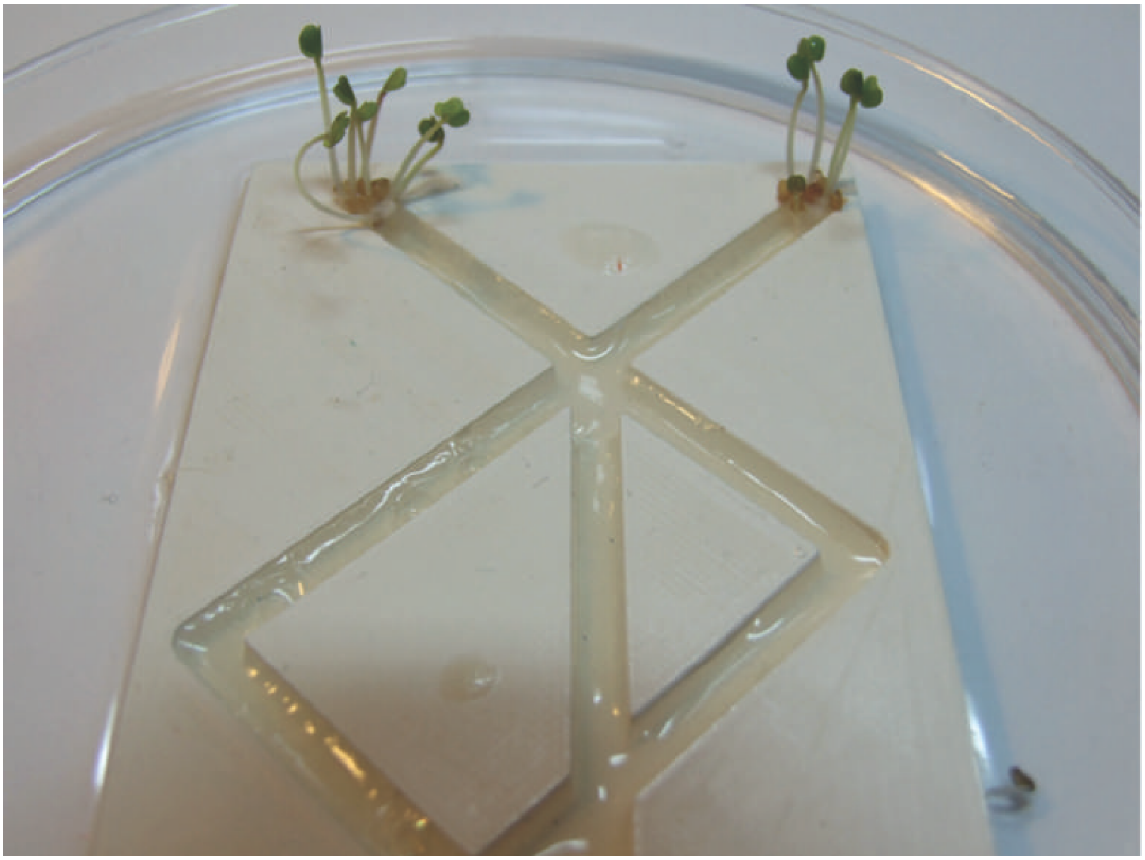

Fig. 3. Experimental setup of plant root collision-based gate. Details are in note 12.

Memory Evolutive Systems and their Applications

Andrée Ehresmann, Jean-Paul Vanbremeersch, Mathias Béjean

Biological, neuro-cognitive, or social systems are evolutionary multi-scale, multi-agent, multi-temporality systems, able to adapt to changing conditions through learning. The Memory Evolutive Systems (MES), introduced by A. C. Ehresmann and J.-P. Vanbremeersch,[1] give a methodology for studying such "living" systems and the problems of dynamical hierarchy, emergence and cognition they raise. MES interweave 2 domains of mathematics: 1) Category Theory[2] to introduce the structure of an evolutive hierarchical system developing a plastic Memory with emergent properties; 2) Dynamical systems to study the local dynamics of a network of "co-regulators", each with its own rhythm. For length limitation, we give MES' main characteristics in an intuitive way. More details are given in the book[3] and papers on the site.[4] For illustrating figures, see the slides of [5].

