MENS: from neurons to higher mental processes up to consciousness

by

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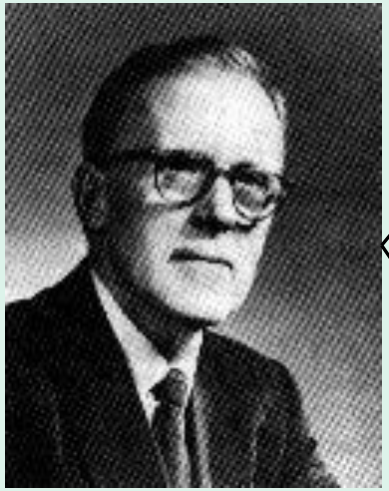
SOME HISTORY



In 1949 Hebb (1904-1985) introduces the notion of a 'synchronous' ***cell-assembly***: "*Any frequently repeated, particular stimulation will lead to the slow development of a "cell-assembly" […] capable of acting briefly as a close system*"

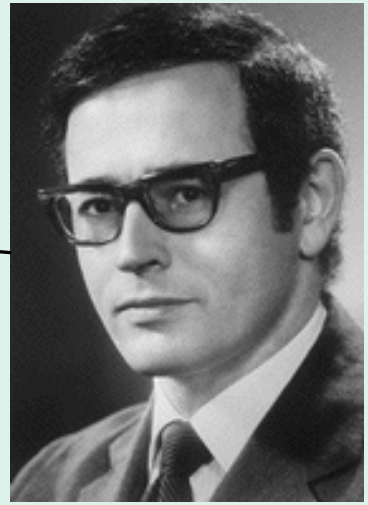
and he gives the ***Hebb rule for synaptic plasticity***:

"*When an axon of cell A is near enough to excite B and repeatedly or persistently takes part in firing it […] A's efficiency, as one of the cells firing B, is increased. "*

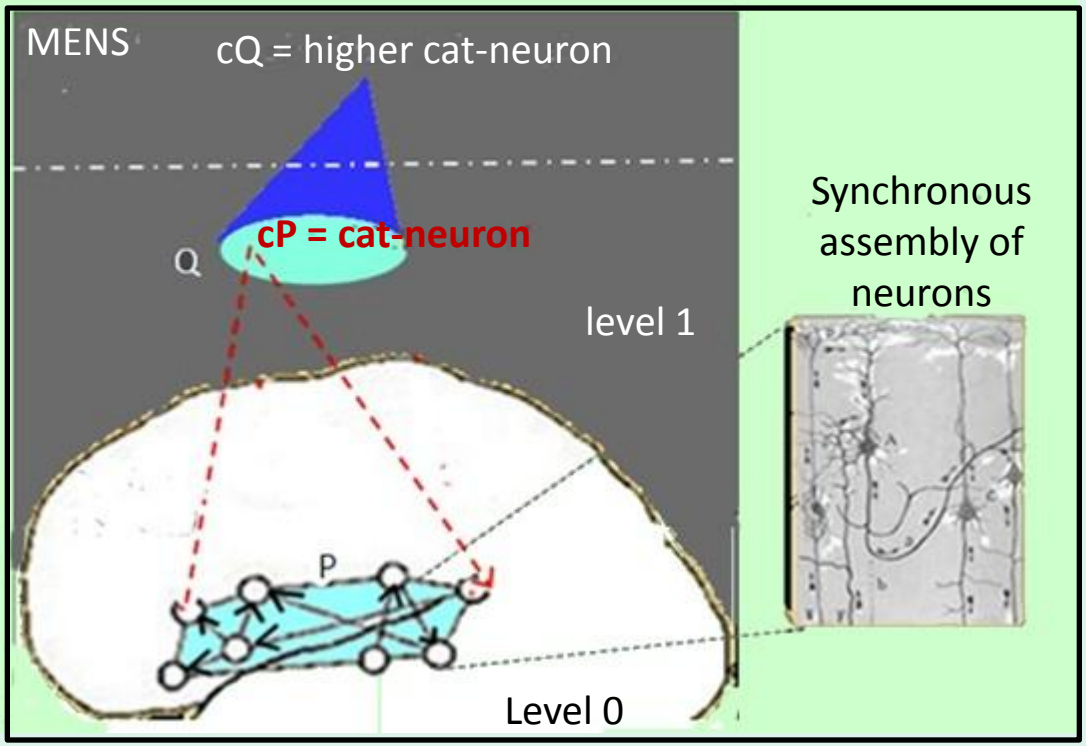
Edelman (1929-) emphasizes what he calls the ***degeneracy property of the neural code***:

"*More than one combination of neuronal groups can yield a particular output, and a given single group can participate in more than one kind of signaling function. …"*

(The remembered present, 1989, p. 50)



GENERAL STRUCTURE OF MENS



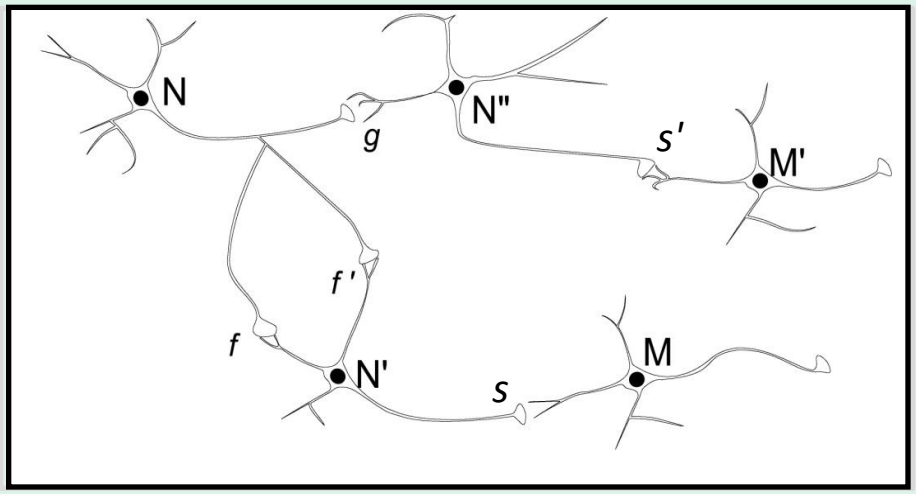
Modified from: "The Brain from top to bottom", McGill

MENS is a MES:

At level 0: the 'physical' neural system (neurons and synapses)

At hiher levels: 'conceptual' objects called *category-neurons*, corresponding to mental objects looked at as the 'synchronous' activation of more or less complex and distributed *(hyper-)assemblies of neurons.*

