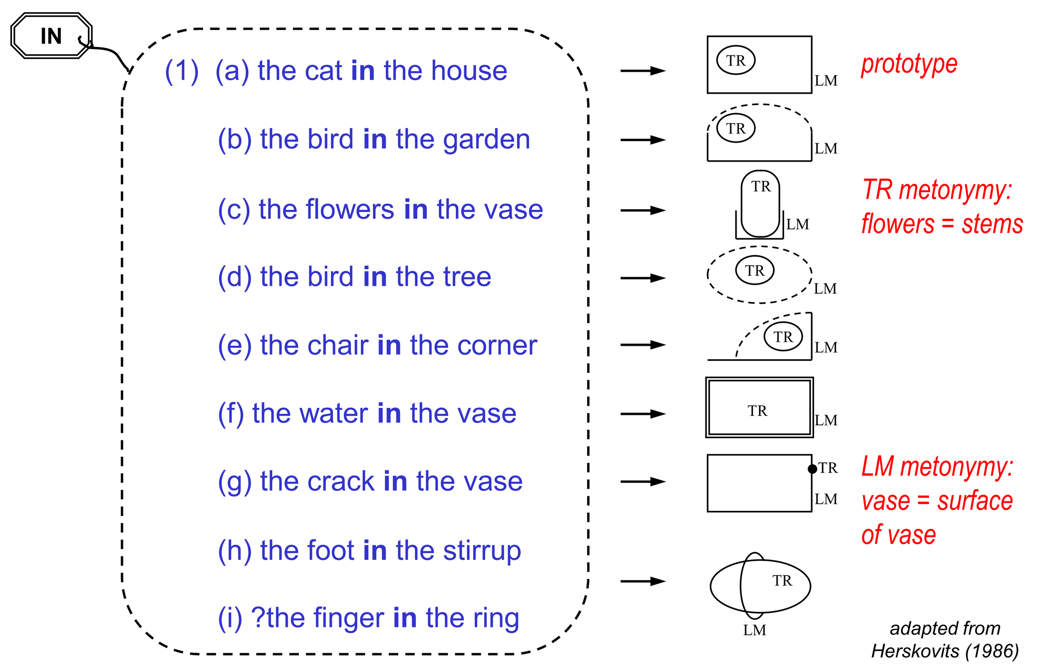
- *by contrast, in the "Gestaltist" or "mereological" conception, things and relations constitute analogic wholes: relations are not taken for granted but emerge together with the objects through segmentation and transformation*



Petitot & Doursat (2011) *Cognitive Morphodynamics*. Peter-Lang.

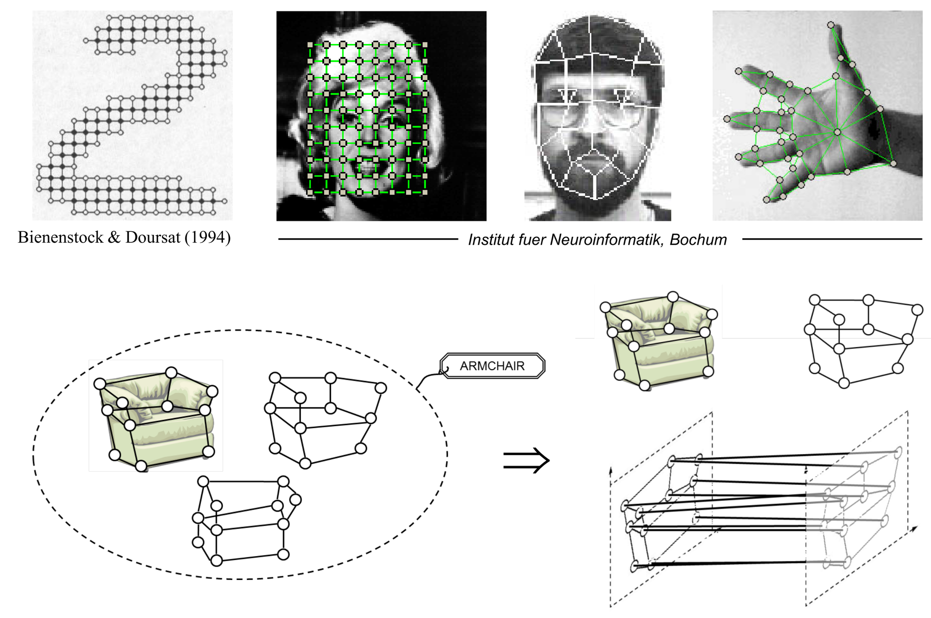
Example 1: cognitive linguistics, iconic grammar

