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Analysis of complex events in Memory Evolutive Systems

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Extended Abstract

Though any phenomenon (in Pierce's sense) can be called an 'event', the usual meaning is rather a noteworthy occurrence; but 'noteworthy' depends on the context where it is observed: in which system? through which viewpoint and timescale?

Complex event processing is generally studied in a social system (e.g., a large enterprise, a society, a nation, …), a biological system (a cell, an organism,…) or a cognitive system. Such a system is evolutionary, with a tangled hierarchy of components of various complexity levels, self-organized thanks to a multiplicity of mutually entailed functional regulatory subsystems, each operating at its own rhythm; an event corresponds to a sudden detection of an expected or unexpected change of state, either by one of them or by an external observer.

Here we analyze complex events in the frame of our theory of Memory Evolutive Systems (MES) developed for modeling this kind of systems, and based on a 'dynamic' category theory integrating multiple temporalities (cf. our book EV, 2007).

1. *Structure of the system*

First we need to make sense of the structure and dynamics of the system, which will be illustrated by the example of a large business enterprise.

(i) *Configuration of the system around a time t*

It is modeled by a category H_t. Recall that a category is an oriented (multi-)graph with an internal 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 more simply a *link*). The objects of the category represent the state at t of the components of the system existing at this date, the links the interactions between them around t. A link operates with a propagation delay and more or less strength, depending on the available energy resources.

The components are distributed in several complexity levels, organized in a 'tangled' hierarchy in which an object A of level n+1 binds together and functionally represents at least one pattern Q of linked components of levels $\leq n$ (mathematically: it is the colimit of Q, cf. Section 3).

For an enterprise, the objects of H_t correspond to the (states at t) of the members of staff, the more and more complex services or departments they form; and also the resources and material necessary for the activities. The links represent channels through which information or material can be transmitted.

(ii) *Change of state*

The change of states from t to $t' > t$ is modeled by a '*transition*' functor from a subcategory of H_t to $H_{t'}$. If a component A existing at t still exists at t', the transition associates to A its new state at t'.

Thus a component of the system is modeled by a maximal sequence of objects of the categories H_t connected by the transitions (representing its successive states). The transitions verify a transitivity condition, and the family of categories H_i (indexed by the timescale of the system) and the transition functors between them form what we have called a *Hierarchical Evolutive System* (EV 1987). The *stability span* of a component of level *n* +1 is the longest period during which it persists and admits a lower order decomposition which maintains its working conditions.

While a transition preserves some components, it may also lead to events of the following kinds: addition of new components, formation (or preservation, if it exists) of a component binding some given pattern of linked components, suppression or decomposition of some components (cf. the 4 "archetypal changes" of Thom, 1988: birth, fusion, death, scission). These changes are modeled by the *complexification* process with respect to a procedure having objectives of these kinds, and the complexification can be explicitly constructed (EV 1987).

For an enterprise, such events correspond for instance to the hiring of new employees, the formation of a higher service regrouping some lower ones, departure of an employee…. The stability span of a complex component, say a service, is related to the period during which it persists with little turnover (same employees realizing the same function).

(iii) *Self-organization*

The system has a multi-scale self-organization. Its dynamic (reflected by the transitions) depends on the cooperative and/or competitive interactions between a net of mutually entailed specialized functional subsystems called *CoRegulators*. Each CR has its own complexity level, some admissible procedures in relation with its function, and its own discrete timescale possibly changing in time; this timescale is extracted from the continuous timescale of the system which allows coordinating the whole system.

The CRs can take profit of previous events and experiences thanks to the development of an evolutionary subsystem, the Memory, whose components flexibly record the knowledge of the system of any kind: past noteworthy events and experiences, behaviors and procedures, internal states…. Each CR has a differential access to this memory, in particular to retrieve the admissible procedures characterizing its function.

In an enterprise, the CRs correspond to various services and departments modulating the dynamic, their rhythm varying from one day for workshops to some years at the manager level. The constantly revised memory collects the knowledge necessary for a correct functioning (different procedures, production strategies, values, past experiences, supplies on hand, ...), as well as past important events and archives of any nature.

2. *Dynamic of the system and associated events*

The dynamic of the system is modulated by the interactions between the dynamics imprinted by the various CRs, each operating independently as a hybrid system at its own rhythm.

