Biological Autonomy

Theoretical and heuristic implications of autopoietic theory in investigating living systems at the basic level

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Summary

1. Limits of the descriptive approach to the definition of life
2. A constructive (synthetic) approach: Biological Autonomy
3. A systemic definition of life in terms of (circular/closed) organization: autopoiesis
4. An example of biological autonomy: the chemoton
5. A possible characterization of autonomous organization in terms of constraints
6. Implications of this approach

Limits of the descriptive approach to the definition of life/1

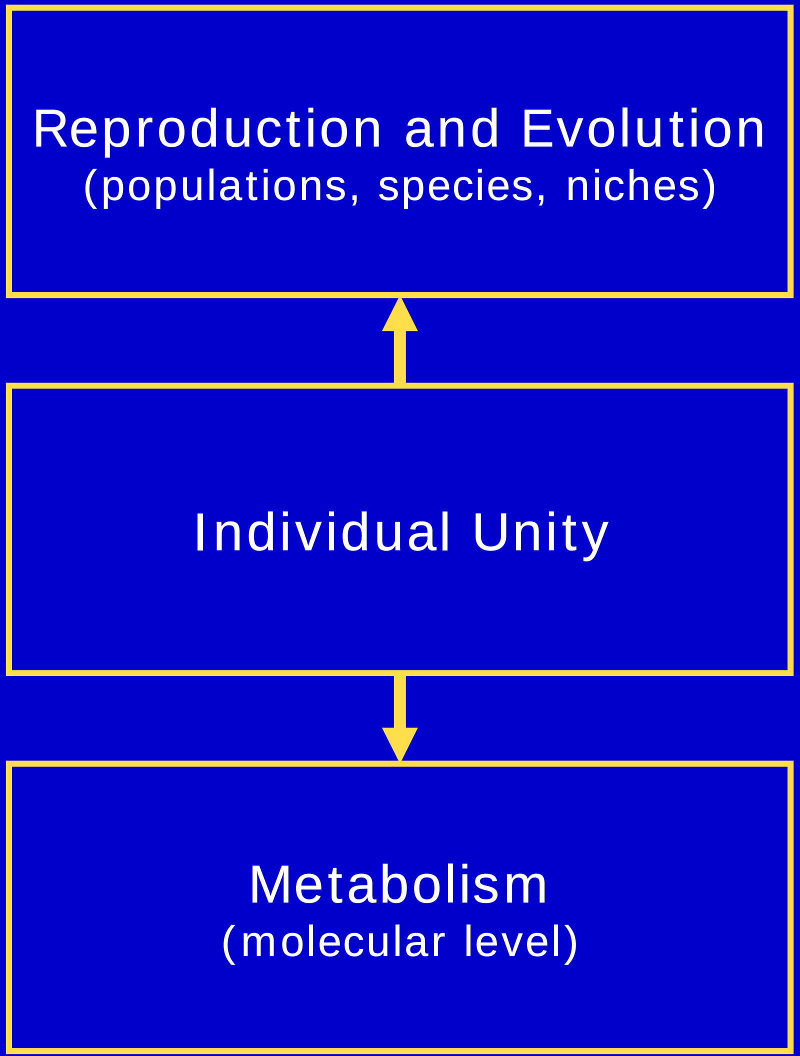
Insufficiency of a definition by a list of properties

(e.g. evolvability, reproduction, metabolism etc...)

- The list is never complete (variety of living forms)
- It is limited to the forms of life we know at the moment
- It requires the *a-priori* knowledge necessary in order to identify an organism
- It risks to identify life with other systems that “simulate” some of the behaviours typical of living organisms
- It misses the internal processes that generate these behaviours and the biological phenomenology in general