→ *Proposal: semantics is a spatio-temporal affair (not nodes in a parse tree)*



Example 2: graph representations in vision

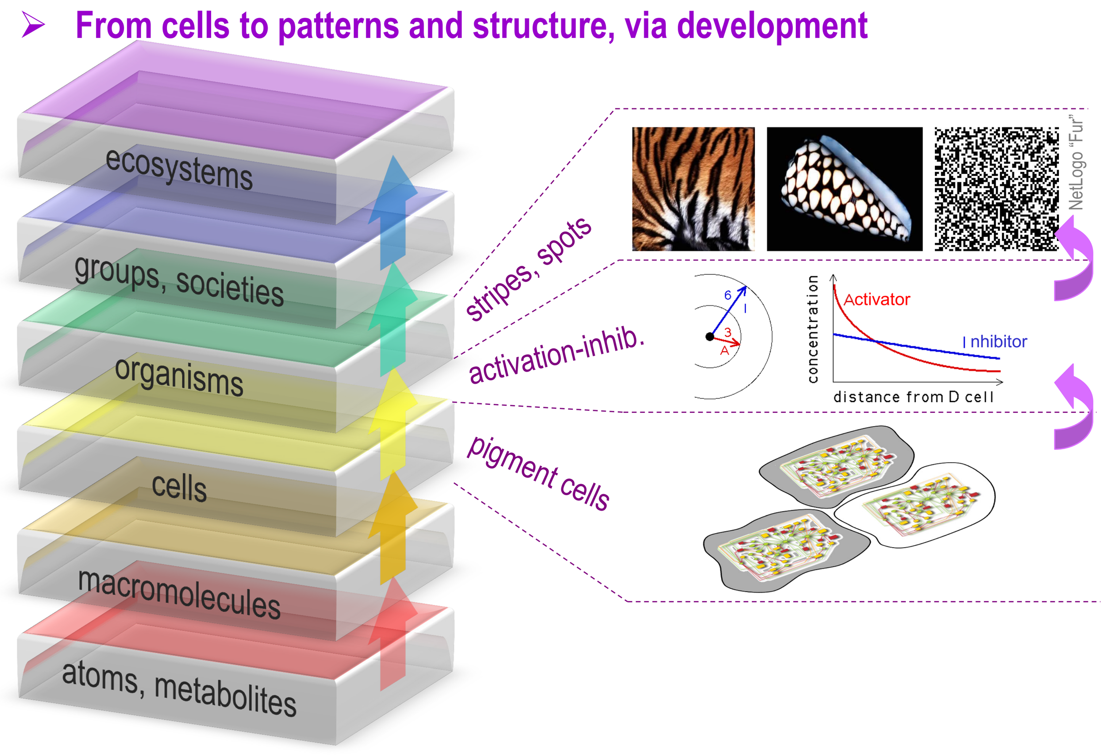
→ *Proposal: graphs representing the same object class are structurally similar and can be matched with each other*



