

# Can Neural Networks reprogram themselves holistically by detecting the emergence of invariant comportments in learning algorithms by means of their own observation ?

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**Abstract:** Neural networks (NNs) are inspired – at least metaphorically – from biological solutions nature selected by evolution. On one hand, learning algorithms' efficacy has been widely demonstrated experimentally, even if the mathematical proof of their convergence is not always very easy to establish (SOM). On the other hand, biological mechanisms like brain wiring or embryology remain partly understood and how life or the bases of consciousness are related to the underlying biological substrate remains a total mystery. The same goes for memory. We don't really know how information is stored in and recovered from biological neural structures. We therein paradoxically use complex systems, the hard core of which we still don't always fully understand, both regarding the models we build, as well as their former roots in the leaving world. In this theoretical paper, we resort to a few biological encoding schemata that bring insights into neural structures' growth, plasticity and reorganization, and we suggest reconsidering the metaphor in an adaptive developmental view.

**Keywords:** Learning, memory, plasticity and adaptation, Self-Organizing Maps, stem cells, meiosis growth, entelechy, Darwinian evolution.

## I. TOWARDS A WHOLE DYNAMIC SYSTEM

This paper concentrates on the theoretical groundings of an approach of how to achieve a more general conception of learning and training methodology, detached from specialized NN models. Our main research concern is to model and simulate the dynamic character of learning structures and processes, and their evolution in the time course.

Only theoretical aspects of cumulative learning, emergent evolution, developmental structures, self-organization and the links with cellular growth we have considered to design the mechanisms of developmental learning in our system are discussed here.

In this section, we briefly set the stage we have reached with regard to our global project. In the following of the paper, we first specify the philosophical and related biological trends we subscribe to in order to draw our general scientific affiliation frame. We therein bring out the fundamental principles that, in our view, broadly characterize the development of biological encoding structures.

From this standpoint, in further consideration to the experimental literature, we try to derive some essential underlying processes and how they intimately entangle in space and time to develop (build and maintain) the structural bases of automatic cumulative learning.

### A. Learning

Among unsupervised NN models, the pioneer algorithms that are ART, SOM and NeoCognitron have now given rise to many variations around their former models. We consider the diversity of applicative and experimental contexts as similar to a selective pressure of the environment that generates a dynamic adaptation of the algorithms. Perhaps the most striking phenomenon is an obvious tendency to hybridization between models.

We resort to the evolution of natural — and mostly biological — systems, to set out to elaborate automatic and incremental knowledge acquisition strategies. In turn, we try to apply them to the NNs. We regard the primitive extractors as dynamically adaptive artificial self-organizing structures, which are submitted to the power of evolution. We examine the possibility to confront NN models to themselves. We use their own observation to lead them to learn, by themselves, the relation between their own configuration parameters and the appropriate structuring for a given problem. This way we try to endow NNs with the ability to extract and self-learn the characteristics of their own evolution in response to environmental variations. We call our system SOH, for self-observing heuristic [25]. Our main assumption is that a dual event-guided growing competitive NN architecture can develop while learning to tune other NNs' parameters. Data driven programming combined with error measures create a self-supervision loop. The system can thus regularly test its efficiency and revert to learning mode when necessary.

The learning algorithm's skeleton has been described in details in previous reports and papers, see [26]. It is related to the SOM model and to more general map models that are able to develop their structure in time. It is currently undergoing implementation and tests. Results will appear in later reports.

We have chosen SOM because it gathers many of the

elementary characteristics we review here after. The underlying biological metaphor is a cortical projection map. The similarity space is a dynamic pattern of connections based on activation states of the nodes, where intra-category similarities are amplified and inter-category similarities are attenuated. Hereafter, we will assume that SOM is known. We will just briefly focus on a few key properties of the model, and refer to [17] and [18] for an entire description.

### B. Data acquisition

Besides this work, we devised a method to classify linguistic patterns extracted from documents into syntactic and semantic classes. It is an incremental text-based process flow founded on the distributional hypothesis from the Prague linguistic school. Training data are exclusively the distributional frequencies of character strings, as they represent grammatical items in texts, without any pre-specified rules. The output is a conventional SOM topology, *i.e.* an ordered bi-dimensional decomposition of the similarity relations found between grammatical items. A detailed description of the system, its theoretical foundations and results for the French language have been presented in [5], [6], [27], [28].

Further developments will attempt to gather both systems to realize a whole dynamic system from data acquisition to permanent learning and investigate its portability to other, alphabetically organized, languages. We are currently considering Greek and Arabic.

## II. DEVELOPMENTAL ADAPTATION

In light of the former current initiated by Piagetian constructivism and the principles of equilibration and adaptation in change, we will here get closer to F. Varela's **concept** of enactment [36] [37] as productive action, to G. Edelman's neural group theory, and to universal Darwinism.

