Folds and refolds of the matter: a complex of plasticity[1]

Plis et replis de la matière : un complexe de plasticité

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ABSTRACT. Plasticity is a fundamental property of the matter, among which the self-folding or the adaptability reflect some laws inherent to the mechanical behaviour of materials, space-time geometry, biochemical processes or morphogenesis at the interface between developmental biology and physics. Contrarily to elasticity, it does not, however, limits itself to it, dressing a high predictive value of the dynamic behaviour of complex systems, what makes it a founding, and not only an emergent or purely systemic property of the matter and the evolution of living systems. Matter-form complexes from which folds are expressions are then defined as aggregates of bound couples directly acting at the anchor of irreducible dimensions or expressions by including the subject in the plasticity of the world.
KEYWORDS. form, fold, plasticity concept, living systems, brain, plant electrome, morphogenesis, mesology.

I. INTRODUCTION

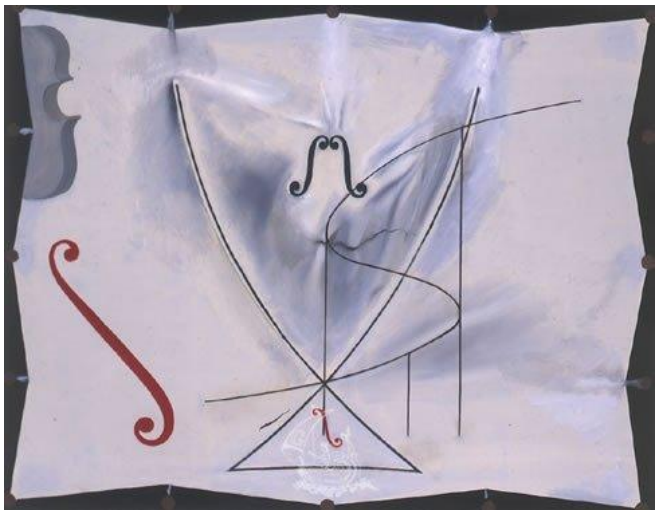

Figure 1. *Dalí i Domènech, Salvador "Queue d'aronde" et violoncelles" (from Disaster series, 1983, Oil on canvas, 73,2 x 92,2 cm. Theater-Museum Dalí Work of art inspired by René Thom's catastrophe theory*

Plastir[2] means distinguishing a shape. Just like biodiversity, epigenetics and cognitive abilities, plasticity describes at the same time a property of a system and its own dynamics, joining the metaphor of the folded code of the DNA, but also at the level of the human brain, that of a space of thought and creativity co-meant by the fundamentally plastic evolutionary dynamics in which it is immersed (Fig. 1), what we define as *a plasticity of thought or of the mind* (Debono, 2012, 2015).

We shall describe here more particularly three terms of this interaction (namely, the epistemic concept of plasticity): i/ the active binding of fundamental pairs (space vs time, formed vs informed,

1. This paper reviewed and widely augmented was presented by the author as a poster at the National School of Decorative Arts of Paris (EnsAD, Paris) during an art-science conference entitled "The fold",Paris, 20-21 September 2016.

2. Plastir is the name of the *Transdisciplinary Review of Human Plasticity* founded and directed by the author since 2005.

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form vs matter), ii/ the action at the anchor point of dimensions or intractable expressions (experience vs consciousness, subject vs object), iii/ the formation of complexes[3] of plasticity (like STP or NMP: space-time or neural-mental couples where P is the plastic process spawning the complexion), to show the prominence of the 3U: Ubiquity, Uniqueness and Universality of this functioning and to wonder about its meaning in term of systems of code, information or representation.

Indeed, the development of the concept of plasticity as a new epistemological paradigm (Debono 1996, 2005) opens new transdisciplinary attitudes opposing to the fragmentation of reality and particularly relevant for art-science relationships[4].

Folds and refolds of brain convolutions including developmental or memory processes can be one of the described examples, as well as tectonic plates or plant morphogenesis and sensibility, in connection with the stimuli of the environment as well as their mesological context (Debono 2019, 2020 : Fig. 2).

