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Chapter 10

Mesological Plasticity as a New Model to study Plant Cognition, Interactive Ecosystems and Self-Organized Evolutionary Processes

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Abstract The plasticity of living systems acts at several levels of evolutionary biology including self-organization, phenotypic, phylo-, onto- and epigenetic processes, while mesology is an approach situated in between ecology and phenomenology. After a description of the specific objects of plasticity and mesology as non-dualist studies of the dynamical coupling between beings and their singular milieu, we will develop some arguments regarding the perception-action loop and the sensory flux of informations crossing the evolution of the living, before focusing on recent discoveries about plant electrome. Using for the first time mesological plasticity as a frame to reanalyze the Uexcküll's assertions about Umwelt and meaning-making theories of plants, this chapter shows the leading rule of electronic interfaces in the generation of spontaneous low-voltage variations continuously emitted by plants via electrophytographic or EPG recordings. Used as early markers, EPGs are considered in this framework as natural systems of monitoring and discrimination of environmental stimuli that allow the identification of the electronic signature of a plant-stimulus pair in a given milieu. More generally, we will develop the trajections associated with complex behaviours of plants: a bottom-up transdisciplinary view of co-evolutionary or ecosemiotic processes highlighting their specific sensitive fields and cognitive accesses to experience (their otherness) as well as new phenomenologies about interactive ecosystems and phytosemiotics.

Keywords Plant electrome. Electrophytography. Plasticity concept. Interactive ecosystem. Mesological plasticity. Cognition. Phytosemiotics. Transdisciplinarity

10.1 Introduction

Plant 'intelligent' behaviors (Trewavas 2003) upset today notions rooted in our evolutionary schemata, largely anthropocentric, questioning self-organized knowledge-accumulating and non-linear dynamic evolutionary systems including as main marker bioelectrical correlates of their extensive communication strategies and embodied or extended cognitive abilities compared to neuroplasticity and the rapid sensorimotor coordination of animals. We will show that plants are plastic interfaces that behave as self-organized entities with protoneural abilities leading to active perception systems close to those of animals and non linear dynamic processes which have progressively conducted to the eclosion of complex brain networks during evolution. The sensory and bioelectrical (or electronic) abilities of plants constitute indeed a privileged field of study of the interface between living organisms and the environment (mesology) as well as their non-nervous ways of processing information (Debono 2013a,b, 2019).

After describing the confluence between the two major approaches of plasticity as a "science of forms" and mesology as a "science of environments", we will detail the electrical dimension of plant life (Toledo et al. 2019) and the primordial role that electronic pathways play in communication and rapid diffusion of information in plants. Among these electronic activities, we will focus on the little known and underestimated role of spontaneous extracellular variations or EPGs (electrophytograms)¹ emitted at the level of plant tissues, looking in particular in the mesological approach for the Uexcküllian flaws that led to this positioning. This will lead us to the modeling of a new approach to the relationship between the plant and its milieu (mesological plasticity) and the discovery of specific signatures of the electrome in relation to some stimuli or field experiments that have important implications and repercussions in experimental works in evolutionary biology or plant electrophysiology, but also in botany, agro-ecology, biosemiotics, ecophysiology and cognitive sciences.

We will also explore throughout this chapter to explore new worlds that intersect and co-signify each other and more generally to re-interrogate around this new botanical front of science on the notions of form, intelligence, sensitivity, metamorphosis, cognition or identity. A journey that, we hope, will allow us to take a new look at the otherness of plants and the primordial impact of epigenetic plasticity as well as the

¹ See paragraph 10. 4.2 related to the epistemological context linked to the discovery EPGs in plants.

influence of the milieu differentiated from the environment during evolution. “What a plant knows?” asked Chamowitz (2012) discussing about the sensory system of plants. It is clearly the question. We will see that plants can show complex behaviors, sensibility and minimal cognition (Calvo 2011). At the level of evolutionary biology, the real question regards their specific relationships with the milieu and their interactive ecosystem, their otherness. In such an area, we will show that plants are: 1/ *plastic interfaces* having as main motor the form/matter couple, acting mainly at the level of phenotypic (direct impact on their life cycle and fitness), morphogenetic and epigenetic plasticity; 2/ *electromic interfaces* using bioelectrical networks and non linear dynamic systems as facilitator and discriminative processes to communicate and spread information; 3/ *mesological interfaces* using phytosemiotics and the plante/milieu entity to grow optimally and fit in (Debono and Souza 2019, Debono 2020). Starting from there, we can break out of the zoocentric or neurocentric mold done by many authors and affirm that, if plants use the same directory of cell signalization (ionic channels, bioelectric currents, chemical neurotransmitters...) without brain and neurons (contrarily to the enteric nervous system for instance) and are eukaryotes as us, they don't have the same sensorial and subjective experience at the end. This is because their links or dynamical coupling with the milieu is singular, based on morphisms, meanings, topological situations and *subjectivity* (Berque 2015).

10.2 The Epistemic Concept of Plasticity: Ontology and Complexion

Born from an observable - the brain plasticity - (which is of course not a metaphor), linked to my activities as a researcher in neurobiology, the scope of this universal property of matter that describes also a process, very early on imposed itself on me as fundamental to be explored, both on theoretical and experimental levels. Indeed, the progressive elaboration of the epistemological concept of plasticity was initiated by the publication of “L'ère des plasticiens” (Debono 1996) describing a new evolutionary logic (non-binary and transversal) taking plasticity out of its ruts (until then focalized on visual arts or biological functionality) and opening it up to transversal grids of lecture. At the experimental level, the implementation of transdisciplinary (TD) research groups working around evolutionary processes using mathematical modelization,

biology, cognitive sciences, neuroplasticity, experimental medicine and posturology, biophysics, genetics, paleoanthropology, neurosemantics or art and science relationships, was effective during several years within the framework of the GDP² founded in 1994 in Paris. The success of this enterprise has allowed to gradually mark out the different plastic interfaces and to create a research background on the concept of plasticity and its evolutions, notably through the opening of a new research area on plastic processes and the regular publications of the Transdisciplinary Review of Human Plasticity Plastir³ founded in 2005 which gathers nearly 150 authors around TD themes having plasticity as a junction point, which you can follow on the official website of the PSA (Plasticities Sciences Arts) research group.⁴

As a matter of fact, the term of plasticity from the Greek *plassein* concerns form and matter in the first place. For a long time exclusively attached to aesthetics, fine arts and the humanities, now concerns all scientific fields (plasticity of materials, of the brain, human plasticity...) as well as philosophical ones. It has been sometimes misused due to its ubiquity (Aristotle), man's power of self-transformation (Plato's myth of epimetheus), universality and historicity (from Harvey with his *vis plastica* and Pic de la Mirandole with his « *De dignitate hominis oratio* » (1486) to different scientific traditions (biology, embryology, genetics, morphogenesis, anthropology...) including the works of Wolffe (2000), Driesch (1892), Pigliucci (2003), Haeckel (1904), Woltereck (1909), Johannsen (1911), Thom (1966, 1977), D'Arcy Thomson (1917), the plastic nature of the neoplasticists More (1641) or Cudworth (1820) and the philosophical approaches of Leibniz (*Monads*, 1646-1716)⁵, Goethe (*Plastizität*, 1749-1832), Heidegger (1961, 1982), Kant (1781) and specifically Hegel linking subjectivity, temporality and plasticity in "The phenomenology of mind" (1939-1941).

At the contemporary level, only two concepts are operational today to my knowledge, presenting common points - about plastic dynamics - and divergence - about objects and methodology -: our epistemic and transdisciplinary approach to the concept of plasticity and the Malabou's philosophical positioning linking ontology, temporality and the post-historical future of man. This approach takes us out of passivity by describing an active and sometimes negative (or explosive, plasticizing)

²Groupe des Plasticiens: see the minutes of the GDP Conferences on the PSA website referenced in 4.

³Plastir: the Transdisciplinary Review of Human Plasticity is available on line on the PSA website (see summary and english abstracts) : <http://www.plasticites-sciences-arts.org/plastir/>

⁴PSA Website: <http://www.plasticites-sciences-arts.org>

⁵ Please also look at the more recent reference on Leibniz (2004) and More (1969 & 1987).

plasticity following Deleuze and the deconstructivist post-Hegelian philosophical current (Malabou 1996). We share this dynamic conception of plasticity (to *plastes* vs to *plasma*, ex. sculpture) taking into account the intelligibility of forms and the temporality of the plastic process, provided that we place it in the transdisciplinary context of the third included which allows us to exceed the active-passive or negative-positive antagonist terms (Contradiction logic, Lupasco 1970, 1986) and indicates that we are dealing with a ternary Lupascian process and/or an imprint-matrix mode (Berque 2014a) more than with an emerging property. This is true for developmental and functional plasticity and at the junction between the humanities and the fundamental sciences embodied by a plastic process in progress. The plasticity of the living includes indeed self-organized and dynamic non-linear systems that co-determine or co-signify themselves reciprocally, participating in the genesis of the forms from which they originate and not only undergoing it. The different interfaces and plastic complexes that we will describe more specifically in the plasticogenetic process allow plasticity to seal this movement and to inscribe it in a common ontology (Table 10.1).

The concept of plasticity is then not dualistic and seeks the principles of coherence and defragmentation of knowledge, following a transdisciplinary approach (Debono 2005, 2010, 2012). More generally, plasticity could be assimilated to the science of forms, being neither emergent nor systemic. It is not either purely descriptive but has a raised predictive value of the dynamic behaviour of nonliving systems, being a founding property and not only a systemic or an emergent one. In this direction, regarding advances in systemic plasticity, biophysical science, cognitive neurosciences or ecosystemics, it is necessary to speak of metaplasticity as a way to explore the genesis of natural processes. As explained in a recent paper summarizing the evolution of the epistemic concept of plasticity - from the concept to the complex of plasticity - and then a description of its mesological part (Debono 2021), plasticity is a key notion in any evolutionary process that looks at form and matter in the first place. It concerns all inert or living systems and contrary to elasticity, flexibility or malleability, leads to an irreversibility of the dynamic link established between two interfaces that cannot be reduced to each other (plastic interfaces) and then to the formation of plasticity complexes⁶ of which plasticity is an included third.

⁶From complexation or aggregation (not from complexity). Look at the main plasticity complexes described in Table 2.