Complex adaptive behaviors are frequently observed in nature. Systems that exhibit such organizational behavior range from particles, cells, organs, organisms, immune systems, central nervous systems (CNS), societies, to galaxies, etc. In those systems, adaptability emerges from nonlinear spatio-temporal interactions among a large number of elementary components<sup>1</sup> or clusters of components assembled in subsystems. To be able to acquire complex behaviors, systems must be open systems. That is to say, components must have temporal interactions with their environment and internalize a more or less elaborated trace of these interactions. As a consequence, the internalization process actively redraws — spatially — the structure of the system in such a way that the new system becomes the system itself. The system's response thereby performs an environmentally driven self-reorganization, down to the unit level.

### A. Darwinian evolution

To achieve this, the efficient solution nature has elaborated is evolution. Natural selection is the motor. It guides evolution and acts as a *sort* that makes the structure emerge. Its origin is set in its environment. “*It is natural selection itself that enters inside the organism*” ([19], p. 63). DNA is the diversity random generator.

Investigating NNs variations in the light of Darwinian evolution leads to consider learning algorithms as open relational entities more than independent entities. From then on, learning becomes an active transmitter between open systems, agents, units or individuals, depending on the point of view we have. The process is active in the sense that it doesn't only store information inside a predefined *innate* structure, but it also permanently reorganizes the structure under relational constraints.

Constraints are of two kinds. The first is internal to the system and refers to the spatial arrangement of its structure. That is to say how each unit relates to the others. The second type concerns the temporal organization of the system (how it keeps the history of its confrontation with the universe it *perceives*).

The result is somewhat different from a sequence of chronologically ordered events. It is rather a kind of motif matching where, as in music, the last event creates, triggers a sense, which brings in light the whole set of related anterior and current events. The organization is not mechanistic. Cause doesn't necessarily chronologically precede effect. Positive retroaction loops can amplify the cause by re-injecting the effect into the process *i.e.* create an autocatalytic reaction. The system's evolution is thus not reversible in time. Moreover, it presents an extreme sensitivity to initial conditions. Rather close initial states can lead to very different trajectories of the system. It follows that we must consider these systems from a dynamic point of view, *i.e.* study their evolution in the course of time.

This implies reconsidering NNs' dynamics at every organization level. These range from units to models, including learning rules and heuristic choices made in implementations and configuration parameters.

### B. Self-organization

Natural systems displaying elaborated structures are not limited to the organic world. Inorganic matter too presents global organization states that exhibit proprieties, either qualitatively different from those seen at the local level, or even new proprieties absent at the local level. Typical examples of non-biological self-organization are, among many others, the Belousov Zhabotinsky reaction, Benard's convection cells, galaxies formation [23], [24], [31]. Similar self-organizing processes exist nevertheless in the biological world. Epileptic fits and heart fibrillation are self-organizing reactions.

Self-organization shows the characteristic emergence of a spatial order, made of whirls and spirals. The appearing

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<sup>1</sup> We will hereafter **equally** use the terms units, nodes neurons or cells to refer to either natural or artificial elementary constituents of systems.

order also has a specific temporal organization that is different, both from the system-environment interactions and from the physicochemical interactions between constituents, here particles or cells. Those processes have a fundamental structural identity together with the flexibility and fluctuations of adaptation mechanisms. Those structures spontaneously develop. More over, they are persistent, resilient, self-propagating and self-replicative, for a while, after which they vanish. An attenuated replica generally follows them. They present oscillations in a cyclic evolution that reveals the presence of a three states of transition process (active, inactive, quiescent), which is the signature of self-organization. Their principles remain structurally stable, almost irreversible, and reproducible as universal attraction rules. The process is not chaotic because the principle includes reproducibility of causes and effects.

Self-organization is a crucial property of certain ordering mechanisms, which don't seem initiated by natural selection, but rather spontaneously present in the universe. This implies either to reject the Neo-Darwinian dogma according to which genes are the support of evolution or to resort to the early universal Darwinism. In this later case, increases of complexity come from chance encounter between structurally stable phenomena that belong to different levels of evolution. Self-organization and natural selection combine together. They cooperate to intensify evolution's efficacy. Adaptation thus provides a means to take self-organizing opportunities acting as attractors, to drive random variation towards efficient forms of organization. This avoids the needle in a haystack problem and enables natural selection to run across the hills and valleys of a varied landscape to find basins of attractors, where it is easy to fall. Indeed, self-organizing processes are not very brittle. Their wide range of diversity, their spontaneous arising, the structured emergence of their organization states, as well as the broad spectrum of the initial conditions for their triggering, seem to indicate that attraction basins constitute wide and numerous areas in the state space.

