A dynamic model for emergence and self-organization in multi-scale systems

by

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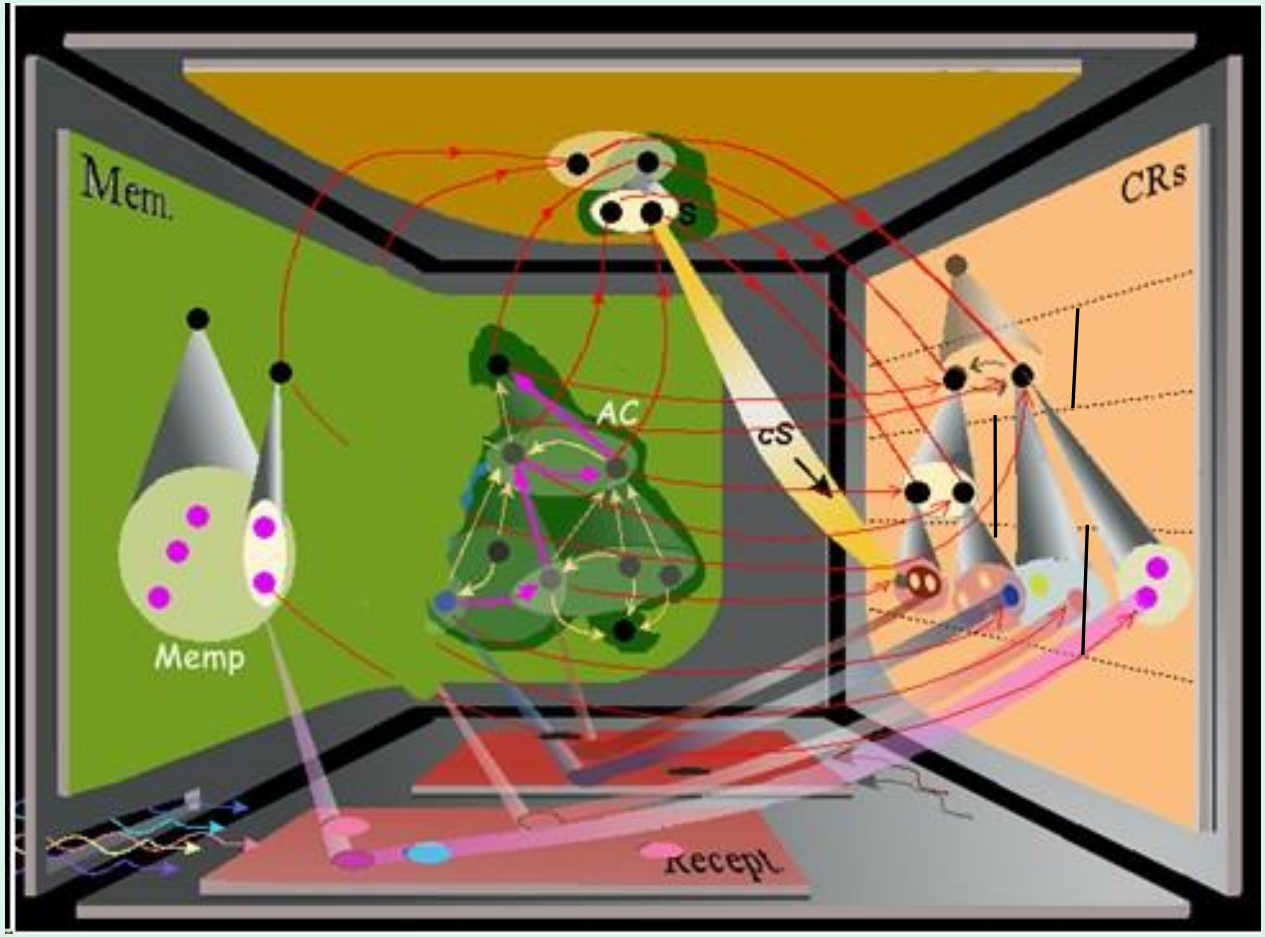
CHARACTERISTICS OF LIVING SYSTEMS



Evolutionary systems with a hierarchy of components varying over time.

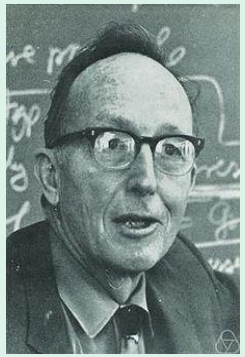
Multi-scale and multi-agent self-organization with:

