

Notes on the possibility of embodied computation based on the emergence of singularities in a large-scale complex dynamical system



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Embodied . . . computation?



perception → *language*

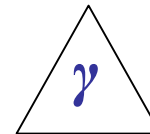
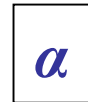
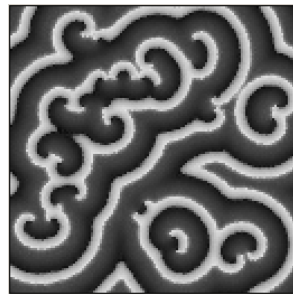
continuous → *discrete*

physical → *symbolic*

dynamical → *logic*

“fuzzy” → *“crisp”*

extension → *intention*



➤ *How are these transitions possible and how can we model them?*

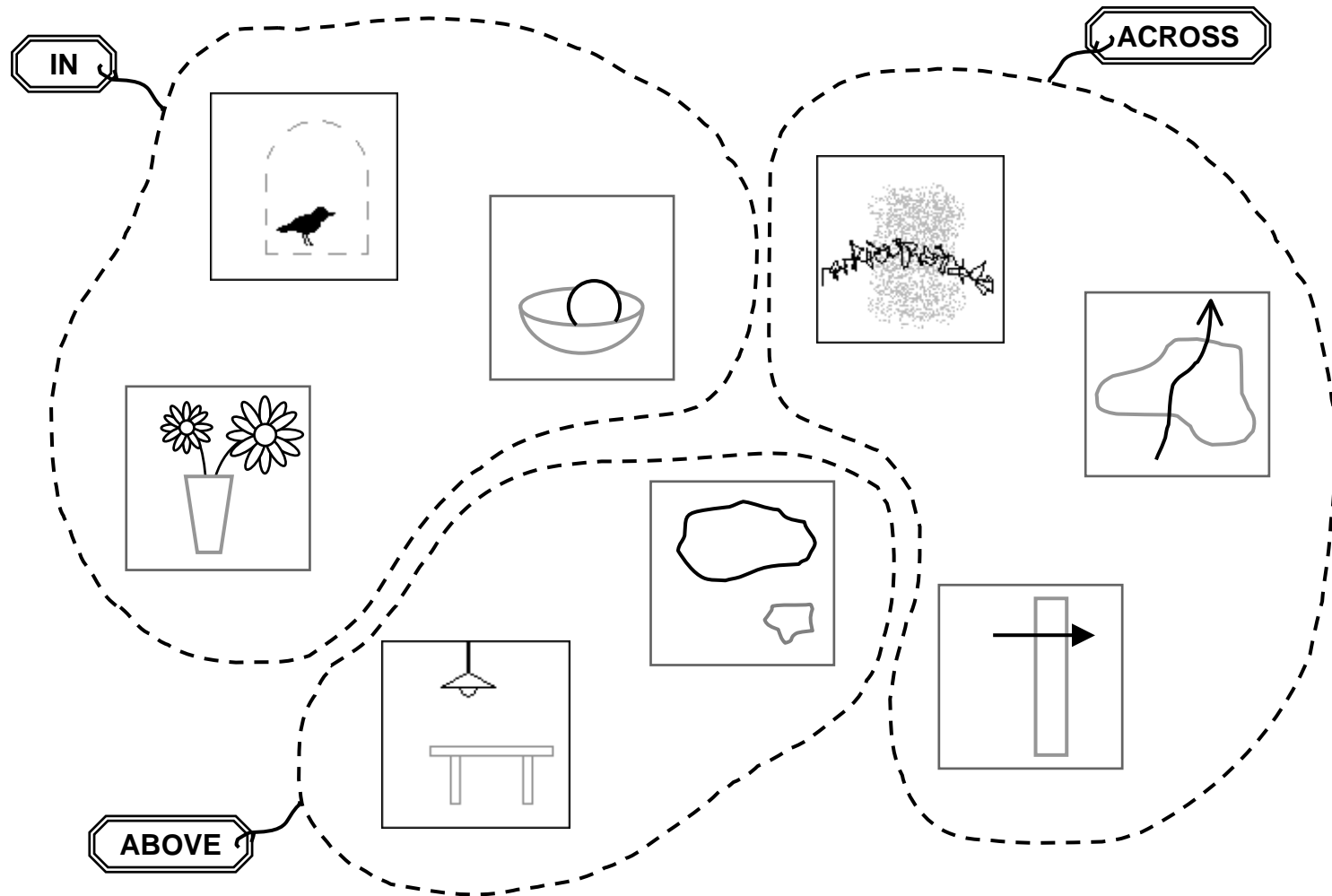
Embodied . . . computation?

