THE GLASS BEAD GAME REVISITED: Weaving emergent dynamics with the MES methodology

by

Andrée C. EHRESMANN* and Mathias BEJEAN

***Université de Picardie Jules Verne, LAMFA**
ehres@u-picardie.fr
http://ehres.pagesperso-orange.fr
http://vbm-ehr.pagesperso-orange.fr

I. INTRODUCTION

1. The Glass Bead Platform
2. Memory Evolutive Systems
3. Problems
4. Is the Glass Bead Game creative?
5. Theory of categories

The Glass Bead platform

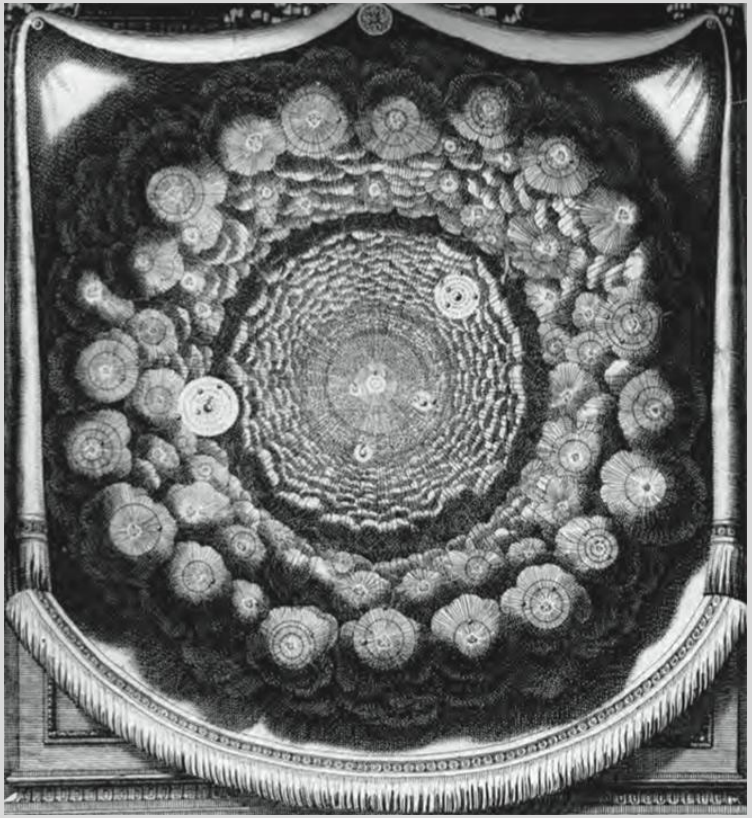


Illustration for Entretiens sur la pluralité des mondes, de Fontenelle (1686)

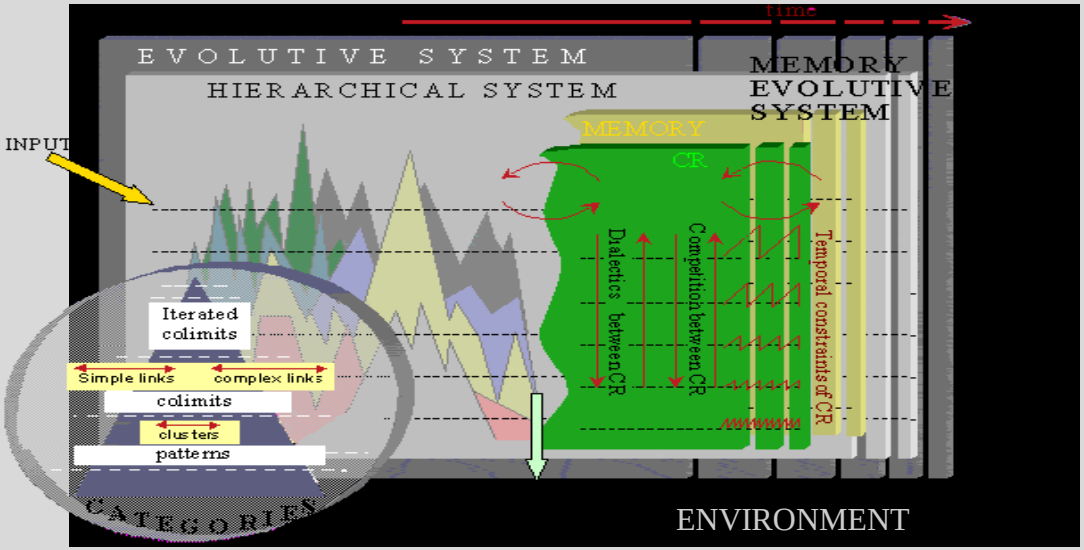
"navigating between heterogeneous and increasingly specialized epistemic sites ";

"construct the conditions for universal transits that transform the sites between which they operate"

" Glass Bead works in immanent relation to the material dynamics shaping knowledge (i.e. morphologies), as much as it works with the geometry of knowledge (i.e. epistemologies).

Memory Evolutive Systems

(A. Ehresmann & J.-P. Vanbremeersch)



Developed since the 1980's to answer: Could category theory lead to an integrative model of living systems with their main characteristics?

(i) Hierarchy of components varying through successive structural changes, modeled as “complexification”,

(ii) Multi-scale self-organization, the global dynamic weaving local operative dynamics, with the mediation of a flexible central "Memory".

(iii) Emergence of higher cognitive processes, up to anticipation, creativity

Problems

What does the Glass Bead Game (GBG) mean since it has different interpretations?

Do its different interpretations allow it to be really a « creative » game?

Could category theory, and more particularly MES, help revisiting it to make it able:

- to fulfill the objectives of the Glass Bead platform?
- to allow for innovative trans-disciplinary research?

Is the Glass Bead Game Creative?

For M. Boden (1990):
" Creativity is the ability to come up with ideas or artefacts that are new, surprising and valuable ".

And she distinguishes 3 types of creativity:

Combinatory creativity*:* " involves making unfamiliar combinations of familiar ideas <…> and the ability to form links of many different types".

Exploratory creativity*:* "explore(s) a structured conceptual space, mapped by a particular style. "

Transformational creativity*:* " thoughts are now possible which previously <…> were literally inconceivable "; " by definition, flouts some of the accepted rules ".

1st interpretation of GBG

" rules, the sign language and grammar of the Game, constitute a kind of highly developed secret language drawing upon several sciences and arts <…> a mode of playing with the total contents and values of our culture ".

" Stress was placed on new, bold, and original associations of themes, impeccable logic, and beautiful calligraphy. "

=> GBG resorts to an essentially *combinatory creativity.*

Example. " *Toward the Glass Bead Game - a rhetorical invention,* Joshua Fost 2014. Combines the Tarantino film "Pulp Fiction" with a passage of the Holy Bible, and Bram Stoker's Dracula.

2nd interpretation of GBG

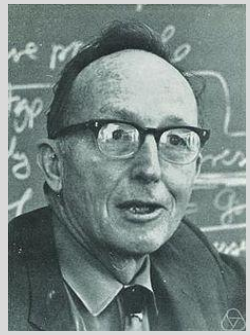
" a universal language and method for expressing all intellectual concepts and all artistic values and reducing them to a common denominator ";
" the quintessence of intellectuality and art ";
" keeping the Game ever at the summit of our entire cultural life, by incorporating into it each new achievement, each new approach ".
However:
" Any enrichment of the language of the Game by addition of new contents is subject to the strictest conceivable control by the directorate of the Game. "

=> *Exploratory creativity* in the conceptual space of the whole culture; *transformational creativity* might be possible at the border but unlikely.

Problem: **Can GBG be revisited so that it achieves transformational creativity?**

Eilenberg

Category Theory
introduced in 1945 by



Mac Lane

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

" This theory of categories seems to be the most characteristic unifying trend in present day Mathematics " (C. Ehresmann, 1966)

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

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

Examples revealing two different approaches

1. Large categories: *Set, Top, Group, Mod*, *Cat*…

==> Enriched categories in monoidal categories; Topos; Theories in Logic; Foundational problems.