As a matter of fact, the specificity of plasticity, apart from its primary function within the matter-form interface, is its irreversibility and ability to active processes of transformation in which the events evolve while co-signifying mutually, in other words are structured as much as structuring, including a reciprocity between ascending and downward systems inside the same system or of interacting systems (e.g. brain/mind or experience/consiousness). This behaviour implies a universal capacity of articulating fundamental pairs such as form vs matter, form vs object or subject, etc. This active binding includes non-linear dynamic systems (like EPGs and electronic interfaces) and obeys a transverse logic by creating irreversible plastic complexes where plasticity is a catalyst. The important point is that plasticity is the third included of the complexes formed (see below) and acts directly at the anchorage point of dimensions or irreducible expressions by including the object or subject in the plasticity of the world. Ontology and complexion are thus two fundamental steps of the plastic process. The following tables summarize the four steps of plasticogenesis, plasticity complexes showing the main plasticity complexes from matter-form-plasticity to brain-mind-world (Tables 10.1 and 10.2).

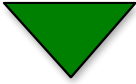
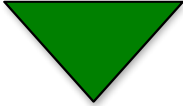
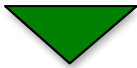

PLASTIC INTERFACES	PLASTICITY COMPLEXES	CO-MEANING PROCESSES	EPISTEMIC PROCESSES
ARTICULATION <i>UNFORMED-FORMED</i> <i>(PLASTID-PLASMA)</i>  MATTER-FORM (MATTER-ENERGY)	ACTIVE BONDING  COMPLEXION (IRREVERSIBILITY)	CO-IMPLICATION CO-CONSTRUCTION  ONTOLOGY SEMIOTICS RECIPROCITY	METAPLASTICITY <i>(PLASTICITY OF THE PLASTICITY)</i>  TERNARY PATHS & COMPLEXES TIERCEITY TETRALEMNA T STATE

Table 10.1: Plasticogenesis - From plastic interfaces to epistemic processes. The unformed-formed step symbolizes the primitive link prefiguring the formation of matter while the matter-form interface is the operational one, which may involve energetic processes. Both interfaces can generate plasma-plastid or structured-structuring relationships, fundamental in morphogenetics or developmental plasticity (Debono 2015). The three main steps of the plasticogenetic process are: 1/ the formation of plastic interfaces (PI), 2/ of active bondings (AB) and 3/ of irreversible plasticity complexes (PC) like BEP-BMP leading to ternary paths conducting to co-meaning metaplastic or epistemic processes (see Table 10.2). © MW Debono

MAIN PLASTICITY COMPLEXES
MFP (MATTER-FORM-PLASTICITY): AUTOPIETIC PLASTICITY, SELF-ORGANIZATION, MATERIALS PLASTICITY (PHYSICS), STRUCTURED-STRUCTURING RELATIONSHIPS, MORPHOGENESIS, COSMOGONIES...
IAP (INNATE-ACQUIRED-PLASTICITY): EVOLUTIONARY BIOLOGY, ONTOGENESIS, PHENOTYPIC, PHILO- AND EPIGENETIC PLASTICITY
BMP (BRAIN-MIND-PLASTICITY): NEUROPLASTICITY, EXPERIENCE-CONSCIOUSNESS RELATIONSHIPS, AFFECT...
SOP (SUBJECT-OBJECT-PLASTICITY): PLASTICITY OF THE LIVING (PL), INTEROBJECTIVITY/SUBJECTIVITY, SOCIOBIOLOGICAL SYSTEMS, ONTOLOGICAL PLASTICITY, ALTERITY, IDENTITY, HUMAN PLASTICITY...
BEP-BMP (BEING-ENVIRONMENT- PLASTICITY, BODY-MIND-PLASTICITY)

Table 10.2: Some of the main plasticity complexes. At the level of vegetal plasticity, the primacy of the form (implying phenotypic as well as epigenetic plasticity) is expressed mainly through plant morphogenesis and the mesological plasticity of the dynamical coupling between plants and their singular milieu (BEP). © MW Debono, 2021.

The plasticity of living systems is more specifically related to our field of study and to the subject we are addressing in this chapter. It is classically defined as a self-organizing and order-generating capacity of living systems and/or a durable deformability of structures. Systemic studies of functional trajectories and variability differentiate rigid systems like robots with functional invariance and flexible or homeostatic systems with structural invariance including systematic variability from plasticity including vicariance and further modifications (Paillard 1976; Debono 2017). Elasticity describes a systemic auto-adaptability to program changes while plasticity assumes the ability of a stable or autostabilised system to be deformed or to deform in a lasting and sensitive way its own structures or sub-structures (synaptic plasticity) and to exceed its own limits (transformation or fine equilibration of thermodynamic couplings or environmental pressures). The plasticity of the function is therefore described as an open system or a systemic unit (Weiss 1941, Jacob's integron) that is specified by its structure, functioning and function (SFF). Only plastic systems can modify this trivalent system.

To summarize: plasticity is opposed to flexibility and systemic stability and an irreversible deformability, capable of surviving its initial causes, distinguishes plasticity from elasticity, flexibility or malleability. It concerns the form as well as the function of living organisms, their sensitivity to the external environment, their structured-structuring relationships of which the phenotypic (Pigliucci 2003, West-Eberhard 2003)

and epigenetic plasticity⁷ are strong anchors. In other words, plasticity is a unique dynamic interface between two sensitive worlds, concerning as much the simplest self-organized systems as cortical representations of the human brain. It includes the capacity of the mature system to reshape its own structure and/or to create new entries in the system: typically motor and somatotopic cards or synaptic and cognitive plasticity leading to structural reshuffling of networks at the cerebral scale (Greenwood and Parasuraman 2010).

The recent rise of the evo-devo approach in laboratories around the world has led to a reevaluation of the effective and dynamic role of plasticity in living organisms, whether it is phenotypic, ontogenetic or phylogenetic, highlighting the major influence of interactions with the environment and the milieu during development. Plasticity has indeed become a major evolutionary concept because it is finally recognized for what it is, an efficient means at the scale of individuals as well as populations to develop innovative adaptive strategies (micro as well as macro-evolutionary) responding to or thwarting the heterogeneous spatiotemporal distribution maps of the environment by optimizing survival as well as the singular relationships between living beings and their environment. More generally, plasticity revolutionizes a part of the history of science by becoming a central concept in evolutionary and humanistic biology.⁸

10.3 The Concept of Mesology: Being, Environment and Trajection

Before focusing on the plant electrome as a privileged interface for the study of this new concept of mesological plasticity, we will present the basis of the contemporary mesological approach and its interest in the study of living systems during evolution. We will adopt here the contemporary scientific approach of the orientalist geographer Berque as to the contemporary definition of mesology, which can be generically described as the science of environments (singular milieu, habitat or immediate environments with which plants and animals directly interact) as opposed to classical environmental sciences. Indeed, this classification was based on the naturalistic foundations of the founder of ethology Jacob von Uexküll about the Umwelt and the

⁷ Related to the historical works from Harvey 1651; Buffon 1749; Waddington 1942, 1957; Lamarck 1815-1822. See bibliography.

⁸The biology of the 20th century in PhasPhen (2017), CNRS Savoie Thematic School, GDR (University of Lyon 1 CNRS (LBBE/ Biometry and Vegetal Biology Laboratory UMR5558)- INRA) .

quasi-contemporary discoveries of the Japanese philosopher Watsuji Tetsurô (1934-1935) who, listening to Heideggerian philosophy (1992), introduced the concept of *fûdosei* 風土性 meaning "the structural moment of human existence" or the dynamic coupling of the being and its environment (Berque 2014b, 2016). This is one of the founding principles of mesology about human or ecoumenal environments (Berque 2000).

The Berquian school or ecologists like Tassin (2020) are more generally opposed to a scientific ecology that considers the environment and biodiversity as socio-economic variables to be adjusted and not the singular and sensible links established directly between living organisms (animals, plants or humans with the notion of *ecumene*) and the milieu. This approach is not limited to niches or to Darwinian adaptation but takes into account the topological, biosemiotic and ontological dimension of these specific links that are independent of the raw and universal data of the environment (*Umgebung*). The milieu is thus regarded as being relative to a subject and conversely, contrary to the dualist or mechanistic considerations of the West. It is what exists concretely for the subject (or a given species: famous example of the tick), whereas the environment is a universal object carried by the glance of an abstract observer. Between the environment and the being concerned expresses itself thus a 'counterpoint' (*Kontrapunkt*) or a 'counter-assemblage' (*Gegengefüge*), which makes that the two terms are inseparable (Berque 2014a,b, 2016).

Mesology can thus be compared to ecophysiology (Souza 2018), a scientific discipline that integrates the behavioral and physiological responses of living organisms in a given environmental context and seeks to understand how populations of different species of living beings constantly face the constraints of their environment during evolution. However, it has an ecophenomenological, semiotic and societal dimension that clearly distinguishes it from classical ecology, a term with which it has historically co-evolved.⁹ Indeed, as already mentioned, the new contributions developed by Berque from the works of Watsuji and Uexküll introduce the concept of trajectory resulting from the landscape trajectory, then resituated as a ternary passage compared to the *Chôra* of Plato - at the same time imprint and matrix - and to the Indian tetralemma: Berque 2014a) and the state of mediance (translation of the dynamic coupling between

⁹ Haeckel published the term *ökologie* in 1866 (*Generelle Morphologie*, Berlin, Reimer Vol. 2, p. 286). See also the recent publication of Levit GS and Hossfeld U (2019) on the subject.

the being and its environment or *fudôsei*). According to the author: "It is the seizure of the *Umgebung* as *Umwelt*"; in other words, it is the "as that" by which the Earth is seized (by the senses, the action, the thought, the word), as a world". This seizure is analogous to a predicate, in which the mesological reality (which is the reality at all for the being considered) can be represented through by the formula: $r = S/P$, where r is the reality, S the logical subject (what it is about, i.e. the Earth or the nature), the oblique or diagonal, the "as that" and P the predicate (what is seized from S , i.e. the world). In other words, concrete reality is neither simply objective (S), nor simply subjective (P); it is trajective (S/P). Several trajective chains like the semiological chains of Barthes or Pierce can be involved (Berque 2019).

