Emergence, Cognition, Consciousness

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Colloque International "Charles Ehresmann : 100 ans"

Faculté des Sciences UPJV, Amiens - (FRANCE)

7-9 octobre 2005

Several of the concepts introduced by Charles Ehresmann in Geometry have had applications outside of mathematics and he thought the same would apply to his works in category theory. The Memory Evolutive Systems (MES) we have developed in a series of papers since 1986 (summarized on our Internet site http://perso.wanadoo.fr/vbm-ehr, developed in a volume in print, Elsevier) justify this expectation by giving a model for natural complex systems, such as biological, neural or social systems. Here we'll insist on the case of cognitive systems, to model the emergence of higher cognitive processes and analyze the "neuronal correlates of consciousness".

1. Memory Evolutive Systems

The modeling of a complex system relies on the following operations:

1. *Description* of its objects, of their interrelations, how they are composed to transfer information and how they evolve over time: The system is modeled by an *Evolutive System* (ES), that is a family of categories (representing the state of the system at a given time) indexed by Time, with (partial) '*transition functors*' between them modeling the change of states (fibration over Time).

2. *Organization* into a hierarchy of different complexity levels: An object is complex if it binds an internal organization in patterns of simpler objects coordinated between them to perform its specific function; the complex object is then represented by the *colimit* of these patterns. The ES is *hierarchical* if its units are separated into levels, with an object of level n+1 being the colimit of a pattern of lower levels objects.

3. *Change and learning*: The changes correspond to the addition or suppression of some objects, and the binding together of patterns of interacting objects to form new complex objects (becoming the colimit of the pattern). In particular the system learns to recognize features of its environment and to develop adapted answers, thus memorizing a hierarchy of representations. This is modeled by the *complexification process* of a category with respect to a procedure (or 'strategy') having such objectives (adapted from the passage from a sketch to a prototype, C. Ehresmann). A sequence of complexifications leads to the long term storage of information, procedures and their result in a sub-ES, called the *Memory*, from which they can be later recalled and possibly modified for adaptation.

4. *Self-regulation*: An autonomous system is internally regulated by a modular organization at the lower levels which gives rise to a coherent global dynamics without a central conductor. A MES has a net of cooperating but possibly conflicting local modules, represented by sub-ES called *coregulators* (CR). Each CR operates a stepwise process at its own time-scale, to gather partial information in its landscape, to select an admissible procedure and send its commands to effectors, finally to evaluate its results. At each time, the the global operative procedure realized on the system is obtained after an equilibration process, the *interplay among the procedures* of the various CRs, possibly causing *fractures* to some CRs whose procedures have to be discarded for coherence. Whence a *dialectics between CRs* with heterogeneous time-scales and complexity levels.

2. Cognitive systems

The brain of an animal is modeled by the ES of neurons Neur representing his neurons linked by (classes of) synaptic paths. This ES is extended over time by adding more conceptual but functional components, called *cat-neurons*, modeling (classes of) synchronous assemblies of neurons. The *MES of cat-neurons* is obtained from Neur by successive complexifications, leading to the formation of more and more complex cat-neurons representing mental objects and cognitive processes. Here are some of its characteristics.

1. *Binding problem*: The construction of a complexification determines not only what are the added new objects, but also the complex links formed between them. In the MES of cat-neurons, it explicitly describes the 'natural' interactions between synchronous (super-) assemblies of neurons, thus solving the *binding problem* raised by neuroscientists. It also displays the emerging properties of a complex object (say, a synchronous assembly of neurons), not reducible to those of its lower levels components (its neurons).

2. *Emergence*: We find the condition for iterated complexifications to lead to the emergence of objects and processes of strictly *increasing complexity orders* (such as higher cognitive processes up to consciousness), which have both robustness and plasticity. It is the existence of 'multifold' objects able to switch between various internal organizations. This degeneracy property (in the terminology of Edelman, 1989) is modeled by the *Multiplicity Principle* (MP): 2 patterns may have the same colimit though their components are not directly linked. If a category satisfies the MP, so do its successive complexifications. As the laws of quantum physics imply that MP is satisfied in the category of atoms, it extends to all natural systems obtained by successive complexification of (sub-categories) of it; in particular higher cognitive or 'mental' processes emerge from physical states of the brain, thus supporting an *emergentist monism* (in the sense of Mario Bunge, 1979).

3. *Semantics, AC, consciousness*: Higher animals are able not only to store representations of particular perceptions, behaviors or events, but also to classify them through the detection of specific classes of invariance. This classification (described through the limit operation) gives rise to a *semantic memory*. It allows for the development, from birth on, of a part of the memory, the *Archetypal Core* (AC), in which the most important experiences of different modalities (perceptual, motor, affective,…) are integrated, strongly interconnected and can be self-activated along specific *fans* (which equip the AC with a Grothendieck topology). The AC forms the basis of the self and allows for the development of *consciousness* characterized as the formation of extended landscapes in which time can be internalized and retro- and prospection processes realized.

This model for cognition uses category theory rather than differential equations or dynamic systems as most usual models do. This is justified by the particular status of category theory which offers a framework for a "mathematical structuralism" reflecting the mathematician's processes. In fact, our model shows that the main categorical operations mirror the capacities of our mind determined by evolution: (i) description of a category = analysis of a class of objects and their interrelations; (ii) colimit = recognition of patterns of coordinated objects; (iii) complexification = formation and learning of more and more complex objects; (iv) universal problems = search for optimal solutions as does evolution.