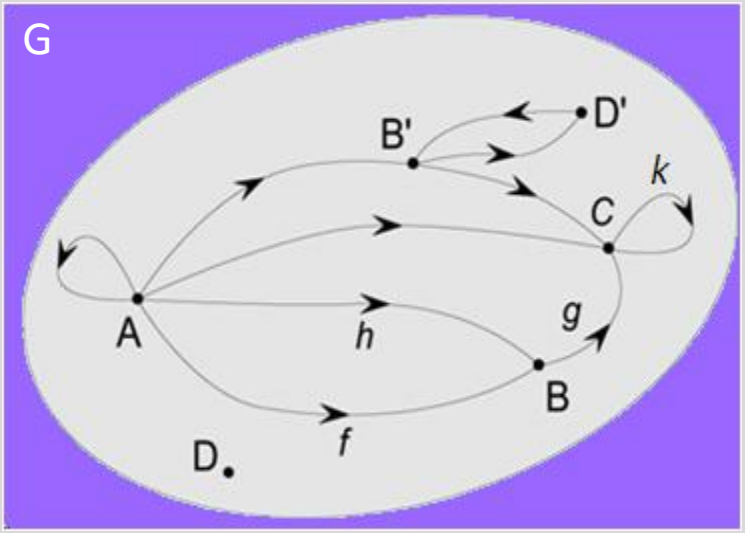
Glass Bead site: " If topos theory operates strictly within the formal languages of mathematics, it remains open as to how it can be effective outside of its domain and thus encompass a multiplicity of expressions "

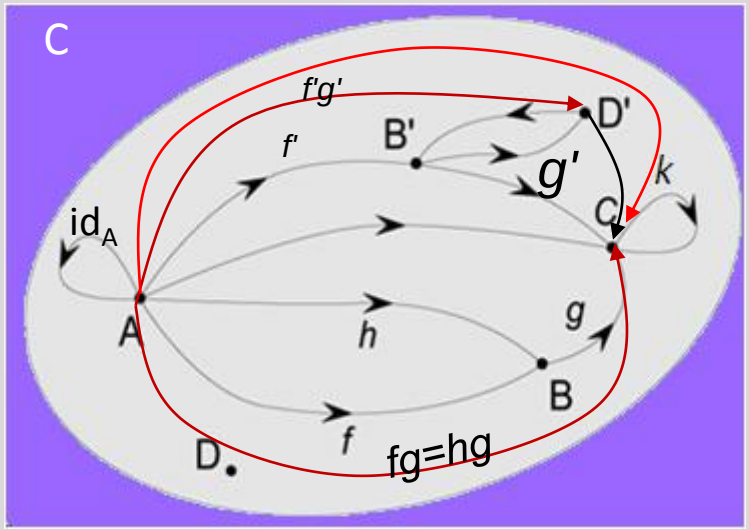
2. Monoids and posets; groups and groupoids.

==> local species of structures and their glueing, partial maps, internal categories, higher categories, sketches and their prototypes acting as presentations of a theory (A. & C. Ehresmann).

More adapted for differential geometry, analysis and applications, e.g. in MES.

Graphs and Categories





Networks are represented by graphs.
A *(multi-)graph* G has vertices A, B, … , and arrows *f*: A → B.
Path = sequence of successive arrows.

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

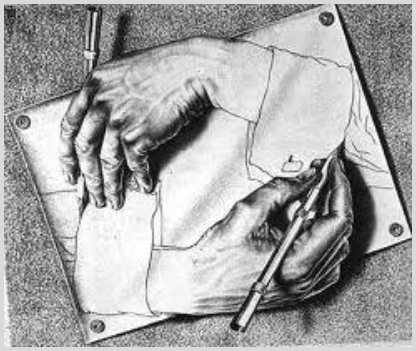
The vertices of a category are called *objects*, the arrows *f*: A → B *morphisms.*

Category of paths L(G) of a graph G: the morphisms are the paths of G, composed by convolution. A category C is the quotient of L(C) by the relation :
2 paths are *functionally equivalent* if they have the same composite.

II. A REVISITED GLASS BEAD GAME:

Categorification of emergence in living systems

re-tracing the making of the MES methodology
by A. Ehresmann & J.-P. Vanbremeersch



A reflexive Game

1. Let us try playing a Glass Bead Game with the theme:

"*Categorification of emergence in living systems*"

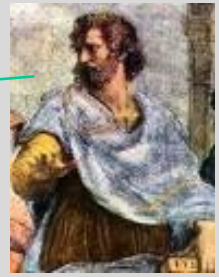
following the different steps of the MES' development from 1986 to 2007. Each step will consist of 2 intermingled processes:

(i) **Retrospection**: Gathering 'beads' of existing knowledge and/or new information in relation with the present situation.

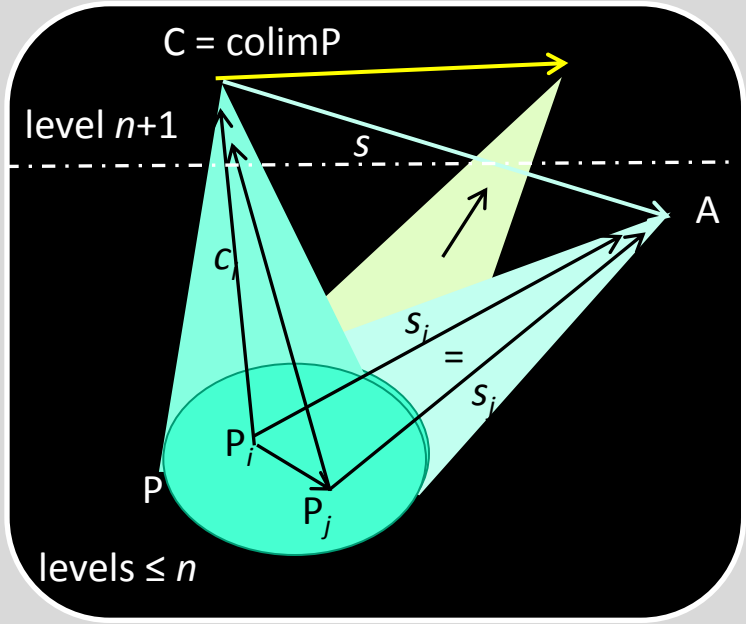
(ii) **Prospection**: Research and/or creation of adapted categorical notions to be combined with these beads, then associated complexification.

2. The problems met during the Game as well as different results of MES will show how the rules of GBG should be modified to make it more creative, thus more adapted to the realization of the Glass Bead program and to innovative transdisciplinary research.

Complexity of a "whole" in terms of colimits



1. Aristotle: " The whole is something else than the set of its parts ".
2. Von Bertalanffy (1956): " A system is a set of units with relationship between them ".



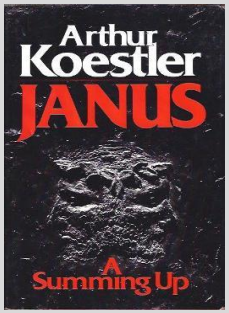
The configuration of a system at *t* will be represented by a category H_t:
objects = state of its components at *t*, morphisms (or links) = their interactions.

A complex "whole" is an object C of H_t which 'combines' (= is the colimit of) a pattern P of linked objects P_i representing an internal decomposition of C, meaning that C has the same operational role as P acting collectively.

Pattern P = diagram in H_t . *Collective link* from P to A = cone $(s_i)_i$: P => A = family of links s_{ii}: P_i → A correlated by the distinguished links *f* of P.
C = *colimit* of P if there is a cone $(c_i)_i$: P => C through which any cone $(s_l)_i$: P => A factors uniquely .

The hierarchy of components

1. Jacob (1970) : "Tout objet que considère la Biologie représente un système de systèmes; lui-même élément d'un système d'ordre supérieur."

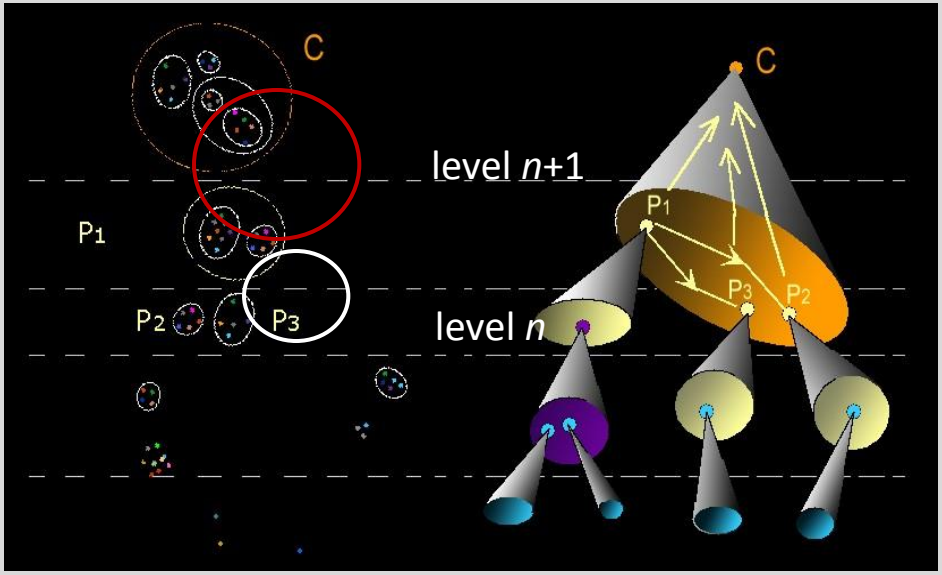


2. Koestler (1960) proposes the word *holon* to describe the "hybrid" nature of the components of living systems, comparing them to 2-faced Janus.

In a biological system, the hierarchy of holons consists of atoms, molecules, cells, organs, large systems; in a social system, of individuals, groups , institutions,…

To account for components with different complexity levels (atoms, molecules, cells,...), we introduce the notion of a *hierarchical category*:

Its objects are separated into complexity levels so that an object C of level *n*+1 is the colimit of at least one pattern of lower levels.

