Extended Criticality in Biology

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Bailly F., Longo G. **Mathematics and the Natural Sciences. The Physical Singularity of Life.** *Imperial College Press*, London, 2011 (français: Hermann, 2006).

G. Longo. Emergence vs Novelty Production in Physics vs Biology. In *Open Historicity of Life. Theory epistemology, practice*, Paris, October, 2023 (to appear in the proceedings: Chollat, Montévil, Robert eds.)

Criticality in Complex Systems

Self-organization and

1 - critical transitions in equilibrium dynamics

2 - critical transitions in far from equilibrium systems

3 – extended criticality in Biology

critical transitions in *least intervals* of time (scale dependent) a (weak) form of mathematical density (a weak topology of least intervals)

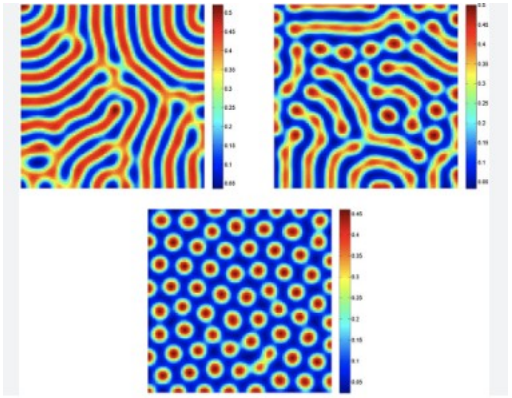
H.J. Jensen. **Self-Organized Criticality, Emergent Complex Behavior in Physical and Biological Systems**. *Cambridge lec. in Physics*, 1998

1 - Physical Emergence

(at equilibrium, self-organised; *a **time** of processes*)

Turing patterns, 1952:

a "**perturbation triggers**" a (chemical) action-reaction-diffusion



New forms « emerge » along the process by **critical** (‘‘catastrophic", says Turing) **transitions**

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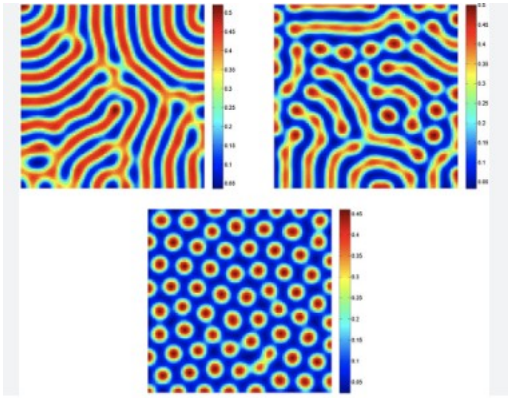


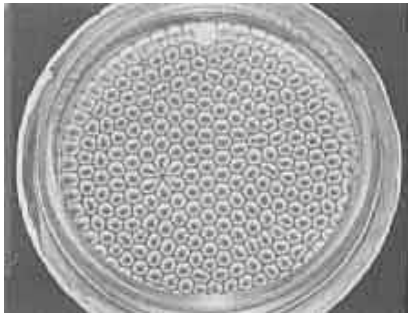
New forms « emerge » along the process by **critical** (‘‘catastrophic", says Turing) **transitions** (*Belousov–Zhabotinsky reactions, 1961*)

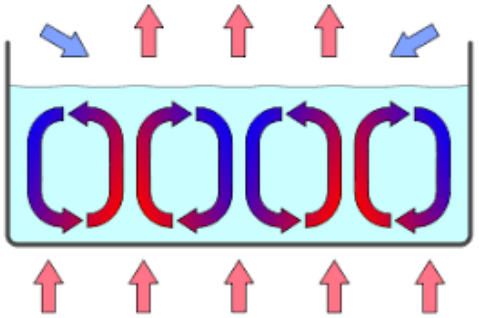
Every surface and path is **optimal** (a geodetic): just physical forces acting on **inert molecules**, that "follow the flow" - ***Thom**'s morphog*.