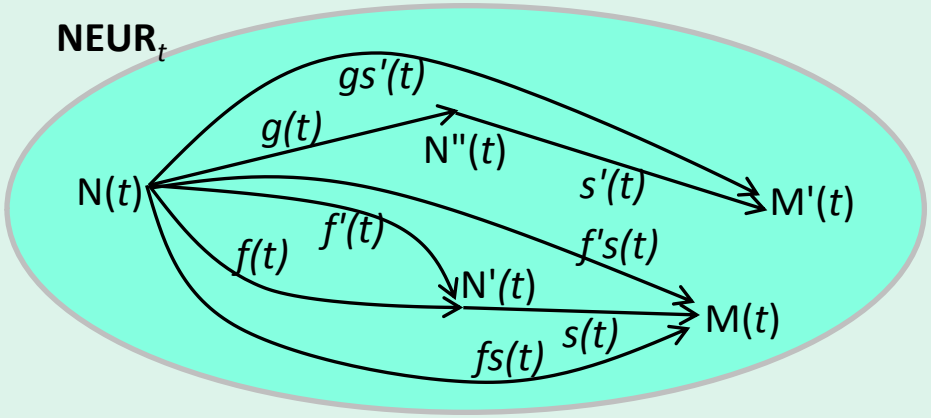
GRAPH AND CATEGORY OF NEURONS



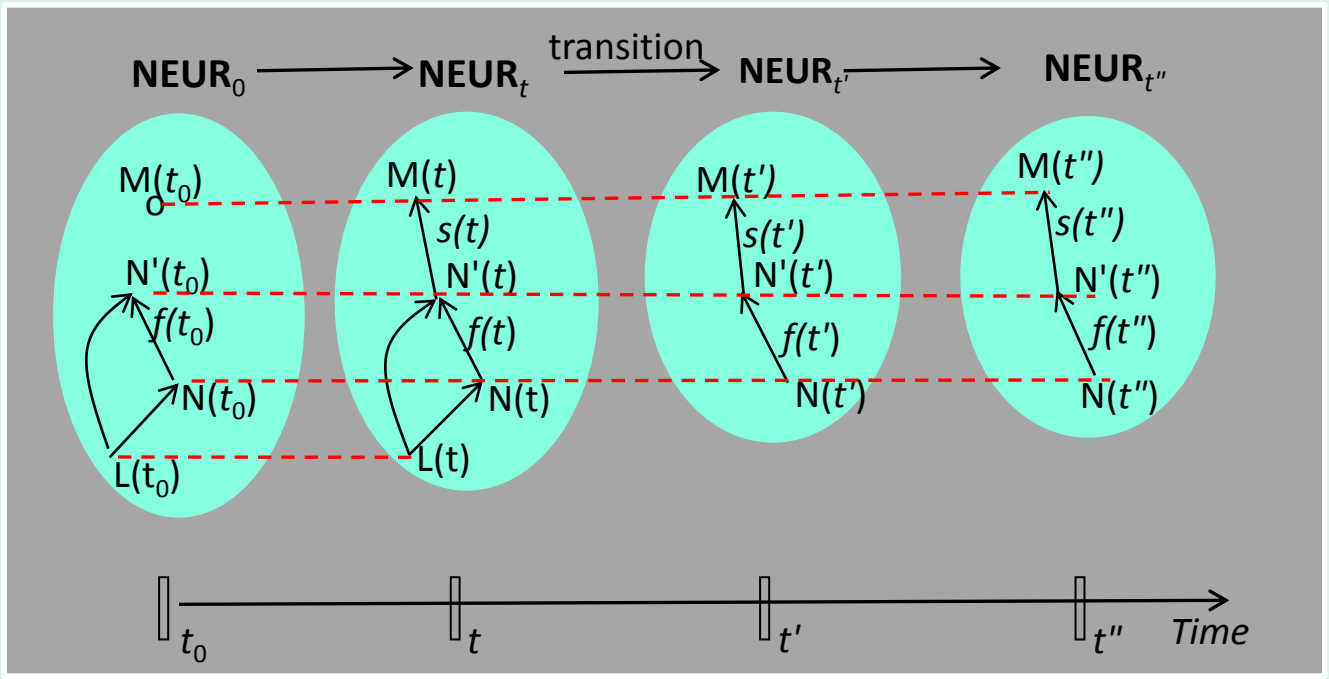
Graph of neurons at *t*: Objects = states N(*t*) of the neurons N, with their activity around *t*. Arrow *f* = synapse from N to N' weighted by its *propagation delay d(f)* around *t* and its *strength* varying through *Hebb rule.*

The ***category of neurons at t,*** denoted **NEUR**$_t$ is the category of paths of this graph. the composition being given by the convolution of paths.

(A *category* is a graph with a composition of successive arrows, which is associative and in which each object has an identity.)



THE EVOLUTIVE SYSTEM OF NEURONS NEUR

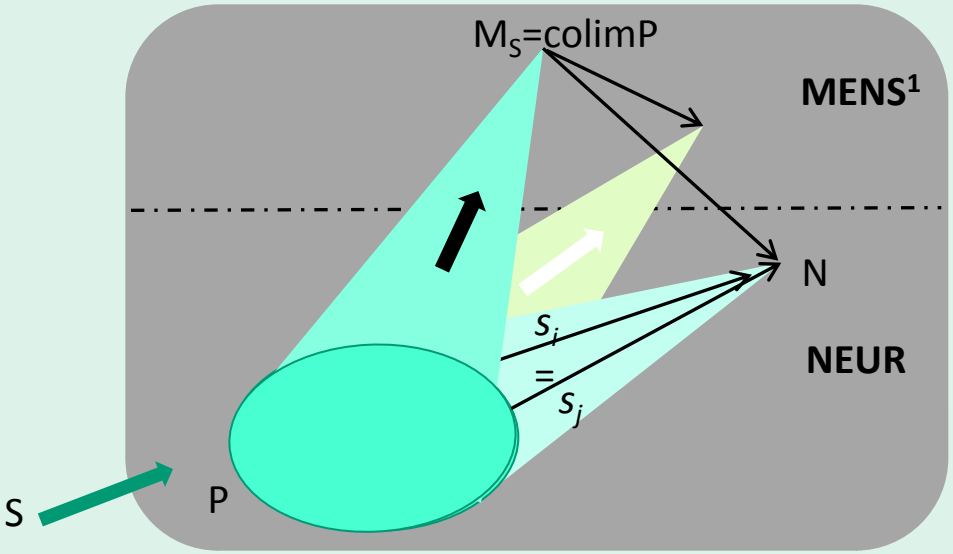


Family of categories **NEUR**$_t$ where *t* varies over the life *Time.*

Transition from *t* to *t'* > *t* = functor from a subcategory of **NEUR**$_t$ to **NEUR**$_{t'}$ relating the states of the same neurons and links at the two different instants. There is a transitivity of transitions, so that a *component of* **NEUR** is a neuron N, looked at as the sequence of its successive states.

MENS is an Evolutive System constructed from **NEUR** by successive complexifications, adding *cat(egory)-neurons,* modeling more and more complex mental objects.