THE CASE FOR "MENTAL SHAPES (PATTERNS)" FROM THE COMPLEX SYSTEMS PERSPECTIVE

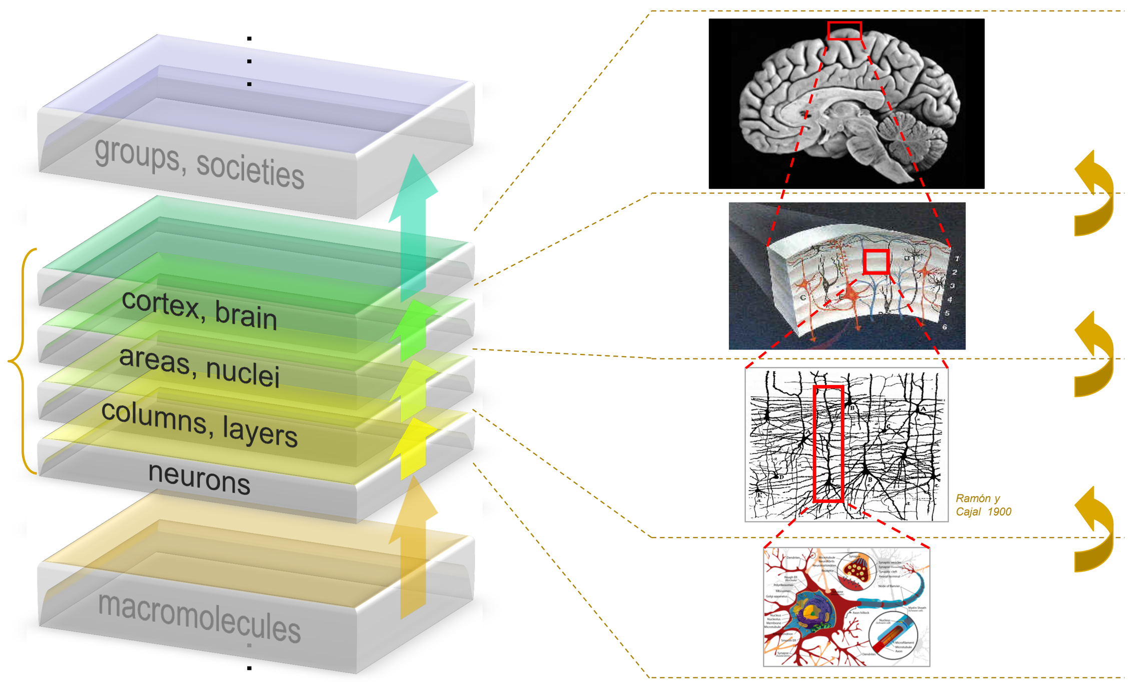
The Tower of Complex Systems in Nature

- From cells to patterns and structure, via development



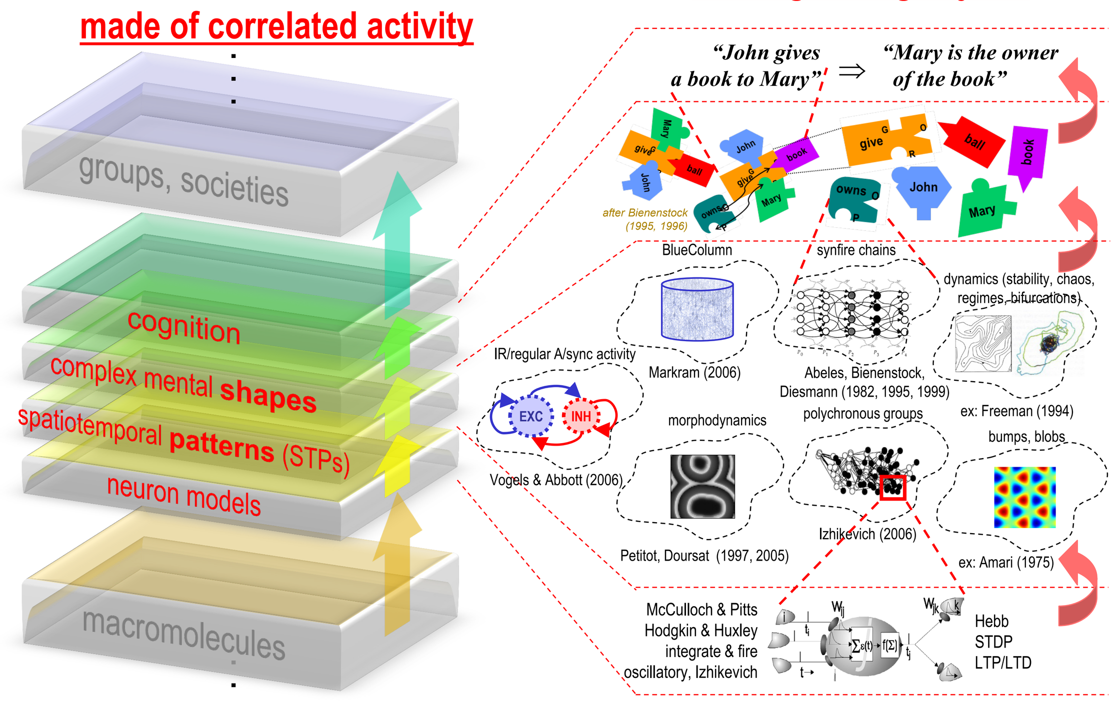
The Tower of Complex Systems in the Brain