in short:

schematization
+
categorization
=
drastic reduction of information

- *The loss of a huge amount of physical / dynamical / morphological details in order to produce a few discrete / symbolic units of knowledge corresponds to schematization and categorization.*

Example: spatial categorization



- *The infinite continuum of scenes is mapped by language to only a few spatial grammatical elements.*

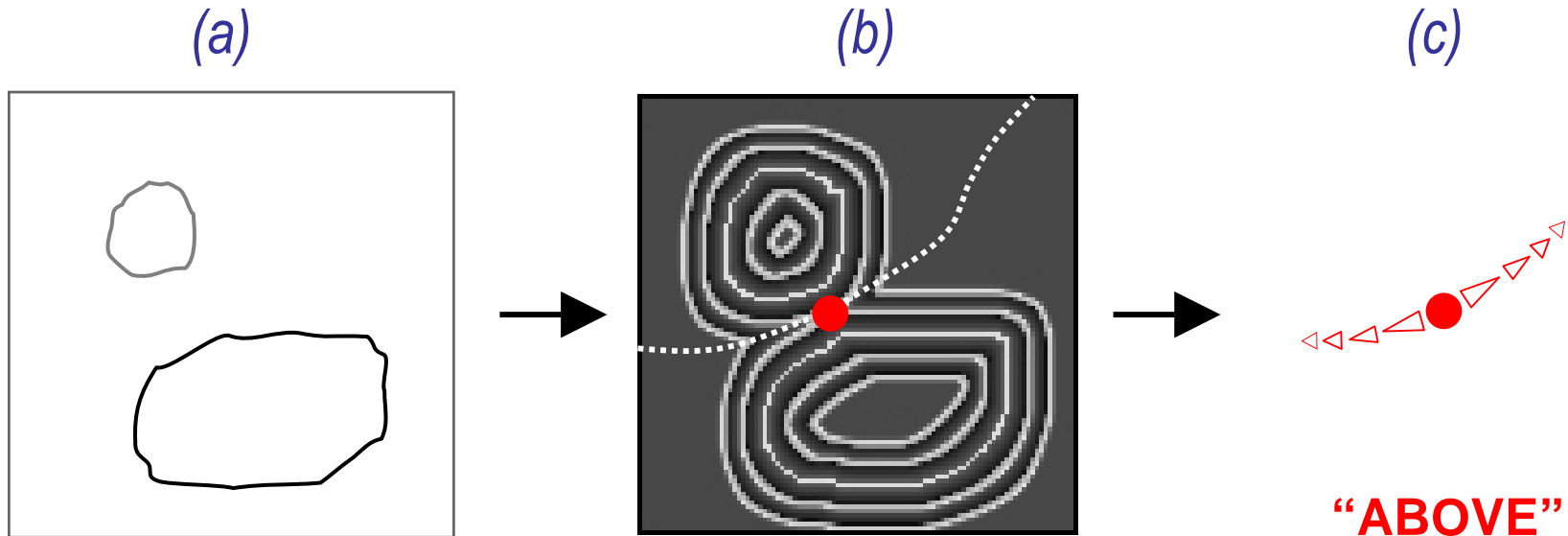
Morphological neurodynamics

Proposal: *Given a large-scale complex dynamical system, discrete symbolic information emerges in the form of singularities created by pattern formation in the system (and in the dynamic evolution of these singularities).*

see: Petitot, J. (1995). Morphodynamics and attractor syntax. In T. van Gelder & R. Port (Eds.), *Mind as Motion* (pp. 227-281). The MIT Press.

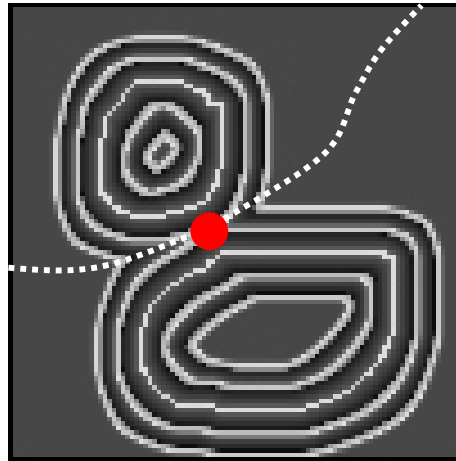
For example: traveling waves

Singularities = collision points



- *Under the influence of an external input (a), the internal dynamics of the system (b) spontaneously produces singularities (c), characteristic of a symbolic category.*

