Self-Organisation in Multi-Agent Systems

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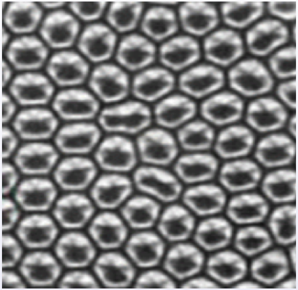
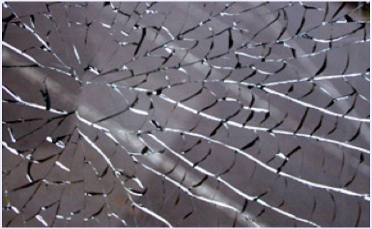
Non Living Systems

Bénard Convection Cells, Sand Dune Ripples





Living Systems

Giraffe, Rabbitfish, Zebra, Shells

Living Systems

Finger Prints, Morel

Social Systems

Ants, Wasps, Termites, Humans

Social Systems

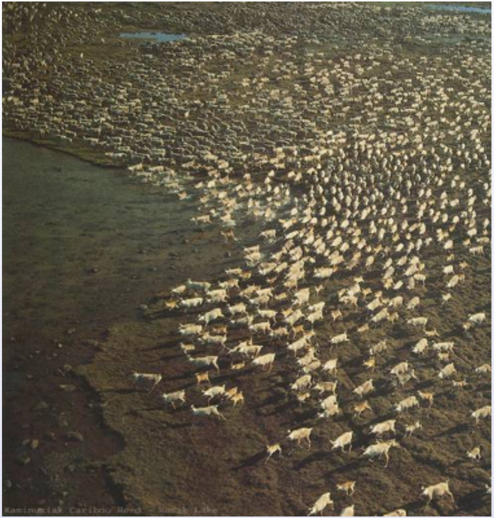
Crustaceans, Ants

Social Systems

Fishes, Birds

Social Systems

Mammalians

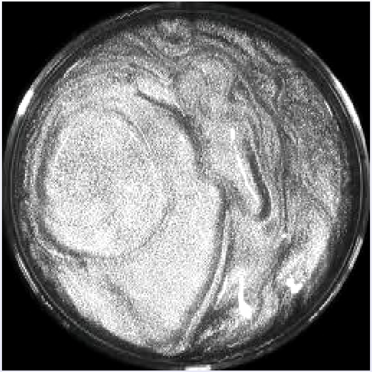


Emergence

- In natural systems
  - Pattern formation
  - Behaviour
  - Phenomenon
- In artificial systems
  - Stable phenomena
  - Behaviour

Emergence in Natural Systems

Pattern Formation



Bénard Cells

Belousov-Zhabotinsky Reaction

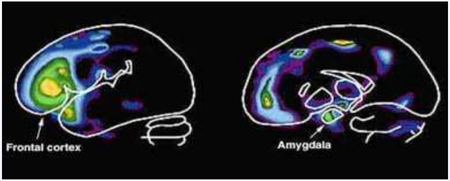
Emergence in Natural Systems

Behavior

Video: Guy Theraulaz, Laboratoire d'Ethologie et Cognition Animale, Toulouse France

Emergence in Natural Systems

Phenomenon



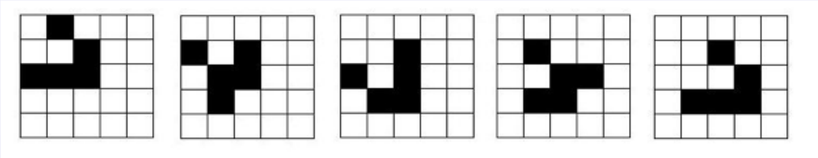
From simple neurons to the thinking brain [Searle, 1992]