- *Brain anatomy*: from neurons to brain, via neural development



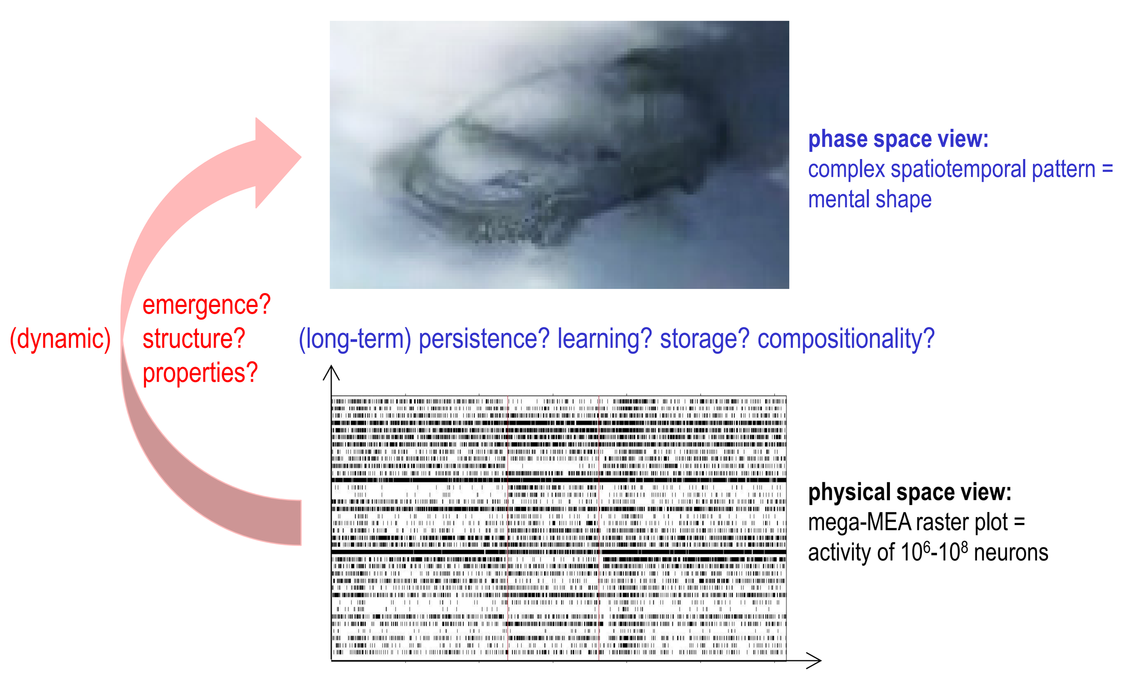
The Tower of Complex Systems in Cognition

- *Mind function*: from neurons to mind, via self-organizing objects made of correlated activity