Limits of the descriptive approach to the definition of life/2

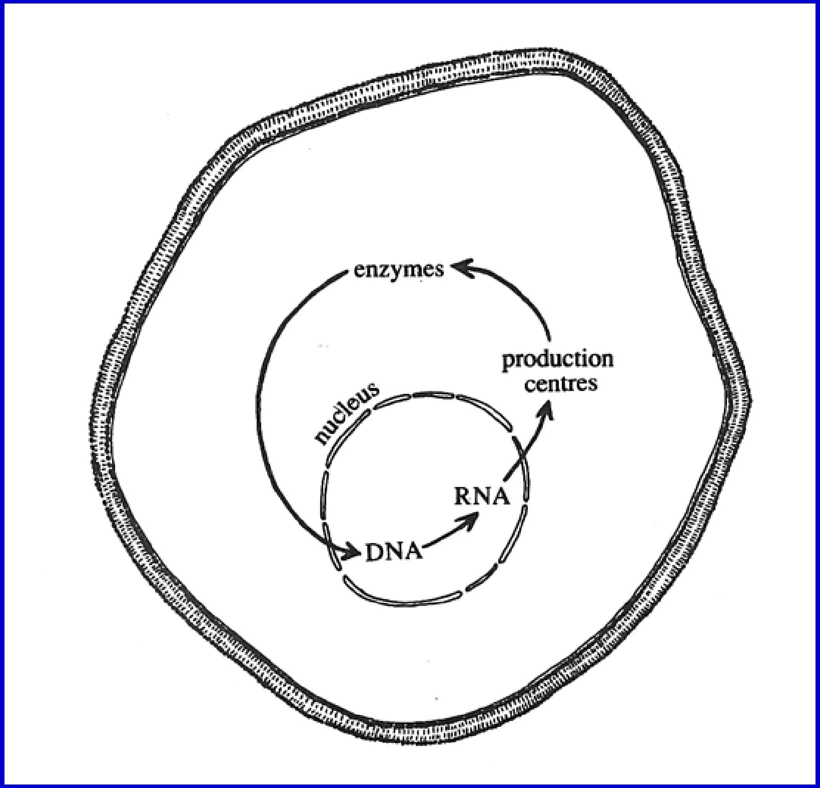
Evolution and reproduction presuppose - on the *logical*, *phenomenological* and *operational* levels – the existence of a biological individual



Metabolism alone does not succeed in specifying the conditions under which metabolic transformations take place, and give rise and are integrated into an individual system

What is life?
(re-posing the question at the level of the individual unity)

What characterizes the continuous and intertwined flux of processes of production of components which we recognize as realizing a living system?



Implications

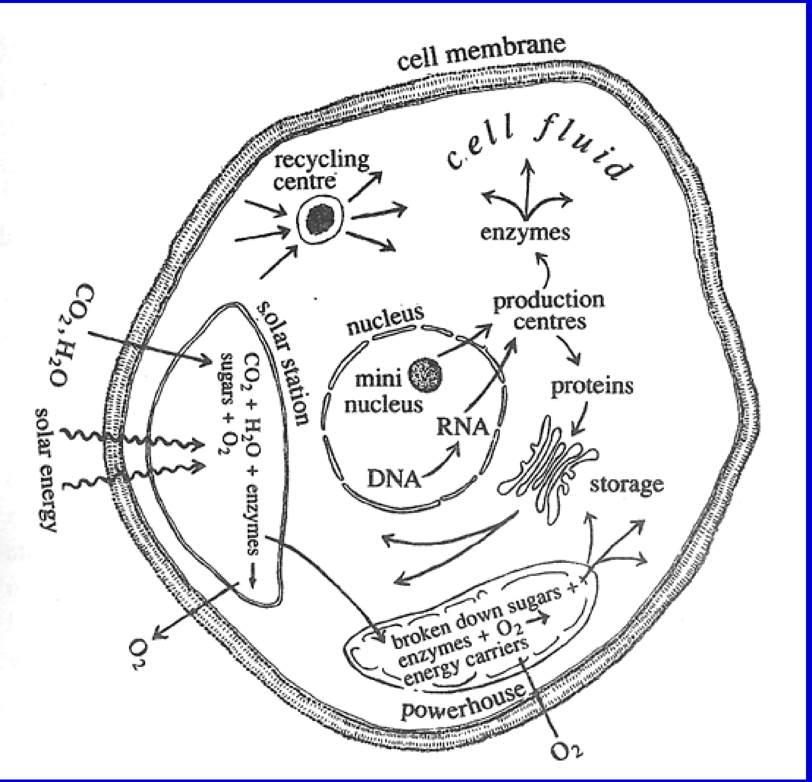
- **Theoretical**

a. What makes an organism a system of a certain class?

b. How being part of a system constraints or influences the behaviour of the individual components?