Figure 2. *Magritte's Hat (1976)*

Indeed, this dynamic coupling observable at different levels of organization of the matter (landscape, geomorphology, links between living beings and their milieu or between imprint & matrix, ecumene..) is very well described by Berque (2008, 2014) as vector of the principles of mediation and structural moment on the basis of the work of Uexküll (Umwelt) and Watsuji (Fûdosei), but also as a trajective way of expression. I described it as a mesological plasticity at the level of plant perception and plastic interfaces (PIs) where plasticity appears as the only entity able to form operational ternary complexes (Debono 2016, 2018).

II. FOLDS & PLASTICITY

Plasticity derived from the Greek word πλασσευν (put in form) is a fundamental property of the matter that concerns metals, stones, plastic and biomaterials. The pliability or ductility appoints the capacity of a material to deform plastically without breaking (Fig.3). These residual deformations are permanent. Folding and unfolding are not elastic but plastic phenomena.

It means that they imply active or dynamic processes contrarily to passive mechanisms observed in elastic behaviours (the skin for living systems, glasses, ceramic, etc..).

3. Not meaning here a complexification but an aggregation of matter or a complexion.
4. More details on the basic concept and its evolution (including links to current publications) can be found on the website of the Plasticités Sciences Arts association.

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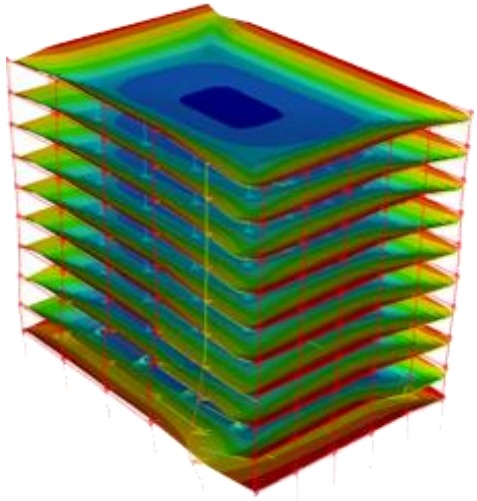

Figure 3. *Earthquake resistance, Sciencedirect*

MECHANICS: Difference between plasticity and elasticity

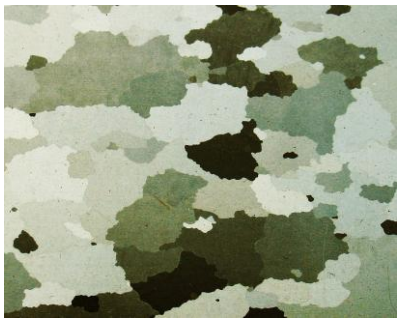

Figure 4. *Grain-oriented electrical steel without coating showing the polycrystalline structure. Image 6.0 x 4.8 cm. © Zureks 2007, Wikipedia*

– Permanent deformation (thermodynamics of irreversible processes).

– Thresholds & ruptures are at elastoplastic structures)

– Non-linear behaviour of solid materials (at the micro- & macroscopic level. ex: polycrystals: Fig. 4)

– Constraints & singularity of constraints (linked to the form & tenacity of materials or structures)

– Dissipation of energy (potential energy, propagation…)

– Not time-dependant

– Dynamic (plasticity) vs passive process (elasticity, ductility, malleability)

GEOLOGY: Fold as a curved structure due to the ductile deformation of the rock

Parts of a fold: hinge (chamela), chest (flanco), crest (cresta). Tensors of deformation can be directed according to a cup of fold, being able to involve shearing or cutting phenomena and several kinds of folds in geology (Fig. 5).