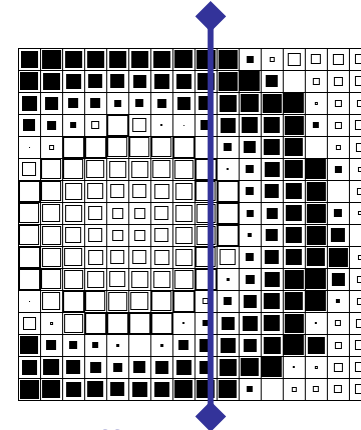
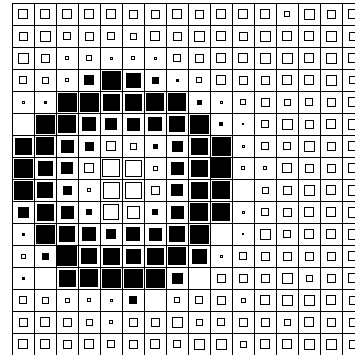
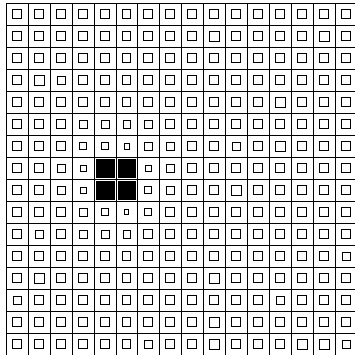
Criticality



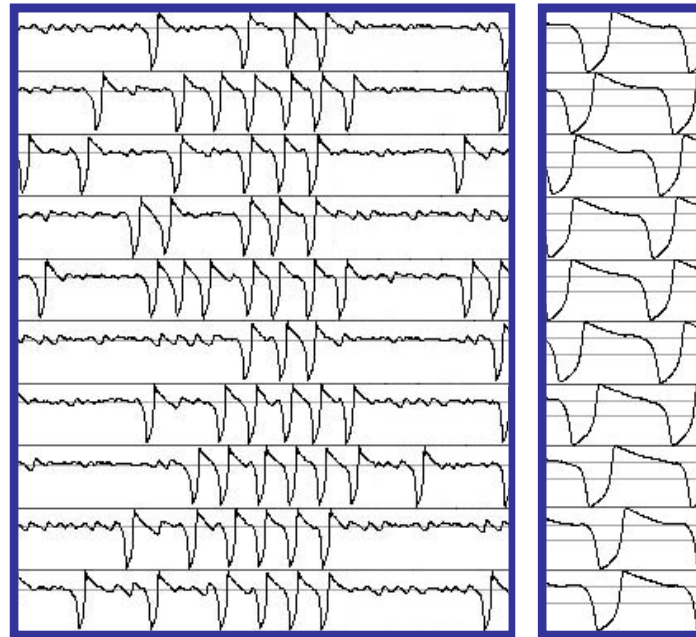
- *A network of excitable units construed as a “sensitive plate”:
when slightly perturbed by an input, it quickly transitions into
an ordered regime whose specific morphology and
singularities depend on the input.*