10.4 Plant Electrome and Cognition

10.4.1 Behaviors and Signalisation in plants

The cellular communication of plants is as complex as that of animal cells with a directory of similar ion channels although with specific differences such as their intra- and extracellular compositions or the existence of proton pumps (H^+ transport against metabolic gradients and ATPases), several membranes (plasma, vacuolar, pectocellulosic wall) of which the plasmalemma is the most important autoregenerated electrome, transporters and membrane proteins forming several dozens of sensory receptors. Among these, growth hormones like auxin, efficient photoreceptors and the ability to distinguish certain wavelengths, chemoreceptors capable of synthesizing some 3000 molecules or chemical compounds emitted and processed by plants, including methyljasmonate, anti-stress substances or BVOCs (Biogenic Volatile Organic Compounds) allowing remote exchange or defense against attacks from herbivores. In the same way, many sensitive sensors allow a direct interaction with the ecosystem or the environment (insect pollinator, soil moisture, gravitation, electromagnetism, exploration of the chemical composition of the soil, air or space - climbing plants -, mechanosensory receptors, phonotropism - effect on the direction of the roots -, emission and capture of clicks for the purpose of intra and interspecies communication etc... Behaviors involving mobility, memorization and certain forms of learning are also described in many species (*Mimosa Pudica*, Venus flytrap, *Dionea Muscipula*, *Nepenthes*) presenting adapted behaviors and learning capacities according to the

danger of predators (insects, lizards, small mammals, worms) or the search for nitrogen in the soil essential to produce proteins (Wildon et al. 1992; Volkov 2010, 2014; Cheung et al. 2020 for a recent review).

Among the many recent discoveries of plant neurobiology research launched by the school of Florence and Bohn and refocused today around the signaling and behaviors of plants (Baluska and Mancuso 2009; Brenner et al. 2006), we can quote the highlighting of the underground communication carried out by roots allied to mycelia and hyphae forming one of the densest symbiotic networks: the mycorrhiza or the 'wood wide web' (Volkov et al. 2019). This signaling network considerably increases the volume of soil and the active surface of the roots (factor 700) by ensuring a dosed distribution of sugars and water to the plants and their neighbors according to their needs and to the changes of situations (drought, stress, priorities, obstacle circumvention, etc.). It can be thousands of years old in some trees and measure several tens of km². The question of individuality and quasi-immortality of the plant kingdom is also raised at this level, given the plurality of possible genomes of a single tree whose own individuality or its progressive colonization of close organisms is not known. In addition, the efficiency of this high-speed network allows trees to communicate with their congeners, or even with other species, that can present behaviors interpreted as solidary or social (intertwining, defense and prevention strategies; Simard et al. 2012).

These complex modes of plant communication relayed by the interconnected meristems and efficient aerial networks of plants through a body anchored to the ground and required to react permanently to environmental stimuli is one of the findings leading us to rethink the scale of plasticity of living systems. In particular, it raises the question of the divergence of the kingdoms; many works underlining the fact that it is not so clear-cut. This taxonomic re-evaluation of the evolution of plants compared to animals (Selosse 2012),¹⁰ added to the classical observation of inter-species co-evolutionary processes between plants and animal pollinators, deserves to be developed. The crucial role of hormones and neurotransmitter analogues in growth, sensory responses (light, orientation, gravity, oxygen, moisture, inorganic nutrients for roots) or stress in plants, the emission of toxic substances or long-distance volatile gases like

¹⁰ Common evolutionary tree until before the divergence of the kingdoms and introduction to a new classification of eukaryotes (Chlorobiont vs Zoobiont).

ethylene,^{11,12} repair or vascularization of plants are also clear signs of high sensibility (different from the nervous system of animals) and access to immediate experience necessary to optimize their survival and growth.

New scientific approaches of plant behavior, signaling and cognition clearly show since two decades that perception-action loop, cognitive abilities (Calvo 2011, 2016) or intelligent behaviors (Trevawas 2014; Mancuso 2013) are widely developed in plants. These extensive studies including the biomolecular, genetic and epigenetic plan as well as the whole plant behavior show the benefit that plant evolution brings in terms of sensory coding, learning, directed individual variation and adaptability (Calvo et al. 2020). Plant complex behaviors and goal-directed changes are used to face adverse or competitive environments, giving them the best response to adapt and improve their survival. Several mechanisms including competition, regeneration, mutualism, local memory or learning are involved using common electrochemical communication and functions (perception, sensory inputs, hormonal system, growth, reproduction, development, cognition maps described here for niche construction) than animals. They legitimately raise questions about the nature of its emerging behaviors in plants, including terms like intelligence, sentience or cognition.

Perhaps the problem has been posed backwards from the start and we should have seen before the "radical otherness" advocated by Hallé (2014) concerning plants rather than trying to compare animal and plant kingdoms at all costs? Still, without entering into this semantic debate, which has ancient roots with the fundamental pioneering work of Bose on bioelectricity and the nervous mechanism of plants (1901,1902,1926)¹³ or even earlier by von Sachs noting the analogies between the responses of plants and those of animal skeletal muscles (1874, 1898) or by Darwin working on the movements of plants¹⁴ and the self-recognition of Orchids (1864, 1881), the observation is that, apart from some overly anthropo- or neurocentric statements, it has given rise to a wealth of indisputable scientific results ranging from botany to epigenetics and interdisciplinary discoveries updating the remarkable capacities of the plant world in

¹¹Plants dose their responses according to the danger involved: from leaves rendered inappetent to some pests to poison like tannins for their predators.

¹²Wouter Van Hoven, Wildlife Management Centre, Pretoria, South Africa. Famous observation of emission of toxic substances and volatile gas by kudu-killing acacia trees (over-interpreted ? as an ability to warn neighboring trees of danger).

¹³See Bose refs and Tandon et al. 2019 for a recent review of Bose's pioneering work

¹⁴Current research on the root apex confirm Darwin's predictions and are described as synapse-like properties by Baluska et al. (2017)

terms of communication or sensitivity (Baluska's 2006). Many philosophers, engineers, anthropologists or ecologists have also taken up the issue with anthropocentric, metaphysical or ethical overtones.¹⁵

10.4.2 Role of Low-Voltage Spontaneous Variations or Electrophytograms (EPGs) recorded at the Whole Plant Level : Dynamics of the Plant Electrome

The electrome, term introduced by De Loof 2016 in analogy to the biome or the genome represents the totality of the ionic and electric dynamics present at different scales of organization of the plant or the electrical dimension of plant life (de Toledo et al., 2019). Knowing that cell signaling and bioelectricity are two major ways of processing information in plants, we have demonstrated by pioneering works (Debono and Bouteau 1992) that spontaneous microvolted extracellular variations or oscillations called electrophytograms (EPGs) contribute actively to the expression and signature of plant's electrome (Debono 2013a) considered as a self-organized complex with "multicolored" noise summing up all of the ionic repertory and bioelectrical activity of plant tissues (Souza et al. 2017). This non-random bioelectrical activity is analogous in terms of amplitude to EEGs conventionally recorded in animals (mathematical derivative representing the algebraic sum of biomolecular signals associated with polarization-depolarization of cell membranes), but present neither the same temporality, nor the same degree of correlation and complexity.

As a matter of fact, the spontaneous oscillations that I described and named electrophytograms or EPGs in a pioneering way (Debono and Bouteau, 1992) due to their EEG-like chaotic characteristics were for a long time confused with background noise due to their weak voltage and amplitude but also obscured by the researchers themselves due to what has been called the "Backster effect".¹⁶ Today this debate is

¹⁵ Philosophers such as Calvo (2016, 2020), Coccia (2016), Marder (2013), Hall, Hiernaux, Morizot; anthropologists like Kohn (2013) or Descola (2015, 2019), ecologists like Tassin (2020), ethicists like Pouteau (2014, 2018), forest engineers such as Zürcher (2014) or Wohlleben (2013) and also legal approaches about plant law, political status, human-plant relationship or the planthropocene (Marder, Myers, Harraway, Tsing) are widely published. See bibliography for details.

¹⁶ This side-effect was related to the pseudo-scientific experiments of a former CIA agent who interpreted the same kind of bioelectrical traces (weak oscillations recorded with a galvanometer) by lending intentions and feelings to plants, which in the context of the New Age had the echoes that one could expect (mediatized by the worldwide best seller of Tompkins and Bird « *The secret life of plants* » Harper and Row 1973), but above all had the serious consequence of obscuring electrophysiological researches in this area, made outside of us by two or three other teams in the world like that of Pickard in the US (1971), for almost three decades!

totally outdated and validated by several independent teams in the world. The aim is now to understand the exact role played by EPGs in the life of plants with various approaches (modeling, quantification, monitoring in natural environment with multisensors or EPG kits, filtering) searching for patterns or specific signatures of the electronic field related to certain stimuli (Parise et al. 2020, 2021), Debono and Soza 2019) We detail in this chapter several of these approaches and our up to date working hypothesis concerning the precise role of EPGs in the operability of the plant-environment relationship and its cognition modes (see also Debono 2013a, b, 2021).

Contextually, much long-muted plant electrophysiology work is now becoming audible and this new perception of two-way information flows and complex communication strategies in plants points to a radically different perspective on our anthropocentric view of life or otherness (Debono 2018) which goes hand in hand with the need to reconsider taxa as well as the notion of boundaries between living beings. One of the fundamental ways to measure these activities at the cellular and organic level is to proceed to a precise bioelectrical survey of the perception-action loop or of the physiological state of plants. Valuable information on the duration, amplitude, type of conduction, function and localization of signals will provide us in the coming decades with essential clues on the communication capacities of plants. Two anatomical sites are particularly promising at this level: meristems, vascular tissues located at the ends of underground (root) and aerial branches that interconnect with each other and the electrome representing the global electrical activity of the plant organism, which can be collected, in addition to the cellular level, in the form of spontaneous low-voltage (20-200 μ V) variation potentials or EPGs permanently emitted at the level of sets of tissues that can propagate themselves in network at the whole plant level (Debono 2013a, Fig. 10.1). This synchronization of EPG activities between different tissues of the same plant has been validated by Masi et al (2009) with a multi-electrode array recording technique (60 channel MEA) able of quantifying them and following their spatiotemporal course in high resolution in maize roots.