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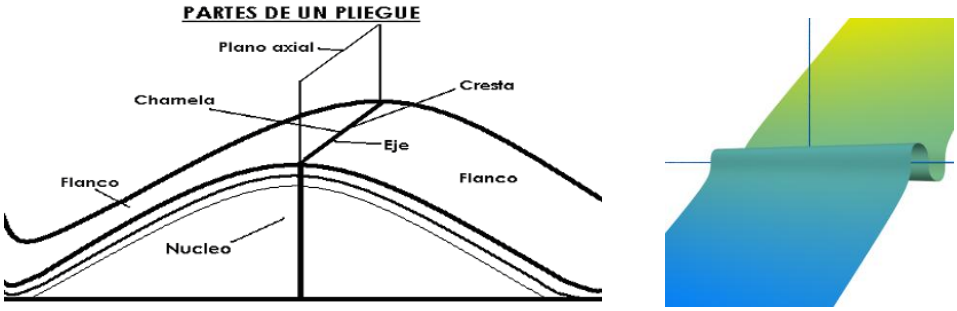

Figure 5. *Left: CC BY-SA 3.0File:Pliegue.PNG Création, 1Jan. 2007. Right: From E. Couturier thesis (see refs).*

BIOLOGY: Plasticity of living systems

The complexity of the folds during morphogenesis and structural development of neuronal structures from animal or human brains, plant leaves or other biological systems in connection with epigenetic processes are well described in the literature.

Plants: Leaf folding, morphology & electrogenesis

The morphogenesis of leaves and of the various plant structures (stem, root, pistil, leaflets, etc.) has long been studied anatomically and histologically. At the morphogenetic level, the leaves are organs specialized in the photosynthesis of vascular plants. They can present a structure in scale, in needles, flat, simple or complex shapes, palmate or pinnate, with or without leaflets and different arrangement on the twig and veins which run through the blade (Fig. 6).

Figure 6. *Left: Skeleton of a leaf with ramifications of its veins L. Ly (Wikimedia Commons) Right: Leaf blade with pinnately venation. J. Sullivan (Wikimedia Commons)*

More generally, it is now experiencing renewed interest in the context of the numerous current studies on the sensibility or communication abilities of plants (Debono, 2020). As previously evoked, the self-organization of living systems results from the occurrence of a form or structure unrelated to a code system or algorithm. According to this theory, SOCs or self-organized critical systems initially described by Bak (1987) concern dissipative structures constantly in the vicinity of a critical state or attractor (for example, the magnitude of earthquakes: Fig. 3), the onset of avalanches, fractal formations, solar flares or biological evolution. They link the frequency and amplitude of a given event according to a power law (scale invariance) and describe well the evolution of non-linear dynamic systems. The amplitude of avalanches is for instance inversely proportional to its frequency.

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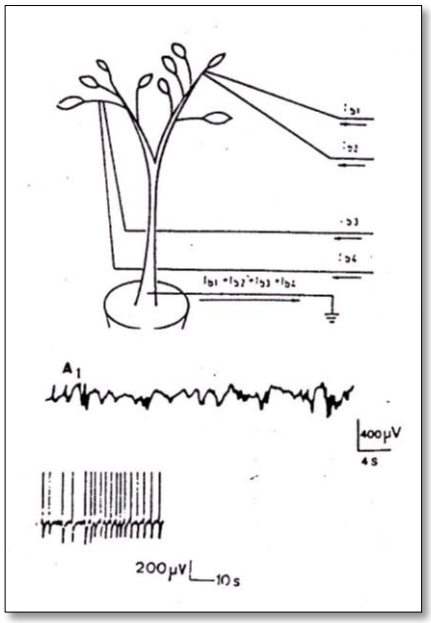

Figure 7. *Spontaneous and evoked low voltage bioelectrical activities recorded in plants by electrophytography (From Debono, Perceptive levels in plants, TJES, Vol. 4, 21-39, Atlas, USA, 2013)*

We recently report that, as classically observed for animal or human EEGs[5], some long-term correlation studies of spontaneous low voltage activities (Fig. 7) called electrophytograms (EPGs) being part of what we call *the plant electrome* in analogy to the genome or the biome (i.e. the overall bioelectrical activity originated from ionic channels and electric fields of a living organism) obey the same laws, namely that they push the electrome towards a relatively stable self-organized critical state due to the permanent stimuli to which the plants are subjected in their natural environment (anchoring to the ground, hypersensitivity to their singular milieu) which can be broken by the occurrence of asynchronous and irregular oscillations showing energy dissipation, multicoloured noises and measurable power density spectra. (Debono et al. 2013, 2019, Saraiva et al. 2017, Souza et al. 2017, 2018).