- **Heuristic**

Modalities of fractionation of the system and identification of the relevant components



A new solution to the problem of the definition of life

The synthetic idea that scientific explanation in this domain coincides with the conceptual (at least) construction of the mechanism able to generate the object studied

- A theoretical biology that is also a constructive biology:

a. It avoids the endless analysis of all the variety of biological forms

b. It consists in constructing a mechanism able to generate, in principle, all the biological phenomenology

The constructive approach: the organism as an autonomous system/1

1. Identification of what is primary in the inquiry on life: not the physico-chemical components but the systemic unity in which they are dynamically integrated

2. Specification of the object of the constructive definition: the minimal living unity, the minimal cell

3. The idea that the cell is not the product of exogenous forces but of internal ones: a creative activity of self-production

The constructive approach: the organism as an autonomous system/2

4. The identification of the generative mechanism of the cell with the mechanism of cellular self-production (and self-maintenance)

5. The conceptual formalization of the cellular dynamics of self-production and self-maintenance: the interplay between structure (variant) and organization (invariant)

6. The idea of *organizational closure* (Rosen, Piaget, Maturana, Varela): a closed chain of operations of transformations of components in which every operation triggers and integrates the others

The constructive definition

Definition of the autopoietic organization

(Maturana & Varela, 1973)

The autopoietic organization is defined as a unity by a closed network of processes of production, transformation and destruction of components, which:

a. through their interactions and transformations recursively realize and regenerate the same complex of processes that produces them;

b. constitute the system as a concrete unity in the space in which they exist, by establishing its boundaries and, thus, specifying its domain of existence with respect to its environment

Some remarks

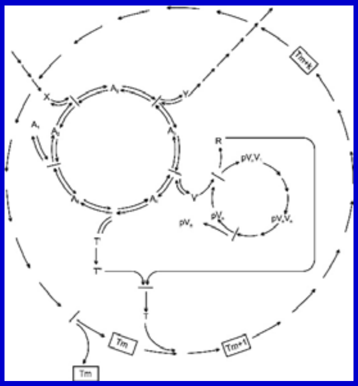
- Emphasis on the unitary character of the system
- What is crucial is how components are related and interact (organization) and not their intrinsic properties
- At least in principle, there can be alternative realizations of life (it is not necessarily limited to chemical composition of life as we know it, that is, contemporary terrestrial life)
- *Weak thesis:* the organization defines the conditions that the components must satisfy in order to be part of the system
- *Strong thesis:* the components are not such in themselves but are specified by the system they belong to (and which, in turn, they realize)

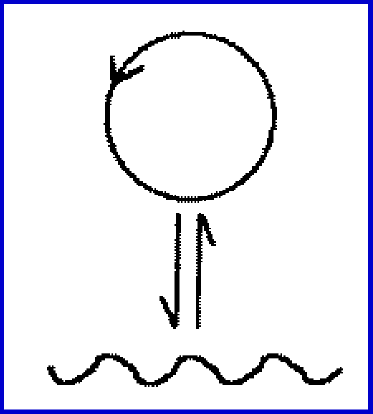
Two theoretical examples of biological autonomy

They focus the analysis on the meta-level of description of what appear to be the global internal dynamics of the system. They differentiate according to the emphasis on the role of organization