FORMATION OF A MENTAL OBJECT AS A CAT-NEURON

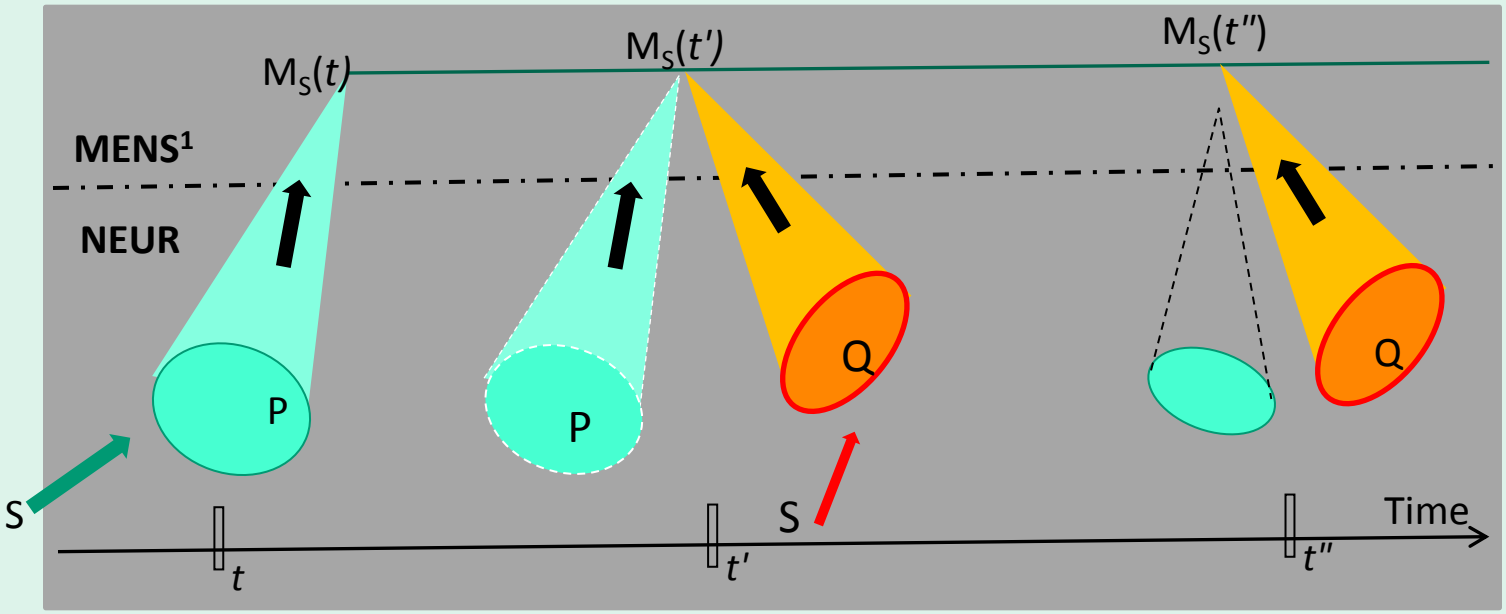


" *Whenever neurons […] do fire with the spike-timing pattern determined by the connectivity and delays, we say that the group is activated and the corresponding neurons polychronize. […] polychronous groups could represent memories* " (Izhikevich, 2006)

A simple stimulus S activates such a '*polychronous*' assembly of neurons, modeled by a *pattern* P in $\mathbf{NEUR}_t$. P can '*synchronously*' transmit its activation to a (cat-)neuron N through a collective link (s_i) from P to N, so that $s_i = fs_j$, whence $d(s_i) = d(f)+d(s_j)$.

If S is repeated or persists, the distinguished links of P are strengthened (via Hebb rule), P can act synchronously on a neuron N, and the *long-term memory* of S is recorded by a cat-neuron (of level 1) M_S 'binding' P (M_S = *colimit* of P) in **MENS.**

DEGENERACY. ROBUST BUT FLEXIBLE MEMORY

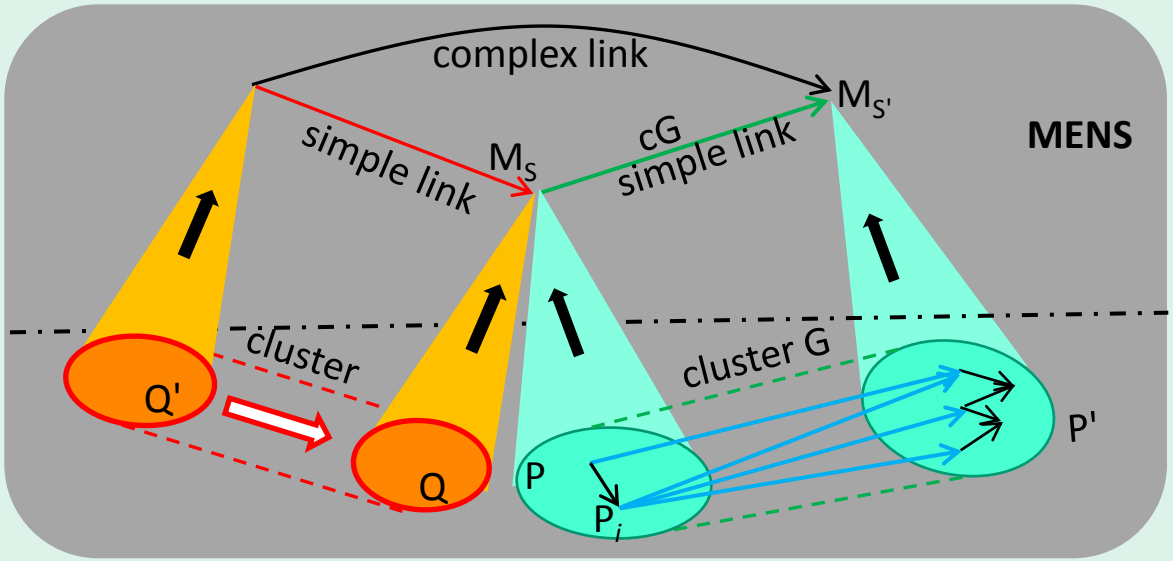


The degeneracy of the neural code implies that different assemblies of neurons may have the same functional role though not necessarily interconnected.

In **MENS**, the cat-neuron (of level 1) M_S recording S is the colimit of each of them. Initially constructed to bind a pattern P, later it takes its own identity. Thus it is not a rigid record, but a *multiform object* representing a flexible memory which adapts to changing situations.