Brain: folds and refolds during the formation of convolutions

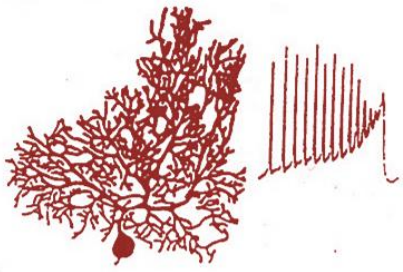

Figure 8a. *Purkinje cell arborescence (cerebellum) & intracellular recording from laboratory data (Crepel et al., 1981).*

The folding of the brain occurs as soon as the 20th week of foetal gestation. The physical process is linked to a mechanical compression (growth of the brain in an intra-cranial restricted space. Unfolding 1-2m2 for a vol. of 1500 cm3 on average), designing the circonvolutive spaces.

5. EEGs (electroencephalograms), the complexity of which is greatly reduced during epileptic seizures or Alzheimer's disease. FIG. 8a shows, unlike macroscopic recordings of the EEG type, a recording carried out at the intracellular scale in an adult PC.

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1/ Folding perturbations could be schizophrenia's markers

Observations at patients with minor neurological signs: "*We observed subtle disturbances of the wrinkling of the cortex*", explains Arnaud Cachia in FuturaSciences. They possess on average folds slightly less marked than the others. "*We deduct that from it there would have been disturbances during the key stages of the development of the brain. The differences seem little marked. But later, the scientists hope that this discovery will allow adapting better the therapeutic strategies by taking into account the individual peculiarities of the patients. One of the next stages will be the identification of the genes of the neurodevelopment which are involved*", they conclude (Fig. 8b).

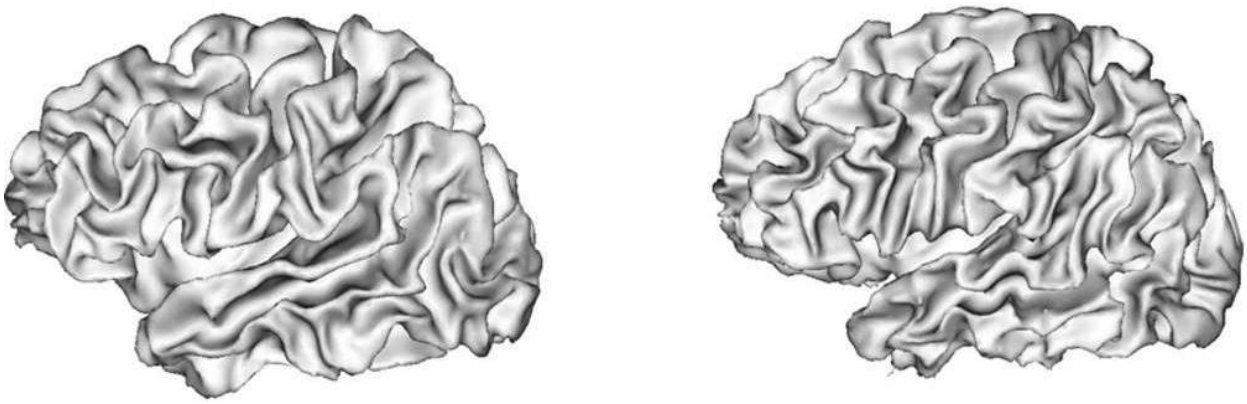

Figure 8b. *Anatomic IRM. 3D Morphology of cortical folding, Left: Folds from a schizophrenic patient with minor neurological signs, Right: The same from another without minor signs © INSERM*

2/ Folds as markers for autism?