2 - Physical Emergence

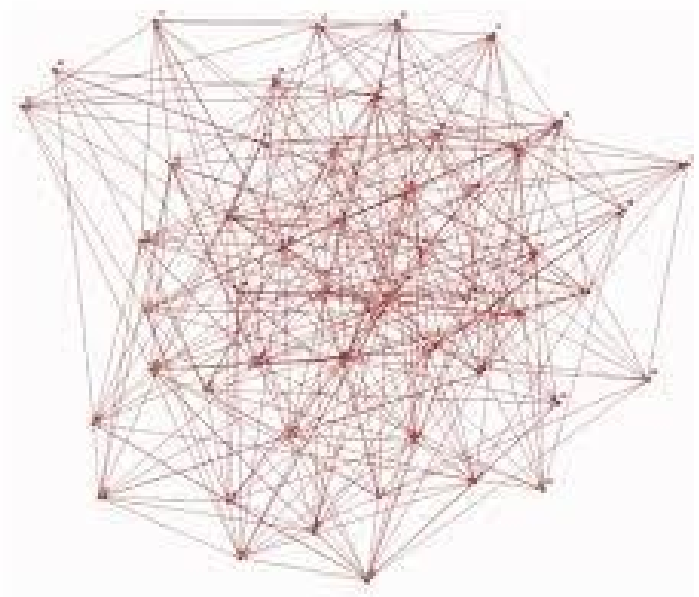
(**far from/at equilibrium**, self-organised; *a **time** of processes*)

- Benard Cells:





- Parisi's Networks
  (Spin Glasses
  and its mathematics)



Mathematically:

- all *point-wise* transitions
- a new "structure of coherence"
- symmetry changes

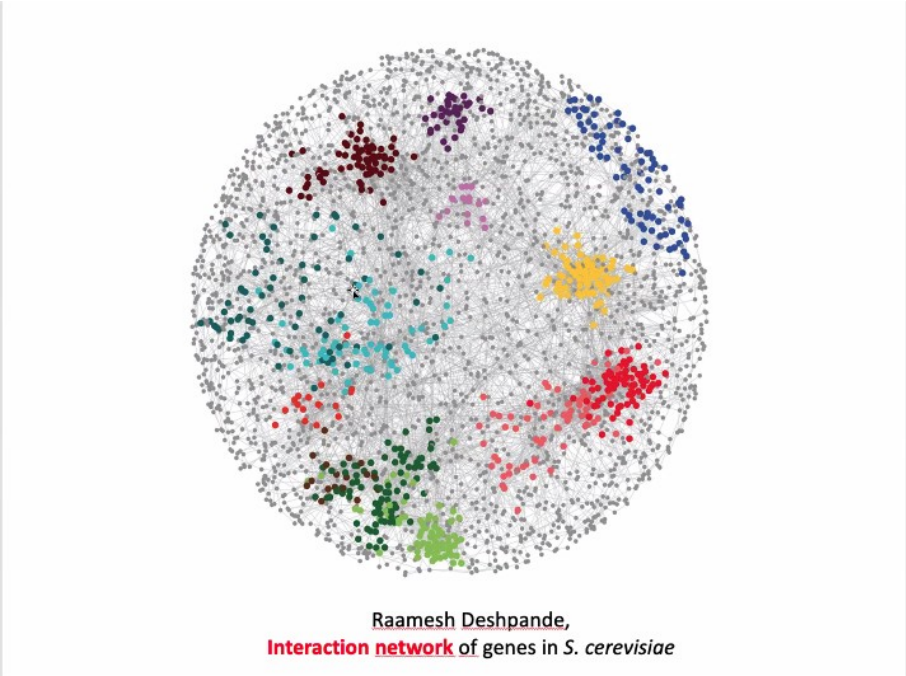
Towards Biology

Darwin:

first principle: “descent with modification”
(At each reproduction: variation)
“even not breeders …”

second principle: “selection”
(the exclusion of the incompatible *stabilizes*
species/populations… organisms)

Biology, molecular level: Gene interaction *networks*



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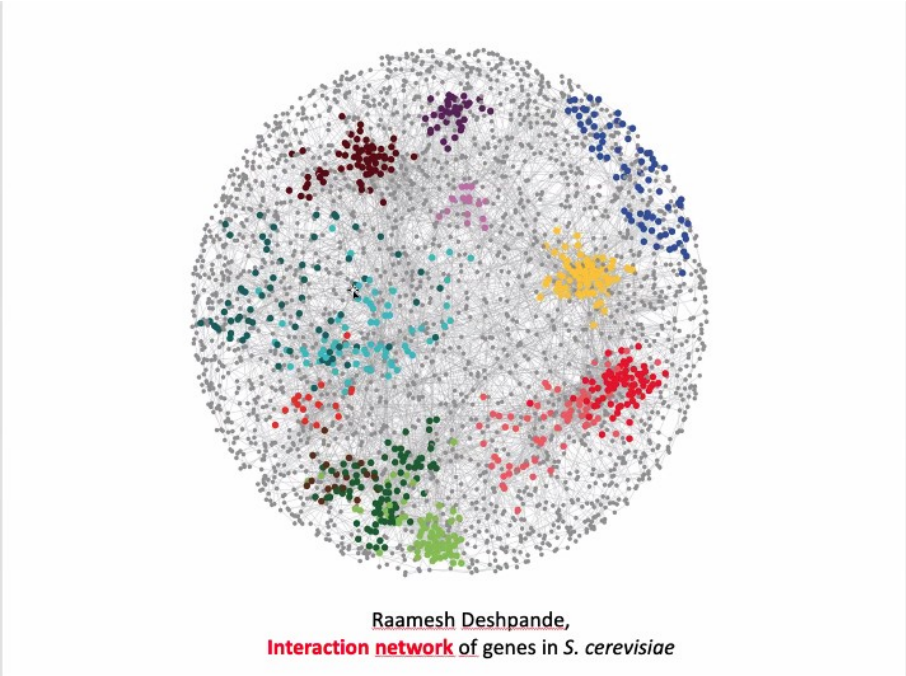