(i) *Dynamic of a particular coregulator*

Each CR operates stepwise. A step extends between two successive instants *t* and *t*+*d* of its discrete timescale, and it is divided in 3 phases: 1. Analysis: formation of the CR *landscape* (modeled by a category) L_t at *t* which gathers the partial incoming or remembered information. 2. Decision: choice on L_t, of an admissible procedure Pr with the help of the memory. 3. Command: the objectives of Pr are sent to effectors to be executed.

The command phase extends during the continuous duration of the present step; its dynamic is generally described by differential equations implicating the propagation delays and strengths of the links, and it should move the dynamic of the landscape toward an attractor. The result is evaluated at the beginning of the next step (by comparing the new landscape L_{t+d} with the anticipated landscape modelled by the complexification of L_t with respect to Pr). If the anticipated result is not reached, we say that there is a *fracture* for the CR.

For example, in an enterprise the step of a given service is divided into a phase of analysis and preparation, leading to the formation of the current landscape; a phase of design and decision, where a strategy is chosen; and a command phase, for the execution followed by its evaluation; in a secretariat: looking for newly delivered mail, sorting the letters by order of urging and answering the most important ones; at the next step, the results of the strategy are evaluated. There will be a fracture if some pressing chores have not been realized.

(ii) *Main events at the root of fractures*

Ubiquitous events may cause errors in the receiving of information, and the selection or carrying out of commands. Particularly important are those arising from the competition with other CRs. Indeed, at a given time, the procedures of the various CRs are selected on their own landscapes, but the commands are executed by effectors operating on the system itself. To avoid fractures, these commands should fit together, that is not always the case, for instance when two CRs need a same non-shareable resource (e.g. 2 services of an enterprise simultaneously need the same repairman). The global procedure actually carried out on the system comes from an equilibration process between their different procedures, called the *interplay among the* CRs, possibly by-passing the procedures of some of them and causing fractures.

In particular each CR has *structural temporal constraint*s due to the temporal and material constraints imposed by the propagation delays of the inks and the stability spans of the components. At each step they are expressed by the inequalities

$$p << d << z$$

where p is the CR *time-lag* (= mean propagation delay of the links in the landscape), d is its *period* (= mean duration of the step, possibly changing over time), and z is the minimum stability span of the intervening components. They must be respected for a step beginning at t to be achieved in time.

Whence the following events may cause a fracture for the CR, or even prematurely interrupt the step:

= increase of the time lag so that information is not received in due time, or no admissible procedure is found, or the commands of the procedure cannot be sent in time;

= decrease of the stability spans: the information is no more valid, the landscape is unreliable, or the procedure cannot be executed by lack of adequate effectors.

3. *Complex event processing in MES satisfying the Multiplicity Principle*

In systems able to develop processes of higher complexity (such as higher cognitive processes up to consciousness for cognitive systems), there occur complex events, generated by an accumulation of lower level events implicating several CRs and only observable by an external observer with a global view of the system, or perhaps by some higher 'intentional' CRs. We have proved that such systems are characterized by a kind of degeneracy property (in the sense of Edelman, 1989) which we call the *multiplicity principle* (EV 1996, 2007).

(i) *The Multiplicity Principle, key to higher complexity*

We have said that a component A of level n+1 admits at least one decomposition into a pattern Q of level < n+1 which it binds. Let us say more explicitly what it means. A *pattern* Q is a family of components Q_i with some distinguished links between them. A *collective link* (c_k) from Q to A is a family of links c_i from Q_i to A commuting with the distinguished links of Q. A binds Q (or is its *colimit)* if there is such a (c_i) through which any collective link (g_k) from Q to C factors. Then A has *ramifications* down to level 0, obtained by taking first a lower level decomposition Q of A, then a lower level decomposition of each Q_i, and so on down to level 0. We define the *complexity order* of A as the length of its shortest ramification (it is ≤ n+1).

If A and C bind respectively patterns Q and P, a (Q, P)-*simple link,* called an *n-simple link* if Q and P are contained in the levels ≤ n, is a link from A to C which binds a *cluster* G of links between components of Q and P well correlated by the distinguished links of Q and P. An n-simple link represents a cluster as an entity, thus just reflects properties of the lower components of A and C. A composite of n-simple links binding adjacent clusters is n-simple.

Besides the n-simple links, there may exist other links which emerge at level n+1. However for that the system must satisfy the following

Multiplicity Principle (MP): There are objects C, called *n-multiform*, which bind 2 patterns Q and P of levels ≤ n though the identity of C is not (Q, P)-simple.