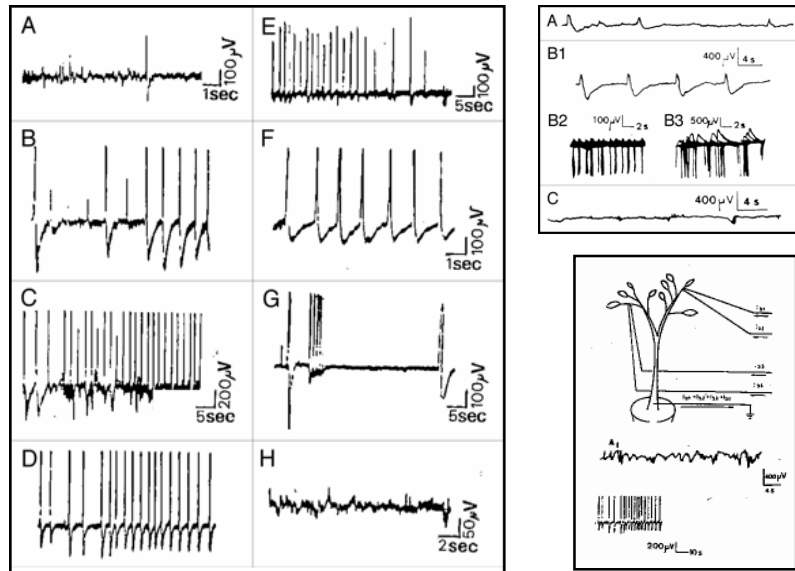


Fig. 10.1: Dynamic protoneural networks in plants: a new approach of spontaneous extracellular potential variations (From M-W Debono, *Plant Signaling and Behavior*, Vol 8, N°6, 2013, © Landes Biosciences). Left plots: Spontaneous low voltage oscillatory activity or electrophytograms (EPGs) and isolated "spikes" recorded in *Kalanchoe Daigremontiana*. (A and H) followed by a train of higher amplitude spikes evoked by a mechanical stimulus (B-G). Right plots: B1-C: Chemical activation (Fusicoccin 3.7 μM) inducing spike-wave discharge for 27 min interrupted by application of a metabolic inhibitor (FCCP 50 μM). Diagram on the bottom right: experimental set-up including both spontaneous and evoked EPGs.

These spontaneous EPG variations were shown interspersed with isolated spikes or sharp oscillations lasting several seconds or minutes after a natural or evoked stimulation (Debono 2013a), evoking a marked reactivity to certain stimuli (Figure 10.1). EPG activities are indeed added to the panoply of classical bioelectrical signals brought into play during the various scenarios physiologically soliciting the plants (Fromm and Lautner 2007, Chen et al. 2016). It is about action potentials or APs triggered by a depolarization of the membrane following ionic flows, variation potentials or VPs specific to plants produced in the xylem and mainly induced by biotic or abiotic mechanical stimuli, injuries or herbivore attacks, systemic potentials or SPs which are hyperpolarized signals (H^+ pump) gradual in nature propagating at long distance (5-10cm/min) in the phloem and local potentials or LPs emitted directly at the stimulated area under the influence of environmental factors (light, temperature, air humidity, water, hormone, pathogen infection...) plus long distance signals using glutamate like Ca^{2+} waves (spiking and oscillations) emitted for plant-defense signaling

(Toyota et al. 2018) following herbivore attacks or mechanical wounding converting local signals to a systemic defence program in the whole plant (Tian et al. 2020).

10.4.3 Signature of the Electrome and Plant Cognition: a new Electronic Reading Grid

More generally, being preponderant in any process engaging perception, reaction or non linear behavior of plants, the electrome dynamics generates a constant electrical activity as a consequence of the movement of electrically charged particles and the emission of electric fields partly due to the electrochemical gradients formed. To this must be added the action of mobile and immobile charges involving polymers or macromolecules, electrogenic pumps or electronic flows in chloroplasts and mitochondria. Propagation of signals at short distance is done via plasmodesmata forming a symplasm and permitting cell to cell or intercellular communication. Propagation of signals at long distance concerning vascular and hydraulic systems like the transport of liquids or sugars (essential energy and photosynthesis) is made bottom-up (Xylem) or top-down (Phloem) with rapid conductivities implying hydric or hormonal signals (auxin), calcium oscillations and chemical mediators (Hedrich 2016).

The EPG chaotic activity was recently attributed by Souza et al. (2017) to a self-organized critical state (SOC) of the whole plant. According to a work to which I am currently contributing, it could correspond to a non-linear dynamic behavior able to manage the permanent influx of stimuli of all kinds that assail the plant (wind, rain, drought, mechanical shocks, predation, etc...) and have a central role in the relational life or cognitive ecology (Real 1993) of plants. The same team recently demonstrated that the EPGs show a distribution according to the power law which is defined by two constants: a (proportionality) and k (exponent) which characterize large systems presenting invariant scales. Under some conditions, they can push them towards a self-organized critical state (SOC) conventionally observed in nonlinear dynamic systems (Souza et al. 2017). Power density spectrum (PSD) and autocorrelation studies respectively show that SOC and nonlinear dynamic behaviors present different patterns and colored noises, depending of the kind of stimulus applied (Mannitol, cold, low light...), corresponding to the previous isolated spikes or evoked potentials in the form of regular oscillations that we had recorded outside spontaneous EPGs (Debono 2013). As previously described, temporal correlations on large scales show also a long distance

treatment of complex information emerging from different temporospatial patterns propagating through all plant tissues (Masi et al. 2009). Other teams like that of Gimenez et al. (2020) have recorded different patterns of bioelectrical oscillatory signals in different *Miconia* species, using learning machine techniques and in non invasive *in loco* recordings, several specific patterns and spectral densities were recorded depending on the species influenced by environmental factors. We therefore assume that EPGs are widely used for the detection and discrimination of the stimuli when dynamic coupling occurs via SOCs, allowing plants to prioritize warning or defense signals and optimize their survival and growth. A constant EPG monitoring of plants will permit to measure this discrimination rate and the management of the environmental stimuli done in real time by plants (water supply during drought, brutal climate changes, interspecies relations, osmotic shock, stress...) in order to ensure their optimal growth (Saraiva et al. 2017, Debono and Souza 2019, Debono 2020, 2021).

Indeed, EPG like signals¹⁷ having been recently validated by several teams in the world like those of Masi et al. (2009) or Cabral et al. (2011), I am now pursuing my research since 2016 in collaboration with the laboratory of plant cognition and electrophysiology (Department of Botany, Institute of Biology, Federal University of Pelotas, Brazil directed by Pr. Souza). This research team has indeed validated and quantified EPG activities in plant tissues analysing the chaotic dynamic of their time series (Pereira et al. 2018). The results obtained also highlighted spikes following a power law only when plants were subjected to specific stimuli such as osmotic stress (Saraiva et al. 2017, Souza et al. 2017). Next experiments will be done in natural environment, assuming that laboratory experiments do not allow having an exhaustive survey of the reactivity and interactivity of plants in their natural ecosystem.¹⁸ As a matter of fact, recordings with EPG kits or multiple sensors in constant monitoring could allow to validate definitively our operational hypothesis and to show synchronization among bioelectrical signals and formation of specific patterns or signatures of the electrome following external stimuli. We hope especially that these *in*

¹⁷Our EPG technique (Debono 2013a, initially published in 1992) must not be confused with a recent technique called electropenetrography or EPG and measuring the electrical penetration graph to study plant-insect interactions. This technique is also used to study plant virus transmission, host plant selection by insects and the feeding process of insects in plant tissues. Lucini and Panizzi (2018) describes for instance experiments with aphids (phytophagous stink bugs or pentatomids) using a simple device for the extracellular recordings at the level of plant tissues (xylem and phloem) that are connected by inserting an electrode into the soil next to the plant. Such recordings are done as soon as the aphid starts plant penetration and allow the registration of EPG waveforms.

¹⁸Work in progress.

loco experiments will confirm our hypothesis about the watch (spontaneous variations) and discriminative role of plant's EPGs responding to environmental stimuli and downstream: 1/ the Uexkül's functional circle as support of meaning-making theory, Umwelt and more generally the value of bio- or phytosemiotics; 2/ the mesological plasticity and 'subjectivity' of plants.

Indeed, our recent publications assimilate plants to plastic electronic interfaces displaying cognitive abilities¹⁹ into interactive ecosystems (Debono and Souza 2019). Several specific signature of the plant electrome using synchronized bioelectric networks of different types of vegetal tissues (phloem, xylem, symplasm) distributed over the whole body of the plant which cells are not separated, were detected highlighting plastic ternary complexes [plant-environment-world] (Table 10.2) and an effective mesological plasticity (Debono, 2020b). This plastic process neither purely phenotypic nor epigenetic was for the first time reported about plants by Debono (2016, 2018) who adapted the concept of plasticity he developed to the trajectory and medial behavior of plant's body anchored to the soil and dynamically coupled to their singular milieu.

As we will develop later, this position allows to attribute to plants a cognitive access to experience whose modes of action will have to be specified (Debono 2020). It can be expressed as the capacity to co-construct and perceive an intelligible world or a sensitive reality activated by the sensory system of plants representing dynamic eco-sensitive interfaces showing communicative, intelligent or resilient strategies. The question of their intelligent behavior is here secondary, because related to all living systems (from bacteria to man) having absolute needs to evolve adequately and survive in their environment; the way to do it being very likely linked to phytosemiotics and plant mesological interfaces (see next sections).

Our experiments have indeed shown, far ahead of current discoveries, that if the nature of bioelectrical events linked to their cellular ionic directory or to local responses is well known, the permanent spontaneous oscillations collected at the level of the whole plant with electrophotographic techniques, actually plays a preponderant role in their sensitive relationship to the natural environment. As previously mentioned, long assimilated to noise due to its low amplitude and the chaotic or EEG-like nature of their signals, EPGs constitute for us, with the whole electrome, a unique facilitating system

¹⁹According to the biological and post-cognitivist acception of this term.

of monitoring, management and discrimination of stimuli allowing plants to make operational choices to survive and grow optimally, i.e. to have a form of sensitive access to experience or cognitive ability without representation, nor the need to use a brain. Collected chronically in their natural environment, it would allow us to draw up the electrical profile of a species, an organism or an individual by reflecting the efficiency and the inseparable character of the direct dynamic coupling taking place between the plant and its environment or Umwelt (mesological plasticity). Moreover, EPGs could constitute valuable early markers of activity in biology or agronomy (diagnostic or monitoring tools, multisensors, EPG kits). We are experimenting in this way. Simmi et al. (2020) also recently showed that infection by pathogens affected the dynamics of the electrome, even when it was located far from the infected site and before these effects were visually detectable.