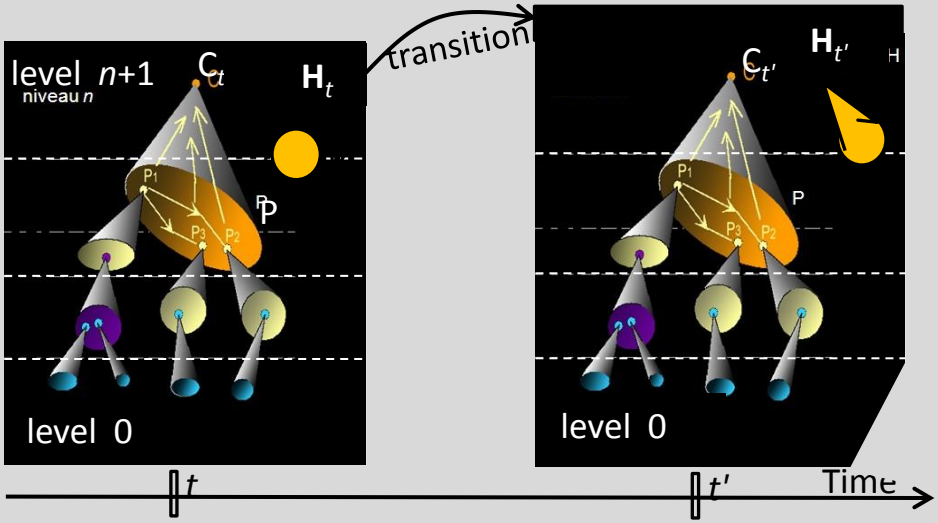


MES for modeling the structural changes

1. René Thom (1971): " la Dynamique, entendue au sens le plus général de science des actions du temps dans les états d'un système ".

2. Bastiani-Ehresmann (1964) defines *Control systems* as categorical dynamic systems in which addition and suppression of components are possible.

In a living system components and interactions vary over time: some disappear (death of a cell), while new ones are formed.
=> A MES cannot be represented by a unique category, but by the family (H_t) of its hierarchical *configuration* categories (indexed by the timescale *Time*) and, for each $t < t'$, a *partial* functor, *transition,* from H_t to $H_{t'}$



A *component* of the MES is a maximal family of objects (its successive states) connected by transitions; idem for a *link* between components. A link has a *propagation delay* and is active or not at *t.*

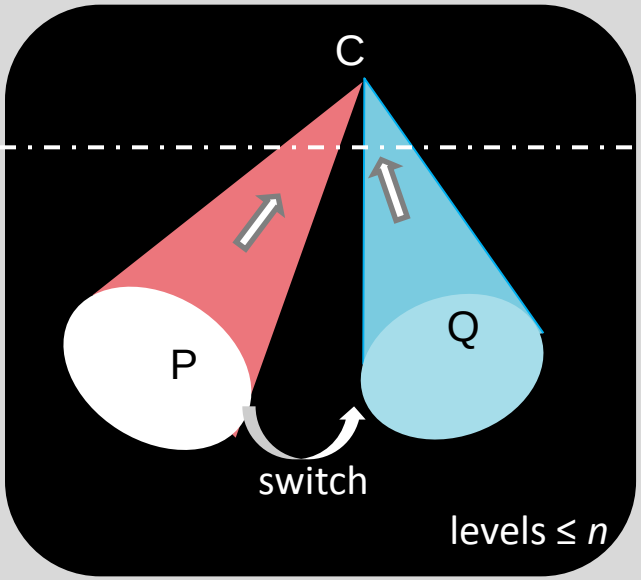
The transitions respect a transitivity condition so that a MES 'is' a pseudo-diagram from *Time* to the bi-category of partial functors.

MP = Existence of multifaceted components

1. Edelman (1989) introduces the "degeneracy of the neural code".

2. Edelman & Gally (2001): " Degeneracy, the ability of elements that are structurally different to perform the same function or yield the same output, is a ubiquitous biological property <….> a feature of complexity " " both necessary for, and an inevitable outcome of, natural selection ".

"Degeneracy" is a kind of "flexible redundancy" at the root of flexibility, plasticity, and emergence of complexity. MP (EV 1996) formalizes it:

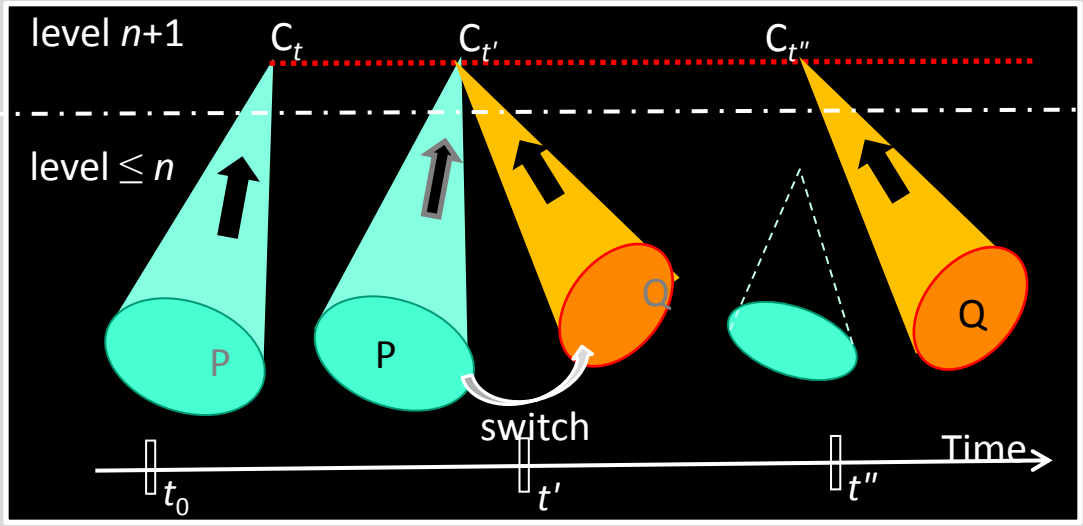


***Multiplicity Principle* (MP)**. *A MES admits n-multifaceted components*.

A component C is ***n-multifaceted*** if it is the colimit of 2 patterns P and Q of levels ≤ *n* which are structurally different and not connected by a cluster of links between their components; then it can 'switch' between them. The number of such patterns is called the *n-entropy* of C

Complex identity of a multifaceted component

Spinoza (Ethics): " a composite Individual can be affected in many ways and still preserve its nature "



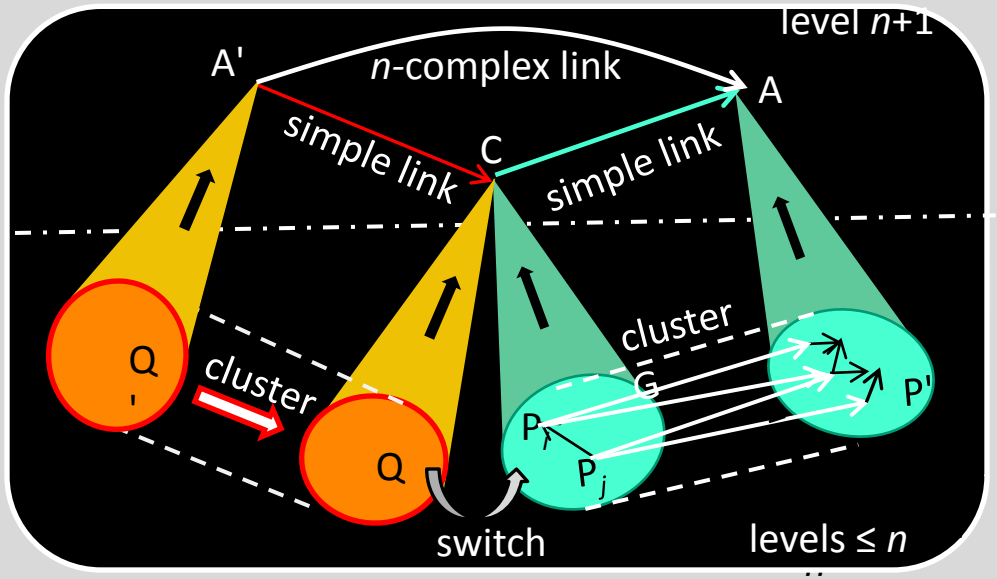
A component C of level n+1 'appears' at a time t_0 as colimit of a lower level pattern P_0. Its internal organization may vary progressively while C as such preserves its identity (e.g. components of a cell vary in time). If C is n-multifaceted, it can operate through different decompositions, switch between them, and eventually lose some of them and/or acquire new ones.

=> MP allows developing a robust though flexible ***Memory*** **Mem** consisting of multifaceted components which provide plasticity over time.

MP => Emergence of complex links

1. G. Farre (1995): " A property is said to be emergent if it is not distributed over the components of the system ".

2. Popper (1959): " change in the conditions of change"



A morphism from C to A is an *n-simple link* if it binds a cluster of links between decompositions P of C and P' of A of levels ≤ *n*.