===> MENS satisfies the ***Multiplicity Principle***

THE BINDING PROBLEM. SIMPLE AND COMPLEX LINKS



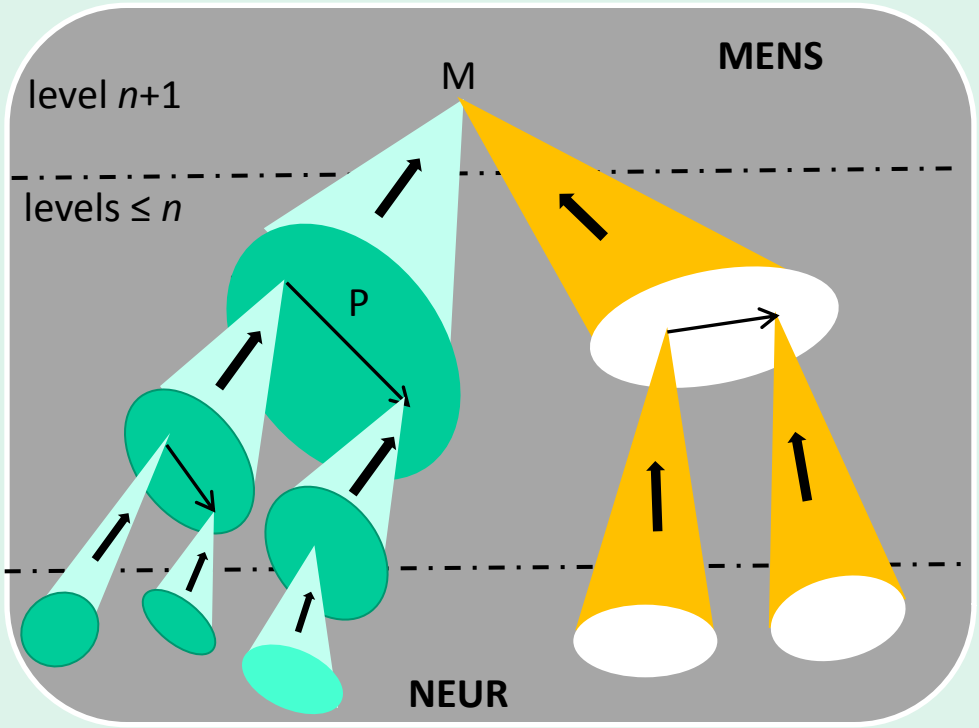
A (P, P')-***simple link*** from M_S to $M_{S'}$ binds a cluster of links between decompositions P and P' of M_S and $M_{S'}$.

Existence of *multiform objects* M_S colimit of 2 patterns P and Q non connected by a cluster (MP) **===>** Emergence in **MENS** of ***complex links*** **c**omposing simple links binding non-adjacent clusters.

Propagation delays and srengths of synapses extend to the simple and complex links, as well as Hebb rule.

===> The construction can be iterated to construct the ***hierarchical evolutive system*** **MENS** based on **NEUR**.

BRAIN-MIND CORRELATION

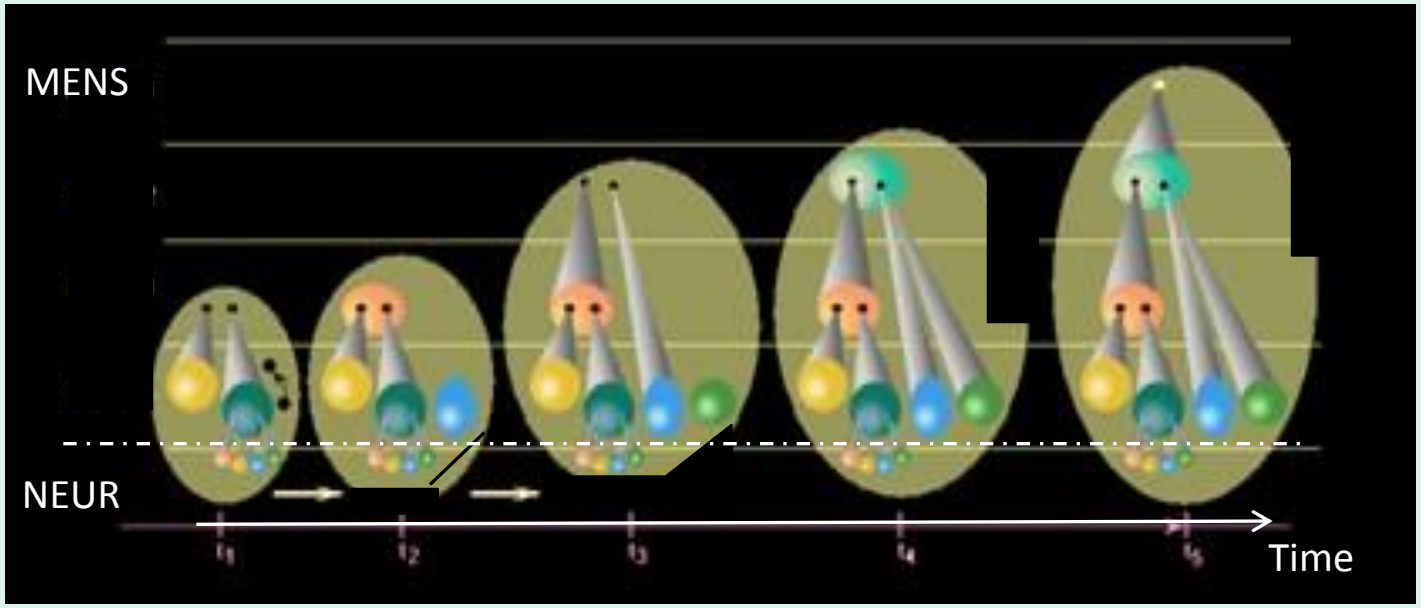


Activation of M = unfolding of a ramification down to **NEUR**: 1. activation of a decomposition P of M in a polychronous assembly of cat-neurons of lower levels; 2. decomposition of each component of P; 3. so on down to the *physical activation* of polychronous assemblies of neurons. At each step, choice between several decompositions **===> activation of M has *multiple physical realizabilities***.

Complexity order of M = least length of a ramification.

MP **===> emergence of mental objects and cognitive processes of order > 1.**

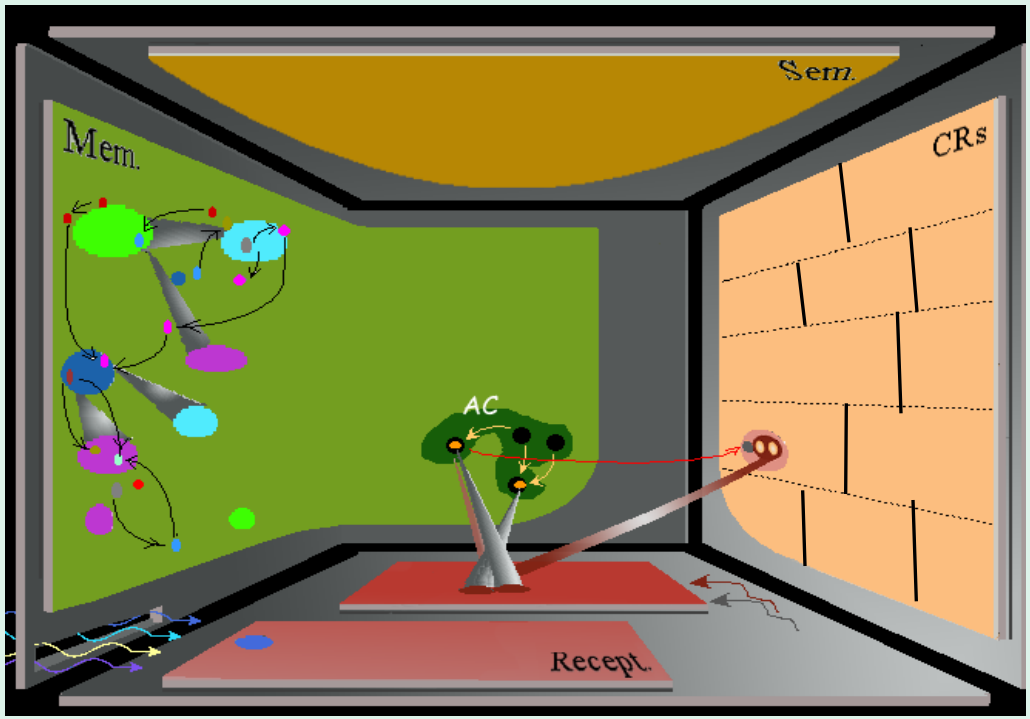
EMERGENCE OF HIGHER ORDER MENTAL OBJECTS