Key aspects of "critical" emergence: the formation of

- extended **correlation** lengths and
- **coherence** structures,
- the **divergence** of some observables w.r. to the control parameter(s) (the **global** affects the local, renormalization, critical exponents), etc….

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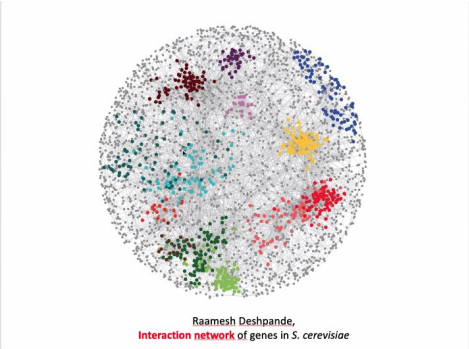
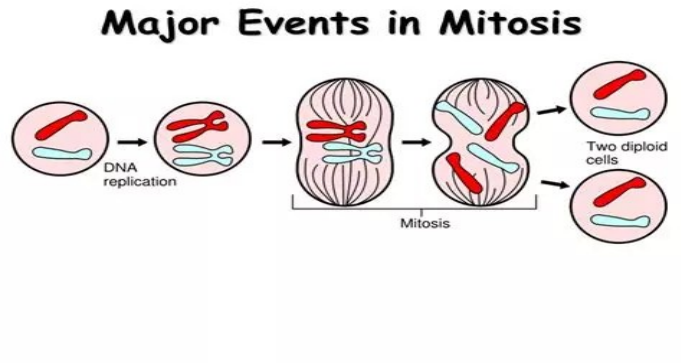
Biology, molecular level:
Gene interaction *networks* in an *organism*





In an organism, **each cell reproduction is *also* a critical transition:**
a bifurcation, a re-organization of the coherence structure: tissue matrix, collagen's tensegrity structure, the cells' molecular exchanges

Biological Time:
always given in **intervals**, by rhythms (metabolic, cardiac, respiration…)

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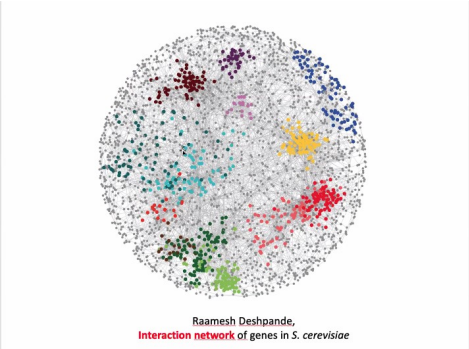

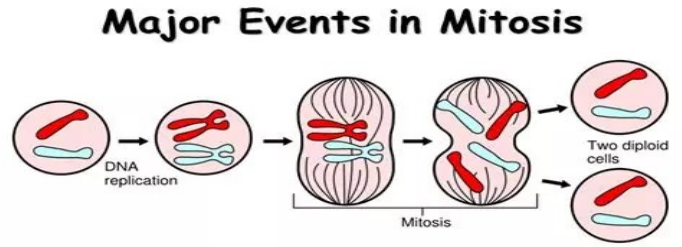

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Biological **stability** (at transitions) is given by **constraints**, in the **nesting** and **interaction** of different levels of organization:

molecular networks, cells, tissue, organism, ecosystem

no preferred causal level

Brain Networks

E. Lovecchio, P. Allegrini, E. Geneston, B. West, P. Grigolini, From self-organized to extended criticality, *Frontiers in Phys.* Vol 3, 2012