Network of Co-Regulators with different rhythms and logics

Development of a central Memory with some plasticity

Eilenberg

CATEGORY THEORY
introduced by
in 1945



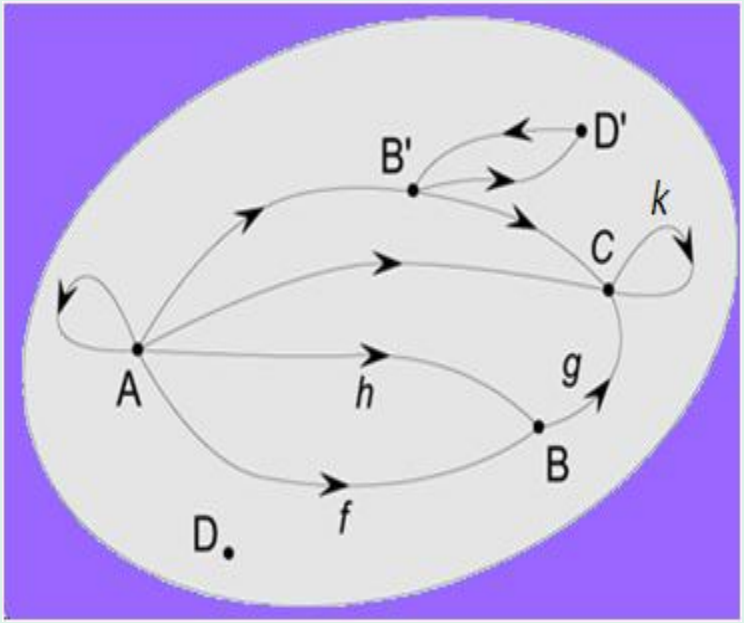
Mac Lane

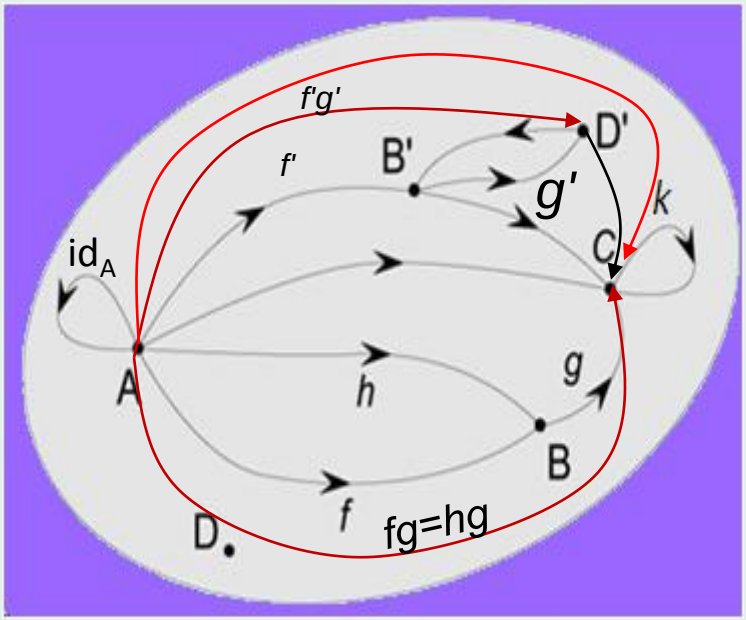
It is a 'relational' mathematics,
at the border between mathematics, logic and metamathematics
reflects the main operations of he "working mathematician"

Applications in computer science,
foundations of physics, biology, social sciences

Memory Evolutive Systems use a
'dynamic' category theory incorporating Time

GRAPHS AND CATEGORIES





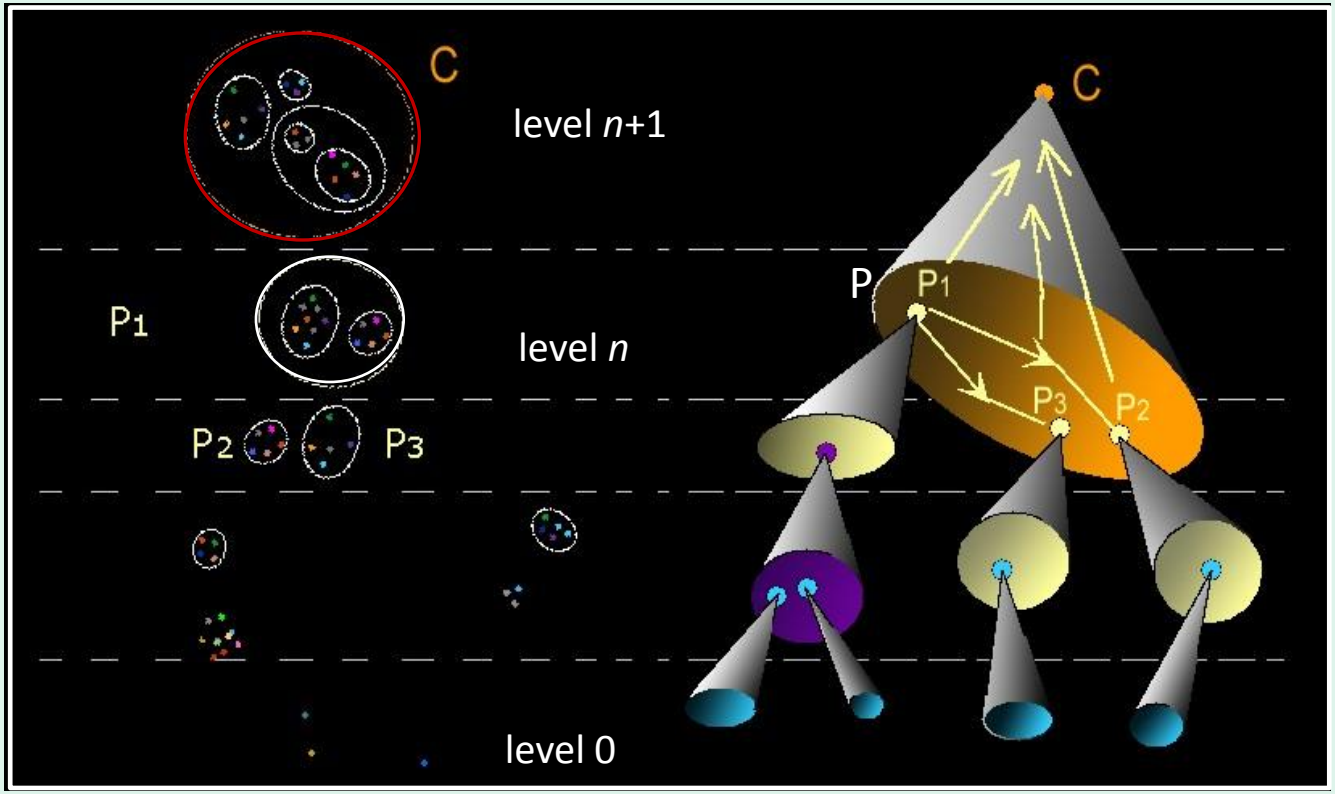
A *(multi-)graph* G has vertices A, B, … , and arrows f: A → B.
Path of G = sequence of consecutive arrows.

Category = graph in which each path (*f, g*) has a *composite fg*, the composition being associative and with identities.

Functionally equivalent paths
<---> their composites are equal

Examples of categories: monoids, partially ordered sets, groups, groupoids, category of paths of a graph.