#### C. Neural Darwinism

In G. Edelman's Neural Darwinism theory, brain itself creates perception. It self-organizes on the basis of experience, *i.e.* the history and context of its own development. Monozygotic twins have the same genes, but not the same mind. Neurons are continuously submitted to selective pressure. The strength of the connections that represent the most appropriately the external world are reinforced. Neuron clusters interact. They permanently re-combine to map the world in the strength of their links. CNS generates its own rules and categories. Recollection doesn't exist. Imaginary productions are reconstructed by generalization. Brain develops by a Darwinian selection process that takes place at the neuron groups' level instead of the individual neuron. The basic organizational entity is the cortical map. Maps are linked either with captors or with other maps.

The Neural Darwinism theory relies on Searle's theory of perception categories formation [34]. The functioning of

the brain strictly relates to physics and biology. The matter-consciousness duality doesn't exist. Consciousness is an ordinary biological state. The relation between mental states and the underlying processes is not a causal factual chronology between distinct elements. It is the instantiation of a feature of the system that comes into being from a resonance between sensations and a mental state. Mental states are singularities, specific to the individual who feels them. Sensations, albeit supported by objective processes, quantifiable physically and chemically, are singular specific qualitative mental states.

#### D. Emergent evolution

Emergent evolution generalizes this standpoint. Mind and brain are simply two different ways to consider a unique entity. Learning is the adaptive process. Sense is a match of patterns and therefore a unique realization. Mental states are processes found in the brain of *higher* vertebrates. These processes emerge from the elementary components of the brain. The link between mind and brain is simply the set of relational interactions between different subsystems in the brain [36]. Life, consciousness as well as other properties just appeared in an unpredictable way through rearrangements of pre-existing entities. The slow and gradual derive of a structuring variability generalizes evolution as applicable to many — not to say every — domain(s) and at various levels. The system enters in a productive action of itself.

### III. INTERNALIZATION PROCESS

Besides environmental pressure, there is obviously a social dimension in learning. A world involving a single entity seems highly unlikely to occur. Knowledge transmission leads to cultural evolution. The transmission process implies a double being, a relation to otherness. Groups of entities, or clusters at the cell level, tend to gather when they share a sufficient amount of features in a common space of similarity. Clustering is a dynamic process by means of which the structure permanently reorganizes in order for the new system to become the system itself. Clustering can be seen as more or less similar to the Darwinian reproduction-based speciation in terms of constituting cooperative / competitive groups of entities. The crucial point to favor clustering (or classification) is the diffusion process, which is the passage from local to global of characteristic features in the similarity space.

#### A. Holistic realization

Novelty always reveals a global increase of the milieu wherever it occurs, not only to push back the frontiers of our understanding, following a preconceived plan, but unpredictably, bringing the proof of an immanent creation, that overwhelms any outside specification [4].

Adaptive behaviors are not simply reducible to the sum of — or the difference between — individual comportments. They involve something more that can't be reached by means of some reverse engineering techniques, something that arises more than results, a temporary concomitance that triggers the matching of a transitory representation

with the current global state of the system. The transitory representation is — in G. Cottrell's [9] denomination — a *holon*, *i.e.* an intricate combination of a *percept* and a process into a holistic realization. The key point is that evolution has progressively integrated the internalization process to itself. The acquisition process is learned as well. It has become part of the structure to the extent that perception is in fact expected on the basis of past learning.

Most of the actual learning algorithms exclusively model the acquisition aspect of learning. They skip the transmission part, as they provide no means to pass on what is learnt. Learning is a dual process. It interacts between both directions of a continuum. It is made of two opposite but complementary processes. To our knowledge, only Fuzzy ARTMAP [7] and the DHP [20] implement a similar kind of interaction, but it remains more in the spirit of a control of the acquisition process instead of an active transmission of knowledge.

### B. Novelty detection

Novel salient features trigger the acquisition process. According to H. Bergson [4], newness is another kind of order relying on the ability of mind to see things in a new light. Mind creates sense from temporally and actively gathered contents. Disorder, or chaos, doesn't come before (precede) reality. It is just the way we figure out what we don't know or understand. It is also, and more than anything, what change emanates from, a movement towards novelty and creation. Newness, as opposed to the static difference between order and disorder, is a dynamic differential process between two orders, or between two opposite tendencies towards two orders. It is a dual process between disorder and novelty regarding mind, and in the living world, two opposite processes that either build up a form by adapting the organic matter and thereby follow a creative impetus by means of those spatial transformations themselves [39].

Novelty enhances species' survival somehow, such as by favoring courtship behaviors and mating. The imitation process may have been selected by evolution to quickly compensate for individual loss of appeal when faced with innovative behavior.

Between wild animals, the transmission of innovative behaviors that brings selective advantage for reproduction or feeding has frequently been observed. Such a case is learning through imitation. Male whales in Australia change their songs every five years. The innovative song generalizes to the whole colony in the two following years. It is also well known that some kinds of more cultural or convenient habits, which don't seem at first sight related to selective pressure, can as well quickly spread over a population like fashion effects do. Macaque monkeys still wash their sweet potatoes at Koshima beach in Japan, since Imo, a young female, did in 1953. In this case, imitation seems to have the leading role in the process. The learner is not taught or trained at all. It actively enters the process to take possession of what appears to be new or different. The saliency of a sensory stimulus of discontinuous abrupt nature is suddenly perceived as contrasting with a con-

tinuous undifferentiated background.