This property is ubiquitous in living systems. Roughly it means that there are patterns Q and P which are functionally equivalent (since they have the same binding) though they are not connected by a cluster. It implies the existence of *n-complex links* from A to A' obtained by composing n-simple links binding non-adjacent clusters; their emergence constitutes a complex event at the level n+1 since they do not depend 'locally' on lower level links between components of A and A', but rely on the global structure of the levels ≤ n.

(ii) *Main consequences of the MP*

We have proved (EV 1996, 2007) the following.

Complexity Theorem. The MP characterizes the systems in which there are components of complexity order > 1: if it is not satisfied any component is 'reducible' to level 0 in only one step, meaning it binds a pattern contained in level 0 ('pure reductionism'). Moreover it extends to a complexification, so that it allows for the emergence over time of an intertwined hierarchy of components of increasing complexity order.

We have shown (EV 2007) how the MP makes possible complex systemic events such as:

= Development of a *semantic memory* in which components of the memory are classified into intransitivity classes called *concepts*, with possible shifts between instances of a same concept.

= Development over time of a subsystem of the memory, the *Archetypal Core* AC, which consists of well connected integrated key components, recalling the most significant complex events experienced by the system; their constant recall make their links stronger and faster, so that they autonomously propagate and maintain their activation. AC acts as a flexible internal model of the main characteristics of the system, maintaining its identity.

(ii) *Role of the MP in the generation of complex events*

Switches between un-connected ramifications of a complex object and shifts among instances of a concept are complex events which give more freedom degrees to the dynamic, in particular to the interplay among the CRs. Indeed, the interplay results from a dynamic modulation between the various procedures selected by the CRs, to comply with the external and internal constraints (physical laws, energy requirements, temporal structural constraints, and so on), and can be compared to a kind of Darwinian selection, with its unforeseen complex events. Now the commands of a procedure lead to the unfolding of any one of the ramifications of their effectors, so that the possibility of complex switches give more possibilities for finding a compromise between conflicting commands. In presence of a semantic memory, there is added plasticity coming from shifts from a command to other instances of the same concept, which allow recalling the instance the most adapted to the context.

The development of an archetypal core triggers still more complex events at various levels. Indeed, an arousing event for a higher CR is propagated to part of AC, either automatically or as the result of procedures chosen by lower CRs after a more detailed analysis of the present situation. Due to the properties of AC, this activation diffuses through archetypal links, is autonomously sustained for an extended period, and spreads to other parts of the system through processes of shifting among instances of concepts and switching among the ramifications of these instances,

(iii) *Cascade of complex events*

A fracture for a CR may remain unknown to another CR; in particular we may have 'epistemological events' coming from the uncovering by the CR of some features up to now not observable in its landscape though already existing in the system and possibly observable by some other CRs. For example a more efficient instrument allows observing some new details which could not be observed before, though nothing is changed for the system itself.

However an accumulation of small events for a coregulator CR may later trigger some events, possibly a fracture, for another CR. This is the case if we consider two 'heterogeneous' CRs, say a 'mini' CR with a short period, and a 'macro' CR of higher complexity and much longer period. Small changes at the mini-level are not observed in real time in the landscape of the macro CR (because of the propagation delays), but a succession of such events can later cause a fracture for the macro CR (for instance if they progressively suppress components which play a part in its landscape or its procedure). Now the repair of this fracture by the macro CR may backfire to the mini CR by imposing constraints and cause a fracture to it. We speak of a *dialectics between heterogeneous CRs*.

For instance in an enterprise if some goods are not delivered to a lower level workshop, it can be unable to send in time the product it produces (say nuts) to a higher level assembly line. A short delay in the workshop will be easily made up, However if the situation cannot be remedied before the users have exhausted their reserves, the fracture is reflected to other units which will have to slow or even stop their production, so that commands are not satisfied. If the lack of nuts persists or recurs often, the intervention of higher CRs (personnel department, or management), may decide to reorganize the enterprise, e.g. by automation with concurrent reduction of the workforce.

When a fracture for a CR represents a small enough event, it can be easily repaired at the next step. Otherwise if it persists for several steps or even blocks the action of the CR, we speak of a *dyschrony* for the CR. It is a temporal event observable by CRs with much longer timescales; its repair may necessitate a higher level intervention, imposing a *re-synchronization* (i.e. change of period) of the CR. This process may backfire to CRs of increasing levels, leading to a *cascade of re-synchronizations*. We have developed a Theory of Aging for an organism based on such a cascade of re-synchronizations of CRs of higher and higher levels (EV 1993, 2007).

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