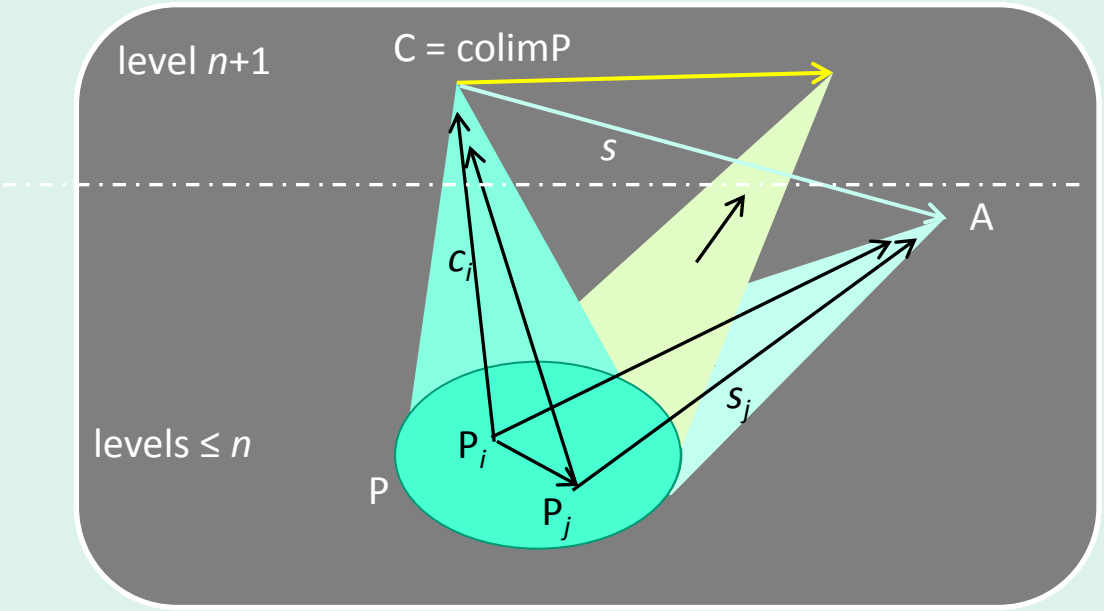
THE HIERARCHY OF COMPONENTS



The system at *t* is represented by a *hierarchical category*:
objects = components at *t*, links = channels for their interacttions.

Objects divided into levels so that C of level *n*+1 has an internal organization into a pattern P of linked components of lower levels. which it 'binds', so that C and P have the same functional role. C is modeled by the *colimit* of P.

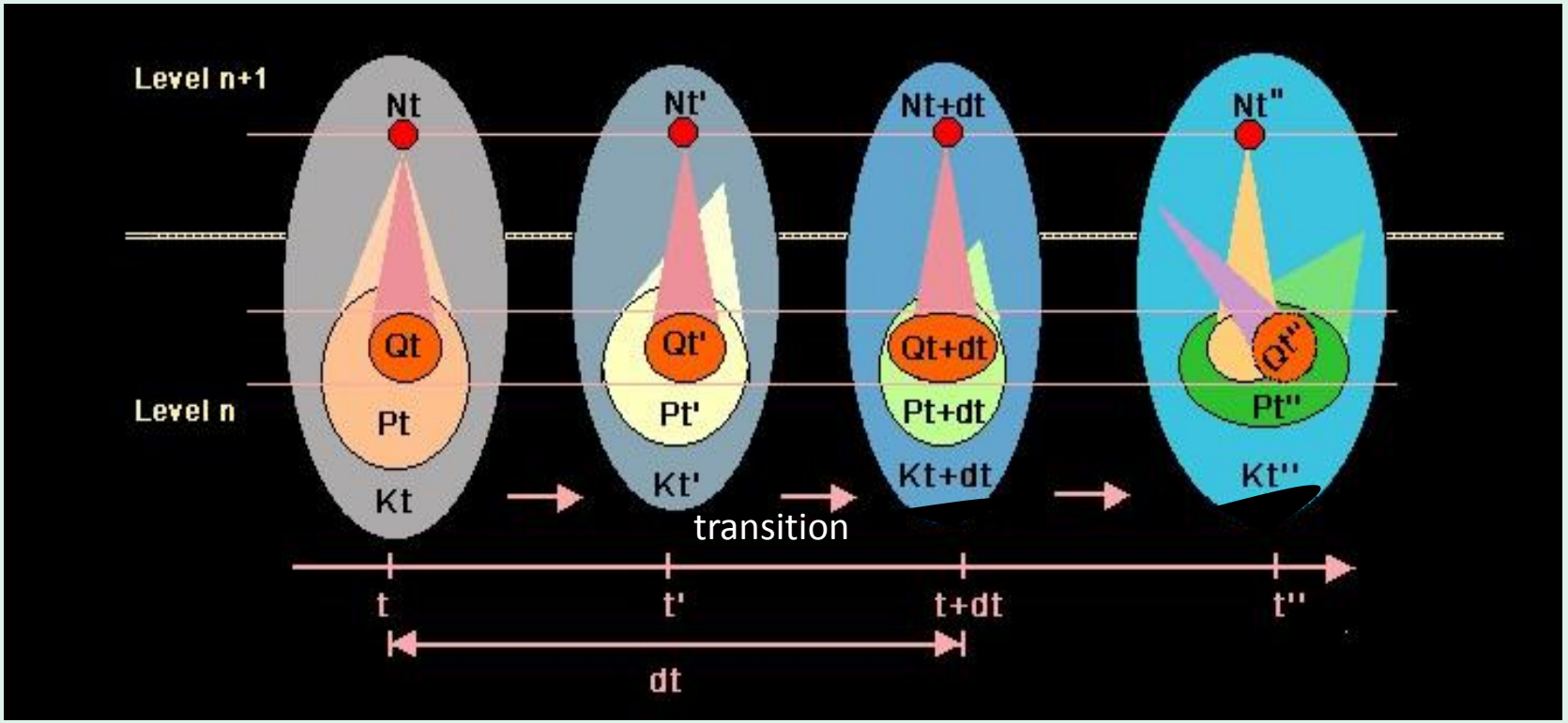
BINDING = COLIMIT



Pattern P = family of objects P_i with distinguished links between them.
Collective link from P to A = family of links s_i: $P_i \rightarrow$ A correlated by the distinguished links of P.