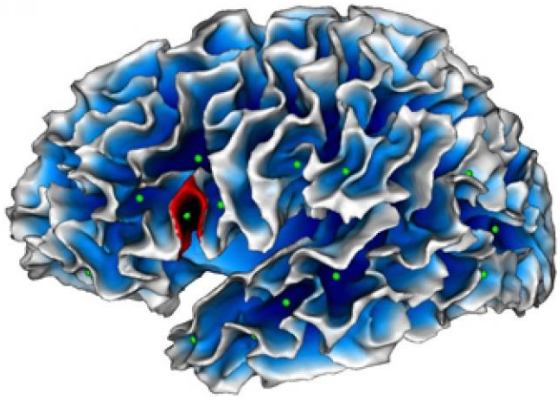

Figure 9. *© SCALP / INT team*

A crease in the brain: anomaly located in the area of Broca, a marker of autism. A mapping of the depth of the cortical furrows shows here this anomaly. In green, sulcal pits (the deepest points of every furrow). In red, localization of the anomaly detected in the area of Broca at the autistic children (Fig. 9).

3/ Mouse vs Human brain folds

One of the working steps of a recent publication on the implantation of a human gene in monkeys in order to increase the size of their brain was to show that under the influence one of the specific human genes ARHGAP11B (Florio et al, 2015), mouse embryos were able to fold their neocortex (which is unfolded in normal mice), thereby confirming the key role of this gene in the expansion of the human neocortex.

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4/ During the foetal period, the brain takes its characteristic form: the cortex complies. It's the same thing at the “small brain”, i.e. the intestine.

Total length of intestines estimated ≈ 6 and 8 m, among which 5 to 7 m for the small intestine. “This one covers to it only an average surface of 250 m^2. The intestinal wall is finely wrinkled. The role of these folds is to increase the contact area with food, so favouring the absorption capacity of nutriments in the blood.” (Fig. 10)

Figure 10. *Small intestine in section from intrascience.com*

PHILOSOPHY: Some contemporary Philosophical or theoretical Concepts about the Fold

Figure 11. *Left: The fold, G. Deleuze by Tom Conley, Right: The folds of Memory, in Plastir, The Transdisciplinary Review of Human Plasticity, Special issue, Nov.2015*

Many contemporary philosophers or thinkers have approached the notion of folds, including Deleuze about the transhistorical concept of the baroque concerning Leibniz and the monadologies (1988) or Malabou about the plastic forms with a post-hegelian posture (1996). More generally, it is the metaphor of the fold, the geometry or the topology of forms (L. Boi, in Debono 2020) and their deployment in the life sciences or art including architecture and the human memory that have questioned man since always (Fig. 11).

III. THE ART OF THE FOLD

Origami, sculpture, design, architecture, so many derivations of the art of the fold which today cover different expressions of the contemporary artistic field. Thus, this literary origami : Crizus’folds books from Bukurama (Fig. 12 on the left), the architectural work of Franck Gehry (Fig.13) who said: “*Human intervention, the brain that turns it into a work of art, is necessary to overcome the identifiable language of software. This is what I think, this is my manifesto"* or again these origami of

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different sizes and sources (in Trebi, 2012, Fig. 14). Art and science intertwine in these polymorphic, trompe-l'oeil or provocative creations which try to lure our brain in the grip of the vertigo of folds, convoluted shapes and mazes in which, like parallel universes, the poetic variations of our perceptions represented on this authentic brain woven of multicolored networks (Fig.15).