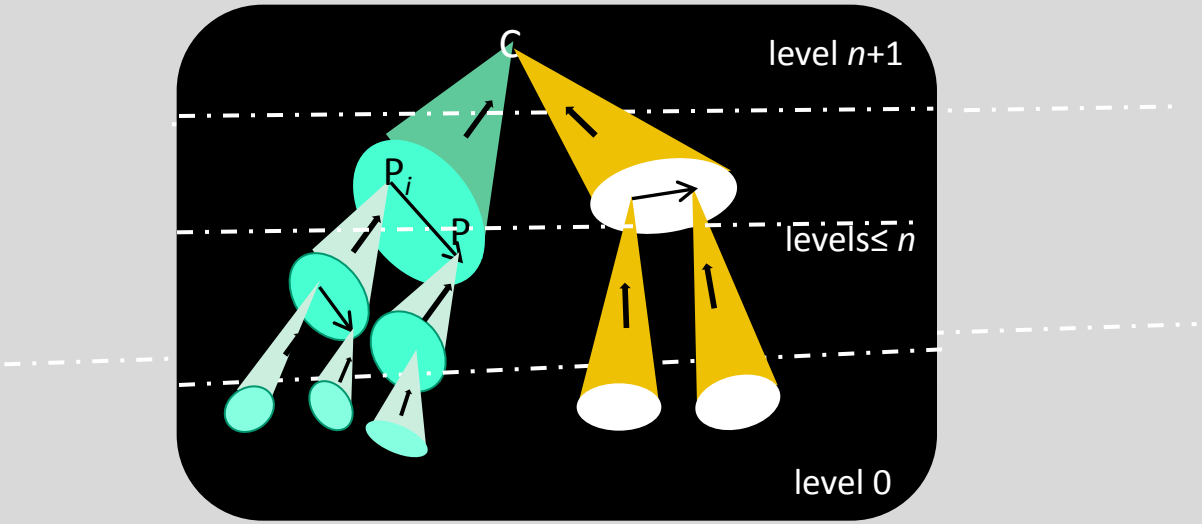
A consequence of MP is the possible emergence of ***complex links*** which are composites of simple links binding non-adjacent clusters. They represent *emergent properties* at the level *n*+1, not observable at the levels ≤ *n* though dependent on their global structure.

Complexity Theorem


Kolmogorov

The *Kolmogorov-Chaitin complexity* of a string *x* is the length of the shortest program that computes or outputs *x*, where the program is run on some fixed reference universal computer.


Chaitin



The *n*-entropy of a multifaceted components C measures its "horizontal" complexity. Its "vertical complexity" is measured by the

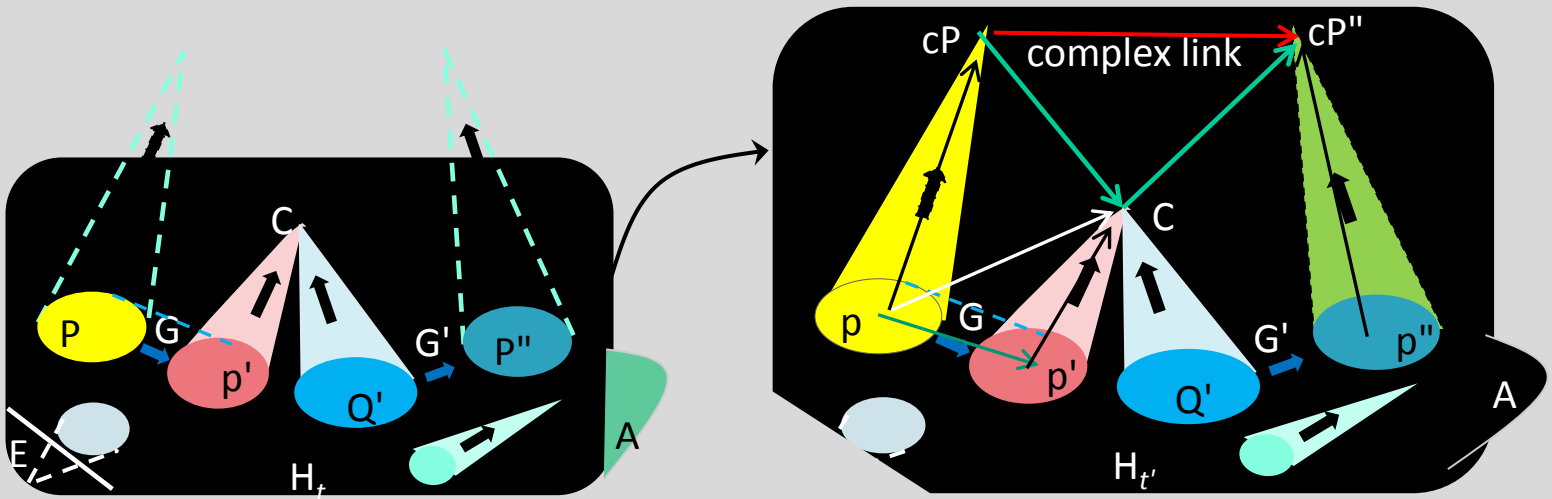
Complexity order of C = minimal length of a ramification down to level 0.

COMPLEXITY THEOREM. ***MP is a necessary condition for the existence of components of complexity order > 1.***

Without MP => *Pure reductionnism.*

The complexification process, an essential construction

1. R. Thom (1988) distinguishes 4 *standard transformations*:
Birth, *Death*, *Scission*, *Confluence* " (1988).
2. A. & C. Ehresmann (1972): Construction of the prototype of a sketch.



The transition from t to t' results from changes of the following types: 'adding' external elements A, 'suppressing' or 'decomposing' some components E, combining the elements of a pattern P by adding a colimit cP to P. It is modeled by the ***complexification process***:

Given a procedure (= pro-sketch) Pr on H_t with such objectives, there is a category $H_{t'}$ called *complexification of* H_t for Pr, in which these objectives are optimally satisfied. (It is the prototype of this pro-sketch.) Objects of $H_{t'}$ on are those of $H_t \backslash E$, those of A, and for each P a new cP 'forced' to become the colimit of P. Complex links emerge.

Emergence Theorem

Robert Rosen (1969): " to what extent does a knowledge of the system at the lowest level of the hierarchy specify or determine its properties at the higher levels ? "

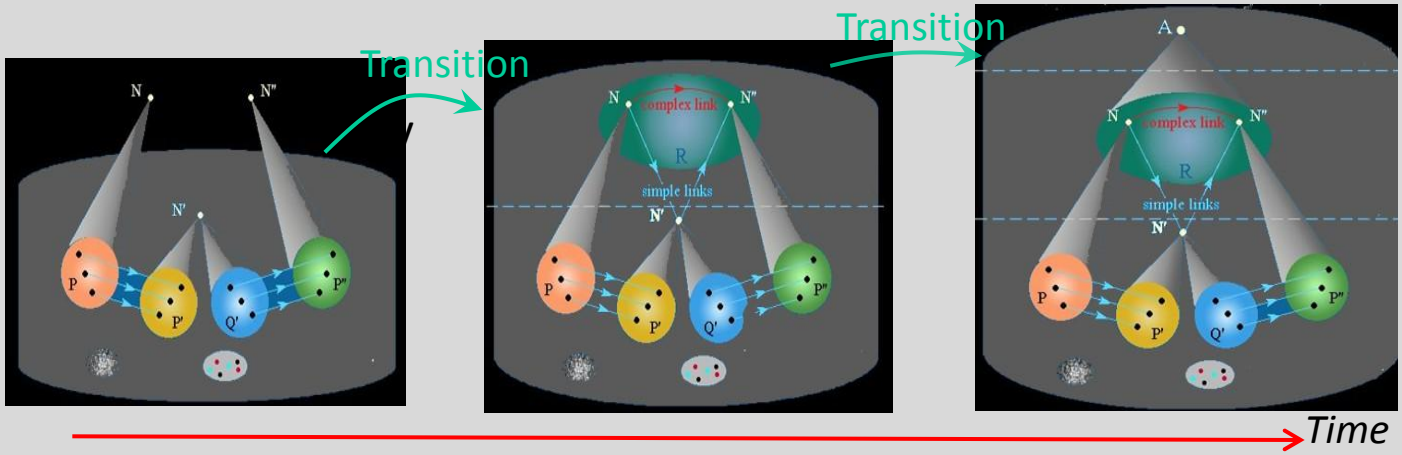
EMERGENCE THEOREM. If *MP is satisfied, and only in this case, a complexification can lead to the formation of multifaceted components of a higher complexity order and to the emergence of complex links. In particular it is at the root of the development of a flexible memory.*

A complexification does not change the structure of the initial category, but superposes on it a superstructure with its own logic (given by the new complex links).

Example: In a social system it leads to the emergence of new social groups, whose interactions are not reducible to a simple combination of interactions between their members. The theorem asserts that this emergence requires that there are initially independent groups which can play the same role in the superstructure (MP).