P admits C as its *colimit* (or *binding*) if there is a collective link (c_i) from P vers C through which any other collective link (s_l) from P to an A factors uniquely.

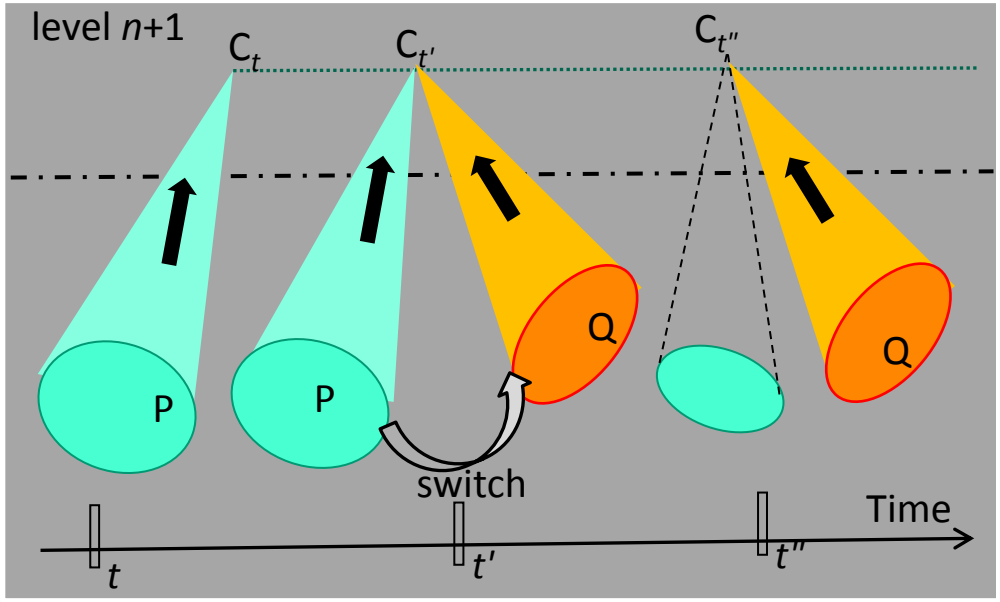
HIERARCHICAL EVOLUTIVE SYSTEM. COMPLEX IDENTITY



HES = family of hierarchical categories indexed by time, and partial transition functors between them satisfying a tranitivity condition, so that a *component* N is a maximal family (N_t) of objects related by transitions.

Stability span of a component N at *t* = greatest period *dt* during which N admits a decomposition Q*t* at *t* remaining a decomposition of N up to *t+dt.*

MULTIFORM OBJECTS ---> FLEXIBILITY



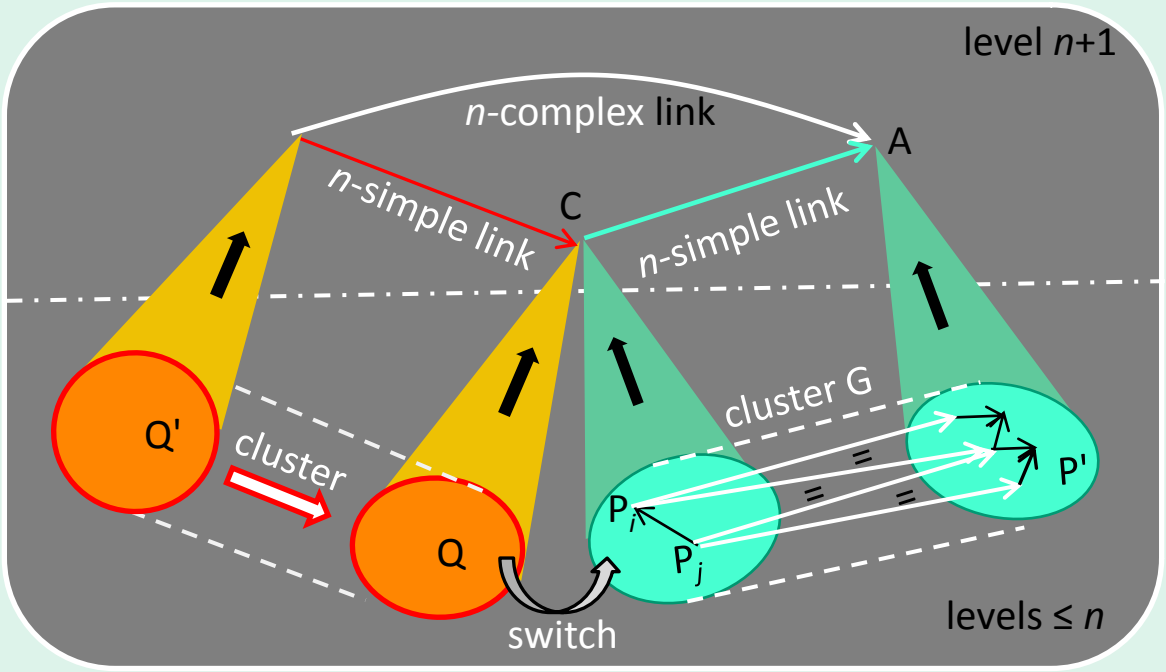
C is *n-multiform* if it has 2 lower levels decompositions P and Q not connected by a cluster of links. The passage from P to Q is called a *switch.*

---> P and Q have the same functional role,though not well interconnected. Edelman calls this property *degeneracy,,* and says that it is

> " a ubiquitous biological property […] a feature of complexity […], both necessary for, and an inevitable outcome of, natural selection." (Edelman & Gally, 2001)

It is formalized by the **Multiplicity Principle** which gives robustness /flexibility to the system via the possibility of switches.