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Cooperatively firing neurons:

(i) infinitely large time period, **temporal complexity** corresponds to Mittag-Leffler complexity;

(ii) For large values of the **interaction coupling** the periodic nature of the process becomes predominant while maintaining to some extent, in the intermediate time asymptotic region, the signature of complexity;

(iii) Focusing our attention on firing neuron **avalanches**

« extended criticality advocated by Bailly and Longo, 2006 »

Ecosystemic interaction *networks* (of organisms)

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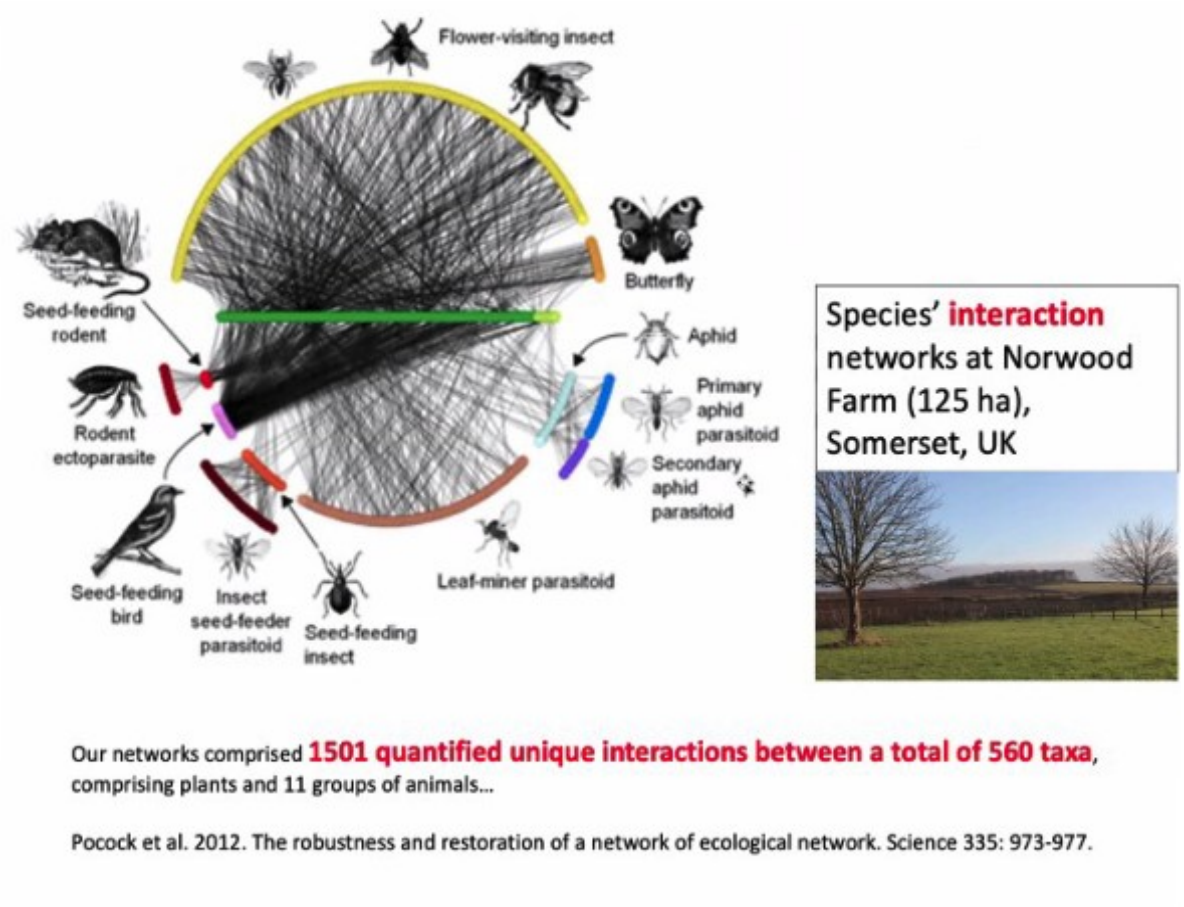
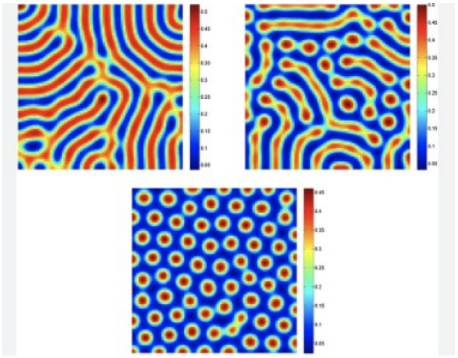
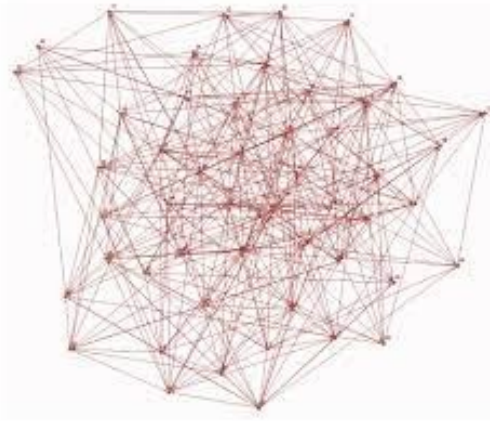