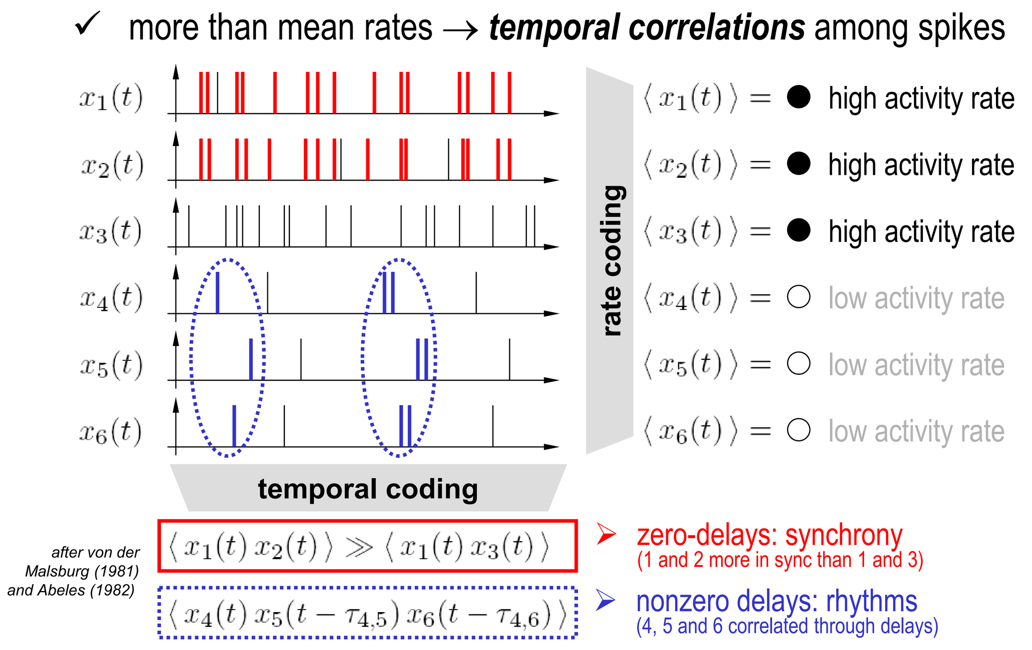
THE CASE FOR "MENTAL SHAPES (CORRELATIONS)" FROM THE NEURAL CODE PERSPECTIVE

Morphogenetic "Neuron-Flocking"



The Brain as a Pattern Formation Machine

- Reminder: the importance of temporal coding
  - ✓ more than mean rates → *temporal correlations* among spikes



$\langle x_1(t)\rangle = \bullet$ high activity rate
$\langle x_2(t)\rangle = \bullet$ high activity rate
$\langle x_3(t)\rangle = \bullet$ high activity rate
$\langle x_4(t)\rangle = \circ$ low activity rate
$\langle x_5(t)\rangle = \circ$ low activity rate
$\langle x_6(t)\rangle = \circ$ low activity rate

$\langle x_1(t)\, x_2(t)\rangle \gg \langle x_1(t)\, x_3(t)\rangle$

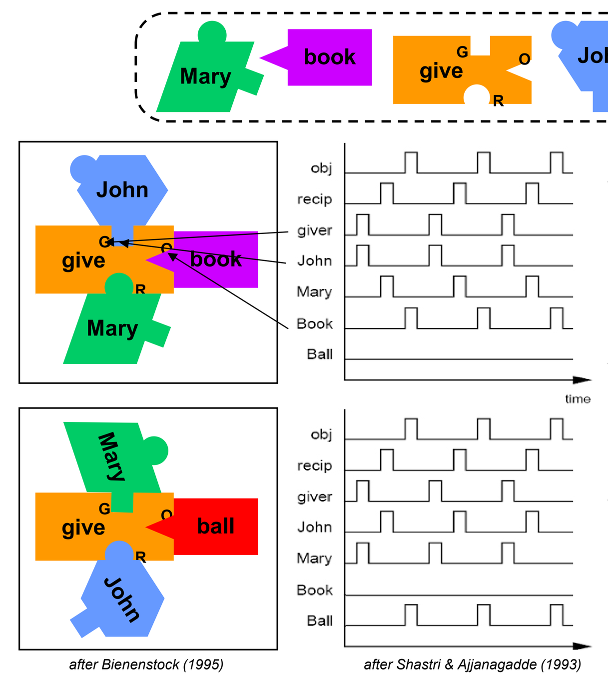
- zero-delays: synchrony (1 and 2 more in sync than 1 and 3)

$\langle x_4(t)\, x_5(t-\tau_{4,5})\, x_6(t-\tau_{4,6})\rangle$

- nonzero delays: rhythms (4, 5 and 6 correlated through delays)

Compositionality from Temporal Correlations

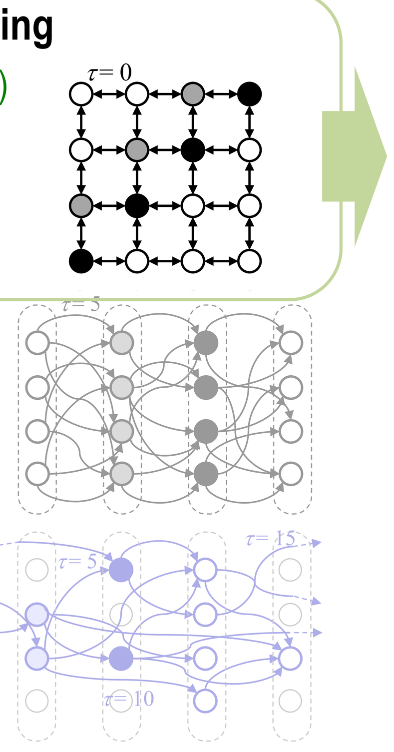
- Temporal binding is the "glue" of shape-based composition