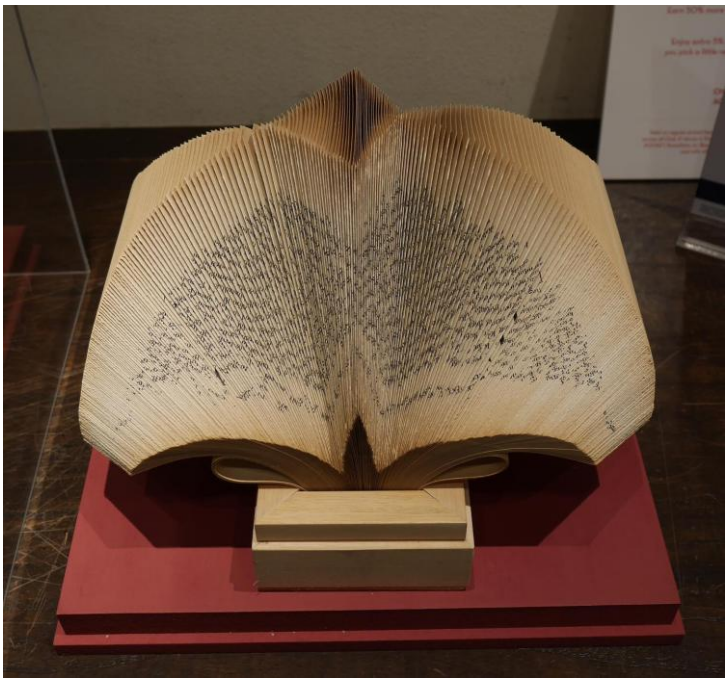

Figure 12. *Crizus'foldes books from Bukurama*

GO BEYOND BORDERS

So many connections to explore that question a now obsolete knowledge that wanted to be peremptory on the relations between poetry and science or art and science. However, research in art today echoes scientific research when it tackles in pairs a problem or a common angle of discovery. Where one experiments in the hard, the reproducible observable, the other interprets the signifier, the hidden face, the alternative and the transversality of the proven scientific fact. However, both work with the matter in the first degree and their meeting by mutual appropriation leads to the development of a work that goes beyond each point of view to find itself in the inherent observation, the aesthetics of the gesture, a scientific reality magnified without being distorted.

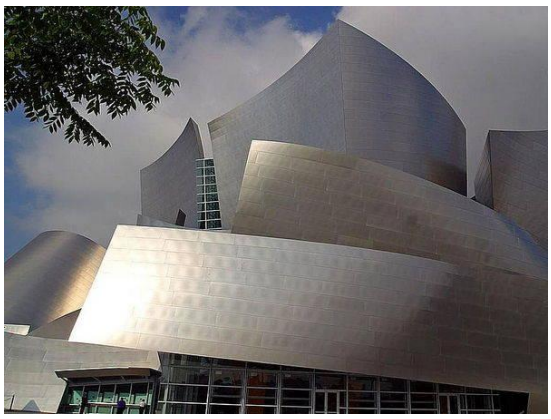

Figure 13. *Frank Gehry : Wall Disney Concert Hall - Los Angeles, by Jon Sullivan, Wikimedia Commons*

This unified reality shows researchers where otherness leads and how this deconstruction leads them to a new vision, new space-time to explore. It's about grabbing the catwalk, to play on liminarities (Oltra, 2020) and to go beyond borders through scores for two or more voices. Actions today favoured

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and supervised by transdisciplinary structures dedicated to the development of art-science relations as the Exoplanète Terre initiative bringing together around ten structures having common concerns around the future of our planet in the Ile-de-France region (IdF) and the transversal arts science networks (TRAS) at the national and European level.

Figure 14. *Different Origami illustration the Trebi's book (2012)*

Figure 15. *Brain Software www.freesurfer.net*

IV. FOLDS & COMPLEXES OF PLASTICITY

As previously evoked, the formation of irreversible plastic interfaces (PI) is the first step conducing to future complexions where plasticity plays the rule of a universal catalyser. Plastic complexes (CPs) are then essential for the construction of dynamic complex systems, particularly the living ones. The plasticogenesis emerging from the epistemic theory of plasticity (Debono, 1996-2012) comes then in three terms:

1/ Natural formation of plastic interfaces (PI)

ARTICULATION / Fundamental couples & bond of irreversible forms

Formed vs unformed

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Form vs matter

Plasm vs Plast

Space vs time

Folded vs unfolded

Determined vs Undetermined…

2/ Action at the anchor point of dimensions or intractable expressions:

ACTIVE LINK / Reciprocity

Innate vs acquired

Experience vs consciousness

Percept vs concept

Subject vs object,

Matter vs mind…

3/ Aggregations or complexion (CP formations)

COMPLEXION / Ternearity, transversal process, trajection

Body-Environment-World (BEW)

Neural-Mental-Plasticity (NMP)

Percept-Affect-Concept (PAC)

Metaplasticity…

Bonding of fundamental PIs & formation of complexes of plasticity (CP) showing the prominence of the 3U (Ubiquity, Uniqueness and Universality) and the 3C (Chiasma or Ontological Crossroad, Complexion, Co-implication) configurations of this functioning and question us about their meaning in term of systems of code, information or representation (Table 1).