MP ---> EMERGENCE OF COMPLEX LINKS



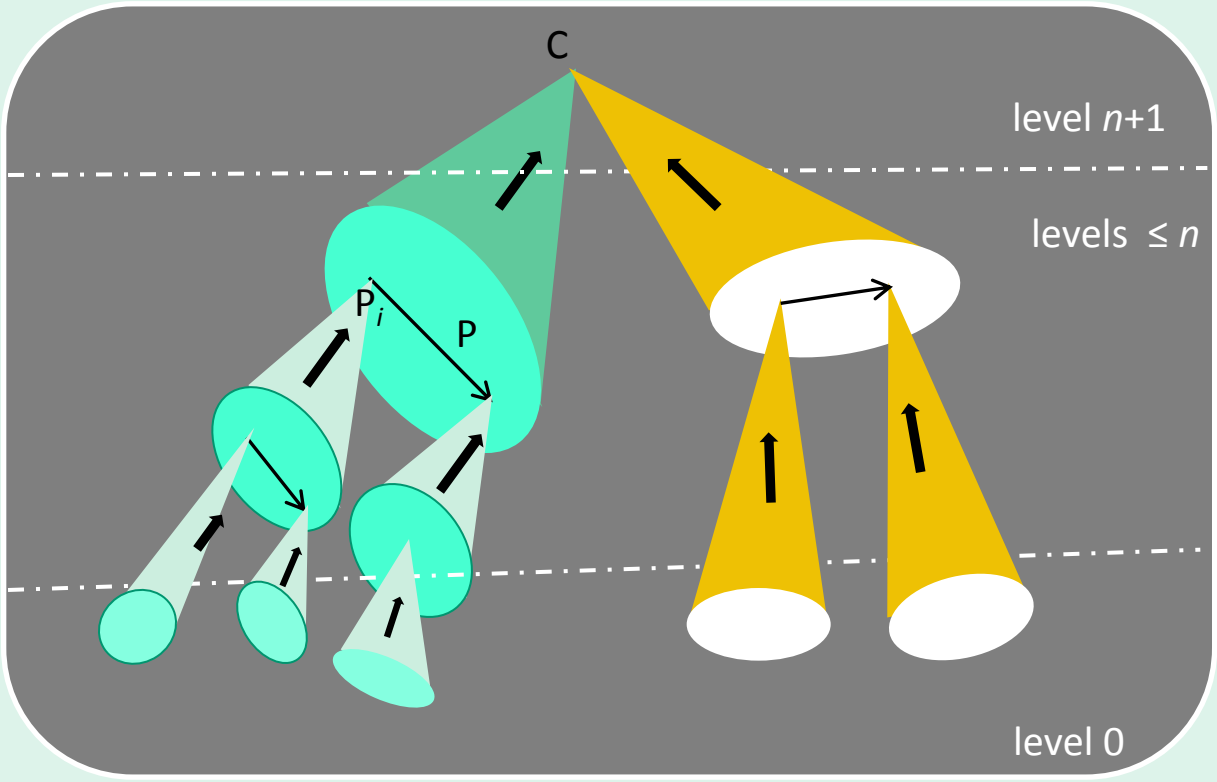
Multiplicity Principle (MP): There are *n-multiform objects* C binding patterns P and Q of levels ≤ *n* not connected by a cluster.

An *n-simple link* from C to A binds a cluster of links between components of C and A.

MP ---> *Emergence of n-complex links*

which are composites of *n*-simple links binding clusters separated by a switch.

COMPLEXITY ORDER

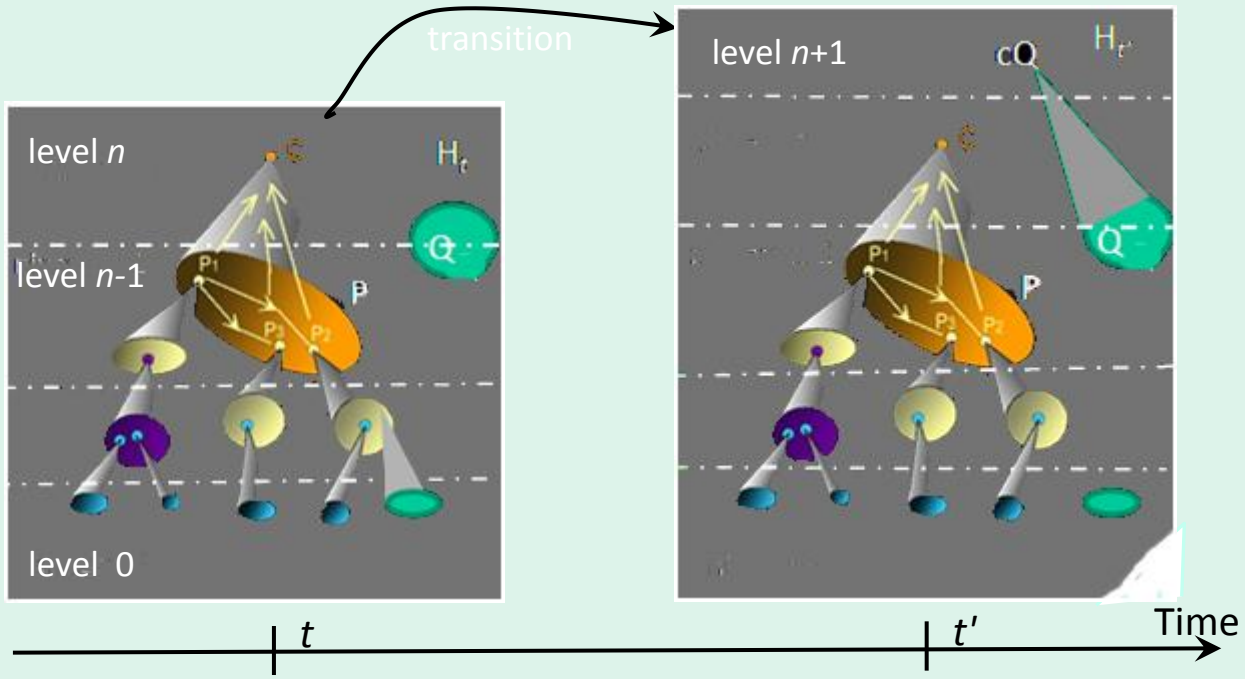


Complexity order of C = smallest length of a ramification down to level 0.