Spiking neural model supporting traveling waves

Detailed view

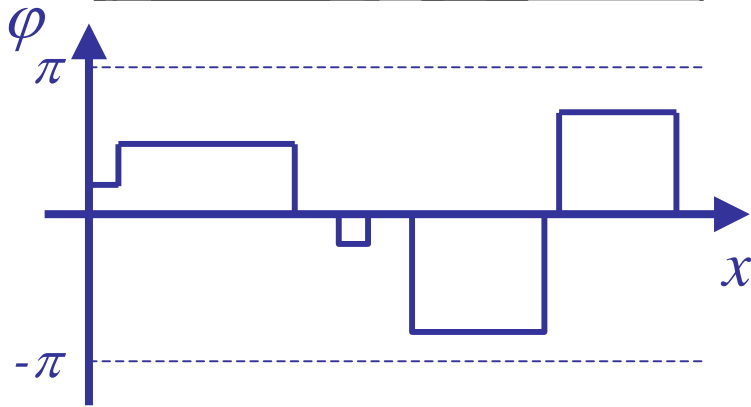
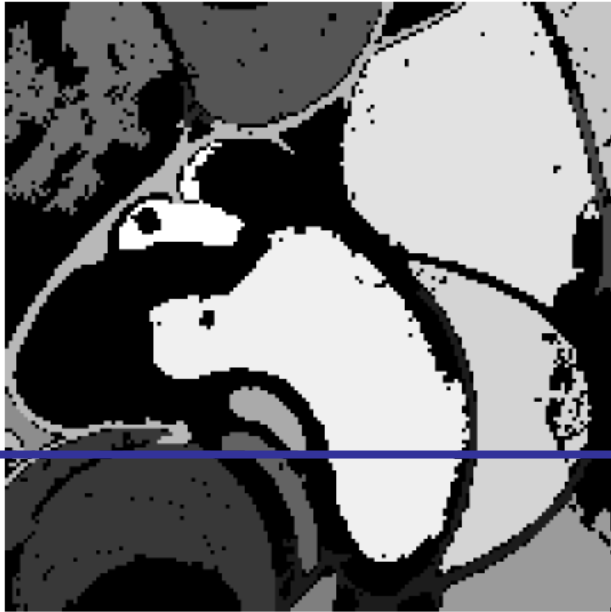


- *“Grass-fire” wave on 16x16 network of coupled Bonhoeffer-van der Pol units*

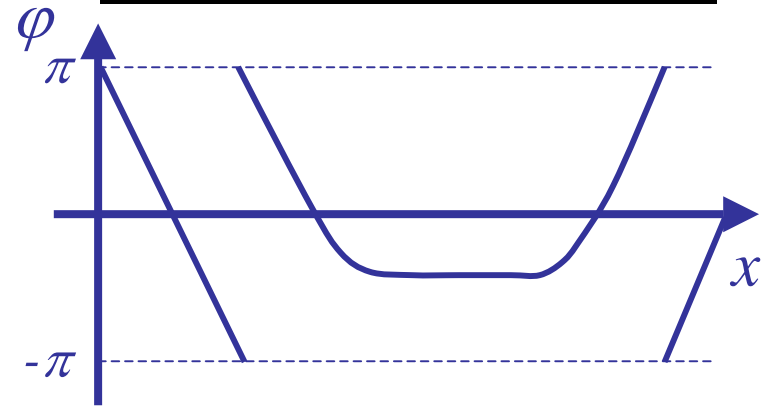
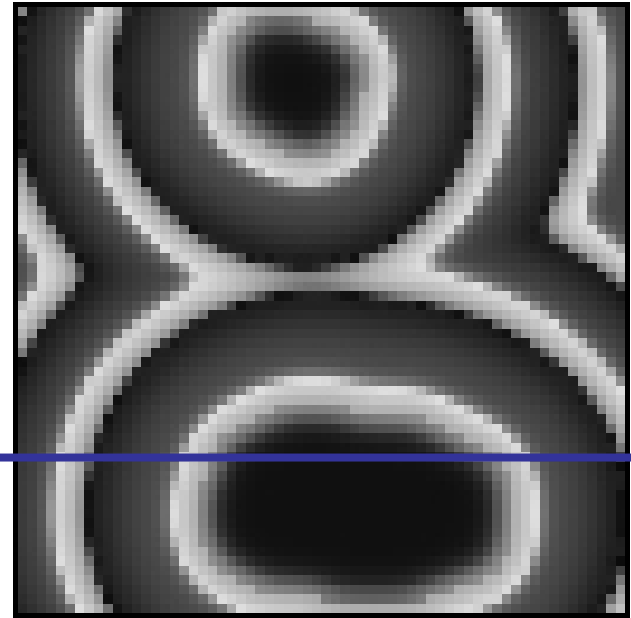