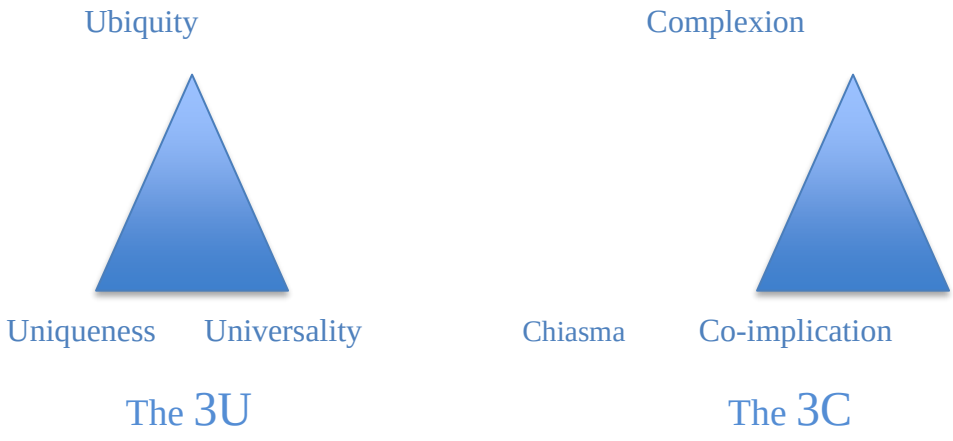

Table 1. *The ternary organization of plastic processes*

Then, following our epistemic point of view:

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i/ any determined plastic or metaplastic system is the fruit of a mutual exchange within the same system: (reciprocity : ascendant-descendant networks, neuroplasticity, epi-, morpho- and ontogenesis) or of interactive systems (plasm-plast, i.e. formed vs forming beings, brain-mind, innate-acquired);

ii/ show that the ternary cycle <interfacing–active binding–complexion > entails a process of co-advenance, co-implication or co-meaning, the outcome of which is always transverse, trajective, ternary (brain-body-world, percept-affect-concept..) and define a plasticogenesis (Table 2, Debono, 2000).

Generic Principle	Articulation	Semiotics	Translation
Fundamental property of the matter-energy	Active Binding Complexion	Co-inherence Co-implication Co-evolution	Noetic Epicentre Active Plasticity of the world
Plastic Interfaces	The Plastic Code of Life	Ontological crossroads	Imaginaries metalanguages Individuation
Universal Processes	Dynamic Processes	Co-signification Processes	Metaplastic processes
Plasticity	Irreversibility	Metaplasticity	Transversality

Table 2. *The plasticogenesis (Debono 2012)*

V. CONCLUSION: the Fold, an uninhibited FORM

The fold takes part among the essential dynamic plastic interfaces acting at the biophysical and/or biosemiotic level, including physical deformation, morphogenesis, information theory and memory processes. As other fundamental processes described by our epistemic concept of plasticity, it plays a rule at the unformed-formed / unfolded-folded interfaces, questioning the emergence of the form and being able to form complexes translating a bound or entangled system, whichever is its level of organization or of observation. This articulation, describing both a system property and its own dynamic and acting directly at the anchoring point of irreducible dimensions or expressions, constitutes the unique property of plasticity and differentiates it from elasticity or malleability which are not dynamic processes.

Our objective will be to bring back this working hypothesis (irreversible complexes of plasticity and a necessary inclusion of the subject in the active plasticity of the world) in the paradigm of the fold with the project to advance the dialogue between fundamental sciences, art and philosophy and to promote an epistemic paradigm regarding more generally what we call “the plasticity of the mind”, i.e. the ability we have as humans to directly convert our brain plasticity into plastic behaviours (metaplastic experiences or co-meaning, brain mind interactions), life attitudes (transdisciplinarity, mesological point of view) or creativity (matter-form PI, aesthetics, art and philosophy of art).

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