- ✓ language, perception, cognition are a game of ***building blocks***
- ✓ mental representations are internally ***structured***
- ✓ elementary components ***assemble dynamically*** via temporal binding

EXAMPLE: A Neural Dynamics Model of Pattern Storage and Retrieval – Temporally Coding Coordinates by Phases, and Shapes by Waves

- **Wave-based pattern retrieval and matching**
  - ✓ Lattices of coupled oscillators (zero delays)
    - group synchronization
    - traveling waves
    - 2D wave shapes
    - shape metric deformation
  - ✓ Synfire chains (uniform delays)
    - wave propagation
    - chain growth
    - pattern storage and retrieval
  - ✓ Synfire braids (transitive delays)
    - shape storage and retrieval
    - 2D wave-matching

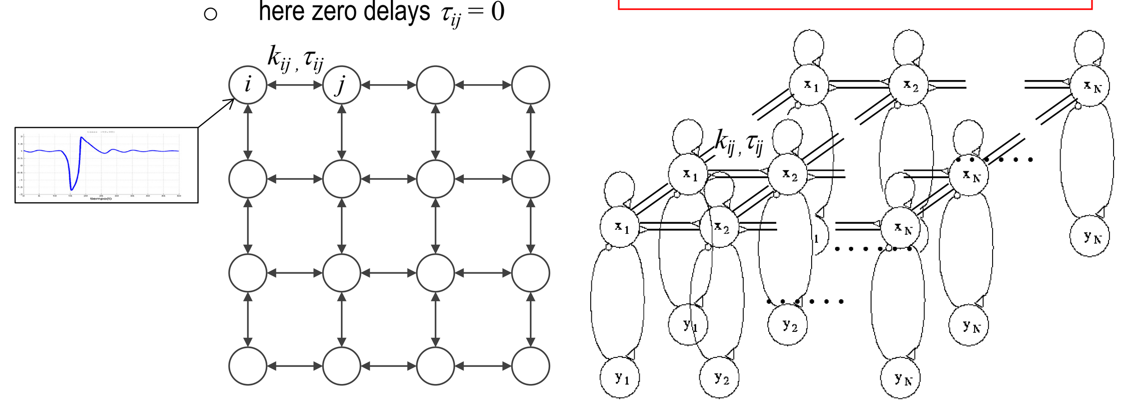


- **Lattice of coupled oscillators**
  - ✓ $i \leftarrow j$ coupling features
    - isotropic
    - proportional to the u signal difference
      - only in spiking domain $u < 0$
    - positive connection weight k_{ij}
    - possible transmission delay τ_{ij}
      - here zero delays $\tau_{ij} = 0$

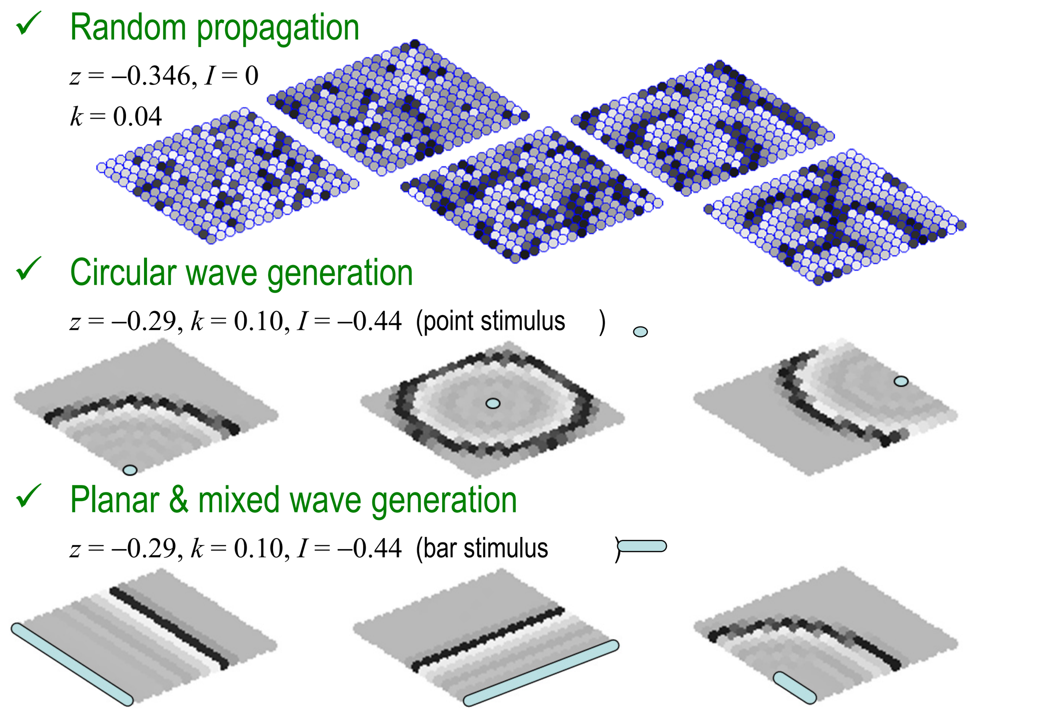
$$\frac{du_i}{dt} = c\left(u_i - \frac{u_i^3}{3} + v_i + z\right) + \eta + K_i + I_i$$
$$\frac{dv_i}{dt} = \frac{1}{c}(a - u_i - bv_i) + \eta$$