"Le mystère de Picasso" (Clouzot, 1958): Painting created through iterated complexifications

ITERATED COMPLEXIFICATION THEOREM. ***A double complexification where complex links play a role cannot be reduced to a unique complexification.***

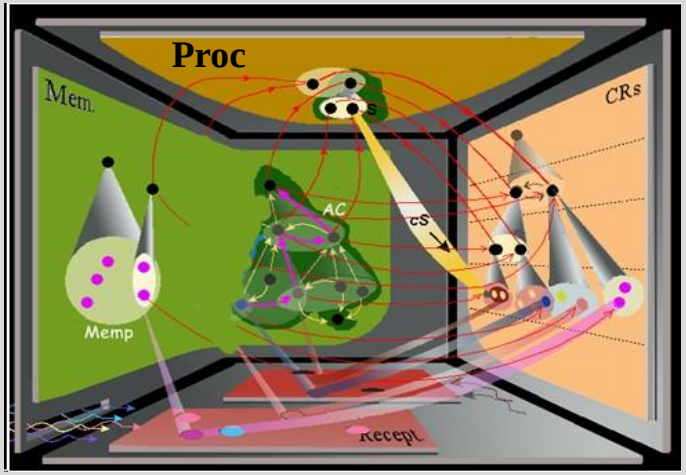


The complexification process is related to *creativity* in different ways:
(i) It resorts to a *combinatory creativity* since each pattern P distinguished in Pr is 'combined' into cP. (ii) The selection of Pr resorts to an *exploratory creativity*. (iii) A sequence of complexifications can lead to *transformational creativity* because of the "change in the conditions of change" resulting from the formation of new complex links in the successive complexifications.

MES as a cognitive multi-agent system

Ashby (1962): " "Memory", as a *constraint* holding over events of the past and the present and a *relation* between them "

Wooldridge (1998): " The multiagent systems field is highly interdisciplinary: it takes inspiration from such diverse areas as economics, philosophy, logic, ecology, and the social sciences. "



The overall dynamic of a living system weaves the different internal local dynamics of its agents, called *co-regulators*, with the help of a developing flexible memory making it able to learn and adapt.

To model it, a MES is equipped with:

= A net of co-regulators (CRs)*:* A ***co-regulator*** is an evolutive subsystem with its own function, complexity, and rhythm. The cooperation and/or competition between CRs modulates the global dynamic, the dualism local/global being mediated through recourse to:

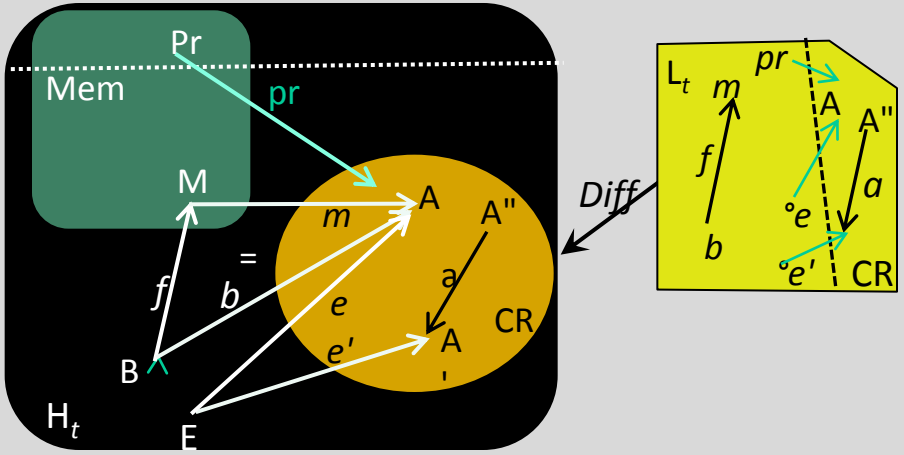
= A flexible long-term ***memory*** **Mem** developing over time. In particular it memorizes various procedures with their commands to effectors.

One step of the local operative dynamic of a CR

1. Hopfield (1982) and his followers: Development of neural networks .

2. Ferber (1995): " Les agents n'ont qu'une représentation partielle de leur environnement, c'est-à-dire qu'ils n'ont pas de vision globale de tout ce qui se passe. "

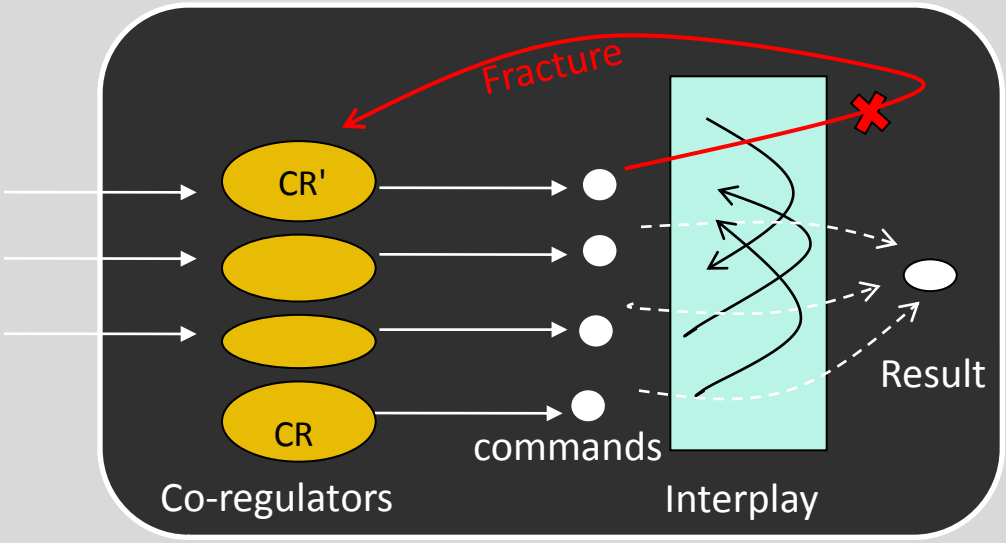
A CR acts stepwise. At the step from *t* to *t'*, it only accesses partial information through the active links arriving to its members during the step; they form its *landscape* L_t at *t*. (i) Exploration of L_t => selection of an admissible procedure Pr (using **Mem**). (ii) Sending commands of Pr to the effectors => dynamic process during the step. (iii) Evaluation at *t'*: if Pr is not realized on $L_{t'}$, there is a *fracture* for the CR, to be repaired later..



L_t has for objects the links from the system to the CR active during the step. The expected landscape for *t'* is the complexification of L_t for Pr, which the evaluation compares to the new landscape at *t'*.

The global dynamic

Woolldridge & Jennings (1995): " ability of agents to autonomously plan and pursue their actions and goals, to cooperate, to coordinate, and negotiate with others ".



The global dynamic results from the interactions between the local CRs' dynamics. However, the commands sent to effectors by the different CRs at a time *t* may not fit together since they have been selected using the partial information contained in their respective landscapes.

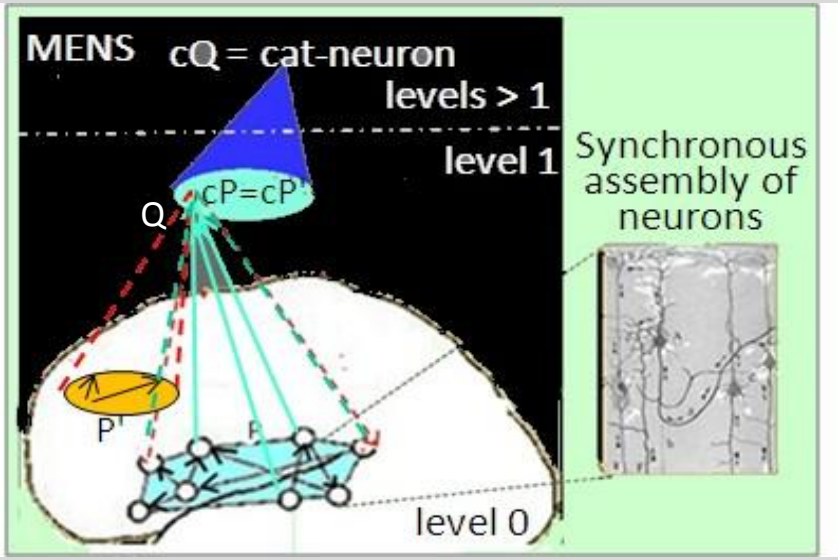
=> *Interplay among the CRs* to harmonize them, made flexible by switches between ramifications of multifaceted commands. It must respect various constraints, e.g. temporal constraints (*synchronicity laws* of the CRs). It may by-pass some commands of a CR => fracture to the CR, possibly leading to the destruction of some component(s).

MENS: a MES modeling the neuro-cognitive-mental system

1. Hebb (1949) defines a *synchronous assembly of neurons*, and he gives the *Hebb* rule of synaptic plasticity.

2. Edelman (1989) emphasizes the role of the *degeneracy of the neural code*: " More than one combination of neuronal groups can yield a particular output ".

MENS unites the neural, cognitive and mental systems. Its level 0 represents the 'physical' neural system. Higher level components are 'conceptual' objects, called *cat(egory)-neurons*, modeling more and more complex mental objects. A cat-neuron is constructed as the combination (= colimit) cP = cP' of the synchronous assemblies of (cat-)neurons P , P' activating it.

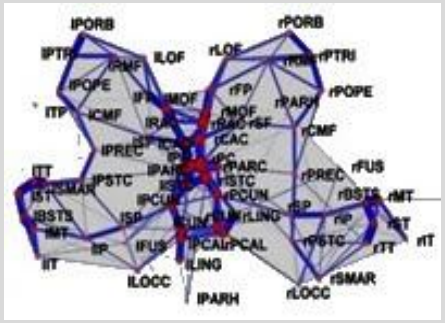


Formally: **MENS** is a MES in which:

- Level 0 = NEUR = Evolutive System of neurons: the objects model the states of the neurons at *t,* the morphisms model the synaptic paths between them, with their propag-ation delay and srength at *t*..