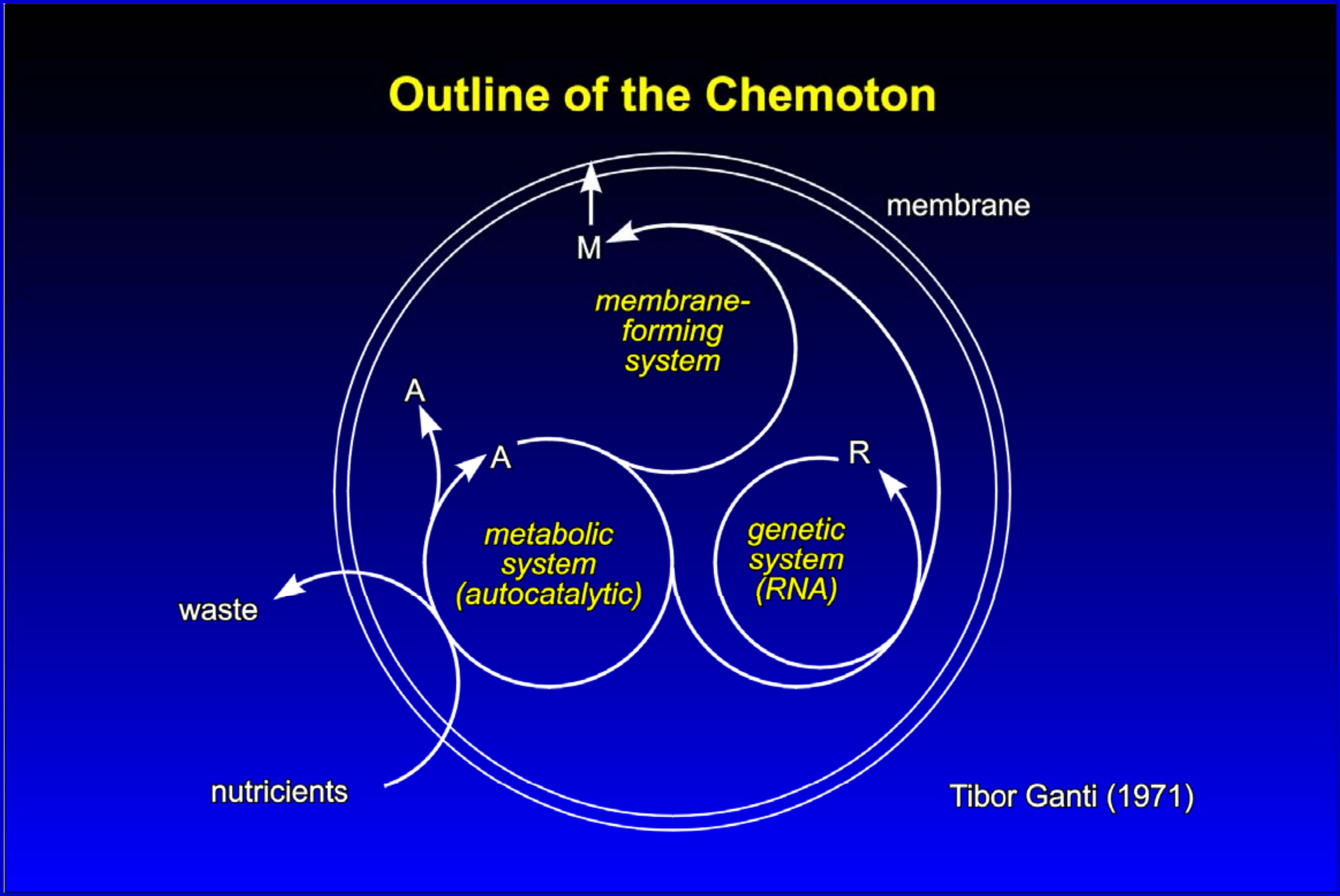
Weak thesis: semi-independence of subsystems (protocells)
Chemoton Theory

Strong thesis: interdependency of sub-processes (minimal cells)
Autopoietic Theory