Emergence in Artificial Systems

Stable Phenomena

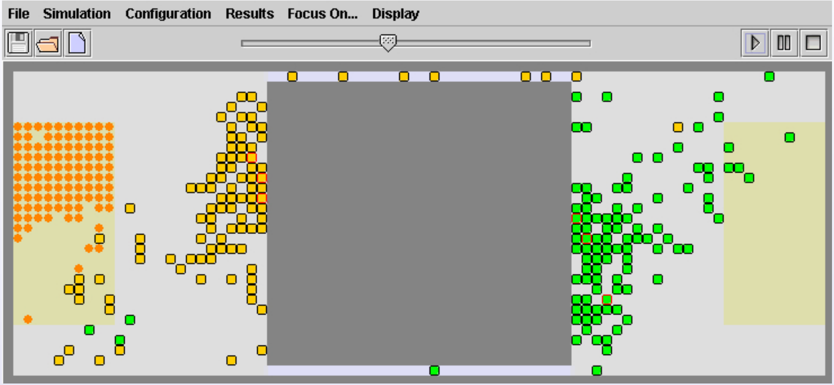
Conway's game of life [Gardner, 1970]

- Cellular automata [von Neumann, 1966]
- Emergence of a stable phenomenon: the glider
- A cell can be dead or alive
  - `If (dead and 3 neighbours alive) then alive`
  - `If (alive and 2 or 3 neighbours alive) then alive`
  - `Else dead`



Emergence in Natural Systems

Social Behavior



[Picard and Gleizes, 2005]

What is Self-Organisation in Artificial Systems?

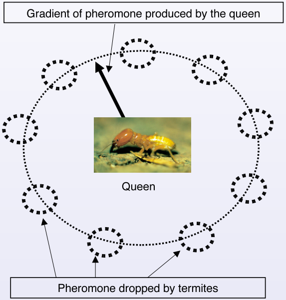
- Self-organisation is the mechanism or the process enabling a system to change its organisation without explicit external command during its execution time
[Di Marzo-Serugendo et al., 2005]
- An autonomous transformation of the system topology (i.e. network connections) by its components as result of this network's functioning
[Camps et al., 1998b]
- A set of dynamical interactions whereby structures appear at the global level of a system from interactions among its lower-level component... The rules specifying the interactions are executed on the basis of purely local information, without reference to the global pattern
[Bonabeau et al., 1999]

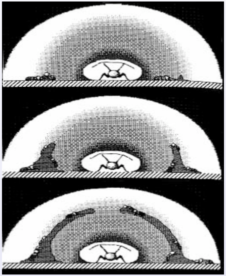
Strong and Weak Self-Organising Systems

- Strong self-organising systems are those systems where there is no explicit central control neither internal nor external
- Weak self-organising systems are those systems where, from an internal point of view, there is re-organisation maybe under an internal (central) control or planning

Strong and Weak Self-Organising Systems

Example





Termite nest construction : weak and strong self-organisation

Self-Organising Systems

[Farley and Clark, 1954]

- A system where a collection of interacting elements gives rise to patterns of behaviors that the individual elements are not capable of when they don't interact
- A system which changes its basic structure as a function of its experience and environment

➥ Emergent properties

- Absence of external control (autonomy)
- Decentralised control
- Dynamic operation (time evolution)

- Additional Properties
  - Fluctuations (noise/searches through options)
  - Symmetry breaking (loss of freedom/heterogeneity)

Characterisation

[Prigogine and Nicolis, 1977; Heylighen, 2001]

- Global order endogenous
- Emergence
- Simple local rules
- Instability (self-reinforcing choices/nonlinearity)
- Parameters sensitivity

- Multiple equilibria (many possible attractors)
- Criticality (threshold effects/phase changes)
- Redundancy (insensitivity to damage)
- Self-maintenance (repair/reproduction metabolisms)
- Adaptation (functionality/tracking of external variations)
- Complexity (multiple concurrent values or objectives)
- Hierarchies (multiple nested self-organised levels)

Requirements for Self-Organisation in MAS

- Two kinds of systems
  - System includes the environment: Ecosystem
  - System and environment can be differentiated: physical real environment
- Several agents
- Many interactions inside the system
- Limited perceptions
- Local behaviors at the agent level

Importance of the Environment

- Dynamic environment
- Coupling between the system and its environment
- At the macro level [Muller, 2004]
  - A collective (« unconscious ») memory
  - A global inscription medium
- At the micro level
  - The resources of the entities
  - An interaction medium
  - The coordination of interactions at various time scales (dissipation rate)
  - Constraints on the agent dynamics

What is Self-organisation in Natural Systems?