The electrome signature of a given species or plant thus indicates a cohesive factor and/or unit of behavior observable in their singular environment despite the sessile, modular, and non-individualized nature of the plant system. The electrome signature or response patterns detected in our EPG experiments or in calcium oscillations are also specific signs of reactivity potentially indicating stress-responses, discriminative choices among stimuli or complex behaviours of plants. At the population level, it could concern resilient or 'empathic' strategies. Consequently, it is necessary to adopt a new ecoplastic (and electronic) reading grid of the levels of sensitivity, reactivity and capacities of adaptation to new situations of plants in a constantly changing environment (Debono and Souza 2019, Debono 2021).

10.5 Mesological Plasticity as a New Model to Study Plant Evolutionary Biology

If we consider now the path that led to the development of the epistemological concept of plasticity, it has totally different sources and objects at the beginning from the mesological one, namely it does not have as object the eco-phenomenological study of the world per se, but overlaps it on many points, mainly ontological, epistemic and transdisciplinary. The plasticity of living systems is however one of its main field of research (see section 10.2). It is indeed instructive in this context and for the rest of the discussion to describe how I came to make this connection with mesology. The tree of

causes has two parallel branches indeed: 1/ my discovery of this school of thought while attending the seminar of mesology at the School of Higher Studies in Social Sciences (EHESS Paris) directed by Berque where I was invited to give a lecture in 2016, and then during a Cerisy colloquium dedicated to the mesological paradigm at the time of the anthropocene (Debono 2017, 2018); 2/ my work in plant electrophysiology questioning the sensitivity of plants and their close link with the milieu while they are rooted in the soil and permanently subjected to environmental stimuli. However, it was the first time that these two concepts (plasticity and mesology) met, and it quickly became apparent that in Uexcküll's precursory work, the place of the plant world had not been studied at all. Only a few allusions to it are made in his great work. We will come back to this in the next sections because we can interpret these elements differently today.

In any case, there are two excellent reasons to study this question further, which is directly related to the subject of this book on the self-organization of living beings during evolution. Indeed, the body-medium-world ternarity is impacted at several scales during evolutionary processes whether they concern phylogenesis, ontogenesis or epigenesis. This concerns as much the development of populations and/or acquired characters as the scale of the individual. However, the mesological part is situated between the micro and macro-evolutionary scale since it refers to a non-dual process of imprinting-matrix and being-environment totally linked to interactive ecosystems and biotopes common to species. It implies therefore, just like the fundamental plasticity of the matter-form, co-constructive mechanisms and bijective Nature-Culture Relations. If we integrate the subject as a predicate and the “as that” as properly trajective, we end up with an operational conjunction: the mesological plasticity.

10.5.1 Plasticity as the “As That” or the Third Included of the Mesological Formulation

The principle raised by Berque in the form of a digression following my work highlighting the potential complementarity of the two concepts and the rule of perception-action loops in plants (Debono 2016) opened up perspectives at the global level on the study of beings-subjects immersed in a given environment, but also, and this is above all what I would like to explain for the first time in the context of this work, on the specific field of plant behavior and cognition. The aim was to describe a

cognitive ethology that differs in form and function according to species, and not to confuse intelligent behaviors or post-cognitivist definitions that can apply to plants, particularly in the observation of mechanisms related to extended or embodied cognition (Debono 2020, 2021) with the notions of animal sentience and cognitive representations or human introspective consciousness. At this level, the preponderant emotional part must lead us to question at another level: the qualifiers or typologies proper to the universal intelligence of the living and the specificity of human or animal feelings (Damasio, 2021). In any cases, an interaction prevails at this stage, whether it is represented or not in a brain, it is that of the immediate presence of the subject included in its singular milieu, the mediance of the dynamical couple formed at this level, and by that, of the operating forms of life which result from it: a meso-logic of the place and of the interaction with the third part or ternarity common to all forms of life.

The concept of mesological plasticity (Debono, 2016, 2018, 2020b, 2021) is then a recent evolution resulting from the combination of my work about the epistemological concept of plasticity developed since the 1990st and that of Berque (EHESS, Paris France) concerning mesology (2014, 2016). It starts from the observation that plasticity is indeed the meeting of two worlds: the world of forms and the world of meanings, which co-signifies the reality that we inhabit. By making a comparative analysis of these two approaches, it becomes clear that the plastic component of this new formulation combining the two concepts (mesology and plasticity) is efficient at the level of living systems, and in particular of the organisms fixed to the ground like plants. As previously evoked, Berque has largely developed and theorized the mesological approach deepening the notion of trajectivity and of the relationship between living beings and their singular milieu (instead of environment). Concerning plasticity, he has precisely located it in the “as that” (*en-tant-que*) or the slash of the major mesological formulation $r = S/P$ where r is reality, S the subject and P the predicate, and where trajection finds its full meaning (Berque 2017, see Fig. 10.3). Trajectivity is synonymous with crossing "beyond", with a close link between the environment and the subject (S/P) through an existent (E) defining the ternary link SEP from the tetralemme of the Indian logicians “both A and not A” (contradictory terms then described by Aristotle and Plato still prisoners of the excluded third) and signifying for Berque a reality neither objective, nor subjective but trajective, "this movement by which there is "subjectivation of the environment and environmentalisation of the subject". This assertion from Imanishi Kinji implies more precisely for all plastic and

trajective processes, the notion of subjecthood (or subjectivity) concerning any self-organized structures during evolution (Berque 2015).

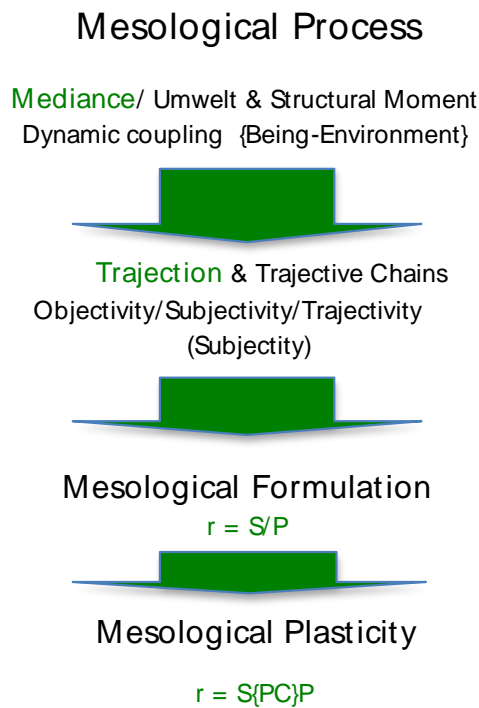


Fig. 10. 3: The Mesological Process. Mesological Main steps. For mesological plasticity, the plasticity complex PC replaces the ‘*as that*’ or the slash of the mesological formulation where *r* is the reality, *S* the subject, *P* the predicate. © Debono 2021 following discussions with Berque (2016, 2017).

10.5.2 Mesological Relationships Between Plants and their Milieu: the Uexküll’s Gap

In the context of an opposition to darwinist, Tainian and especially monistic theories of Haeckel, Uexcküll describes the correlate of the perceptive activity of animal perception and the irreducibility of the milieu to a given species by focusing on the perception-action loop and the relations between the environment and its living being. Canguilhem will analyse this relationship on an epistemological level later (1965), showing that the transition from the notion of milieu to that of Umwelt described by Ratzel (1899) shortly before Uexcküll²⁰ is not so clear-cut, at least on a linguistic and terminological level (Feurhahn 2009). Uexcküll, focused on animal ethology, will consider indeed very early on the living being as a subject in its own right. In this regard, he interprets the environmental data adopting a new vision of specific links

²⁰ Uexcküll replaces it with Merkwelt in certain writings: see following paragraphs and note 27.

between species and their milieu. Numerous examples of specific flora or fauna support these observations, which ensure the dynamic couple established between a living being and his singular milieu, an optimal growth and mutualistic links. The example of the tick is classic. More generally, what turns out to be a sign associated with the typical behavior of an animal or plant species (the stem for a bird or such a color associated with a specific wavelength for bees or the direct effects of a given human culture), leads to a specific biosemiotic (Kull, 2020) or a globalizing semiosis if we refer to the anthropologist Kohn (2013). This author reminds us indeed, that as far as our human societies are concerned, they are inscribed in the symbolic function of the language and the representation and that it is necessary to go out of it by taking into account a globalizing semiosis exceeding the human. According to this hypothesis, all forms of life or forest's signs would admit representations and symbolic functions that are expressed differently from us, i.e. according to an eco-bio-semiotic paradigm (a living thought) for anthropologists like Kohn taking into account a globalizing semiosis that goes *beyond the human being*. One can noticed here that if the biosemiotic value of plant-environment relationships has a strong value in animism and Amazonian cultural approaches, it should be primarily interpreted here according to its subject status. We have seen that it would rather be for plants and all living systems a subjectivity (*shutaisei* 主体性) according to Imanishi, than a classical subjectivity that is limited to the individual organism. This subjectivity is extended to the whole biotic society (different from the biosphere) according to Imanishi or a speciesity for Berque that translated him (2015), indicating in our context the unique otherness of plants rooted in a specific milieu compared to object-subject relationships of classical societies.

Indeed, the central object here is not the environment, but the dynamic coupling of the being with its milieu, which is always interpreted singularly and differs from the raw data of the environment interpreted similarly by all living species. This posture of subject inscribed in an environment and in strong interaction with the adjacent ecosystems is radically opposed to the dualistic or Cartesian positions separating body and brain or subject and object. What is important in our biologic, plastic and mesological position is the relation and its significance in a lived reality. We will see that it has strong implications: 1/ at the level of the individual and the species for what concerns the autonomy of the living being and 2/ at the level of a possible access to experience (sensitive, sensible, cognitive, conscious or not).

Concerning plant plasticity, a point of importance is noted for the first time in this chapter: the almost total absence of reference to the mesological relationships between plants and their environment by Uexküll, the father of ethology and mesology. Indeed, he barely mentions them in 1940, when he had completed his pioneering work while Rowohlt published the original text of Uexküll related to the plant world in 1956.²¹ We will quote here the extracts of the few pages of his major work "Animal Worlds and Human World" followed by the "Theory of Meaning" (Bedeutungslehre") and in its French translation by Denoel/Pockett (1934)²² evoking the place of plants and their relation with the environment. A later translation was made in Semiotica in 1982 where Uexküll mentioned plants for the first time in 1940, as part of his attempt to define the meaning theory.²³ "The question of meaning is, therefore, the crucial one to all living beings", he says, including plants considered as able to use or be immersed in habitats or "houses" despite their lack of brain, receptor-effector relations, mobility and "meaning-carriers". However, they are considered as not autonomous, contrarily to animals, and totally dependent of the environment.²⁴

Uexküll admits however that plants have in common with animals "to make selections among the environmental stimuli that constantly assail them" and unlike inert systems use meaning to evolve and grow optimally in their immediate environment. If we consider these assertions in their historical context (early XIX^e, governed, biologically speaking, by mechanicism at one end and vitalism at the other), and before discussing Uexcküll's arguments related to his positioning as a precursor of ethology and biosemiotics, this simple observation or hypothesis regarding the possible selective rule of plants vs environmental stimuli is fundamental regarding our discoveries on the function of EPGs and the signature of the electrome in the relational life of plants, whose discriminative role it would be precisely on the functional level via electronic mechanisms and mesological plasticity (Debono and Souza 2019, Debono 2021). We hope that new *in loco* or *in situ* EPG monitoring experiments will confirm this hypothesis as soon as possible.