The Chemoton/1



The Chemoton/2

Three coupled subsystems:

a. A chemical motor (self-producing metabolic subsystem)

b. A chemical information system (control subsystem)

c. A chemical boundary system (boundary subsystem)

The system is characterized by a topological closure and by a specification of components instructively induced by a control subsystem

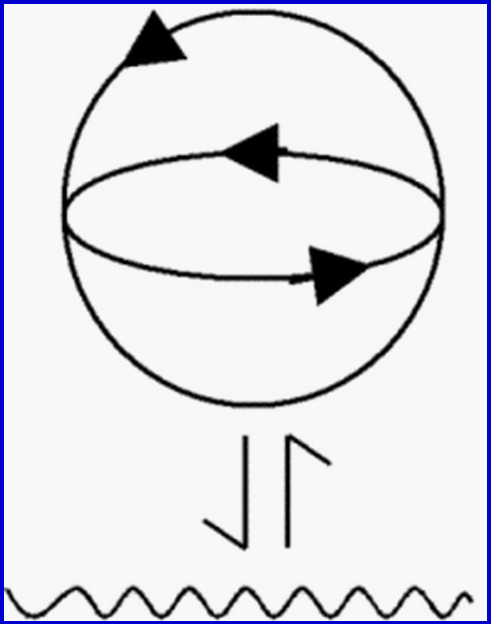
Subsystems depend on one another for their existence but they have a certain degree of independence and the mechanism of regulation can be identified with the activity of specific components

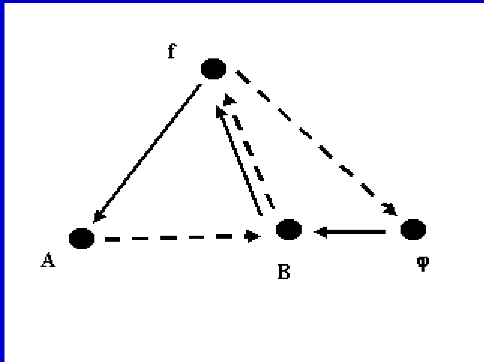
Autopoietic systems/2

•The attention is focused on the global unitary mechanism of conservation of organization (not on identifiable subsystems)

•Interdependency of components specified by the identity of the system they belong to (autopoiesis)

•The system is characterized by both topological and functional closure. The specification of components is not due to the activity of an instructive component but derives from the higher order organization



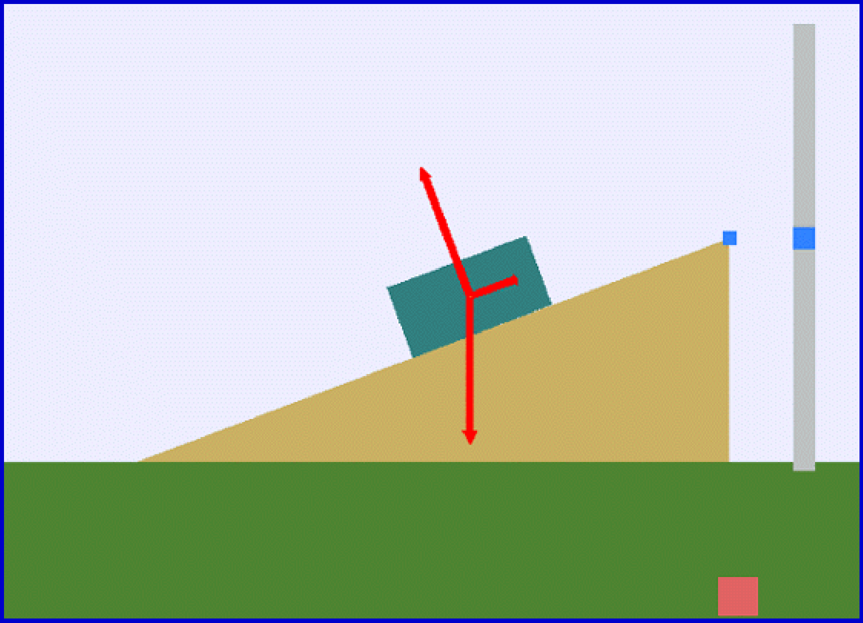


The classic notion of constraint

- It is usually a relation between a system and its surroundings
- It is usually introduced in those cases in which the behaviour of the system is causally underspecified inside the system itself
- It constitutes an alternative description that provides the missing specification (e.g. *boundary conditions*)