In **MENS**, a transition amounts to a *complexification* process with objectives: formation (or preservation, if it exists) of a cat-neuron binding a given polychronous pattern P of cat-neurons; elimination or inhibition of a (cat-)neuron; formation of a cat-neuron 'classifying' other cat-neurons (becoming their projective limit, notion dual of a colimit) . It is explicitly constructed.

EMERGENCE THEOREM. ***The degeneracy of the neural code (===> MP) allows for the emergence, over time, of mental objects and cognitive processes represented by cat-neurons of complexity order > 1 and possibly > 2 (with language).***

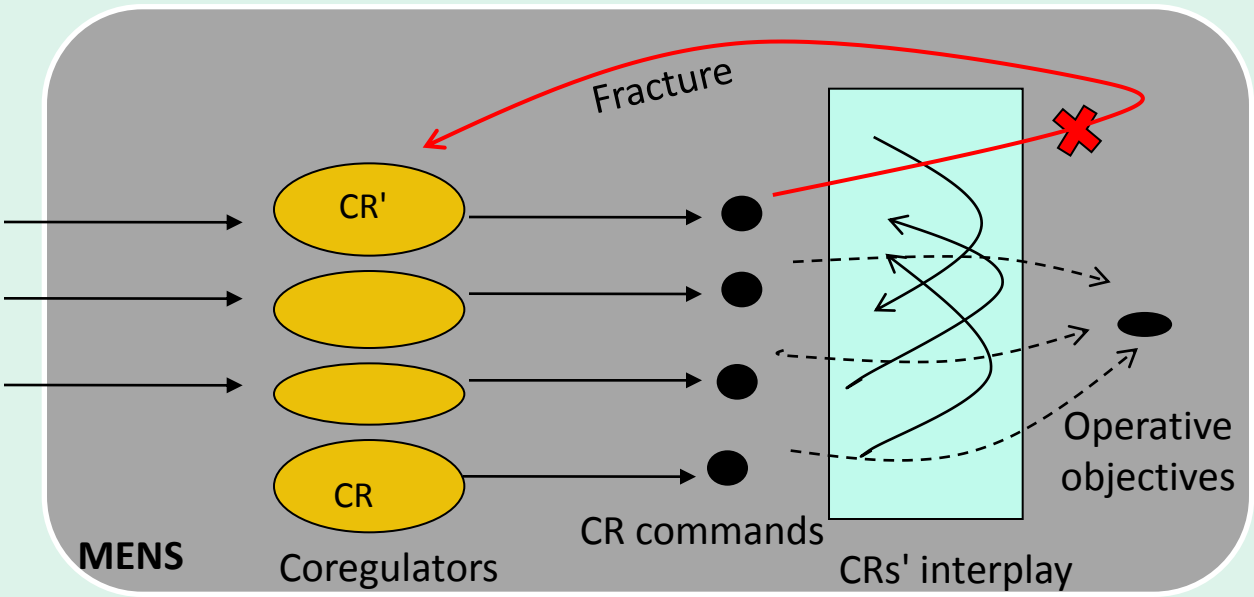
MENS AS A MES. THE CO-REGULATORS



MENS is self-organized by a net of ***co-regulators***, based on specialized brain modules, which modulate the dynamics through their competitive interactions. They help developing the subsystem **Mem(ory)** which models the mental objects and knowledge of any kind with flexibility and plasticity for adaptation to changes.

Each co-regulator acts stepwise, at its own rhythm and with its specialized objectives. At each step it forms its *landscape* with the partial information which activates polychronous patterns in it, selects objectives adapted to respond to them, using its access to **Mem.** and sends the corresponding commands to effectors.

THE MULTI-SCALE DYNAMIC OF MENS

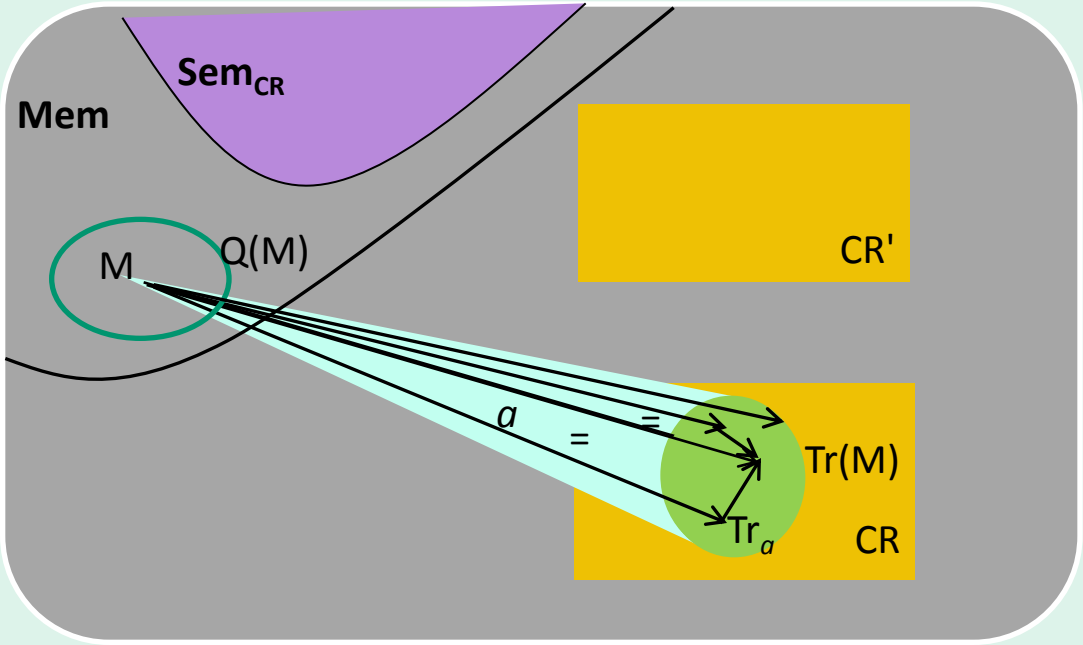


The commands sent by the various co-regulators at a given time may not fit together, each CR having its own temporality and logic.

The objectives defining the global logic carried out on the system comes from an equilibration process between them, the ***interplay among the Co-regulators***, possibly by-passing the objectives of some of them, thus causing a *fracture*.