Uexküll uses indeed the term 'Wohnhülle' (dwelling-integument) in place of Umwelt for plants, considering them to be sensitive through their lipid cell bilayer and use

²¹von Uexküll (1956) p.110-111.

²²von Uexküll (1934) p. 101-102.

²³von Uexküll (1982) p. 33-53.

²⁴Like fungus-cells differentiating themselves from bacteria by interpreting their surroundings and signs like food in term of meaning-carriers and minimal perception-action loops).

primary meaning-making where stimuli act as cofactors through the *wohnhülle*. Another important consideration that can be linked to the current knowledge of plant physiology in Uexcküll's hypotheses is the fact that plants capture and respond to environmental stimuli through their shape and all their organs (medial body), even though he associated it in its historical context to a “building plan” or bauplan. It means for the author that take often the example of the deformation of trees under the influence of the wind or of the form of tree foliage directing rainfall towards the root tips, a meaning-factor operating between the shape of plants and the environmental conditions (rain, wind, drought) which corresponds today to mechanosensitivity, proprioception or thigmomorphogenesis commonly observed in plants (Mouliia and Fournier, 2009, Hamant and Mouliia 2016).

Many other authors have addressed this issue in different contexts. Among these, Sharov's definition (2013) issued in the context of primary meaning-making modeling states that "an agent is a system with spontaneous activity that selects actions to pursue goals". Kull, who quotes the Sharov's concept of agentivity in 2020, rightly makes the difference between selection and choice, the first qualifier pertaining to purely sequential algorithmic operations, while the second concerns the presentation of non-sequential options constantly arriving in the present (simultaneous interactions in place of stochastic or deterministic ones), which corresponds to the case of plants rooted in the soil and subjected to permanent and changing stimuli. This point of view caught my attention because, like Uexcküll's initial observation previously noted about the meaning theory, it strongly supports our discovery of the presence of a spontaneous bioelectrical activity permanently emitted at the level of the whole plant (recorded by electrophytography or EPG). Indeed, as previously shown, EPGs correspond to biological signals of low amplitude and voltage that are an integral part of the plant electrome that we had detected very early (Debono et al. 1992)²⁵, hypothesizing that they would have a functional role, and in particular an essential function as a radar or discrimination window for all the environmental stimuli in order to allow the plant to develop optimally in an environment that is often adverse, stressful and that requires minimal cognition to survive. On going field experiments following the validation of our results by several teams are projected with Souza's team (Debono and Souza 2019, de Toledo et al. 2019, Parise et al., 2020, 2021) and would confirm our intuition.

²⁵See section 10.4.2

10.5.3 Semiosis, Uexküll's Primary-Meaning Making and Functional Circle: an Ecosensitive Complexion?

As shown in two synthesis done by Kull about Uexküll's work in *Semiotica* (2001) and more recently in Michellini and Köchy (2020) about the study of primary-meaning-making and evolutionary biology, Uexküll's great contribution related to classical genetic considerations about mutations and natural selection concerns the introduction of subjectivity and biosemiotics. Choice-making done by living beings is described as a necessary interpretation of the environment by living beings (mainly animals and humans) and not as a nervous or conscious prerogative. Meaning-making is then considered here as a semiotic process using signs and the Umwelt to survive and evolve. Uexküll as a functional circle modeled it. This circle means that any cell or multicellular organism having enough complexity is able to use functional circles in which its subjectness or subjectivity can emerge as relation signs in 'the phenomenal present' (the here and now singular milieu). This interpretation constituted by the reciprocal link Umwelten or Umwelt established between living beings and their singular milieu is essential to describe any semiosis, joining classical assertions about logical or literary languages by Pierce (1979) or De Saussure (1995).

Quoting Deacon (1997, 2012), Eco (1979), Sebeok (1997), von Uexküll (1986) or Hoffmeyer (1997), Kull (2020) recalls us that "semiosis is co-extensive with life". Thus rather than focusing on the Eco's semiotic thresholds, he suggests to pay attention to perceptual and action signs that are included in meaning-making operations defining functional circles that could be related or differentiated to functional cycles or closed sequences (Sebeok 1994) or also in another context to the operational close described by Maturana and Varela for self-organization and autopoësis (1980, 1983). Gestalt, feedback or situationist approaches were also adopted by Dewey following Pierce primacy, by Thure von Uexküll and Wesiak (1997) concerning elementary sensations linked to receptor-effector relationships and emergent perceptual properties and also by von Weizsäcker (1985) introducing the temporal factor or Plessner, the ontogenetic one. The time factor is indeed essential to insure the operability of the functional circle for agency and the dynamical couple formed by living beings as subjects incorporated into a singular milieu and a present moment. This unique conjunction allows the simultaneous elaboration of a semiogenesis and an Umwelt in a given environment. Now, a fundamental difference between animals and plants resides in this limited and

conditioned time factor for the former and almost unlimited and indeterminate for the latter, which may constitute at first sight an obstacle in the operability of the functional circle. Another potential obstacle raised by Plessner (1940) at the ontological level: the "open form" of plants which are divisible, are never finished and live in immediacy, directly incorporated into the external environment compared to the "closed form" (or completed form) of animals or humans whose embryogenesis follows precise stages, whose organs are positioned in the body and who acquire an autonomy and an individuality of their own with regard to their learning and their indirect experience (passing through representation) of the external world. This experience of the lived world, if it is not internalized, individuated and even less conscious or existential in plants, is not absent for all that at the sensitive level where it is on the contrary exacerbated (plants are hypersensitive to the environment) and embodied cognitive (in the post-cognitivist sense of the term). It corresponds to minimal cognition (Calvo 2011), extended or distributed cognition according to the authors and the behaviors observed among the thousands of plant species. With regard to extended cognition, Parise et al. (2020) have for instance recently shown that the root system of plants would constitute, as the whole body of the spider weaving its web, an extension of the environment where external physical objects are part of the cognitive system.

The model of mesological plasticity describes more precisely three stages at the level of the plant plastic interface, including: 1/ an active binding directly resulting from the dynamic coupling between the plant; 2/ a medial organism by excellence (body rooted in the soil and in permanent interaction with aerial elements) and its singular environment and 3/ an ecosensitive complexion allowing a trajective access to experience. This experience is not subjective as in the animal, capable of projecting targeted actions in relation to the object of its instincts or life projects, or introspective and represented (image) as in the human being, but it constitutes a subjectivity in the sense of Imanishi as noted by Berque (2015). Moreover, our mesological and plastic approach is a counter-argument to the Plessner's considerations linked to the open form of plants, where precisely their immediacy and direct incorporation into the external environment are presented as a handicap to acquire an autonomic or ontological status. Their subjectivity and open source behavior in close interaction with the interactive ecosystems from which they cannot extract themselves constitute on the contrary the signature of their specificity or otherness and are guarantors of their unique mode of exchange with the environment.

Namely, many authors associate the complexity of certain plant behaviors to minimal agentive capacities without mental representation. For instance, Barandiaran memorization or perceptual learning (2009), deriving in part from Simondonian perception's level assimilated to sensibility (2006) and Gibsonian affordance or direct perception phenomena (1986) showing the direct contribution of the action to the perceptual process introduces the concept of *perceptual systems* like the dynamic touch (Turvey 1996) or the visual system. It means that perception may be active and not only driven by external stimuli giving rise to a cognitive representation or a mental reconstruction. This direct access to the experience or perception-action loop concerning here an animal doing a motor exploration of his environment doesn't exclude learning and memory processes but describes another mode of cognition close to the mesological relationship linking the subject and its singular milieu.

A lot of works about mesology (Berque 2014, 2016, 2019) or biosemiotics (Kull et al 2020) show indeed that Uexküll, as an anti-behaviorist, had clearly anticipated the anthropocentric tendency separating the notion of *Umgebung* (unique consideration of the raw data of the environment) from that of *Umwelt* where living subjects are in strong interaction with their singular environment (milieu or habitat for animals) and the other species of its ecosystem. In this sense, they interpret the environmental data and make them their own milieu, establishing specific links that the other species do not have. Numerous examples of specific flora or fauna support these observations, which ensure the dynamic couple established between a living being and his singular environment, an optimal growth and mutualistic links. The example of the tick is classic, but symbiotic and mutualistic exchanges are observable at the level of many plant species and by extrapolation could be the symbol of a symbiotic planet (Margulis 1996). So, they are for us not only included in the Uexküll's functional circle, but also have an Umwelt. A recent study of Clements (2016) compared the circle and the maze with an ecosemiotic grid of lecture showing that Uexküll's functional circle corresponds more to a solipsist view of ecological relations while Peirce's drawing maze is more chaotic and not predictable, both concepts being linked to a subjective factor - causality for Uexküll and self or man as sign for Peirce (1979).

Indeed, if we consider the historicity of the theory, the teleological view of Uexküll (the bauplan), the idea that plants were inferior beings, lacking sophisticated receptors, sensory organs and mobility, incapable of exchanging or co-constructing with the environment, we understand that Uexküll did not give them an Umwelt status. We all

know, however, that the scientific discoveries that followed have shown, on the contrary, that the sensitiveness of plants was flagrant and their communication capacities, even learning, very extensive. This is why it is important to reconsider these pioneering works in the light of current knowledge in biochemistry, electrophysiology, genetics, ecology and epigenetics, where the extent of phenotypic as well as developmental plasticity is widely demonstrated. In addition, there are numerous semiotic, philosophical and phenomenological approaches that take plants as subjects of study today (from a metaphysical to a political point of view respectively for Coccia - 2016 and Marder - 2013).