- A process in which pattern at the global level of a system emerges solely from numerous interactions among the lower level components of the system [Camazine et al., 2001]
- Rules specifying interactions among the system's components are executed using only local information without reference to the global pattern
- The pattern is an emergent property of the system, rather than a property imposed on the system by an external influence

What Does Emerge?

- The appearance of a property (or feature, or state) not originally observed as a functional characteristic of the system
  - Generally, higher level properties are regarded as emergent
- What can be qualified as emergent
  - Properties
  - Phenomena
  - Behaviour
  - Relevant/adequate function
  - State
  - ...

System Characteristics

- At least two levels (micro-macro)
- Dynamical
  - A form of self-maintained equilibrium
  - The ability to self-organise allowing an emergent phenomenon [Goldstein, 1999]
- Self-organisation, capacity of adaptation

Criteria to Decide whether there is Emergence

- Need to be observable at some level
- Novelty [Lewes, 1875; Van de Vijver, 1997]
- Coherence Irreducibility [Ali et al., 1997]
- Interdependency between levels [Langton, 1990]

$$\mathit{local}\ \frac{\mathit{causes} \rightarrow}{\leftarrow \mathit{constraints}}\ \mathit{global}$$

- Non linearity

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$$local \; \frac{causes \rightarrow}{\leftarrow constraints} \; global$$

- Non linearity

The Role of the Observer

- Necessary to qualify the emergence
- Outside the system and no action on the system

Definition of Emergence

[Forrest, 1991; Muller, 2004]

- A phenomenon is emergent if and only if we have:
  - A system of interacting entities whose states and dynamics is expressed in a theory D
    - Example: the cells and its transition rules
  - The production of a phenomenon (a process, a stable state, an invariant) which is global relative to the former system:
    - Example: the regularities in the dynamics of the cells
  - The interpretation of the phenomenon via an inscription mechanism in another theory D':
    - Example: the glider and its laws
- The non-linearity of the interactions guarantees the irreducibility of D' to D

Towards an Operational Definition

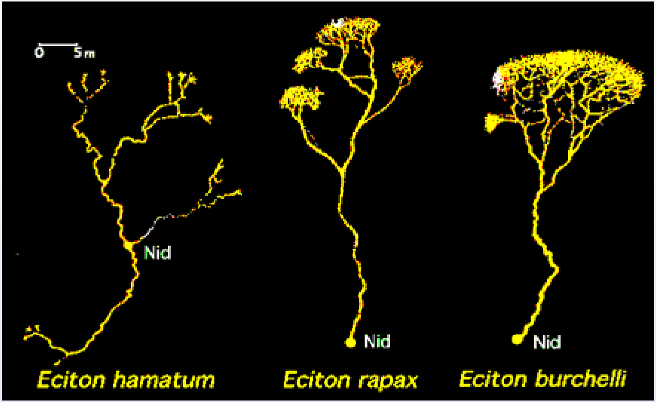
[Georgé, 2004; Georgé et al., 2004]

- The subject
  - A computational system has to realise a function which must be adequate to what is expecting a relevant user. This function, which may evolve during time, has to emerge
- The condition
  - This function is emergent if the coding of the system does not depend in any way of the knowledge of this function

  This coding has to contain the mechanisms allowing the adaptation of the system during its coupling with the environment, so as to tend anytime towards the adequate function

Emergence vs. Self-Organisation

- Emergent
  - = Result of the collective
- Self-organisation
  - = Means to obtain emergent phenomenon



Motivations

- Observations
  - Problems or applications too complex
  - Difficulty to have a complete global view, a global control
  - Self-organisation → adaptation capacity
  - Open systems
  - Incomplete specified problem
- Advantages
  - Simplification of the design: Bottom up approach
- Aims
  - Understand and control self-organisation
  - Find theories of the emergence

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Emergence and Problem Solving

- Classical solving problem
  - Designer → Process leading to the solution
- Emergent solving problem
  - Designer → Agent, interaction and environment
  - The process by self-organisation builds the solution

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