Example of the inclined plane: a boundary condition that allows the description of the movement of the object (reducing its degrees of freedom)

Asymmetrical relation: it is assumed *a-priori* (as a prerequisite) and affects the motion of the object without being causally affected by it

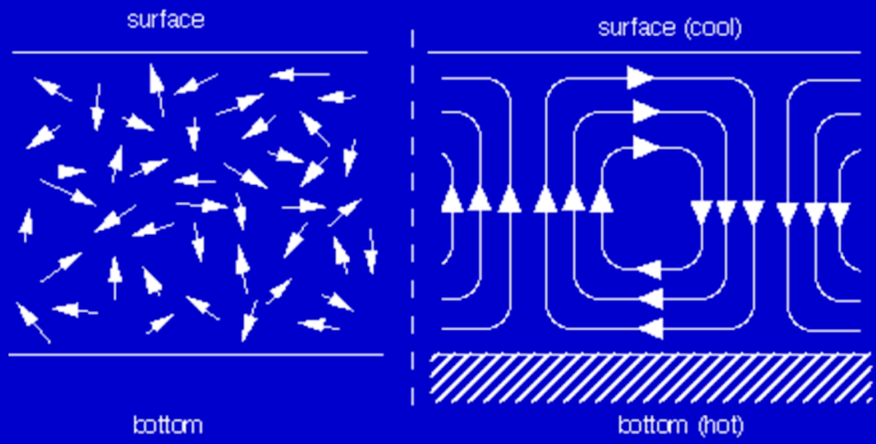


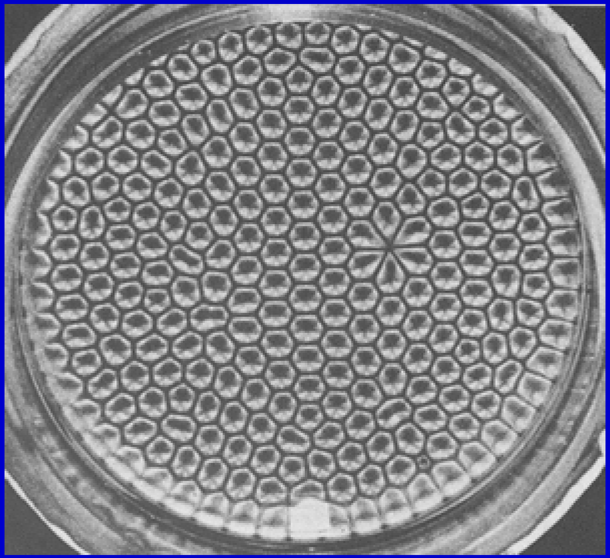
Constraints in *self-maintaining* thermodynamical systems/1

- *Benard cells* appear when some boundary conditions are satisfied (e.g. threshold of temperature)

- The maintenance does not depend only on independent constraints but also on some constraints exerted by the same configuration.

- Their action consists in capturing surrounding molecules and in turning them into components





Constraints in *self-maintaining* thermodynamical systems/2

• The system is self-maintaining when a constraint is able to act on some dynamics in such a way that, in turn, the same dynamic contributes to maintain some of the boundary conditions that allow its existance

•The configuration (Benard cell) constraints its surroundings by turning them into a subset of its boundary conditions

•It is a reciprocal, but external and indirect, constraining action between two systems (the cell and its surroundings) which are separated and distinct

Constraints in basic living systems/1

- Considering just the relation between the system and its surroundings it is not sufficient

- The system does not just capture components which exist freely in the surroundings but produces them from some external substrates

- It separates the internal self-specified environment from the external one

- It realizes a self-production and self-maintenance of the whole dynamics and structure (the internal environment)