Among the major findings of these fields of research is the fact that all forms of life, however elementary, need to exchange with the environment in order to grow, reproduce and survive. This evidence, on which everyone can agree, has gone unnoticed, as is often the case with the obvious, although it alone justifies the status of subject anchored in a meaningful reality granted to plants by transdisciplinary researchers. This status is linked to their active perception of the environment, which is volitional or intentional in this primitive sense, that is to say capable of discerning an inside from an outside, of distinguishing their own entity from the otherness of the world. An informal identity, blurred, internalized, without nervous system, a form of ipseity or radical otherness (Hallé 2014) differentiating itself clearly from the subjectivity, from the marked individuality and from the implicit self-consciousness of the animal or the man, but which leads the plant kingdom, in spite of its fundamental differences with these species (timelessness, divisibility, sessility, autotrophy...), to establish perception-action loops and to develop, not only 'intelligent' behaviors proper to all living beings (reactivity, problem solving, etc..), but efficient and significant exchanges with the environment which are its own.

For instance, plants mobilize their whole bodies in an environment spatially constrained but which they do everything to optimize, widen, develop by all the means: chemical communication by means of odorous or volatile substances, co-evolution with insects, propagation of electrical signals at long distance via the electrome, development of the mycorrhizae within gigantic root networks, proprioception (perception of their own deformation by plants or trees), elementary cognition, cellular or biological memory (habituation in the sensitive, motor response in the diptera), developmental and epigenetic plasticity (often transgenerational), remediation, meaning-making, local memories and learning abilities approaching animal procedural memories (Gagliano

2016, Thellier 2017). The concept of interface and plastic complex linked to the mesological approach that we develop puts forward this inextricable link between the living being and its environment, widely described at other levels of organization of the living being (neuroplasticity) and of reality (biophysical, energetic).

The notions of plasticity of the living being that we develop on the one hand, and of morphosis and semiosis or semiophysics (Thom 1988) on the other hand, best translate this consideration of plant phenomenology, which ensures in a simple and efficient way the optimal growth of the plant, without the need to have recourse to an integrative and centralized nervous system. This is possible through the trajection of living forms or a sensitive reality which, since the dawn of time, establishes an unconditional and inextricable link with nature, which we tend to over-interpret or anthropize, but which has no less value as a sign. Sign marking in an indelible way the singularity of the living compared to artificial intelligences (Benasayag 2017) and translating a ternary reality plant-environment-world, which leads to an anoetic highly sensitive reading of the reality of the world. This essential reading on the scale of self-organized evolutionary processes allows relativizing the predominant and self-centered vision of humanity on the world. It is a matter of taking into account the ecoplastic and ecosensitive nature of the world in all its dimensions (Debono, 2022)²⁶ and this requires certain humility. The sensitive experience means being for Nietzsche (1878). And that concerns all the living beings. There is apart from us, an intelligible and sensitive world that lives in an autonomous way, has its own codes and cognitive borders or of access to the experience founded on its interactions with this world. The plant body represents a major one, because contrary to the sectorized and indivisible animal body secured by shelters or habitats, it lives constantly in an open environment and does not have separate cells, but a diffuse body with zones of exchanges from near to near (some of which are purely electrogenic) and activate genes coding for receptors emitting defense molecules for example, which will induce a local response and can be propagated at long distance via the electromic field (de Toledo et al. 2019).

So, elementary life (from protists like amoeba to bacteria, fungi, plants and animals) not only can but also need to feel. This notion of primary 'feeling' differentiated from

²⁶ Debono MW (2022) Plant cognition: when science questions the ecosensibility of the world. IIIrd World Congress of Transdisciplinarity, Mexico City, Nov. 3-8

emotions and the basic intelligence of any living being by Damasio (2021) and that could be linked to direct perception and meaning-making in plants is important to take in consideration in evolutionary biology. We will come back in the next issue to this point considering homologies vs semiosis or ontologies when comparing animal to vegetal behaviors. Indeed, some arguments oppose the consideration of the sensitivity of plants, the reality of the lived experience, confining them to a simple reactivity to a given stimulus. However, this ignores the medial and trajective effectiveness of plants (their mesological plasticity), which are by definition extremely sensitive to their immediate environment (they are anchored in it and totally dependent on it), capable of movement and of developing defense or communication strategies elaborated in their interactive ecosystem and presenting a degree of cognition necessary for their survival in a hostile environment.

10.5.4 Phyto- vs Ecosemiotics as an Experimental Field of Mesological Plasticity: Evolutionary Biology and the Umwelt of Plants

One potential issue to assess plant biosemiotics could be to consider the field of phytosemiotics. Kull (2000) made a nice synthesis on the subject, comparing the concept of biological need as “the primary holistic process in living systems” to that of semiosis, where signs, according to their categories (respectively cellular, vegetative, animal, linguistic, and cultural) are considered as meronomic entities and plants as semiotic systems. Excluding the presence of semiotic thresholds (Eco 1979), he shows, quoting a lot of biosemioticians like Deely (1986, 1990) that semiosis is a general process in biological systems from unicellular cells to fungi, protists and multicellular organisms and asks « whether there may be anything special in plant semiosis in order to justify its distinction from the other fields of biosemiotics? ». Phytosemiotics is often mentioned, he said, quoting mainly Krampen that lunch the term in *Semiotica* (1981) and also Nöth (1990, 1994, 1998), but not clearly defined and differentiated. He excludes then the generic semiotic attributes of living organisms to search the specificity of evolved plants (like bryophytes and vascular plants) excluding algae and differentiates phytosemiotics from human-plant interaction studies (plant as signs to communicate) belonging to the ecosensitive field. The Krampen in deep analysis of von Uexküll’s statements about autonomy and semiosis in plants have several phases from 1981 to 1997, first agreeing with him (neither Umwelt nor effector/receptor

relationships, feedback cycles but not functional circles and meaning factors only) and then admitting their specificity (plants' signs being considered as indexes, sensing, meaning used by plants via their forms, chemosensitive responses) compared to the iconicity of animals and humans as symbols, on condition of detaching from any anthropomorphic or phyto-centric enterprise (Krampe 1986).

This assertion is at minima in adequation with the Uexküll's *Umwelt* of plants describing their singular relationships to the habitat and corroborates a lot of plant behaviours using via bioelectrical or chemical networks, insects, fungi, other plants and their own form as signs or meaning-factors. However, Thure von Uexküll (1986) assimilates plants to solipsistic systems using only iconic signs and not able to discriminate objects (only self and nonself) because they are not subjects and use only vegetative signs. For him, indeed "they are not signs for occurrences outside the plants, as there is no "outside" for vegetative systems". Kull (2020) rightly points out in his synthesis about phytosemiotics clear contradictions between these positions and the attribution by many of the same authors, Uexküll in first place, of an *Umwelt* to fungi (Hoffmeyer 2000) but also protists and unicellular organisms like the paramecium or other flagellates provided with a plasma membrane, receptors and effectors inducing body movements characteristic of the animal kingdom. We can thus better understand the historical genesis of these classification battles including few botanists, the outcome of which is clearly in favor of plants, which have no reason, whether it is at the cellular or organic level, not to have their own *Umwelt*.

A lot of plant signalization and behavior studies attests to it (Baluska et al. 2006) and as we discussed before, functional circles are most likely present in plants, knowing their ability to move (even slowly), to show an important phenotypic, developmental and epigenetic plasticity, to recognize and answer specifically to a lot of external signals by means of differentiated and specialized structures showing mechanosensitivity, gravi- or proprioception (Mouliat et al. 2009, 2016) to communicate via direct intercellular junctions, root networks and the electromechanical between themselves or other species (pollination, reproduction, mutual exchanges, symbiosis), to have defence strategies based on hormonal or chemosensitive receptors, to present some degree of memory and learning (Thellier 2017, Gagliano, 2016) and perhaps more specifically in relation to the *Umwelt* of plants, to show, as previously evoked, a morphogenesis directly acting as phytosemiotic agent. Kull (2020) says in this way that a "correspondence between the spatial placement of leaves and roots will be achieved due

to a functional relationship that has originated from a specific biological need”, where the need is not a feedback process but a semiotic and universal one using meronymy - objects as parts of a whole - in place of taxonomy as typological vegetative sign recognition (compared to the Sebeok’s zoosemiotic system 1994). To conclude, phytosemiotics is conformed by this analysis.

10.6 Assessments of *in loco* Mesological Plasticity using Monitored EPG Kits: a Key Approach to study Electrome Patterns in Natural Conditions

Let's come back to our experimental results in this perspective. Previous bioelectrical experiments have quantified spontaneous electrophytographic activities and shown the presence of specific patterns related to certain types of stimuli on long-term EPG recordings (Perreira et al, 2018). They constitute specific signatures of the electrome (Souza et al. 2017, Simmi et al. 2020) validating our key hypothesis about the role of these micropotentials in plant communication (with their milieu as for interspecies exchanges). The next step is to plan monitoring experiments using miniaturized EPG kits or sensors in natural environments, which is challenging and very important to understand the behavior of plants outside the constraints of the laboratory. The aim is to find specific patterns of electrome responses highlighting the cognitive capacities of plants, especially in terms of operational mode of communication at long distance (Debono and Souza 2019; Debono 2021, Gimenez et al. 2021). These patterns could include synchronization among electrical signals at the level of single plants (Debono 2013, Masi 2009) and discrimination of environmental stimuli or propagated defense signals (Reissig et al., 2021)

This still on going methodological part related to the operability and nature of *in situ* mesological plasticity of plants constitutes a key point of our experimental approach. As a matter of fact, the electrome signatures, addressed in a new way in this book, are related to the plant Umwelt (their eco- and phytosemiotics) and the lessons that can be drawn from Uexküll's succinct approaches to the plant kingdom in the context of current research. We show here that our field of research on the plant electrome and the particular role of EPGs could corroborate or at least support the reality of a plant Umwelt characterized by a cognitive access to its singular

environment. This environment taken into account at the plant mesological interface is not a habitat as in animals, but can be seen as a somatotopic mapping of plant spatiotemporal evolution. Its selforganization and dynamic coupling with the milieu (or its mediation) open up trajectory perspectives describing precisely the mesological interface that they form intimately with it, especially since plants are anchored there and must necessarily develop elaborate and interactive defense and communication strategies with regard to both the elements (aerial, terrestrial, aquatic, etc.) and the surrounding species (insects, fungi etc.).