The interplay is constrained by the temporal constraints (synchronicity laws), but made flexible by the possibility of switches (MP).

CR-SIMILARITY CLASSES

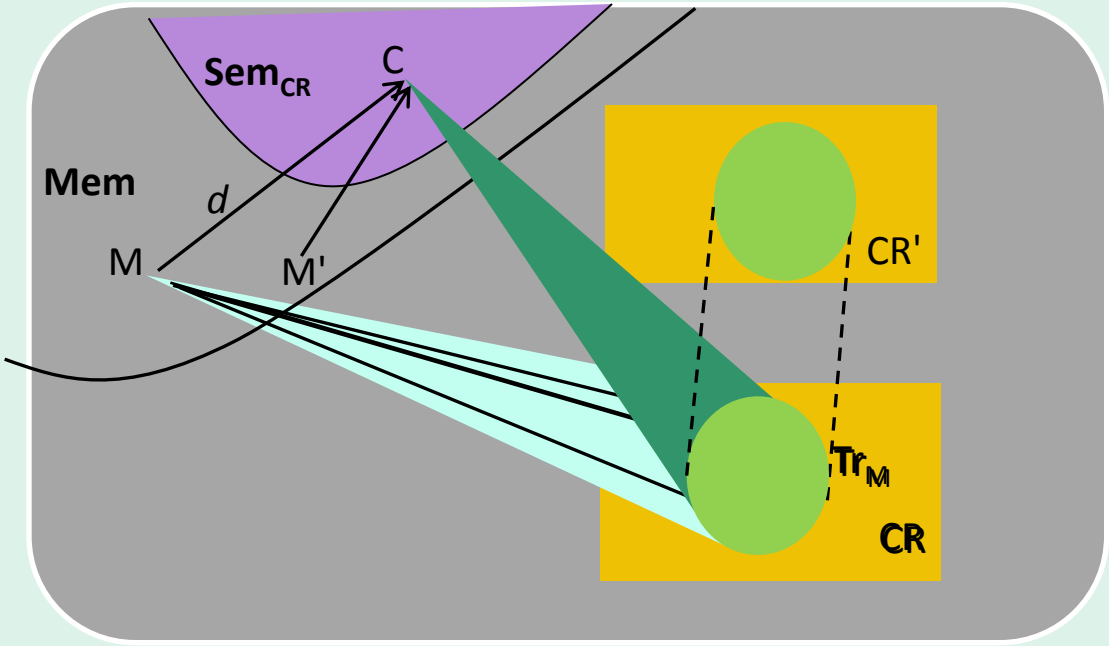


Sem is an evolutive sub-system of Mem developed (without language) in 3 stages: CR-similarity classes (sub-conceptual), 'basic' concept with respect to a CR-attribute, more abstract concepts (symbolic stage).

If CR is a co-regulator (e.g., color-CR), the CR-*trace* of a cat-neuron M in Mem is the pattern Tr(M) of CR activated by M: it is indexed by the aspects *a*: M → Tr$_a$ of M for CR, and its distinguished links correlate them.

Different M with pro-homologous traces are CR-*similar.* their set Q(M) is the CR-***similarity class of*** M.

BASIC (CR-)CONCEPTS

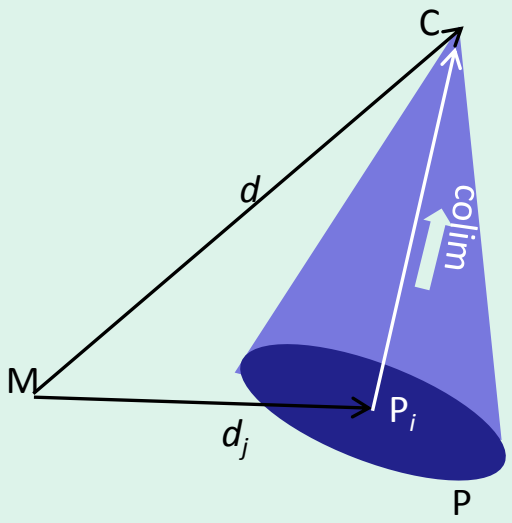


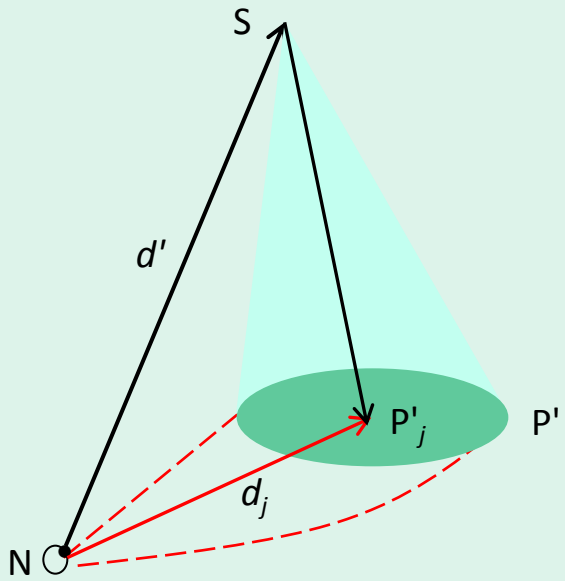
CR-***concept*** of M = projective limit C of the trace Tr(M) of M.
The CR-concepts and their links constitute an evolutive sub-system **Sem$_{CR}$** de **Mem** obtained by complexifications (via higher level co-regulators CR' observing CR). The strength of links between concepts measure their distance.

Instance of a CR-concept C = cat-neuron M which has C for reflection in **Sem$_{CR}$.**
C plays the role of a *prototype* (in terms of Rosch) and the strength of the reflector *d*: M → C measures the distance between M and C.

Over time, C takes its own identity and its instances can vary.