What is true with sophisticated individuals in more or less elaborated species is also true at the cell level. In vitro culture of chicken embryonic heart cells have been shown to tune their beating frequency when submitted to repetitive electric shocks. Progressively, they adopt a new intermediate frequency halfway between their initial one and the frequency of the applied electric shocks.

### C. retroaction loops

There are two varieties of retroaction loops. They can be positive or negative. Negative retroaction is a weakening mechanism, while positive retroaction is an amplifying one. A retroaction process settles a feedback from the environment to the system, which thereby controls its action on the environment. Dynamic regulation results from the strength of the mutual interactions between components and tends to equilibrium.

Data driven programming and error measures constitute self-supervision loops. Unsupervised learning is driven by events that are significant enough to generate an evolution change in their adaptation to the data distribution. An error — or cost — function brings this information back. Global error accounts for convergence quality. For some algorithms, the global error (statistical methods, MLP, etc) is efficient. In SOM, neighborhood dynamic is the key in the encoding process of the topological ordering. A more sophisticated measure must then be drawn to account for local error. Local error reflects the topological ordering quality and thereby representational conflicts. Conflicts point out where the environmental pressure accumulates activity, as a consequence of an insufficient resolution of the representation zones.

Various levels of retroaction loops provide recursivity to the structuring process. To the main loop correspond temporal scales that characterize interactions between units, between units clusters and between the system and its environment. In implementations, to each of those loops, correspond a process that the programmer translates in terms of heuristic choices. The extern loop environment-system is represented by a measure of convergence. The inter-structures (clusters) loop correspond to local error. It is coded by methods of insertion-suppression of the units. The intra structure loop (between units) brings context states in terms of activation.

### D. Different time scales

Different separate and independent levels of evolution combine into a unique structuring process. To those levels, correspond feedback loops that provide recursivity to the process. To the main loops correspond temporal scales that characterize interactions between units, between units clusters and between the system and its environment. At an upper level, rules that govern these mechanisms also evolve on and by themselves. Learning thus appears as a dual process, which includes memorization and forgetting, and that unfolds at various time scales.

The system can thus exhibit a comportment by means of which certain features, which have existed before, but disappeared a long time ago can suddenly reappear after a quiescence time that can last over very long periods.

An example is brought by phylogenetic evolution. The chicken would have had teeth and lost them 80 million years ago when birds differentiated from dinosaurs. In a recent experiment on mutations in chicken [14], this feature, which had disappeared with phylogenetic evolution, reappeared. Chick embryos with teeth were obtained.

#### IV. EMERGENCE VS. SYMBOLIC APPROACH

Albeit still fiercely discussed, the notion of holistic emergence allows to account for structures arising, transformation, and vanishing, in a wide range of domains. Be it a convenient transitory working hypothesis, only designed to draw the line from where we leave aside our lack of knowledge when faced to complexity, we will make the assumption that there exists an ascending encoding scheme and further concentrate on the review of a couple of questions inherent to this view.

Resultant phenomena are accessible analytically. Conversely, emergent ones are not merely understandable from the study of their elementary constituents. Morgan [29] considers evolution, from inorganic matter to man, as a reorganization of the relations between entities into more and more complex structures. Progressively, structures interlink to become more and more intricate into higher organization levels (electrons, atoms, molecules, cells, organs, organisms). Each step being characterized by new properties which in turn constrain events in the inferior levels.

To specify our position, regarding the top down approach, we will refer to I. Prigogine [32] who doesn't reject reductionism as such, but points out its limitations. In essence, for him, reductionism can be efficient in relatively simple situations, but quickly becomes ineffective as soon as the number of factors to consider is important. If we consider a few organization steps ranking from molecules, neurons, neural networks, brain to mental states, nobody could explain the latest based on an analysis of the interactions in the former. The fact remains between two more *closely related* organization levels like neurons and neural networks. Even though the increasing power of medical imagery now permits deeper investigations, to set the matters straight, what we have found so far is complexity at all, and we still must resort to modeling and computing simulation, be it in a complementary full spoon approximation only, to try to figure out how brain's structures assemble and cooperate.