Instead of group synchronization: traveling waves

Instead of phase plateaus: phase gradients



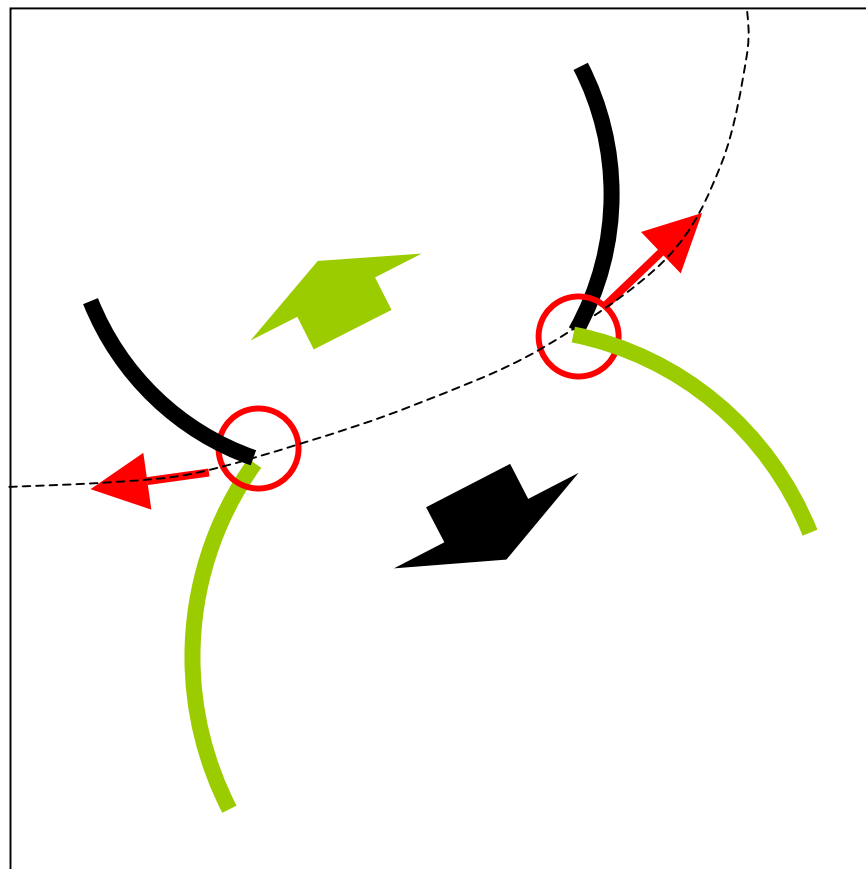
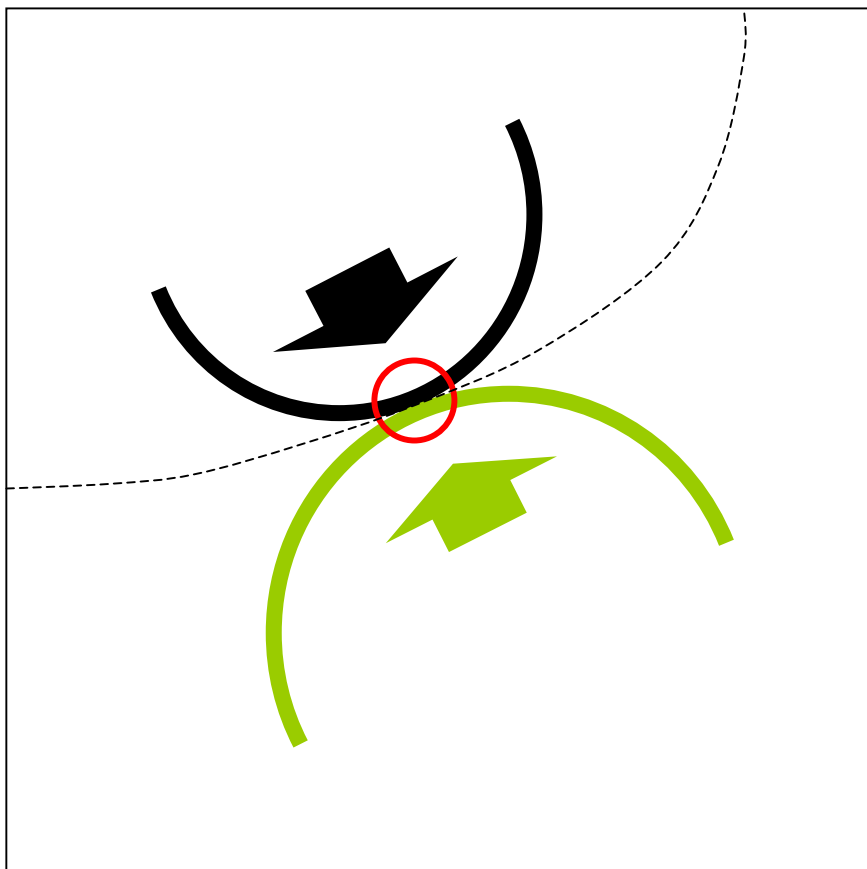
Wang, D. L. & Terman, D. (1997) Image segmentation based on oscillatory correlation. *Neural Computation*, 9: 805-836,1997