Hierarchical Evolutive Systems

The configuration of the system at time t.

Following Ludwig Bertalanffy, a system S consists of interacting components. In a living system both the components and the links through which they can interact vary in time, with addition or suppression of some of them. The *configuration of S* at a time t consists of the states at t of components and links between them existing at t. This configuration has a *compositional hierarchy* (or "scale hierarchy").[6] It means that the components are distributed into a finite number of *complexity levels* (say, from 0 to m), verifying the condition: a component C of level n+1 admits at least one internal decomposition into a pattern P of interacting components P_i of levels ≤ n which C "aggregates" and subsumes, meaning that C alone has the same operational role that the P_i acting collectively while respecting the constraints due to their interactions in P.

In MES, the configuration of S at t is represented by a category K_t which has for objects the states of the components existing at t, and for morphisms the links between them. A *pattern* is represented by a diagram P in K_t; to say that C aggregates P means that C is the *colimit*[7] of P.[8]

Multiplicity Principle.

In the hierarchy, C has at least one *ramification* down to level 0 obtained by taking a lower level decomposition P of C, then such a decomposition of each P_i and so on down to level 0 patterns (Cf. note 5 slide 8). The *order of complexity* of C is the smallest length of a ramification of C; it is less than or equal to the level of C.

Reductionism would mean that the complexity order of C is always 0 (at level 0) or 1. In living systems the "degeneracy property"[9] avoids it: there are components C, said to be *multifaceted,* which have several lower level decompositions into structurally non-isomorphic patterns (think to polysemous concepts). In MES, we call *Multiplicity Principle* (MP) the existence of such objects which are colimit of several structurally non-isomorphic lower level patterns.

MP implies the existence of 2 kinds of links: (i) if C is colimit of P and C′ colimit of P′, a (P, P′)-*simple link* from C to C′ binds a cluster of links between components P_i of P and P'_j of C′; (ii) a *complex link* is obtained as the composite of a path of simple links binding non-adjacent clusters.[10]

The transitions.

The components and links of the system S vary over time, with possible loss or addition of such elements. The change of configuration from t to t′ > t is measured by the *transition* from t to t′ which is defined on the components and links at t which still exist at t′, and then maps their state at t on their new state at t′.

In a MES, this transition is modelled by a "partial" transition functor from K_t to $K_{t'}$. The whole system is modelled by a *Hierarchical Evolutive System*, defined as the data of an interval J of the reals corresponding to the life of S and a functor from the category defining the order on J to the category of partial functors.

A component of S is identified to the family of its successive states, modelled by a maximal family of objects of the K_t related by transitions.[11]

Complexification process. Emergence. Memory

In a MES, the transitions are generated by *complexification processes* which, given a configuration K_t and a selection on it of components to suppress and patterns to aggregate (by adding a colimit) describe the new configuration after these operations have been effected (Complexification Theorem).[12] A main result is:

Emergence Theorem[13]

MP implies that successive complexification processes can lead to the emergence of multifaceted components of strictly increasing complexity orders.

Over time, the hierarchy of a MES will gain higher complexity levels: "it is open at the top".

The Emergence Theorem explains the development of a hierarchical subsystem forming a *Memory* of the system; it develops over time by successive complexifications to store ever more complex multifaceted records of new items and experiences. As the "recall" of a multifaceted record can be obtained by activation of any of its ramifications, the memory is flexible and allows adaptation to changing conditions. For complex cognitive systems, this development can lead to deep learning.

The local dynamics of the co-regulators and the global dynamics

For a physical system, its state at time t is represented by some numerical (“observables”) attributes and its dynamics consists in studying their variation in an appropriate phase-space. This does not extend to living systems, where: “the phase space itself changes persistently.”[14]

In MES, the state of a component still depends on various numerical attributes (e.g. its activity); idem for a link which has for attributes its *propagation delay* and its *strength* and can be *active* or not at a time t. However, these attributes will only intervene in “local” phase-spaces related to one step of a specific co-regulator.