Constraints in basic living systems/2
A definition of *closure*

• *Organizational closure* as a mutual dependence between constraints: the system contains a set of structures ($C_1 \ldots C_n$) acting as constraints such that, for each one C_i some of the boundary conditions required for its maintenance are determined by the immediate action of another constraint C_j whose maintenance depends, in turn, on C_i

• They are *generative constraints*: each one acts on the boundary conditions enabling the existence of other constraints (on whose action, in turn, it depends) and not only exerts a causal power on the behaviour of the structure

• Difference between *organizational closure* (cycle of actions on boundary conditions of structures) and *operational closure* (causal cycle between structures: e.g. circular interaction between balls with independent constraints)

Organizational closure and components

- *Organizational closure,* according to this approach, consists in a circularity between internal constraints: it is a mutual, direct and generative relation

- In normal configurations the existence of components does not depend on their being involved in the configuration (they exist and can be described independently from it)

- In organizationally closed configurations the various components acting as generative constraints ($C_1 \ldots C_n$) exist as far as they are involved in the configuration (unlike in physical self-maintaining systems like Benard cells they cease to exist if the configuration disappears): they are determined and specified by the organization of the system.

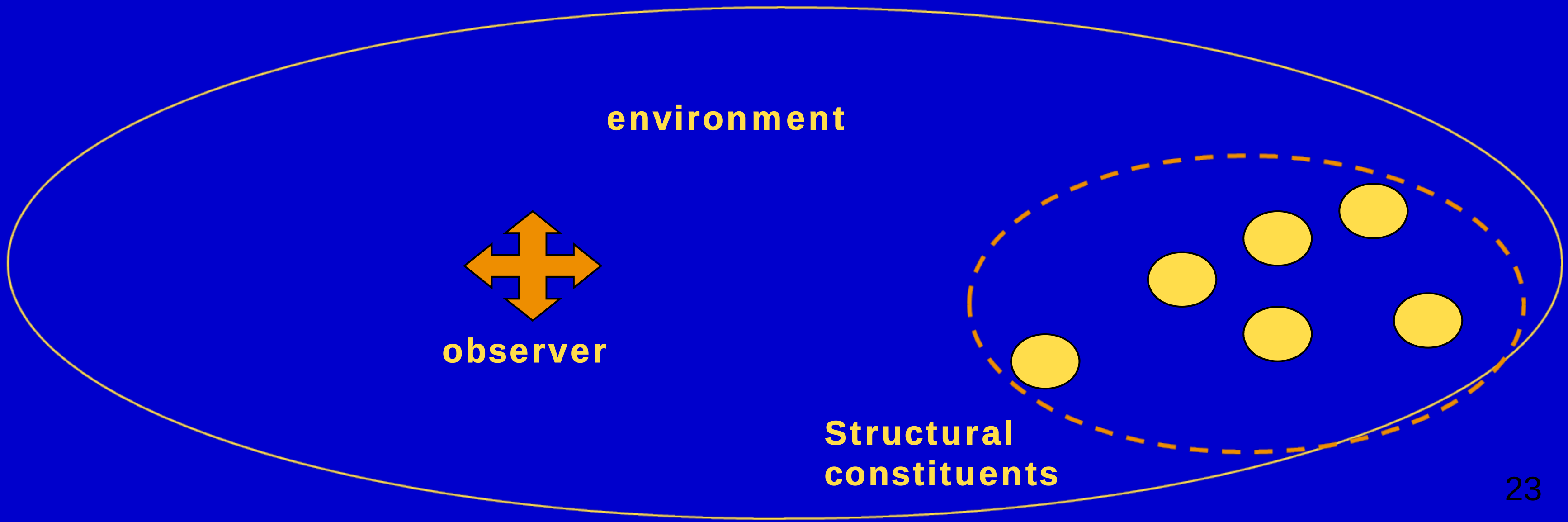
- As a consequence, organizational structure entails some limitations in the possible operations of fractionation of the system