COMPLEXITY THEOREM (EV 1996)**.** ***MP is a necessary condition for the existence of components of complexity order strictly more than* 1.**

Without MP ---> *Pure reductionnism*.

CHANGES VIA COMPLEXIFICATIONS

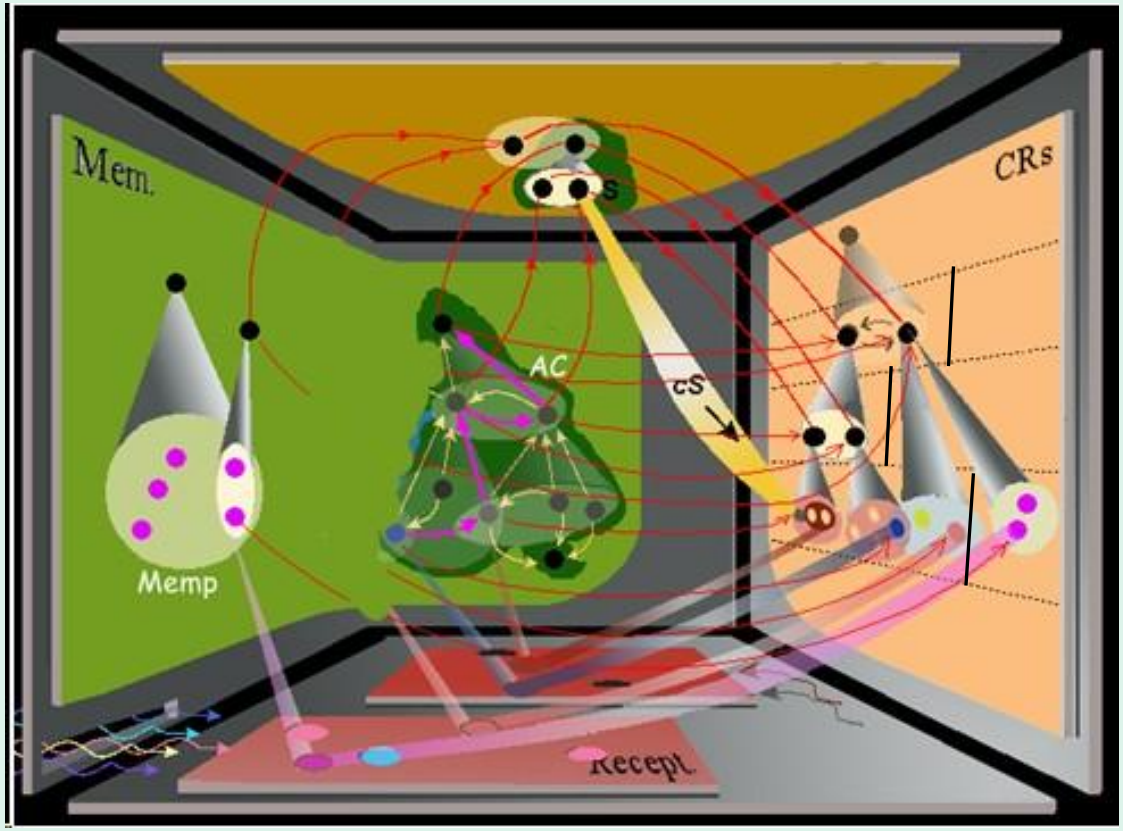


Changes via addition or suppression of components and binding of some patterns. They are modeled by the *complexification process* (it is explicitly constructed). Probably accessible to 'spatial computations" (e.g. MGS, Giavitto & Spicher) or to "diagrammatic computations" (Lair & Duval).

EMERGENCE THEOREM. ***MP is preserved by iterated complexifica-tions, and is at the root of the emergence over time of increasing complexity orders and of the mixing of causalities.***