These perspectives characterize the Umwelt or the proper world of plants in relation to their singular environment²⁷. Starting from the idea that matter, and thus the living, are semiotized, biosemiotics, which can be criticized²⁸, imply a stable imbalance or homeostasis on the scale of a territory where each species is the sign of another. Finally, scientific ecology, which is necessary, but whose perverse effects on agricultural policies, excessive urbanization or the use of biodiversity as an argument for the capitalocene (Haraway 2003, 2008) tend to antropomorphize the notion of the environment. Hence the birth of an ecocritical watches wishing to counteract the nature-culture opposition by using biosemiotics or Piercean and Uexckülian ecosemiotics as a field of investigation. Vignola (2017) thus reminds us that "Jakob von Uexküll developed the concept of Umwelt, a key concept in biosemiotics that refers to the fact that each species, that each individual within each species, perceives its environment according to what is significant to it for the purposes of its survival and according to the senses conferred on it by its anatomy." This Umwelt is particularly marked in man where the influence of the environment - of the habitat, the ecumene in particular, of the geography, of the climate, of the city - has a direct impact on his behaviors (whether they are individual or group) and the culture they convey. Kull (1998) relied in particular on the Lotmanian concept of the semiosphere to describe specifically the

²⁷ Uexcküll, who, as we have seen, was little concerned with plants, distinguishes in an interesting way in his work of 1934 on the animal and human worlds the Umwelt of the "higher" animals able to internalize (to replicate, to represent) the external world (Gegenwelt), to perceive it (Merkwelt) finely (landscape, intention, danger...) with the proper notion of animal affect or Stimmung, notably developed in comparison to the man by Buytendijk, one of his pupils and to act (Wirkwelt), drawing up there clearly a classic loop perception-action of the Umwelt of the lower animals (molluscs, insects etc..) whose merkwelt only perceives the stimuli of the environment, without relating them to a sense or a function.

²⁸ As we have seen in the chapter speaking of the differences between cycle and functional circle: for instance on its understanding of function and the biologization it sometimes grants itself in excess can lead to contradictions such as Uexcküll attributing an Umwelt to unicellulars and not to plants or Umwelt-Umwelten semiotic configurations that are ambiguous to say the least.

human Umwelt, characterized by a place, a language, a psyche that can induce biases and an imaginary. It forms a powerful network of exchange whose semiosphere corresponds to “the whole of all the interconnected Umwelten”.

This large-scale network includes the ecosystem and all the Umwelten that it contains, some of the species concerned. Plants are consequently in the the sensing or the sensitiveness, a form of sentience in opposition to the intellecting²⁹ and have obviously, like all living organisms a non-explicit intelligence (neither representational, nor affective or conscious), anchored in a territory or an environment, a milieu whose dynamic coupling has given rise to a biodiversity and an ecosensitivity like no other, the explosion of life on Earth and the rise in complexity that we know with the advent of consciousness and mind³⁰. Several authors in this way show that plant (specifically roots that use homeobox proteins able to control the morphodynamics of the shoots) could use sensing to draw up spatial and even cognitive maps of the soil and the environment. They use as well qualitative as quantitative informations directing growth or other behaviors like fitness, following local conditions (light conditions, moisture, drought, mechanical stress, temperature, attacks of pathogens and insects, pollution, gravity, symbionts, nutrients), competitive or mutualistic strategy with other species, abiotic inputs or obstacle (Falik et al. 2005, Trewavas 2005). Memory and learning processes or proprioception (Gagliano 2016; Hamant and Mouliia 2016) are also widely described in the litterature in plants showing their ability to control the environmemnt and growth optimally. The electrome of plants including cellular action potentials, systemic responses, calcium waves and EPGs have a key role in long-distance signal propagation as we stated before (Masi et al. 2009, Debono 2013a, Souza et al. 2017), but could also act at the level of defensive responses, memory, learning and biological rhythms (Volkov et al. 2014). More generally, sensitiveness, otherness or ipseity of plants could be considered as sufficient to explain their cognitive abilities whose nature is under study to interpret the world in a sensible and agentive mode without the need for a nervous system. Parise et al. (2021) have in this way recently shown in *Cuscuta R.* that electrical signaling of dodders could change according to host species perceived in patterns recorded by machine learning, suggesting a recognition system but also for the first time a vector of ‘attention’ in plants.

²⁹In another context, Deleuze (2004) interestingly compare plant behaviors to the intellective process.

³⁰What I called protoneural dynamic networks in my paper referenced in 2013a.

Deacon (1997, 2012) clearly shows that sentience is an emergent property of teleodynamic systems, but distinct emergent forms of sentience found in animals and humans (higher-order forms) from that found in plants and other multicellular organisms (lower forms). He shows however about the sentience of individual neurons compared to the brain that we cannot reduce the former to the latter because teleodynamic processes are irreducible to the thermodynamic processes that they depend on and that higher forms could not exist without lower levels of sentience serving. This level-specificity can be attributed to any emerging teleodynamic processes from the molecular level to autoorganized systems such as single-cell organisms, multicelled plants and animals having brains. So, for Deacon, lower sentient forms like those of all cellular-level adaptive responsiveness permits the higher forms to emerge. The interesting report concerning our considerations at the plant level, is that the author assimilates this second-order operation related to brain-neurons interactions to “the way that the teleodynamics of interacting organisms with an ecosystem can contribute to a higher-order population dynamics, including equilibrating (homeodynamic) and self-organising (morphodynamic) population effects”. It includes morphodynamic processes as well as self-recognition by teleogenic closure, but also the key notion of Bateson (1979)³¹ opposing the neuronal matter-energy (firing pattern) constitution to the informational one of the mental worlds embodied by distributed dynamical attractors. Yet, network activity patterns and attractor forms are present in many non-linear dynamical systems, including in particular the electrome of plants which can relay the microstates constituted by permanent spontaneous low voltage EPG’s regularities to macrostates involving “large-scale global attractor dynamic produced by an extended interconnected population” of plant cells (neurons for Deacon). Indeed, there is no need for a brain to accomplish this qualitative leap, as long as we examine the whole homeodynamic process and that we “disregard the level of complexity reached in mental operations due to the synchronization of hierarchical and highly specialized structures”. The result obtained in plants will be different, being limited to a minimal cognitive access to experience and to a specific interaction with its environment, which is already far from being negligible!

³¹See also Hoffmeyer J (2008)

10.7 The Plant Mesological Plasticity: A Unique Cognitive, Electronic and Ecosemiotic Interface

To sum up our discussion, we can say that the way in which plants exist is based on sessility, unlike animals, which implies a dependence on environmental constants and their variations. It is thus a question of playing on other factors than movement and immediacy, of composing with the physical forces in presence and their spatiotemporality. Although chemistry and taxonomy have long occupied botany, the essential role of bioelectricity in all motor phenomena, communication and exchange with the environment and other species has long been underestimated.

The first objective of this chapter was therefore to introduce this prevalence by describing in detail the plant electrome and the potential of mesological plasticity as a new theoretical model of self-organising evolutionary systems considering the plant and its environment as inseparable. Indeed, this framework of analysis combines two distinct concepts: the plasticogenesis of living or non-living systems and the dynamic coupling between living beings and their environment. It has the advantage of not being limited to a reductionist, dualistic or, conversely, too permissive or deviant reading grid, but of giving the clearest possible vision of the place, the role and the prerogatives that can be granted to new plant signaling and behavior discoveries (Brenner et al. 2006) in the context of the Anthropocene.

Our second objective was to highlight the fundamental role of spontaneous low voltage variations or electrophytograms (EPGs) within the whole plant's electrome dynamics and more generally of systemic plant electrophysiology. These bioelectrical activities are indeed directly linked to their singular continuum via symplams and plasmodesmata as well as the progressive establishment of efficient non-linear dynamic systems that occur during evolution (Debono 2013, Souza et al. 2017, 2018). The resulting operational and cognitive modes allow establishing a precise mapping of ecosensitivity and complex processing of information within a plant or between plants in their natural environment. These behaviors and ways of communication are currently under studies focusing on new patterns of electrome responses in natural conditions (Debono and Souza 2019; Reissing et al. 2021, Parise et al. 2020, 2021). We show more precisely here that the plant electronic reading grid integrates the key role of EPGs as early markers, permanent scans and discrimination tools for environmental stimuli or

stresses, allowing the whole plant reaching self-organized critical states or SOCs to have vigilance systems and an active perception of their milieu.

As for the architectural relationships between these systems or interfaces, we describe them through plasticity complexes set up during evolution. More precisely, we have established plastic links between the matter and the form, the nonlinear dynamic systems linked to the plant electrome and the activation of operational ternary models during some of these evolutionary processes. The resulting plant electrome signatures will allow us to identify how plants survive and grow optimally in their interactive ecosystem as well as in their singular milieu. Similarly, it will allow the description of a specific flora, of the close interactions between an environment or milieu and a particular species as well as its relations with other animal or plant species.

Our third goal was to clarify for the first time key points about the Uexckülian gap or positioning on the Umwelt and the primary-meaning making of plants showing as a new reading grid to study ecosensitive complex systems and to question plant evolution and emergent cognitive or intelligent behaviors (Debono 2020a).³² More precisely, the selective role of EPGs at plant electronic interfaces and mesological plasticity are proposed as the best bottom-up approaches of co-evolutionary and ecosemiotic processes. Indeed, they cover two essential fields: the intrinsic cognitive capacities of plants to internalize without representing it the external world by quantifying and discriminating the stimuli of the environment (biotic or abiotic, degree of humidity or dryness, rate of luminosity...) and their high sensitivity to the milieu (singular mesological link) by means of morphogenesis and semiosis (Sebeok 1997, Kull 2000, von Uexküll 1986, Deacon 2012), in other words of the direct relation between form and function or form and environment (epigenetic plasticity). In this way, new experimental fields like phytosemiotics or mesological plasticity will permit to support fundamental research areas questioning the sensitive and cognitive nature of plants.

To conclude, evolutionary biology is particularly illustrated at the scale of the action-perception loop and of the communication established within a species or between the species. This is precisely what is operated at the plant's electronic interface that irreversibly bind form and matter, the living being and its environment, subject and object (by forming plasticity complexes) with a single purpose: to express the singular

³²Reference to the last book of the author questioning in a transdisciplinary way plant intelligence, Hermann, Paris, 2020.

existence of plants in their alterity (Hallé 2014) or simplicity (Berthoz 2009): a mesological and cognitive relationship to the world which does not have an equivalent in the animal and human world.

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