GENERAL CONCEPTS





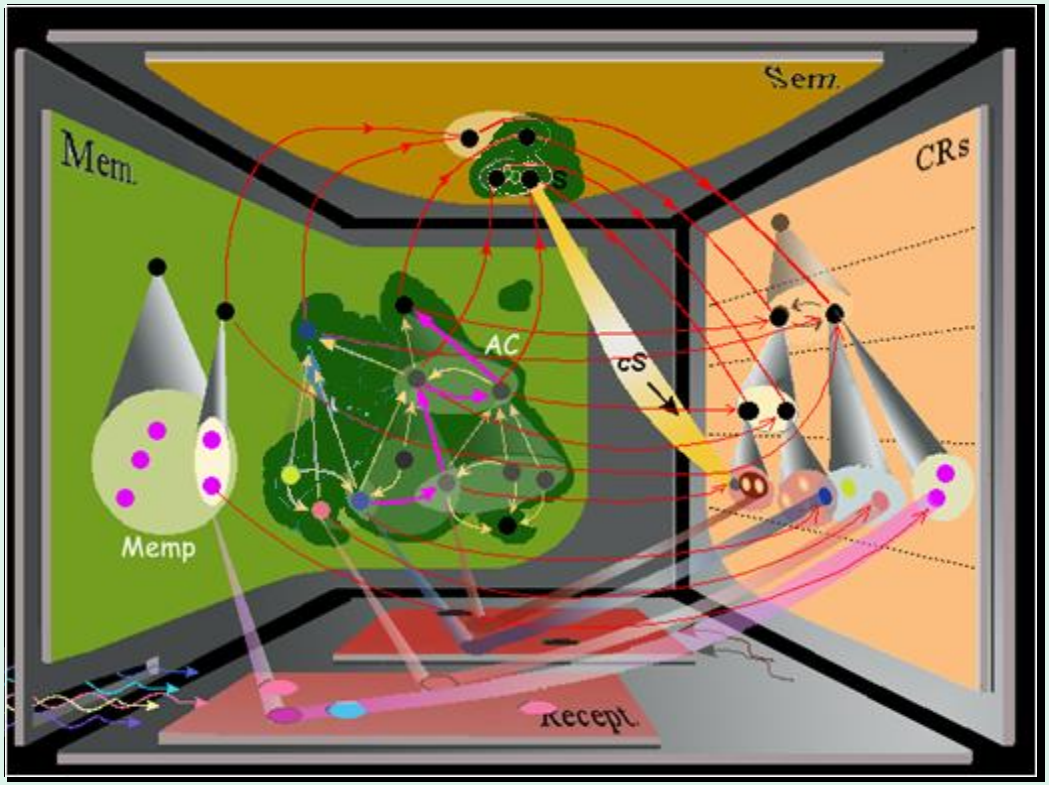
The ***semantic memory*** **Sem** is constructed by mixed complexifications adding ***concepts*** which are obtained as colimit or projective limit of polychronous patterns of CR_i-concepts for various co-regulators CR_i.

If C = colimP, where P is a pattern of basic concepts, its instances M are all the instances of the various P_j.

If S = limP' an instance N of S is an instance of each P'_j such that their reflector links d_j to P'_j form a distributed link to P', classified by the reflector links d' from N to S.

Concepts take their own identity over time; they are activated through their instances, with possible switches betwenn them.

THE ARCHETYPAL CORE

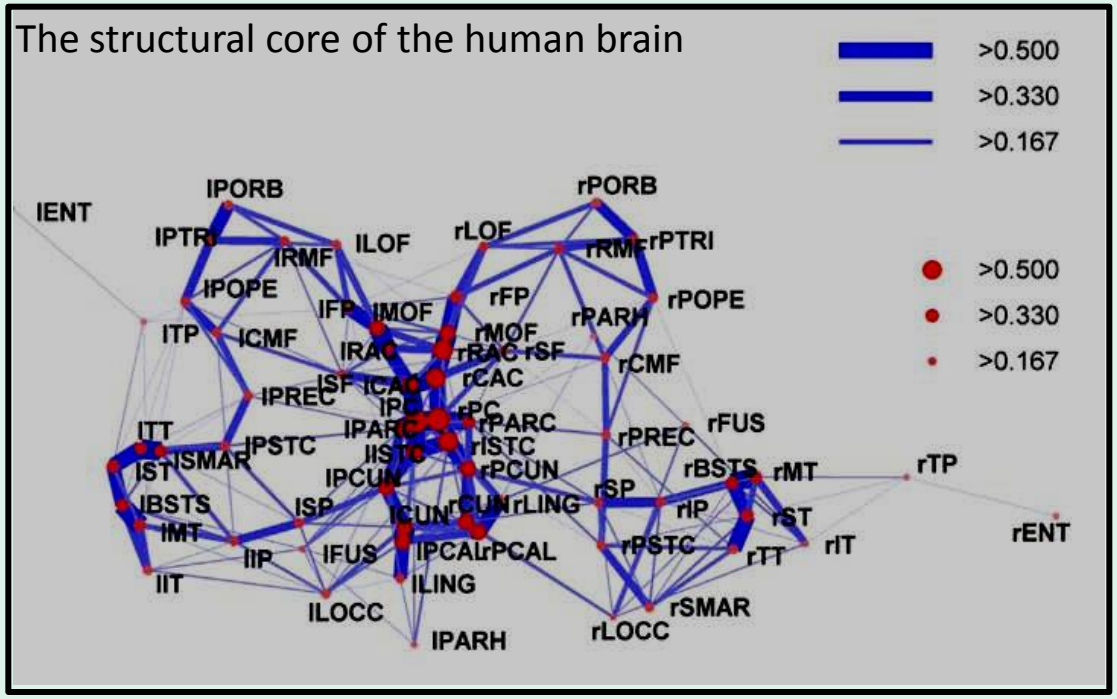


MP and **Sem** allow for the development over time of the ***Archetypal Core*** **AC**.

AC = subsystem of **Mem** formed by higher order cat-neurons integrating significant memories, with many ramifications and possibility of switches. Their strong and fast links form *archetypal loops* self-maintaining their activation.

AC embodies the complex identity of the system ('Self'), and acts as a *flexible internal model.*