In traditional cognitivist AI, the top down approach is directly related to the obvious requirement to fit logic formalism needs and its claims to universality, namely symbols' sense and form sharing and the innate assumption [2], [36]. Another drawback is that *a priori* specified symbols, rules and therefore representations are not autonomous. In the living world, they can nevertheless gradually vary in time in different ways, and not only in

terms of membership strength as covered by K. Zadeh's fuzzy logic. Rules are everything but static. They change in the course of development [2], [36], [37]. What has always been pertinent until now can become detrimental, either suddenly or progressively. One striking example is graft reject by the immune system. Additionally, emergence constitutes a contradiction for traditional logic. In an organization level, the appearance of new properties, which were neither present nor predictable in lower levels cannot be taken into account. The symbolic computational model is a closed system of rules operating only on the symbols. Moreover, inference rules for symbol's manipulation are applied sequentially. And last but no the least, the interpretation of the symbols is not intrinsic to the system. It is the programmer, as a *deus ex machina*, that makes it.

According to F. Varela, it is the structural coupling history that enacts (makes emerge) a world by means of a network of interconnected elements, capable of structural changes in the course of a non-interrupted history. Symbols, in the conventional sense of the word, are excluded. Significant elements are not the symbols but complex patterns of activity between the multiple elements of the network. Varela just discards the cognitivist axiom according to which cognitive phenomena explication requires a distinct symbolic level. Sense is not enclosed inside symbols. It appears as a function of the global state of the system and remains closely related to the general activities that are recognition and learning.

##### A. *Entelechy*

To our knowledge, everything in the universe is finite in the sense that it has a lifetime. If we want artificial systems to exhibit properties similar to those living beings do, it seems essential that they intrinsically include their own end. In order to endow NNs with an *artificial vital impetus*, nodes must have a restricted life span.

Darwinian selection doesn't favor perfection, but efficacy. Winner take all (WTA) NN models present the advantage of allowing a fitness function at the unit level. Nodes the links of which have less strength can thus easily be eliminated. This reinforces the *survival of the fittest*. A converse mechanism must maintain links' survival. The system can thus remember (strengthen) good relations while forgetting (weakening) bad ones. The three main approaches used to optimize the size of NNs can be summarized as constructive (incremental), reductive (pruning), and evolutionary (mostly genetic algorithms (GA) and their combination with NNs) [38].

In accordance with the general approach developed here, we have chosen a dual process alternating between creation and suppression. Suppression is controlled by the local error (a measure of the topological ordering) among neighboring units. New units are added by a meiosis growth inspired mechanism, which acts at the unit level, as if its memory vector was a phenotype.

##### B. *Meiosis vs. mitosis replication*

Meiosis is an equitable process, by which growth generates diversity. Duplication recombines the genetic material by crossover. The process thereby differentiates resulting daughter cells from the initial ones. Mitosis is only a multiplicative process. New cells are identically alike the original.

In growing models related to the SOM algorithm, the duplication dynamic is generally mitosis inspired. To realize meiosis growth, when we initialize new cell's weights, we insert a trace of the triggering data prototype together with a trace of the features gathered in the relational neighborhood of the cell it splits from. Immediately after, the daughter cell enters the process of migrating towards the most related cells inside the whole system. This is achieved by re-computing the widest neighborhood tree possible.

### C. Stem cells

The three main properties of SCs are their ability to proliferate, to migrate and to differentiate. SCs in human are from prenatal or postnatal origin. Postnatal (adult) SCs are available from the umbilical cord, placental tissues, and most of the corporal tissues. Prenatal SCs are available from embryos (4-7 days) and foetal tissue.

SCs' differentiation potential is wide and progressively restrictive as specialization increases. Possible differentiation ranges from totipotent, pluripotent multipotent, to unipotent. Totipotent SCs can potentially recreate a new complete embryo. They differentiate into any postnatal and extra embryonic tissue. Pluripotent SCs are able to generate most — not to say every — of the tissues in the adult organism. Multipotent SCs can provide several cell types. Unipotent SCs (precursors) can only generate one kind of cell [30]. Areas in the adult CNS of mammalian and human contain pools of quiescent multipotent neural stem cells (NSCs) in reserve [1]. Multipotent NSCs, can differentiate into any kind of cell in the NCS (neurons, astrocytes and oligodendrocytes). Differentiation arises while NSCs migrate to find their target.

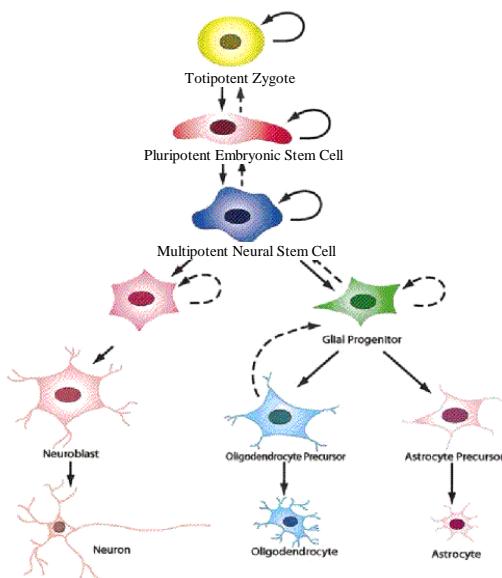


Fig.1 – Stem cells and precursors hierarchy. Reproduced from [1].