coupling term; input term

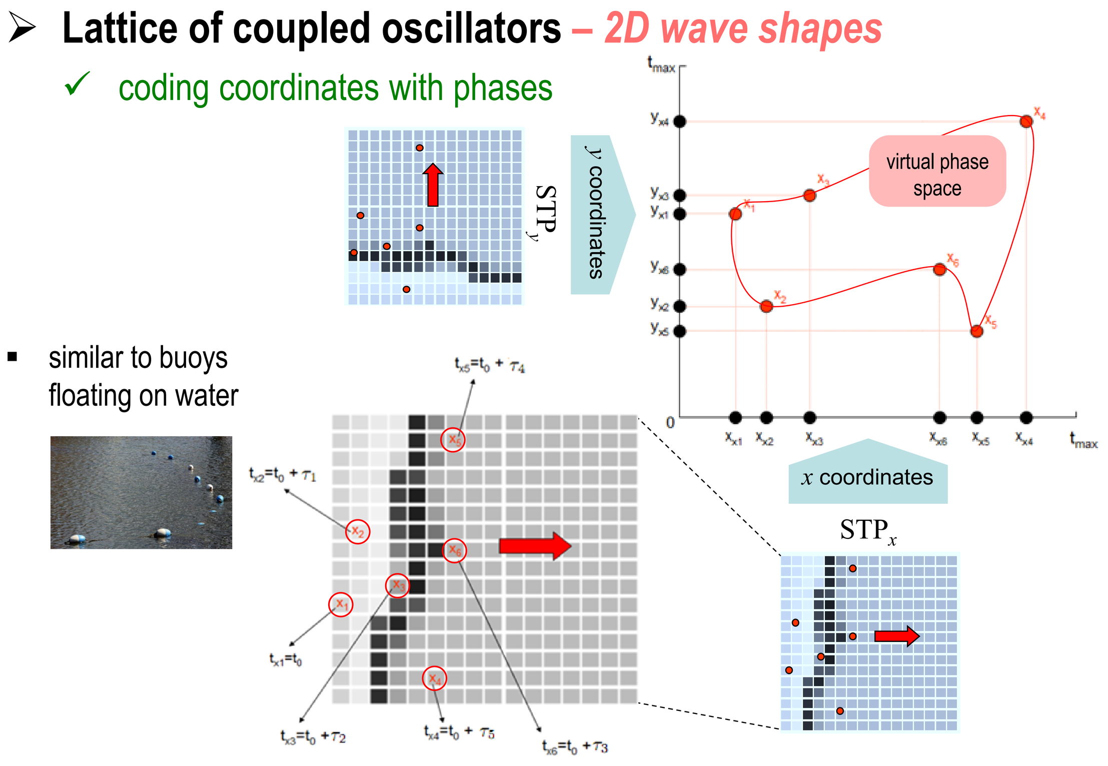
$$K_i(t) = \sum_{j=1,\ u_j(t-\tau_{ij})<0}^{N} k_{ij}\left(u_j(t-\tau_{ij}) - u_i(t)\right)$$