Doursat, R., & Petitot, J. (2005b) Dynamical models and cognitive linguistics: Toward an active morphodynamical semantics. To appear in *Neural Networks* (special issue on *IJCNN 2005*)

Spiking neural model supporting traveling waves

Detection of singular points



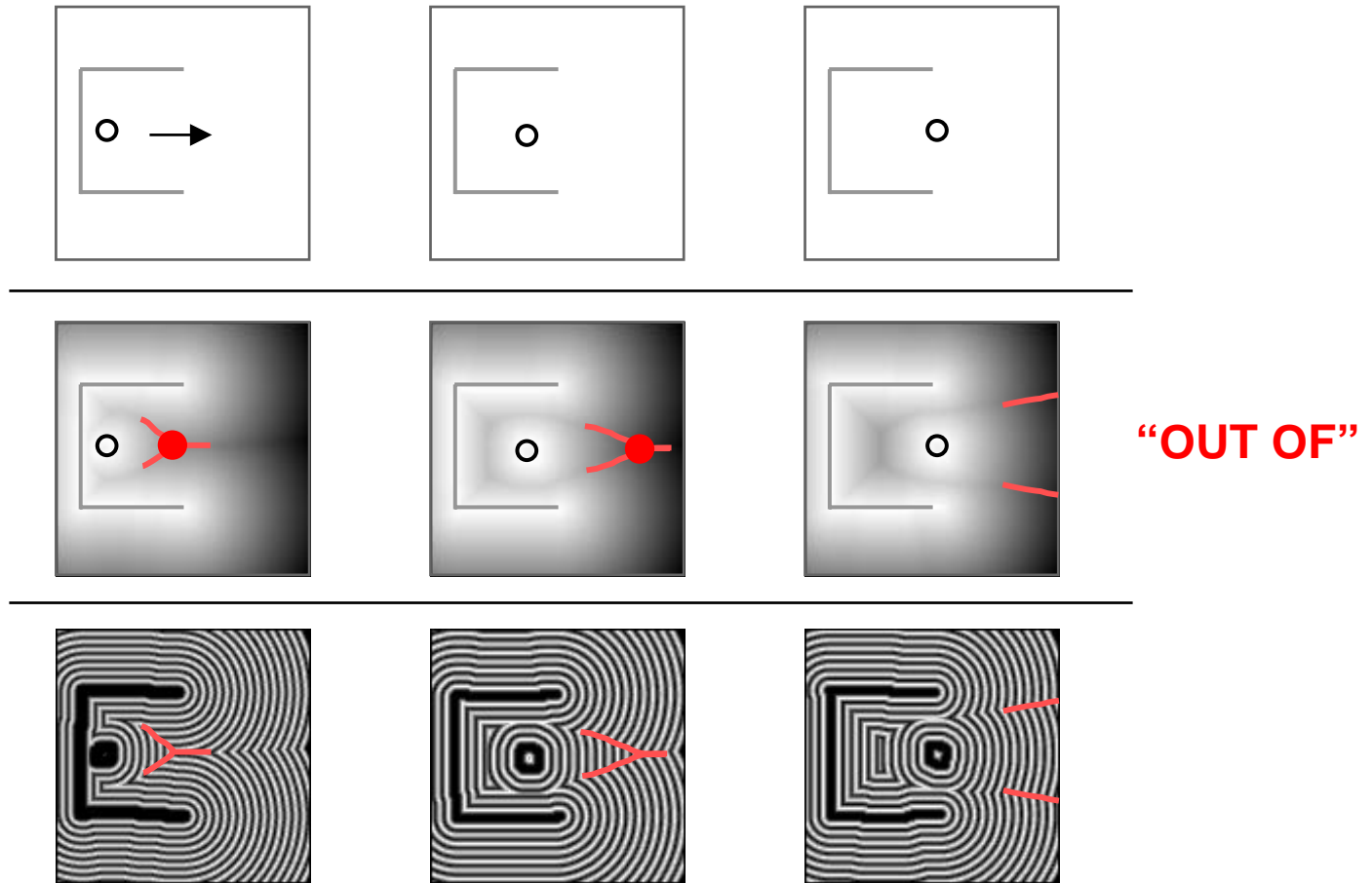
Morphodynamics: summary

- *input images are boiled down to a few critical features by the complex system's dynamics*
- *these singularities constitute the characteristic “signature” of the input's category (e.g., the spatial relationship represented by the image)*
- *key idea: singularities encode a lot of the input's information in an extremely compact and localized manner*