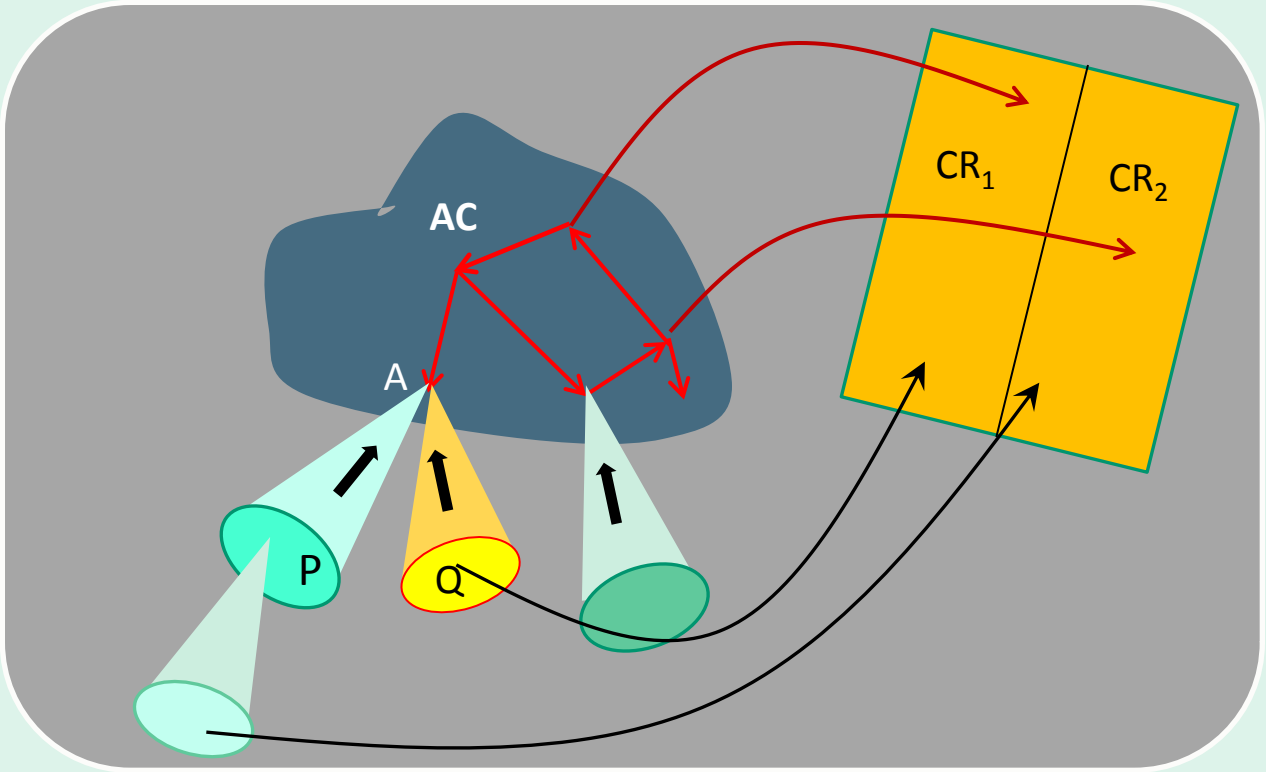
THE NEURAL BASIS OF THE ARCHETYPAL CORE



In 2008, Hagmann & al. find an integrative part of the brain, the ***structural core***, with the properties required for being the basis of **AC**. They write :

> *" Our data provide evidence for the existence of a structural core in human cerebral cortex […] both spatially and topologically central within the brain. Its anatomical correspondence with regions of high metabolic activity and with some elements of the human default network suggests that the core may be an important structural basis for shaping large-scale brain dynamics. " "linked to self-referential processing and consciousness. "*

INTENTIONAL CO-REGULATORS. GLOBAL LANDSCAPE

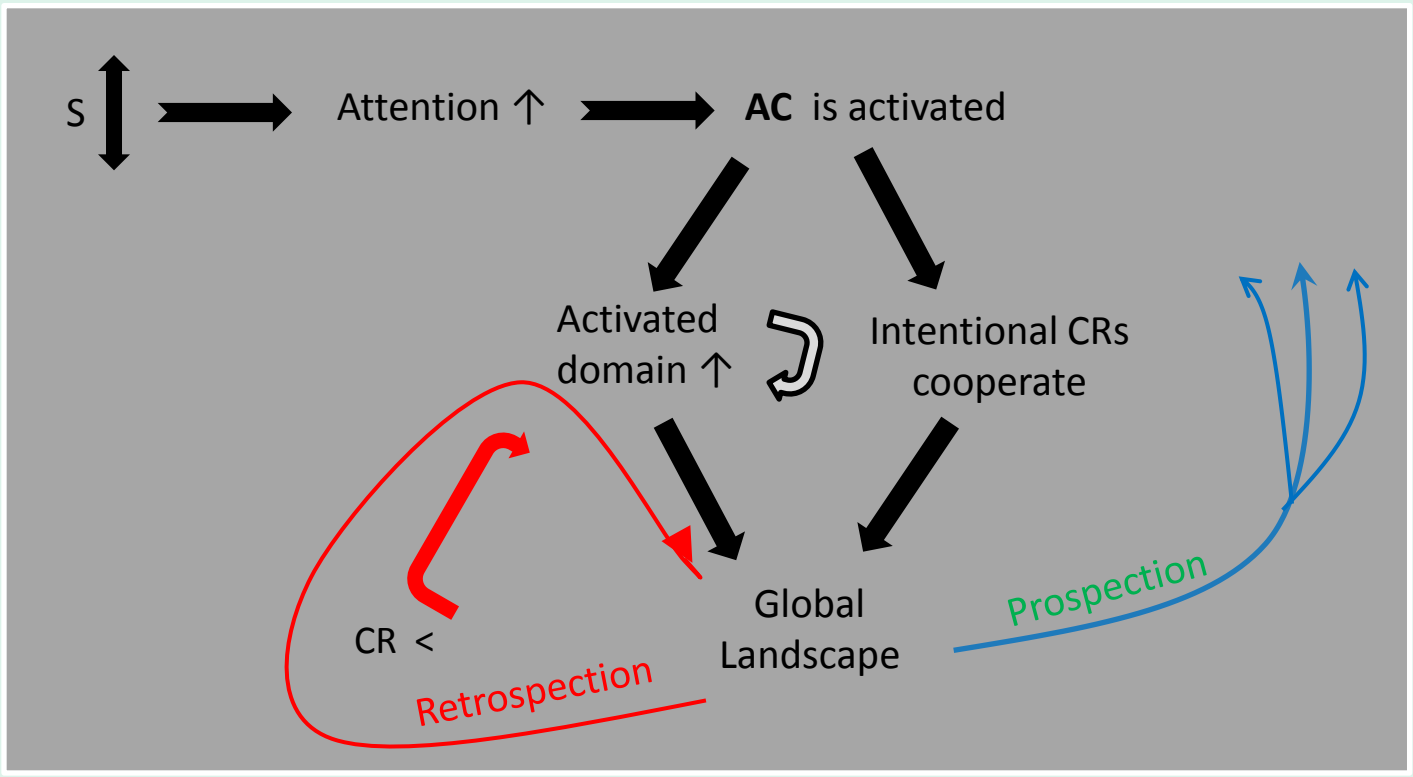


Intentional co-regulator = higher CR_i based on associative brain areas, linked to **AC**. Activation of part of **AC** diffuses through self-maintained archetypal loops.

It propagates to a decomposition P of some A, then, via a switch, to another decomposition Q of A and down a ramification.

Transmitted back to intentional CR_i, it allows the formation of a *global landscape* **GL** uniting and extending their landscapes (*Baars' theatre*).

CONSCIOUS PROCESSES



Event S increases the attention, leading to an activation of part of **AC**

===> formation of a longer term global landscape **GL** by intentional co-regulators, in which they start a ***retrospection process*** (in several steps) for making sense of S.

Then a ***prospection process*** is developed in **GL**, using the motor role of **AC,** to iteratively construct virtual landscapes in which sequences of long-term strategies are tried and evaluated, and an adequate one is selected.

CONCLUSION

Changeux

MIND	MENS	BRAIN
Simple Mental Object	(Cat)-neuron level 0 Cat-neuron of level 1	Neuron Class of polychronous neural assemblies
"Algebra of mental objects"	Cat-neuron of level *n*	Class of polychronous neural hyper-assemblies (= assembly^{n})
Emerging Properties	Multiform objects, MP Complex links	Degeneracy of the neural code
Self	Archetypal Core Global Landscape	Structural core
Conscious processes	Retrospection Prospection	Structural core Consciousness loop (Edelman)

The degeneracy property is the characteristic making possible the emergence of higher mental processes, the development of the Archetypal Core at the basis of the self, allowing for consciousness, seen as the integration of past and future.
Some quantification is possible using the propagation delays and strengths of links.

FOR MORE INFORMATION

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

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

Internet sites containing most of our papers:

http://ehres.pagesperso-orange.fr

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

THANKS