- Higher levels are obtained through iterated complexifications of NEUR.

The Archetypal Core AC



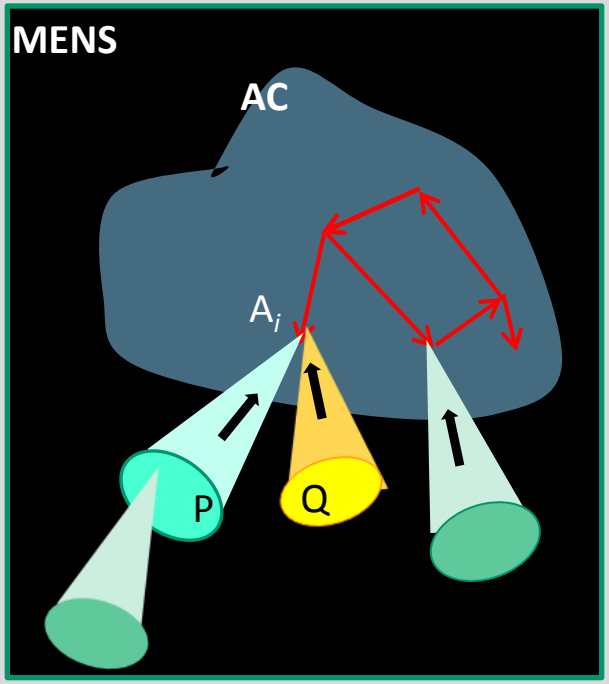
1. Rosen (1985): A living system is *anticipatory* if it contains " a predictive model of itself and/or of its environment ".

2. Hagmann & al. 2008: " existence of a structural core in human cerebral cortex, both spatially and topologically central. " linked to self-referential processing and consciousness. "

MP allows for the development over time of a strongly connected subsystem of the memory, the ***Archetypal Core*** **AC**, based on the structural core. Its components are higher order multi-faceted cat-neurons with many ramifications, integrating significant memories.

Their strong and fast links form *archetypal loops* self-maintaining their activation for a long time and diffusing it to lower levels.

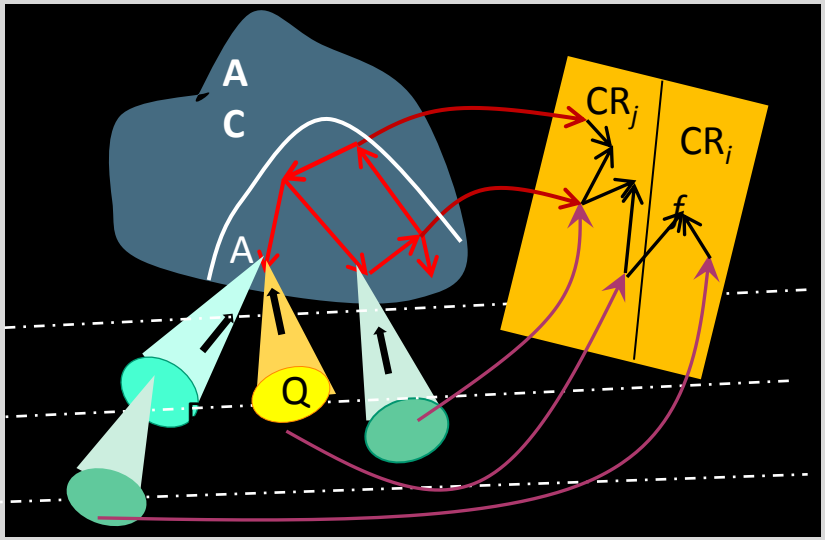
As a *flexible internal model* **AC** acts as a motor in the development of higher cognitive processes.



Macrolandscapes

1. Baars (1997) defines a " Global Workspace <…> closely related to conscious experience, though not identical to it ", that he illustrates by the "Theater of Consciousness".

2. Husserl (1904): " Il y a dans le présent une *rétention* du passé (rétention primaire si c'est un passé immédiat, rétention secondaire si c'est un souvenir plus lointain) et une *protention* du futur (de ce qui va immédiatement arriver). "



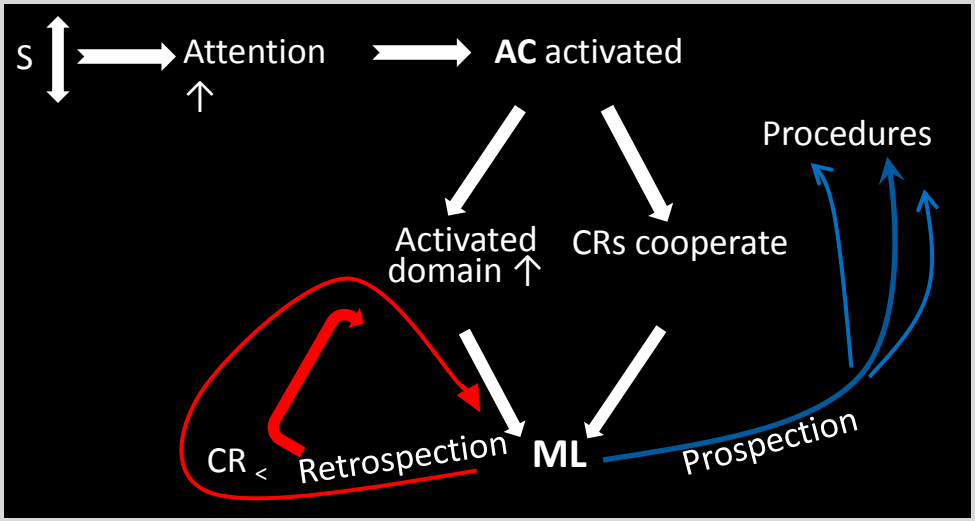
Activation of part of **AC** diffuses via archetypal loops and propagates to lower levels through ramifications and switches between them.
Transmitted back to higher CR_is linked to **AC** (based on associative brain areas), it allows the formation of a *macrolandscape* **ML.**

ML unites and extends spatially and temporally the CR_i landscapes through exchanges *f* between them. As archetypal loops are self-maintained, **ML** persists during a long time, providing for Husserl's *retention* and *protention.* Successive macrolandscapes overlap, ensuring the unity of Self, and giving a space for the development of higher cognitive processes.

Higher cognitive processes, up to creativity

1. Brentano (1973): " Conscious processes arise spontaneously and display intentionality, i.e., for the most part, each is about something " (cited by Edelman, Gally & Baars)

2. Brain-Mind Problem



An unexpected or striking event S activates part of AC => formation of a long term macrolandscape **ML** in which conscious mental processes develop through the iteration of the overlapping processes:

1. ***Retrospection:*** analysis of the situation and recall of near past for "making sense" of the present situation (by abduction), its trends and future potential, in relation with the past.

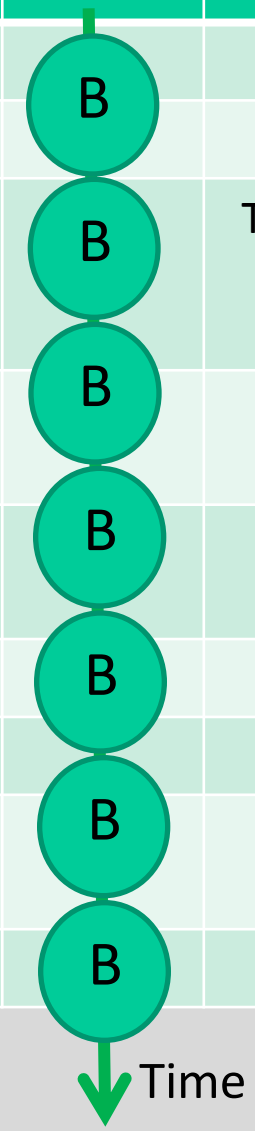
2. ***Prospection***: Construction of 'virtual' landscapes ("mental spaces") in **ML** in which sequences of procedures are tried and 'virtually' evaluated.

3. ***Complexification*** for the selected procedure(s).

DISCUSSION

How the revisited GBG weaves living systems and categories

Living systems	'Beads'	Categorical notions
Whole ≠ sum of parts		Complex object as a colimit
Hierarchy of holons		Hierarchical category
Becoming-in-action: Variation of components Information transfers		Time in MES: Transitions as partial functors. Propagation delays
"Degeneracy property" => Flexibility, plasticity		Multiplicity Principle Multifaceted components
Standard changes Emergence of complexity		Complexification process Emergence Theorem
Multi-agent organization		CRs' landscapes and interplay
Higher dynamic Memory. Self		Archetypal Core
Higher cognitive processes up to creativity		Retrospection/Prospection in Macrolandscapes
Transformational Creativity		Iterated complexifications



Characteristics of the revisited GBG

Playing a GBG can be interpreted as the evolution of a particular MES. The components are: those interested in the game, especially players and the judges (who constitute CRs); the Archives of the game representing the Memory, in particular the hierarchy of beads. The game combines patterns of already existing glass beads from different domains, forming colimits named by the corresponding hieroglyphs.