Epistemological and heuristic implications/1

According to this framework from the epistemological and heuristic point of view organizational closure entails a difference between “structural” and “functional” identifications of subsystems

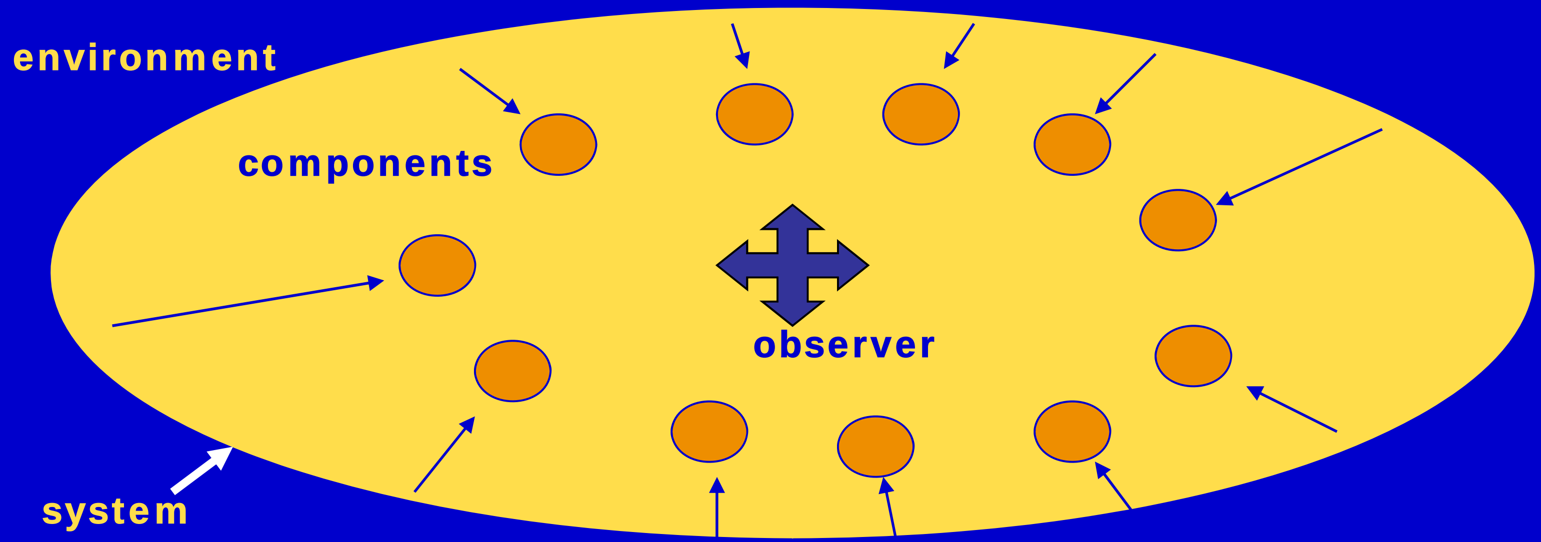
Epistemological and heuristic implications/2

In the case absence of organizational closure the relevant components are just the **material parts** considered in isolation, distinguished from a generic background (direction *bottom up*): they can be identified logically and phenomenologically *ex ante* with respect to the realization of the living system they belong to



Epistemological and heuristic implications/3

In presence of organizational closure sub-systems or sub-processes are characterized and identified only *ex-post* with respect to the theoretical or effective realization of the living and in relation to the the system they integrate (direction *top down*): they constitute the level of the interactions betwen the functional components as distinct from the structural ones



Conclusive Remarks

- From a conceptual point of view this framework requires a top-down approach

- In the autopoietic framework a problem of identification of the relevant components arises:

1. A hard problem for the bottom-up approach: not necessarily the (independent) subsystems we would combine are the same that we would distinguish in a already living minimal system

2. This activity requires a multilevel complex strategy which considers both structural and organizational/functional aspects (dynamical use of models): an interplay of bottom up and top down heuristics