Courtesy of
A. Hilbeck

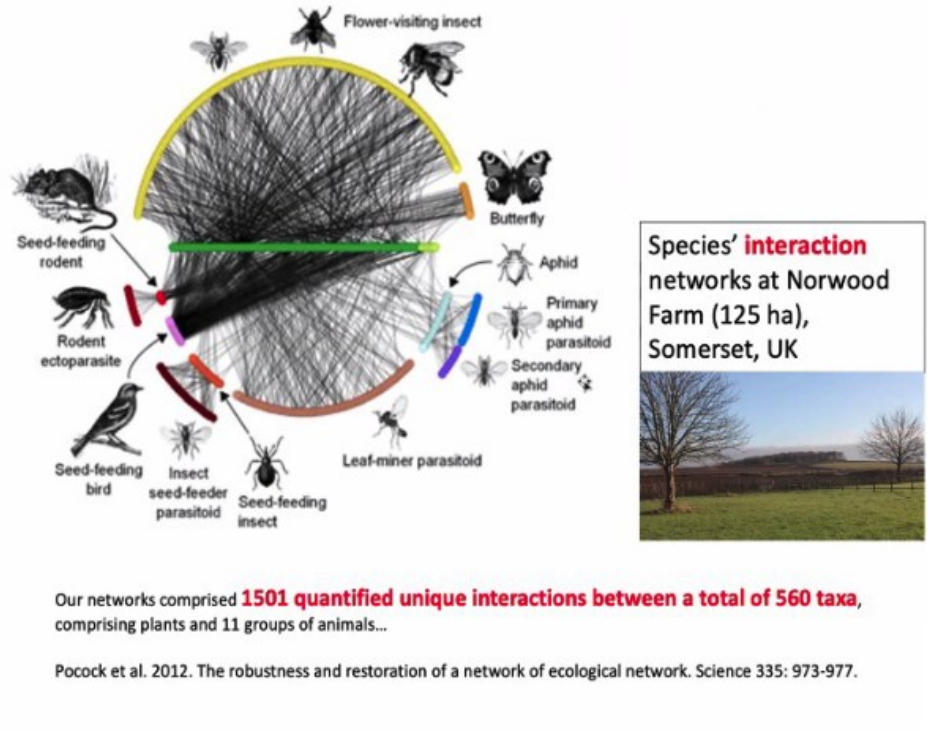
A fine-tuning of **rhythms** (metabolic, circadian… *global* and *individual*)
All different individuals, they are **specific**, the *result of a history*
cf the **generic** (identical) elements of a physical network

Criticality and Emergence in physical *vs* biological interaction networks





Generic components/elements
Emergence and transitions: in the network, pointwise



Changes in **individual** organisms (phylogenetic paths) are *causes* and *consequences* of network deformations

Rhythms give least **intervals of time**, many "transitions" in each interval

Summary: Physical vs Biological networks ("*emergence*")

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- Emerging collective behavior, many possible equilibria
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- Coordinating or disrupting *bio-rhythms* (and physical frequencies)
- Rhythms produce *least intervals*, that contain **numerous critical transitions** (at least: gene and molecular networks, reproductions)

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Extended Critical Transitions (dense in a time of viability)

Some readings in Biology

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G. Longo and M. Montévil. From physics to biology by extending criticality and symmetry breakings. *Progress in Biophysics and Molecular Biology, Systems Biology and Cancer*, 106(2):340 – 347, 2011 (more papers on this are in https://www.di.ens.fr/users/longo/download.html)

E. Lovecchio, P. Allegrini, E. Geneston, B. West, P. Grigolini, From self-organized to extended criticality *Frontiers in Phys.* Vol 3, 2012