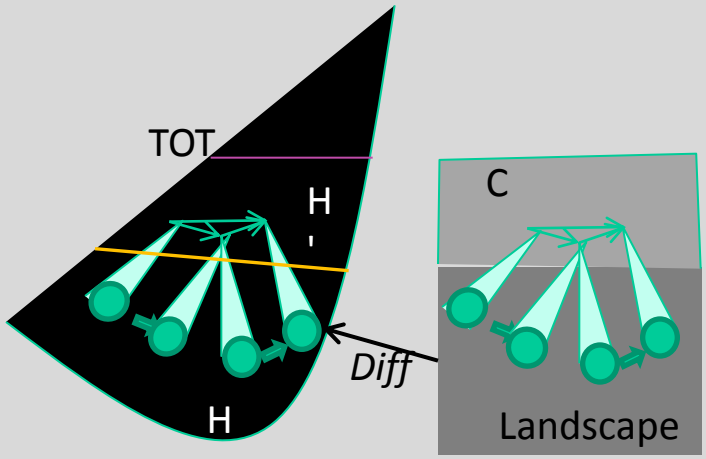
Now for a MES to develop creative processes, it must satisfy MP, so that it has flexible multifaceted components with many ramifications, able to disappear. Whence the characteristics to add to the beads for 'real' creativity.

1. The beads should be multifaceted to allow for 'real' emergence (MP).
2. They should be destructible (suppression of no more valid knowledge).
3. "Rules for changing the rules" (complex links) should be accepted.

Comparison with the 'usual' Glass Bead Game

In Hesse, the Game takes place into the complete "large category" (topos?) TOT representing the whole of knowledge, values and culture. The players only know a part H of it in their landscape L, and they try to discover more of its structure. However this remains inside of TOT: they just try to find "presentations" of part of TOT thought of as a logic theory.

A game consists in exploring H, selecting a procedure Pr on it (through L) and constructing the complexification C. As TOT is complete, the functor Diff: L → TOT extends to C (universal property of C), and its image H' in TOT reduces to a Pr-complexification of H 'internally to TOT '. Thus the landscape of the players is extended to H'.



These operations can lead to combinatory or exploratory creativity. For transformational creativity, we have seen that it depends on the formation of new complex links in successive complexifications. Now the image of a complex link appearing in C already exists in TOT, hence in H', thus it does not lead to further change in a later complexification.

Pursuing the Game with recent MES developments

1. **R(etrospection)-P(rospection)-C(omplexification) method for creativity:**

In particular it characterizes "transformational creativity" by iteration of complexifications where emergent complex links introduce new rules which are slowly integrated (each complexification taking some time): a break allows an internal re-organization incorporating these new rules => "aha".

To be compared with Mazzola's *generic model of creativity* (1998) and with the *Concept-Knowledge theory* (Hatchuel & Weil, 2003).

Mazzola (1998)	C-K Theory (2003)	RPC Method (2012)
Open Question	"Undecidable" concept C_0	Surprising event
Identify context	Determining initial knowledge	Forming macrolandscape **ML**
Critical concept	Partitionning C_0 using **K**	Perspective pS of S in **ML**
Concept's walls	Restrictive partitions in **C**	Retrospection to analyze pS
Opening the walls => new perspectives	Expansive partitions in **C** and new knowledge in **K**	Prospection => Procedure Pr Pr-Complexification
Evaluation and iteration of the process		

2. **D-MES** *(*M. Béjean & A. Ehresmann, 2013 →)

They are MES able to analyze conception and design operations in a specific social group. They introduce a notion of *collective Archetypal Core* (extending the AC of MENS). It allows the formation of collective macrolandscapes in which creative exchanges and processes can develop, such as innovative design or "Novel Futures" integrating "change in the conditions of change".

CONCLUSION

A revisited GBG may lead to transformational creativity if it includes the following changes:

= The 'glass beads' are multifaceted and develop their own individuation with possible addition or suppression of 'facets', up to possible total destruction;

= "Rules for changing the rules" are accepted

With these modifications the Game could cover the aims of the Glass Bead platform, and lead to innovative interdisciplinary research.

FOR MORE INFORMATION

Memory Evolutive Systems: Hierarchy, Emergence, Cognition (with J.-P. Vanbremeersch), Elsevier, 2007.

MENS, a mathematical model for cognitive systems (with J.-P. Vanbremeersch), *JMT* 0-2, 2009.

MENS, an info-computational model for (neuro-)cognitive systems up to creativity, *Entropy* 14, 2012, 1703-1716.

A theoretical frame for Future Studies, On *the Horizon,* Volume 21 issue 1, 2013.

D-MES : conceptualizing the working designers (with Mathias Béjean), 8th *International. Conf. on Design principles and practices*, Vancouver 2014. ube.com/watch?v=tOgfyOSWbXw&feature=youtube_gdata

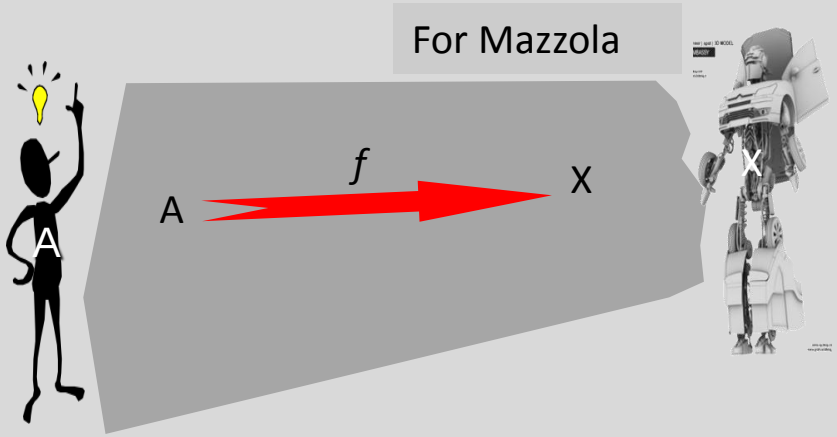
Most papers are downloadable from the site: http://ehres.pagesperso-orange.fr

http://ehres.pagesperso-orange.fr

THANKS

The following slides explicit some of the categorical constructions

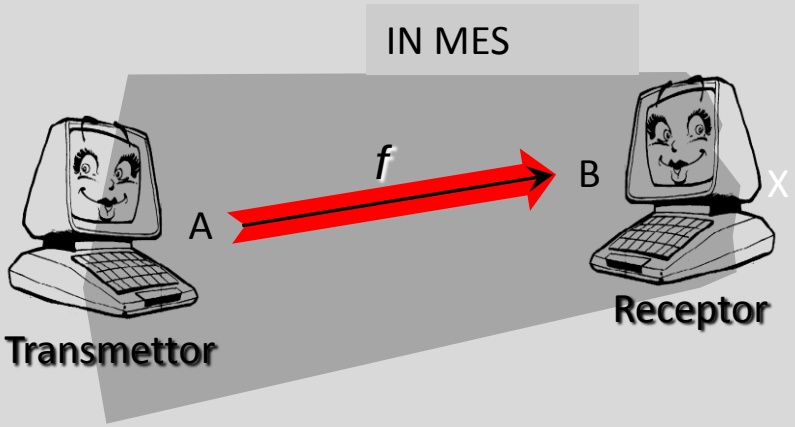
Different meanings of the morphisms



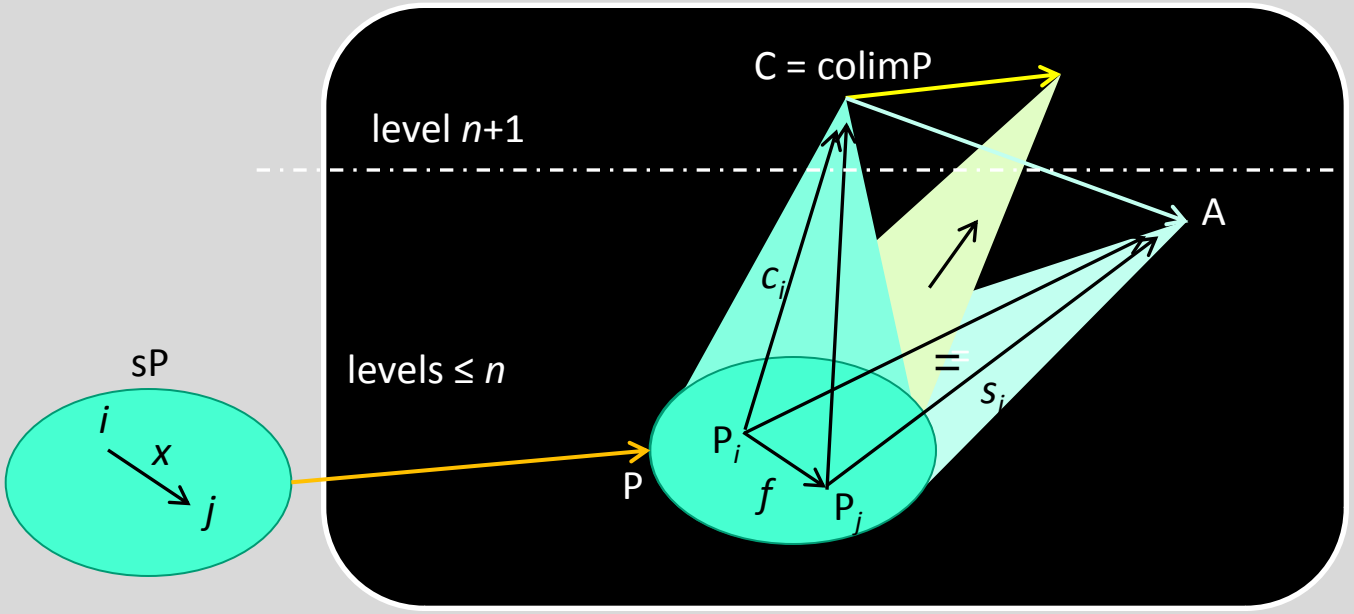
Mazzola interprets *f*: A → X as a *perspective on X with address* A :
"Intuitively, A is looking at X".
A is the *tail* and X the *head* of *f*.

