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:**

\[
\text{schematization} + \text{categorization} = \text{drastic reduction of information}
\]

- 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.
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).

For example: traveling waves
Singularities = collision points

(a) ➞ (b) ➞ (c)

“ABOVE”

- 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


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
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