Morphodynamics: summary

- *singularities define static schemas*
- *future step: movie-schemas (verbal scenarios) and the composition of schemas could be implemented by the dynamical evolution and composition (bifurcation, interference) of singularities*

Dynamic evolution of singularities



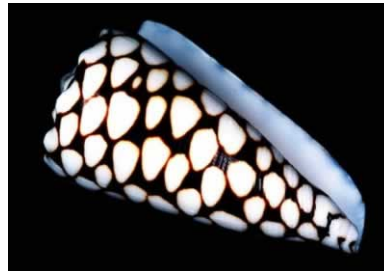
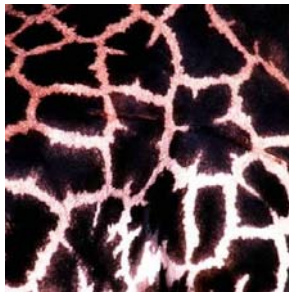
- *The movie-scenario “out of” is revealed by a bifurcation: the singularity (red) disappears as the ball (black) exits the interior of the box; this is a robust phenomenon largely independent from the shape of the actors.*

Pattern formation

- *pattern formation is pervasive in physical and biological large-scale systems . . .*

Spatial (static) pattern formation

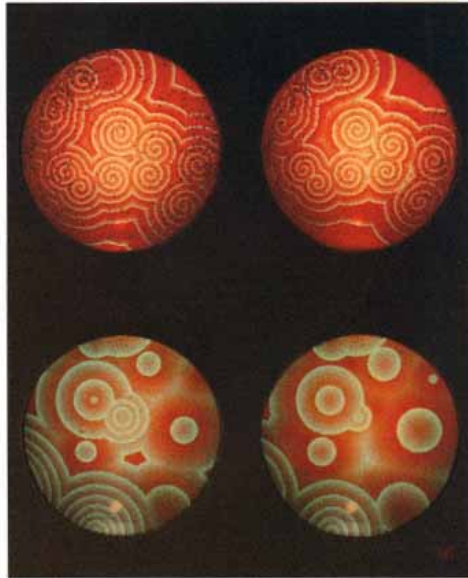
Spots and stripes



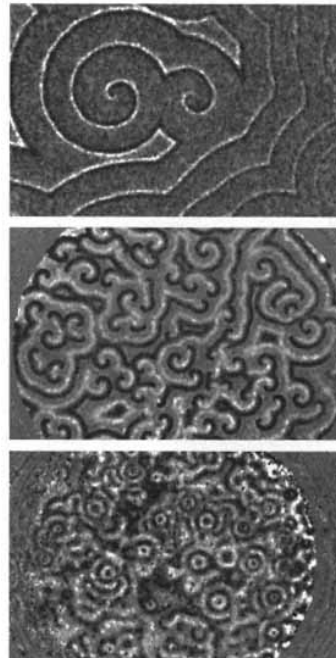
Mammal fur, seashell, and insect wing patterns
(Scott Camazine, <http://www.scottcamazine.com>)