MP ---> *Emergentist reductionism*

MULTI-SCALE SELF-ORGANIZATION

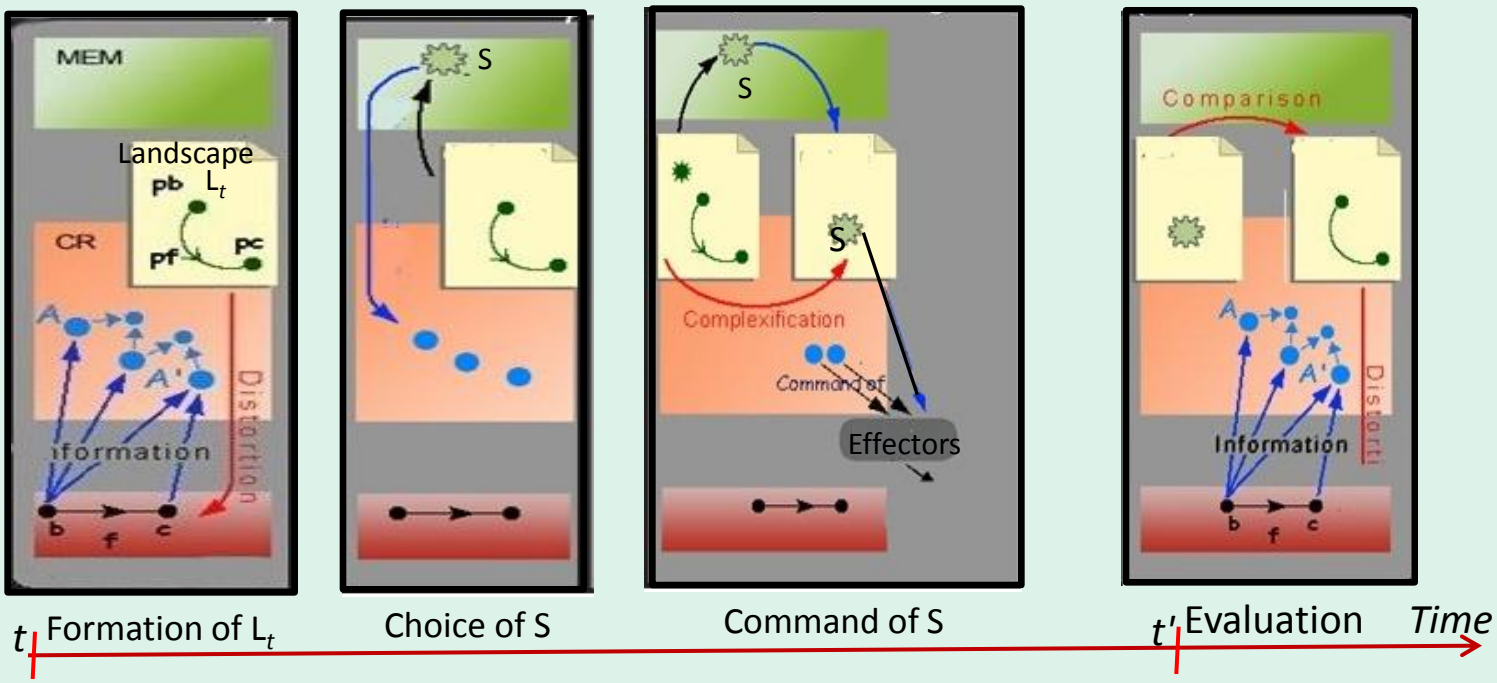


Dynamic of a MES modulated by:

A heterarchical net of specialized subsystems, the *co-regulators* CR, each with its own complexity, rhythm, logic and differential access to a long-term *memory* which develops by learning and has plasticity thanks to MP.

Each link has a *propagation delay*, a *weight*, and can be *active or not*.

A CO-REGULATOR CR AS A HYBRID SYSTEM



CR acts stepwise at its own rhythm. At each step from *t* to *t'*:

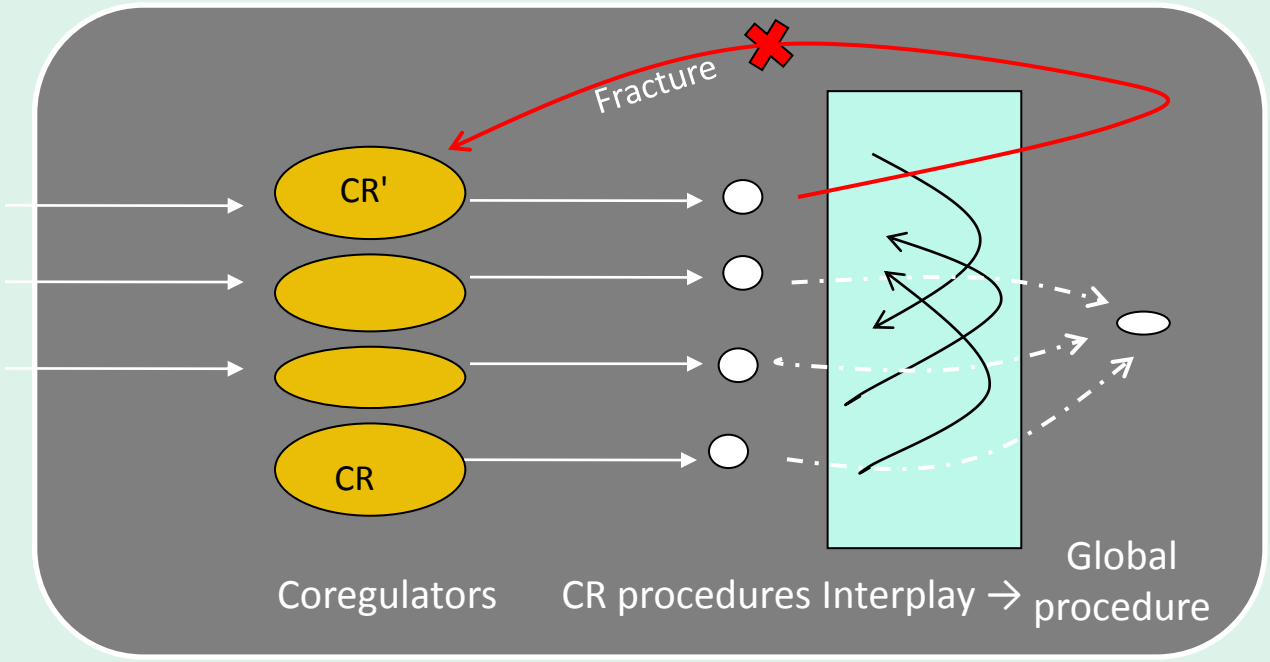
(i) Collect of information (through active links to CR) in the *landscape* L_t

(ii) Choice of a procedure S to respond

(iii) Sending commands of S to effectors ---> dynamic process from *t* to *t'*
(computable via differential equations or 'spatial' computing)

(iv) Evaluation and storing of the result at *t'*
---> *Fracture* if objectives of S not attained.

MP ---> FLEXIBILITY IN INTERPLAY AMONG COREGULATORS



The local logics of the co-regulators being different, their procedures at a given time may not fit together.

---> *Interplay among the co-regulators* to obtain a global procedure MP gives it more freedom degrees via the possibility of switches (but also makes it non 'computable').

---> *Fracture* and, if it persists, *dyschrony* for some co-regulators, possibly leading to a change of their period (*re-synchronization*).

APPLICATIONS

Ubiquitous complex events processing, with repair of fractures and dyschronies :