Migration constitutes a hierarchical flexible network that includes various multistep possible reversible changes of expression (Fig.1). Cells precursor's progenitors can be *reprogrammed* (reverse broken lines in Fig.1). They may go backwards steps to change their final expression as well as to return to proliferating states (solid and broken circular lines) where they self-renew. They can replace local or distributed targeted neuron clusters. Grafted human NSCs survive in the brain, and take over the function of lost neurons. In [15] modified stem cells<sup>2</sup> naturally migrate *in vivo* across the brain, towards multiple targets, to successfully track and treat areas damaged by tumors with numerous satellites. Precise migration can cover long distance inside the brain, even along nonstereotypical migratory routes. Inflammation, or similar general perturbation mechanisms that characterizes many pathologies, provide pathways for migration and final homing. Final differentiation steps are not reversible and occur according to the specificity of the neighboring cells. Transplantation of NSCs, either from *in vitro* culture or from heterotopic endogenous origin, shows remarkable survival and differentiation into site-specific neurons. Diffusion of molecular recruiting stimuli provides pathways for migration and final homing.

Proliferation of quiescent NSCs is triggered by inflammation [Ref], or similar general perturbation mechanisms, which characterize many pathologies.

Moreover, SCs bypass the species frontier. Successful embryonic NSCs transplants between human and mice or human and monkey demonstrate that NSCs can survive, correctly differentiate from human's to mammal's neurons and incorporate the site-specific brain structure, including gene expression.

### D. innate structure importance

A further aspect that plays a key role is the size and modularity of the initial structure. In neural computing we usually proceed by trials and errors to determine an appropriate size of the network for a given application.

Among inherited brain disorders, a rare genetic disease, the William's syndrome (WS), generates peculiar effects on astonishingly spontaneous savant-like musical abilities of the affected people. Their brain organization seems to indicate that there exists an encoding schema not only relaying on the number of units devoted to one functionality, but also on the ratio between the respective proportions of the various neural clusters which participate in functions encoding and the whole size of the rest of the brain.

WS appears in every population with a prevalence of about 1/25,000 live births. Affected people show serious neurological and neurophysiological developmental troubles associated with a special brain organization [22]. They hardly carry out very simple visuo-spatial coordination tasks (walk, lace up shoes, use knives and forks, ...).

2 Adding a gene that made the cells express TRAIL antitumor molecule.

Spatial organization tests show a selective attention to details, regardless of the whole. Despite a general deficit of spatial and cognitive functions, their linguistic capacities stay partly preserved [3]. They talk easily but their speech, albeit rich semantically, sometimes proves to be absurd.

Surprisingly, WS persons spontaneously exhibit auditory hypersensitivity and uncommon musical skills, very unusual in confirmed musicians (absolute pitch, complex rhythms reproduction, rhythmic dialogues production).

People with absolute pitch memorize sound height while those with relative pitch memorize intervals. Absolute pitch offers the advantage of no reference point needs (diapason). Actually<sup>3</sup>, the European reference is an A at 440 hertz. People with relative pitch identify sounds' height based on this reference. Interval-organized memory is more suited for height variations of the diapason. Any reference change shifts all the notes the same way. In addition, ageing modifies hearing. The reference is less and less accurately perceived. Height-organized music sound perception prevents chords synthetic appreciations or intervals. Both must then be computed.

Anatomically, WS subjects' limbic, frontal and temporal structures remain relatively preserved compared to the mean size observed in non-affected people. The interesting fact is that musicians generally present an oversized region in the temporal lobe. WS affected people's brain is globally undersized by an amount of about 30 %, but the size of the same zone in the temporal lobe is *normal*. The proportion between this zone and the rest of the brain seems to encode their unusual musical skills.

## V. STRUCTURAL PLASTICITY

Brain's developmental plasticity results from a slow gradual iterative process of progressive specialization. It can nevertheless prove to be capable of rapid developmental and experience-based plasticity.

Profusion and diversity of the living species demonstrate the universal plasticity of brain structuring. Change in shape and wiring affects neuronal growth and development, at almost every level in the brain. Reorganization occurs during learning, to establish spatiotemporal correlations between *percepts*, built from sensory origin, and their projections in the brain structures. The process is a real co-evolution between the organism and the milieu it interacts with.

Brain organization and plasticity rely on its capacity to remodel and reconfigure neural wiring. Various underlying mechanisms contribute to reinforce links and structures. Those mechanisms can stimulate dynamic growth of new synapses, create new neurons [21], trigger growth or shrinking and even redeployment of cortical maps. Furthermore, the size of the functional structures, as well as the amount of potentials exchanges reveal architectural constraints of interdependency that play a key role in

encoding.

### A. At the synaptic level

Both the number of units as well as their branching connections is not regular and thus cannot be specified in advance. Specialization leads to a volume increase of the concerned regions.