For Guitart, A is a pointer to X and *f* measures a difference which added to A produces X.

In MES, Time is integrated in the system. Aan arrow *f* A → X is thought as way for A to transmit an information or a command to X which X receives after some *propagation delay.* A is the *source* and X the *target of f.*
f can be active or not at an instant *t.*



COMBINING = BINDING = COLIMIT



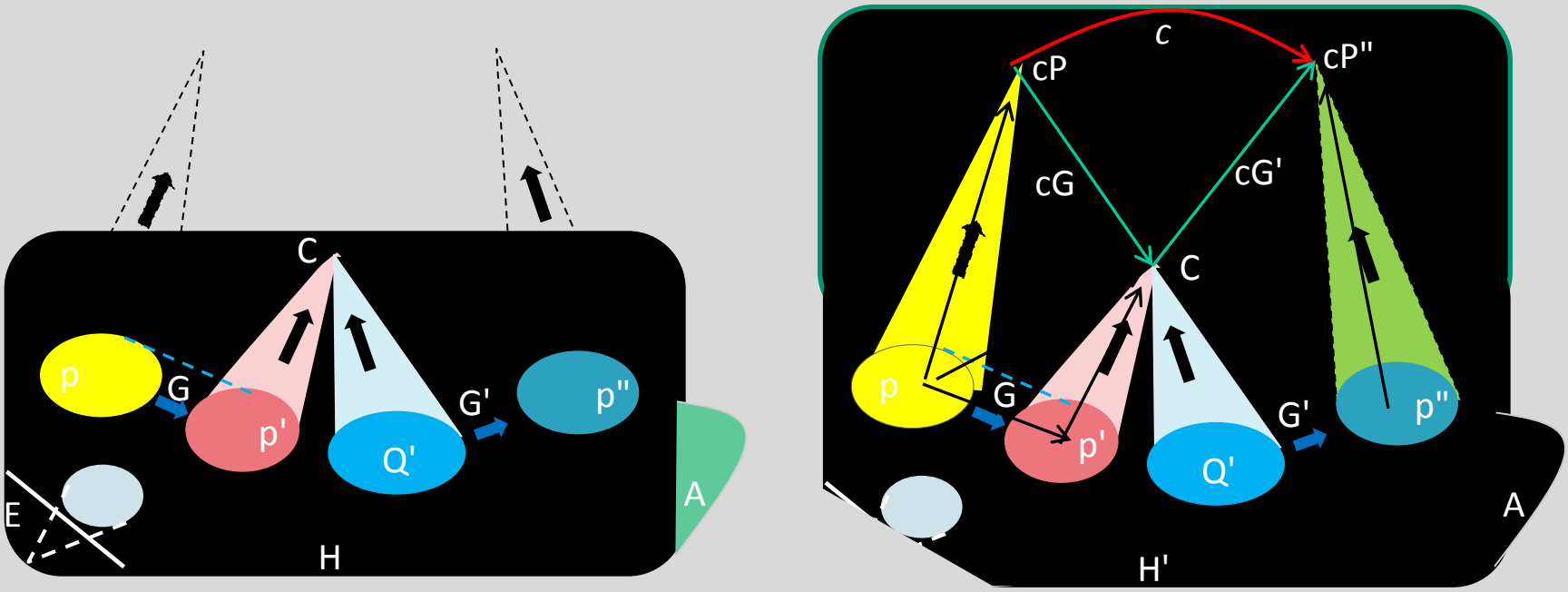
Pattern P = diagram P: sP → H

= family of objects P_i with distinguished links $f = P(x)$: $P_i \to P_j$.

Collective link from P to A = cone $(s_i)_i$: P => A, i.e. family of links s_i: $P_i \to A$ correlated by the distinguished links of P: $fs_j = s_i$.

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.

HOW COMPLEX LINKS EMERGE



Objectives: Suppress E, Add A, Bind given patterns P and P'.

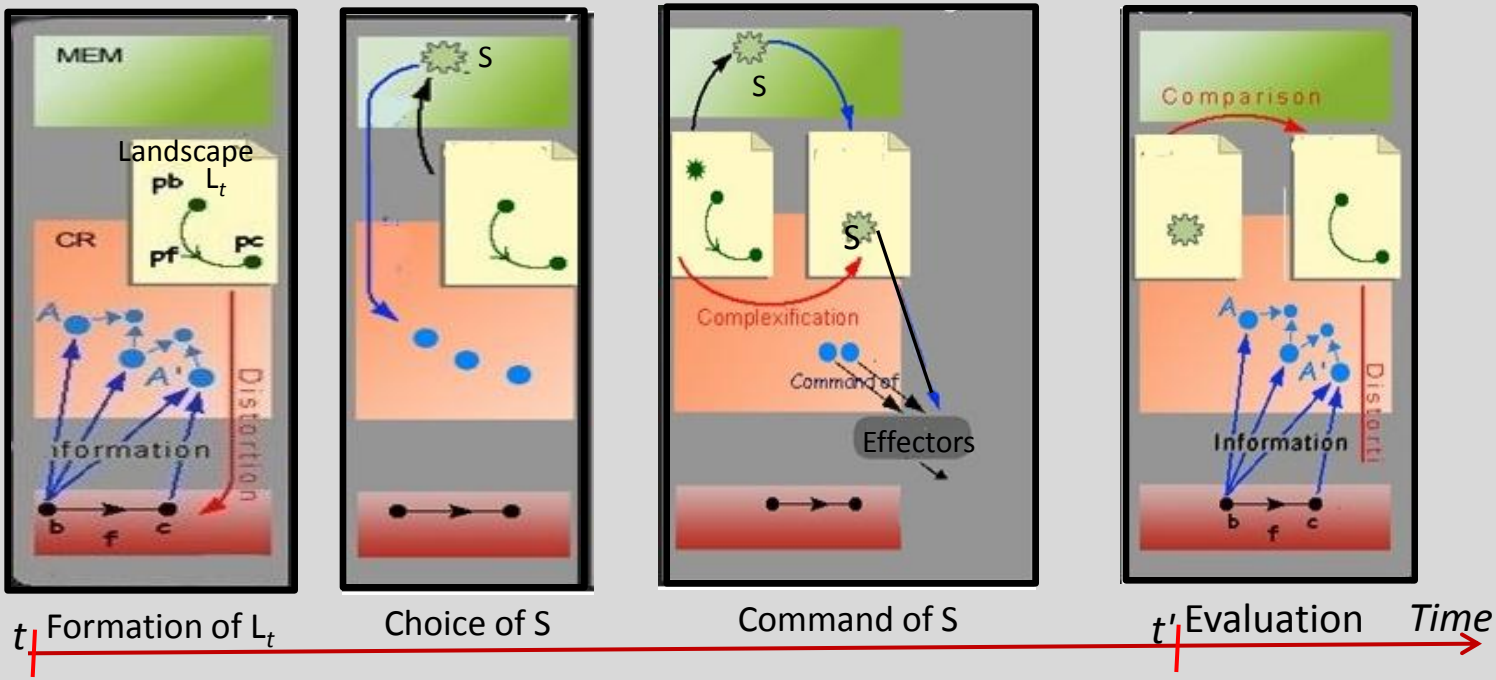
Complexification: E is suppressed with links with one extremity in E, A becomes a sub-graph. Then iteration of the operations, each with delay:

A cone of basis P and vertex a new cP is added. For cP to be its colimit, we must add a simple link from cP to C binding the cluster G.

A cone of basis P' and vertex a new cP' is added. Since C is the colimit of Q', we must add a simple ink from C to cP' binding the cluster G'.

Finally we have an emerging complex link *c* composite of cG and cG'.

A CO-REGULATOR CR AS A HYBRID SYSTEM



CR acts stepwise at its own rhythm. At each step*:*

(i) Information received by CR (perception) is processed in its *landscape* L_t.

(ii) An adapted procedure (action) Pr is selected on it with the help of **Mem**.

(iii) Sending the corresponding commands to effectors starts a dynamical process carried on during the step (modeled by differential equations implicating the propagation delays and strengths of the links).

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