Spatiotemporal (dynamic) pattern formation

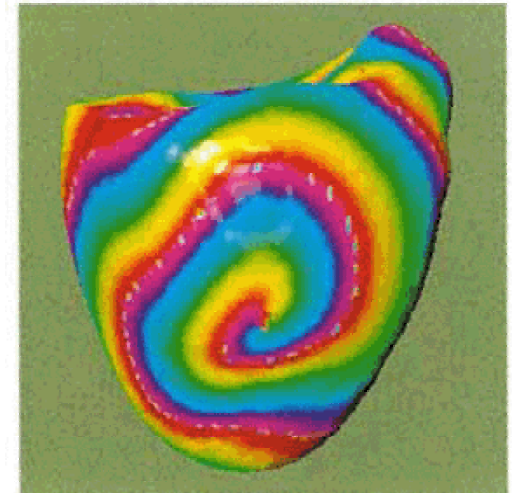
Waves in excitable media



***Circular and spiral traveling waves
in the Belousov-Zhabotinsky reaction***
(Arthur Winfree, University of Arizona.)



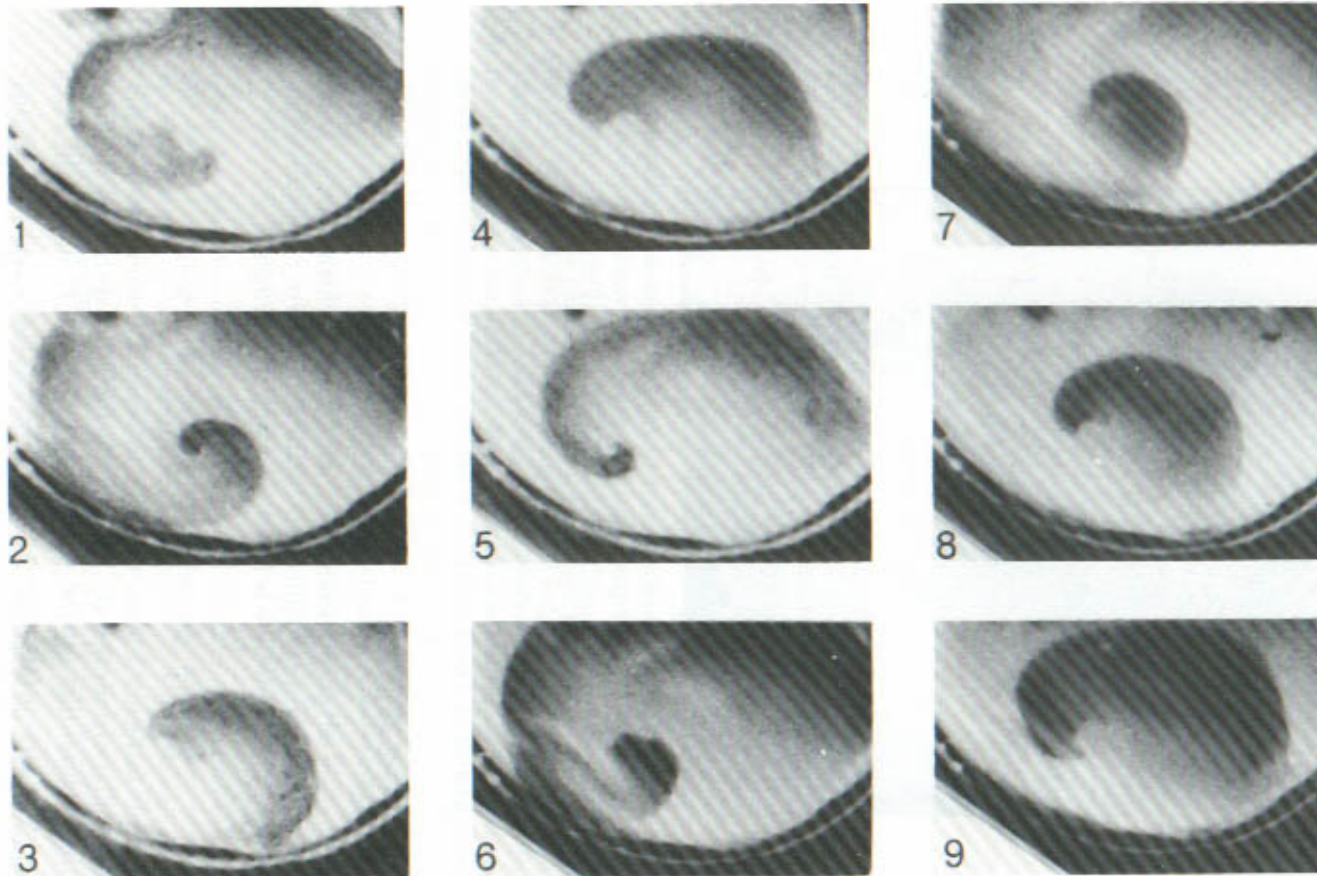
***Wave patterns in aggregating
slime mold amoebas***
(Brian Goodwin, Schumacher College, UK.)



***Spiral waves
in a model of a dog heart***
(James Keener, University of Utah.)

Spatiotemporal (dynamic) pattern formation

Waves in excitable media



*Dark front of spreading depression rotating on the retina of a chicken
(40-second interval frames)
(Gorelova and Bures, 1983)*

Pattern formation

- *. . . so why would the brain be fundamentally different?*
- *idea: the brain construed as a **spatiotemporal pattern generator**, combined with a **singularity decoder***

References

- Doursat, R., & Petitot, J. (2005a). Bridging the gap between vision and language: A morphodynamical model of spatial categories. *IJCNN 2005*
- Doursat, R., & Petitot, J. (2005b). Dynamical models and cognitive linguistics: Toward an active morphodynamical semantics. To appear in *Neural Networks* (special issue on *IJCNN 2005*)