Long-term potentiation (LTP) is a prolonged increase of the synapses' efficiency due to high frequency stimulations. It has three proprieties: cooperative, associative and is specific to the stimulated junction. LTP results from backward diffusion from the target neuron towards the source neuron. It can change the synapses' form and size and recruit inactive synapses in the neighborhood. It can even trigger the growth of new synapses', insert new receptors or set in motion the genetic machinery to grow new neurons from a population of progenitor cells (see C.) that migrate and differentiate into neurons.

LTP can arise within a few dozens of milliseconds and persist during weeks, or even months [21]. It is learning induced and most of the reorganization arises within the half hour following induction. The mechanism seems to self-regulate to avoid saturation. A converse long-term depression (LTD), acts to compensate for increases of activity. While some synapses are reinforced, others are weakened.

In addition this confirms the existence of retroaction loops at the synapse level. Those proprieties demonstrate Hebb's rule validity, which postulates that synaptic efficiency is adjusted based on coincident pre- and postsynaptic activity. Constraints of interdependency between the converse processes of the LTP/LTD mechanism suggest the plausibility of a redistribution of a finite amount of activity inside the brain. PLT plasticity doesn't seem ageing dependent. Neuro-genesis was confirmed for humans from 57 to 72 years old [12]. Moreover, learning increases new neurons' survival.

### B. At the unit level

As well as being synaptic efficiency dependent, functional change is also determined by the number of active neurons. [40] reports investigation of structural plasticity at the neuron level in the center of memory and learning in fruit flies' brain. This center is located in a small cluster of about 5,000 neurons, and thus allows precise observation. Growth, guidance and branching occur in a sequence of discrete steps under control of three genes (Rac genes), found in the DNA of all species, and that produce proteins (Rac GTPases), with rather identical molecular structure, from fruit flies to humans. Results indicate that cells' steps of development correspond to gradually increasing amounts of protein from relatively small for growth, medium for guidance, and large for proper branching. The sequence of events begins by sending out an axon from neuron, while several dendrites carry impulses back to the neuron. The axon then migrates towards its target, and dendrites undergo extensive growth and branching.

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<sup>3</sup> Historically, until the 19<sup>th</sup> century, each important town in Europe had its own diapason.

### C. At the cortical maps level

The size of the cortical region devoted to functional representations reflects their sensorial importance. Size varies depending on species and evolves among individuals. Cortical areas permanently increase or shrink, depending on system-environment interactions.

Experiments carried out on monkeys show that learning induces very short-term deep reorganization of cortical maps for fingers in the motor cortex. Extensive use of a specific finger (a few hours are enough), cause an increase of its cortical representation area.

### D. At the cortex level

The cortex of higher vertebrates—and especially humans—has evolved as a gradual adaptation of the structure in accordance with function change. Considering the phylogenetic evolution of the central nervous system (CNS) in an inter-species paradigm reveals that structure's modification follows architectural constraints. When new structures appear (neo-cortex), they are not simply added to the previous ones. The whole size of the brain does not change according to the size of the new part. Pre-existing parts, which were devoted to other functions, are also utilized and fed into the new structure. An increase in a zone is correlated to the diminution of other parts of the brain.

A study of brain structures' interdependence during evolution [8] states that the neocortex increase in volume is proportional to the decrease in size of other brain structures (medulla, mesencephalon, diencephalon). The cerebellum, where orientation and balance centers are located in, has a relative volume that accounts for 13 % of the total volume of the brain among the majority of the mammals. It increases in bats and Cetacea. Conversely, the neocortex, that plays a major role in complex cognitive functions, only accounts for 28 % of insectivores' brain against 81 % in primates.

## VI. FUNCTIONAL REDEPLOYMENT

Recent extensive use of imagery techniques like nuclear magnetic resonance (NMR), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) allows deeper exploration of the functional neuroanatomy of cognitive functions. Study of brain reorganization in humans with sensory deprivation, either of congenital or traumatic origin indicates further aspects of adult neuronal plasticity.

### A. Reorganization

Areas corresponding to unused functionalities are recruited to represent other functions **spatially related or not**.

In [33] the occipital cortex of congenitally blind humans activates during verbal-memory tasks. Activation was found in regions along and inside the calcarine sulcus corresponding to the retinotopic visual areas of sighted humans, including the *main* primary visual area (V1). **No**

**such** occipital activation was found in sighted humans. The study concludes that visual areas in the posterior occipital cortex (including V1) of congenitally blind is likely to be involved in episodic retrieval.