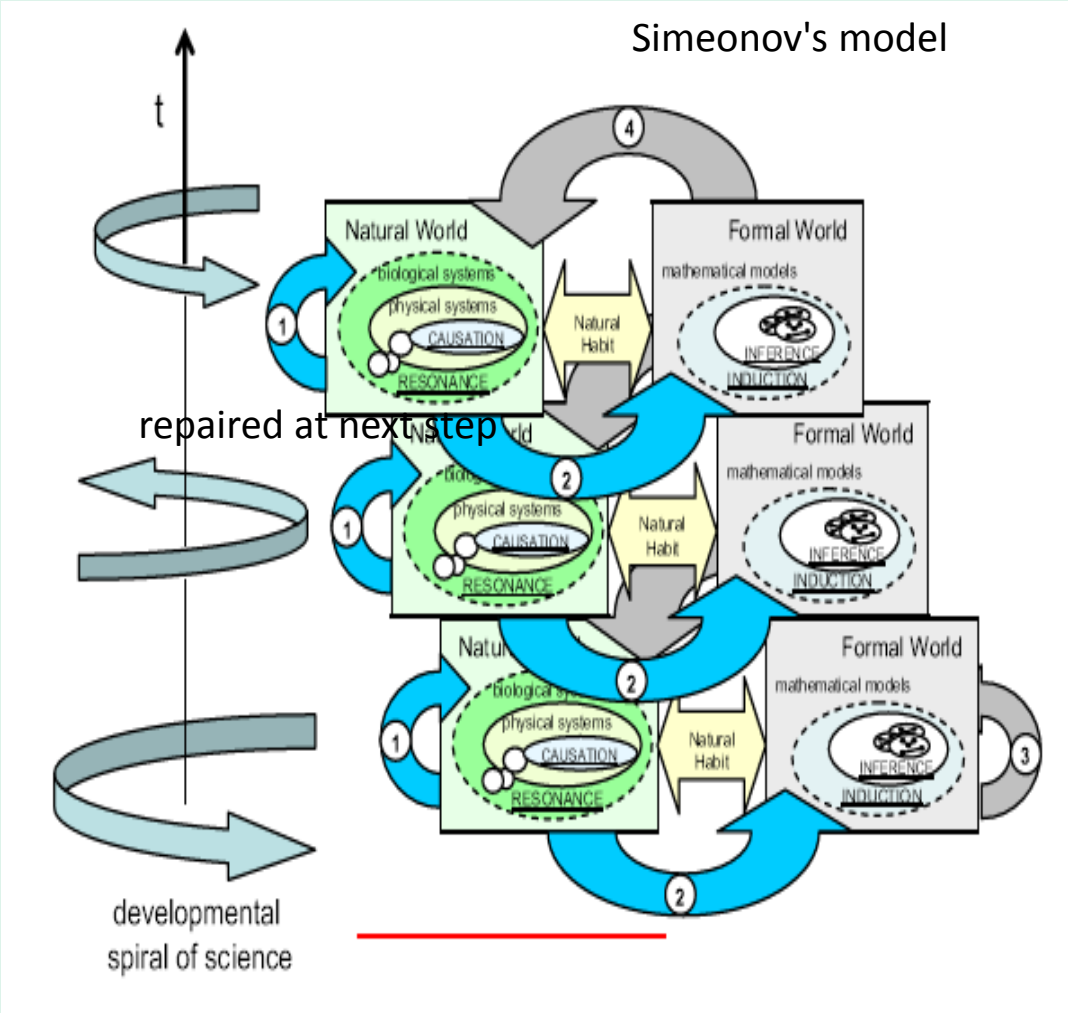
---> Theory of Aging by a cascade of re-synchron-izations of co-regulators of increasing levels (from molecular to cellular to organ levels). (EV 1993)

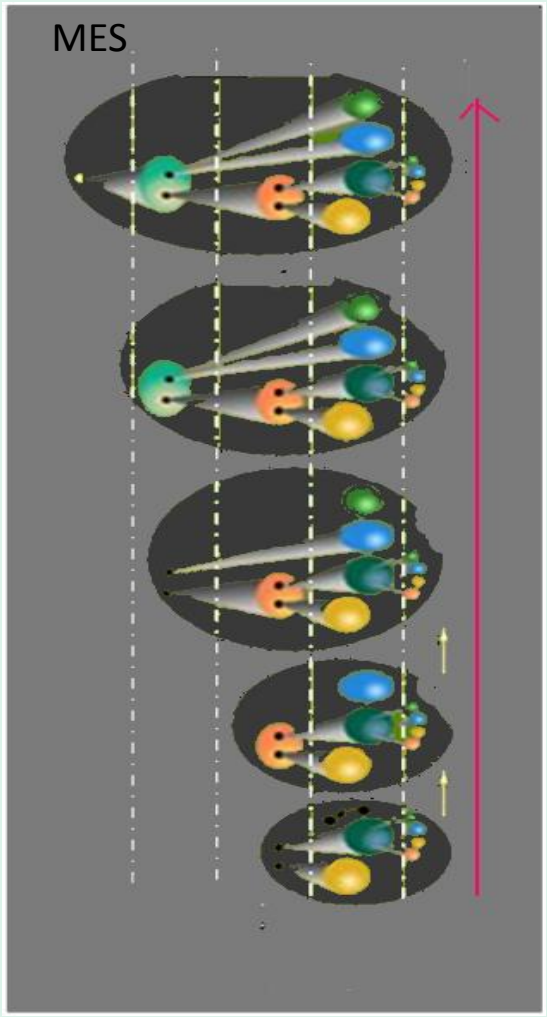
Model MENS for a neuro-cognitive system, allowing for a better understanding of mind processes

---> Strategies to cope with mental deficits:

---> New methods for increasing mental and learning capacities

CONCLUSION





MES not an invariant a-temporal (Rosen) model, but a dynamic one, adaptable to any kind of living system and regulatory networks. Proposes a methodology in progress. Raises the problem of how to 'compute' it?

WLIMES?

Can MES and the *Wandering Intelligence Logic* of Plamen Simeonov be merged for approachng the computational problems raised by MES?

The CRs and the *netbots* of WLI play similar roles. What of the shuttles? In MES a link is 'active' at *t* if some information passes through it. This information (of various kinds: physicial, chemical, code,…) could be carried by a *shuttle*, activating several consecutive links.

Problem: At time *t*, the commands sent to effectors by the various CRs can be conflictual, making competitive shuttles. Is this 'interplay' problem be solved using WLI methods?

FOR MORE INFORMATION

Memory Evolutive Systems: Hierarchy, Emergence, Cognition (Elsevier, 2007).

MENS, a mathematical model for cognitive systems (*JMT* 0-2, 2009)

The following internet sites contain a large number of papers

http://ehres.pagesperso-orange.fr/

http://vbm-ehr.pagesperso-orange.fr/

THANKS