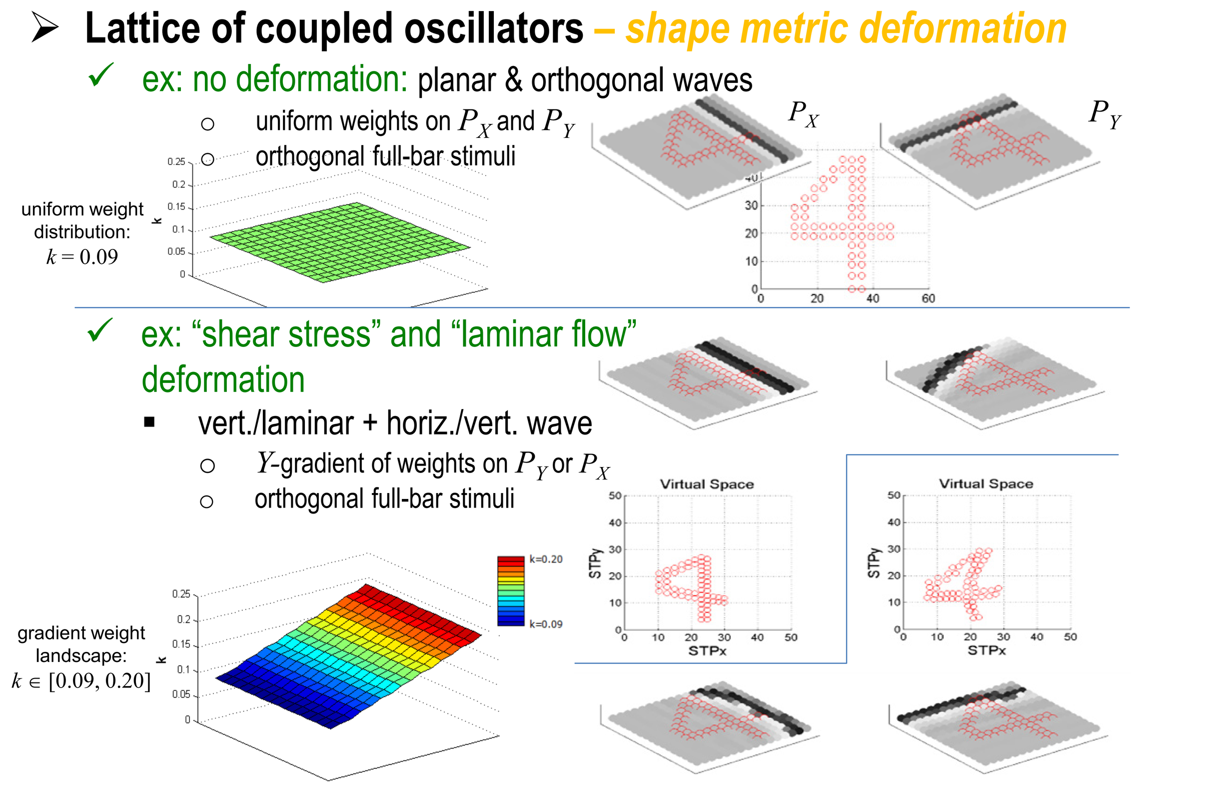
- **Lattice of coupled oscillators – *traveling waves***
  - ✓ Random propagation
    $z = -0.346,\ I = 0$
    $k = 0.04$
  - ✓ Circular wave generation
    $z = -0.29,\ k = 0.10,\ I = -0.44$ (point stimulus)
  - ✓ Planar & mixed wave generation
    $z = -0.29,\ k = 0.10,\ I = -0.44$ (bar stimulus)



- **Lattice of coupled oscillators – *2D wave shapes***
  - ✓ coding coordinates with phases
- similar to buoys floating on water



- **Lattice of coupled oscillators – *shape metric deformation***
  - ✓ ex: no deformation: planar & orthogonal waves
    - uniform weights on P_X and P_Y
    - orthogonal full-bar stimuli
  - ✓ ex: "shear stress" and "laminar flow" deformation
    - vert./laminar + horiz./vert. wave
      - Y-gradient of weights on P_Y or P_X
      - orthogonal full-bar stimuli



- **Lattice of coupled oscillators – *shape metric deformation***
  - ✓ ex: irregular deformation
    - heterogeneous weights
      - random weight distribution (bumps & dips) on P_X and P_Y
      - orthogonal full-bar stimuli
  - ✓ various weight combinations