The co-regulators and their local dynamics.
A living system S is a multi-agent system: its dynamics is not centrally directed, but depends on the interactions between the local dynamics of a heterarchical network[15] of specialized subsystems, called *co-regulators*. Each co-regulator CR acts stepwise as a *hybrid dynamical system*[16] with its own rhythm, function and partial perspective on the system.

One step of CR, from t to t′, is divided in 3 phases:

(i) ***Observation***: Formation of the *landscape of* CR at t which gathers the partial information on the system obtained by CR through the links activating at least one component of CR during the step. In a MES, it is represented by an evolutive system with such links for components.[17]
(ii) ***Decision***: selection of an admissible procedure Pr thanks to the memory.
(iii) ***Action***: The realization of Pr can lead to a dynamical system in a local phase-space in terms of attributes of components and links. The results are evaluated at t′ and memorized. There is a “fracture” for CR if the objectives are not achieved.

Global dynamics.
At a given time, the local dynamics of the different co-regulators (which operate with different rhythms) enter in competition and can be conflicting. Whence the need of an “interplay” among them, with risk of fracture for some CRs.
A main cause of fracture is the non-respect of the temporal structural constraints of a CR.[18] If the fracture cannot be repaired soon enough, it becomes a *dyschrony*, which may lead to a long-term *desynchronization* of the CR. Fractures and dyschronies can propagate between CRs of different complexity levels and rhythms.

Conclusion and some Applications of MES

The MES methodology allows studying the problems of dynamical hierarchy, emergence and cognition in “living” systems. It has been applied in different domains:

(i) ***Biology***: MES give a methodology to study Integral Biomathics,[19] Aging theory,[20] Immune systems;[21]
(ii) ***Cognition***: MENS[22] gives an integrative model of the neuro-cognitive system, leading to the emergence of higher cognitive processes up to consciousness, with application to Creativity[23] and Neuro-phenomenology;[24]
(iii) ***Collective Intelligence and Design (D-MES***);[25]
(iv) ***Anticipation and Future Studies (FL-MES)***.[26]

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Entretien sur l’entropie, le vivant et la technique 1

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BS. Giuseppe Longo, Francis Bailly et toi avancez le concept d’anti-entropie pour le distinguer du concept de néguentropie, tout en conservant celui-ci. Wiener utilisait lui aussi l’expression « anti-entropique ». Qu’est-ce que cela t’inspire ?

MM. Wiener ne parle pas exactement d’anti-entropie, il parle de *processus* anti-entropiques. J’entends cela comme des processus qui luttent contre l’augmentation d’entropie dans un système. Ceci diffère du geste théorique consistant à poser une anti-entropie comme une quantité « positive », en quelque sorte.

BS. Je comprends cela, et ça m’intéresse d’autant plus d’avoir ton point de vue sur l’histoire de ces notions d’entropie, de néguentropie et d’anti-entropie. Si ces questions sont en rapport avec un travail auquel je m’essaye en ce moment, je me les pose depuis beaucoup plus longtemps. Il y a trente ans, quand j’étais à l’université de Compiègne, je m’y suis intéressé en les mettant en relation avec une critique des sciences dites « cognitives », et plus généralement du comportementalisme en découlant. Mais je ne connaissais pas alors le concept d’anti-entropie, jusqu’à ce que je lise le texte de Bailly et Longo[3]. Sans avoir jamais abandonné le sujet, je me tenais en réserve sur ces questions. J’avais le sentiment, comme beaucoup de nos collègues, que l’on en venait à dire un peu n’importe quoi, hormis peut-être les thermodynamiciens. Mais eux s’en tenaient à la thermodynamique.

MM. Eux aussi se disputaient beaucoup, et continuent de le faire. Ce que l’on accepte en thermodynamique, c’est que l’entropie est bien définie par l’équilibre thermodynamique. Les physiciens, gens subtils, parlent de changement d’un système étant en permanence à l’équilibre. Ils regardent des changements dits quasi-statiques où l’on passe d’une situation d’équilibre à une autre de manière infiniment lente. Le second aspect du cadre théorique qui le rend véritablement utile : on peut faire un