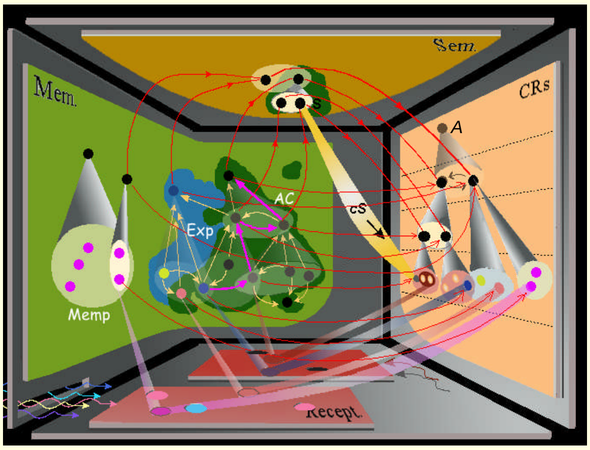

Figure 1

MES: A theoretical approach to multi-scale emergence and dynamics

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In *Memory Evolutive Systems: Hierarchy, Emergence, Cognition* (Elsevier, 2007) and earlier papers we have proposed the model MES for evolutionary multi-scale autonomous systems, based on a 'dynamic' category theory, integrating multiple temporalities. The configuration of the system around time t is modeled by a hierarchical category[1] H_t and the change from t to $t' > t$ by a '*transition*' functor[2] from a subcategory of H_t to $H_{t'}$.

BINDING PROCESS. HIERARCHY

The system has several levels: an object A of level n+1 is the *binding* (or *colimit*) of at least one pattern[3] Q of linked objects of levels ≤ n, which it functionally represents. It means that there is a *collective link* (c_k) from Q to A (cf. Fig. 2) through which any collective link (g_k) from Q to C factors. Then A has *ramifications* (cf. Fig. 1) down to level 0, and its *complexity order* is the length of its shortest ramification (it is ≤ n+1).

If A and C bind Q and P, there are *n-simple links* g from A to C which bind a *cluster* G of links between components of Q and P, correlated by the distinguished links of Q and P (cf. Fig. 2). A simple link just represents a cluster as an entity, thus translates properties of the lower components of A and C

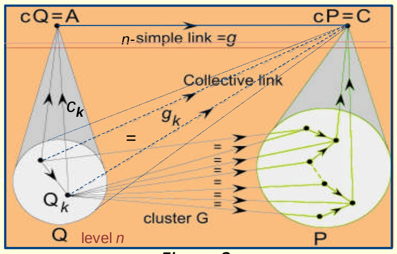

Figure 2

DEGENERACY. COMPLEXITY. EMERGENCE

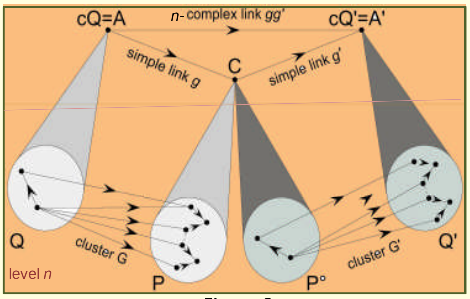

Figure 3

The system satisfies the *degeneracy property* if there are *multiform objects* C binding 2 patterns which are functionally, but not structurally, equivalent. Then there are *n-complex links* composing simple links binding non-adjacent clusters (cf. Fig. 3). They *emerge* at level n+1 depending on the whole structure of the lower levels.

COMPLEXITY THEOREM. Degeneracy characterizes the systems having some objects whose complexity order is > 1.

In a MES the transitions will result from *complexification* processes relative to procedures to 'suppress' some objects, 'absorb' external objects, 'bind' some patterns.

EMERGENCE THEOREM. The degeneracy property extends to a complexification. In a MES, it allows for the emergence over time of an intertwined hierarchy of elements of increasing complexity order, e.g. higher cognitive processes in the model MENS of a neuro-cognitive system.

MULTI-SCALE DYNAMICS

A MES has a multi-scale self-organization depending on the cooperative and/or competitive interactions between a net of specialized functional subsystems, the *coregulators,* having their own complexity level and their own discrete timescale extracted from the continuous timescale of the system. It has a central flexible memory **Mem** which develops over time and possibly contains a robust though flexible internal model **AC** of the system (cf. Fig. 1). Links are labelled with a propagation delay and a strength (in $\mathbf{R}_+$) .

Each CR acts at its own rhythm as a hybrid system: 1. At a step of its discrete timescale, it forms its *landscape* (modeled by a category) with the partial information it can access, evaluates the result of the preceding step, and selects an adapted procedure with the help of **Mem**. 2. The realization of this procedure during the continuous time of the present step is directed by differential equations implicating the propagation delays and strengths of the links, and it should move the landscape to an attractor. These operations should respect the *structural temporal constraints* of the CR.

The procedures of the various CRs at a given time may not fit together. The correlation between their dynamics is ensured by an equilibration process, the *interplay among the CRs*, possibly by-passing the procedures of some CRs and causing dysfunction (temporary '*fracture*' or *dyschrony*) to them. In particular there is a 'dialectics' between the dynamics of CRs with heterogeneous complexity levels and rhythms.

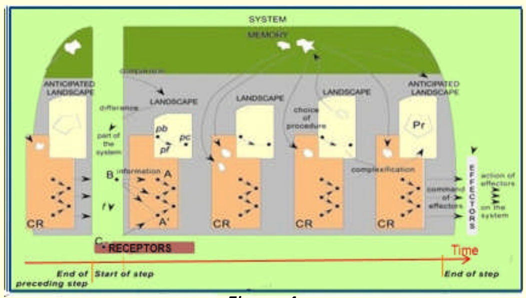

Figure 4

The repair of dyschrony backfiring between very different levels may lead to a change of the rhythm of some CRs. For instance, we have proposed a *theory of aging* for an organism through such a cascade of *desynchronizations* of CRs of higher and higher levels.

DEFINITIONS

1. A *category* is an oriented (multi-)graph with an internal (partial) composition which maps a path (*f, g*) from A to B on an edge *fg* from A to B, is associative and such that each object has an identity; a vertex is called an object, and an edge a morphism (or a 'link'). In particular a (multi-)graph is included in the category of its paths, and each category is the quotient of a category of paths. 2. A functor F from a category H to H' maps an object A of H to an object FA of H', a link from A to B on a link from FA to FB, and preserves the composition. 3. A pattern (or diagram) P in a category consists in a family of objects (P_i) and distinguished links between them.