Degenerative changes in the neural organization of auditory structures in congenitally deaf adults [11] highlights another aspect of neural structure reorganization. **Degeneration in the central auditory system follows profound hearing loss. Cell size reductions appears in the cochlear nucleus.**

**In case of deprivation from birth, subcortical projections to the primary auditory cortex remain active. Cortical auditory regions continue to receive input from subcortical regions and might not exhibit degeneration. However, functional deficits observed in synaptic activity and organization within auditory cortex suggest the possibility of variation in the structure of auditory cortex as a consequence of congenital deafness.**

Neurons within auditory association cortex may not atrophy because these neurons may come to respond to nonauditory input. Responses to both tactile and visual input have been reported in auditory cortex of congenitally deaf individuals.

### B. Reversibility

**Another characteristic is that once developed and clearly established, should the representational structure become unused, it progressively diminishes in time but not totally. There remains a part from which the representation can be restored.**

**The first transplant of the two forearms in human, allowed a quasi real time access to cortical sensory motor projection maps reorganization [13].** On the Penfield's motor homunculus hands' mapping is spatially close to the face area.

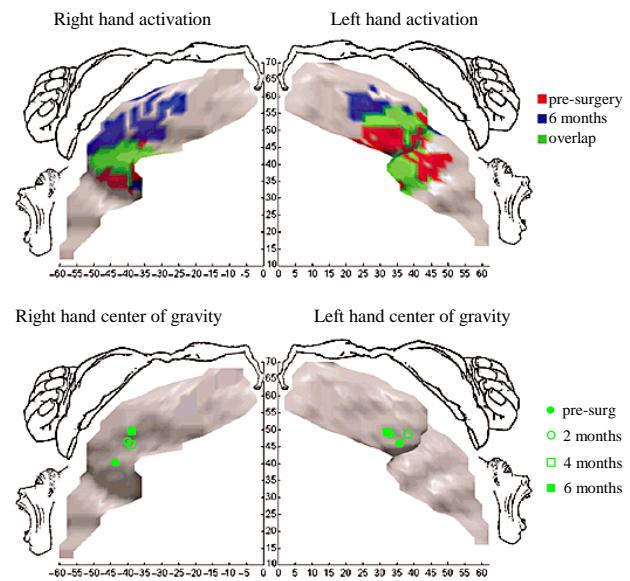


Fig.2 – Hands activation motor cortex and shifts of their center of gravity. Reproduced from [13] by courtesy of A. Sirigu and Nature Neuroscience.

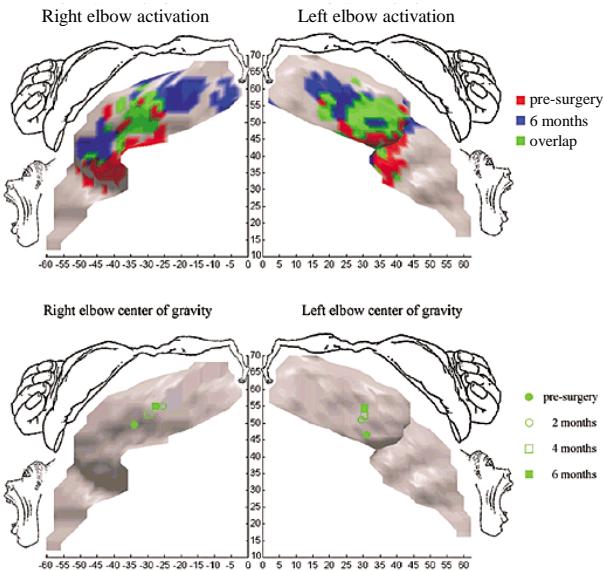


Fig.3 – Elbows activation motor cortex and shifts of their center of gravity. Reproduced from [13] by courtesy of A. Sirigu and *Nature Neuroscience*.

Fig.2 and Fig.3 show the various steps of the hands and elbows projection maps' shrinking between the amputation and the transplant, together with the shifts of their centers of gravity. The re-colonization process clearly appears after transplant. In the interval, the face representation area, which is close to the hands' map, considerably expanded to colonize the unused zones.

## VII. CONCLUDING REMARKS

The retroaction process we consider here doesn't only involve system-system and system-environment regulation control. It is somewhat more sophisticated in that it takes into account dynamic interactions that contribute to enhance the system self-producing capability. It is closer to recursion in the sense of an organizational dynamic interaction, where the output retroacts on its former process to incorporate itself into the originating process it emanates from, to end up as the new former process of the system. As stated in [Deuneubourg : (From [Article deneu sel nat.htm](#))], Natural selection can occur in any group of elements holding three elementary proprieties, which are reproduction, slight variation and a transmission mechanism between the reproduction cycles.

The elementary components of a minimal developmental adaptive system are thus: a random diversity generator, a sort (selection) and a dissipative structure. Retroaction loops relate them. Two opponents processes create the first level competition loop: meiosis growth (reproduction) and cellular death. Four processes, two by two opponents, create an autocatalytic reaction and a dissipative structure at the lower level:

Regarding the aim of our community that is to simulate brain and more generally biological systems functioning by means of AI connectionist techniques, we would like to make a few remarks.

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