PRINCIPLES OF MINIMAL COGNITION IN SMART SLIME MOLDS AND SOCIAL BACTERIA

ÓSCAR CASTRO GARCÍA
Universitat Autònoma of Barcelona
Segurilla Astronomical Observatory (OAS)

ABSTRACT: The perception of the environment as well as sensorimotor coordination of unicellulars organisms competence as the foundation of a cognitive principle that goes beyond minimum metabolic processes. I study the recognition of the environment in case of slime mold and bacteria as significant learning processes in differentiating between hostile environment or optimal and physical transformations of each agency on the basis of received signals in both the membrane and within the agencies. Sensorimotor coordination mechanisms of metabolic adaptation expanded shapes. Some of these coordination mechanisms are linked to the perception with the environment through pulses, as temporal processing of signals.

KEY WORDS: Umwelt, subjectual, enaction, haptic perception, Weber-Fechner Law, bio-fenomenology.

RESUMEN: La percepción del entorno, así como la coordinación sensomotora de los organismos unicelulares competen como fundamentos de un principio cognitivo mínimo que va más allá de los procesos metabólicos. Trato de estudiar el reconocimiento del entorno en el caso de los mixomicetos y de las bacterias como los procesos significativos de aprendizaje en la diferenciación entre entorno hostil u óptimo, y en las trasformaciones físicas de cada organismo en función de las señales recibidas tanto en la membrana como en el interior de los organismos. Los mecanismos de coordinación sensomotora expanden formas de adaptación metabólica. Algunos de estos mecanismos de coordinación están ligados a la percepción con el entorno a través de pulsos, según el procesamiento temporal de las señales.

PALABRAS CLAVE: Umwelt, subjectual, enacción, percepción háptica, Ley de Weber-Fechner, biofenomenología.

1. Cognition in slime molds

One of the clearest and most surprising turn in favor of accepting «*intelligent behavior*» in cognitive biology has been revised through real slime molds or myxomycetes. The Physarum polycephalum is a kind of mixogastreas that varying its structure to amoeboid plasmodium or sclerotium on favorable or unfavorable environment depending and their nutritional needs. When his phase is amoeba, this is the plasmodium authentic polynuclear with a single membrane, which maintains a topological unity, something significant in his description as an autopoietic system.

It has been demonstrated that the Physarum polycephalum can find the shortest route through a maze to locate food sources placed at exits, and so absorb the maximum amount of nutrients in the shortest time possible (Nakagaki, Yamada and Toth, 2000; Nagakaki, 2001)[1]. This suggests that the cell is able to «*smart* behavior», even in complex situations

[1] As the speed of locomotion of Physarum polycephalum is 1 cm/h, the transport of intracellular material in tubes that are built with greater thickness increases to reach a top speed of 1mm/s.

that is difficult to optimize the tasks of survival. Two important questions are raised by this hypothesis: how is this behavior and how they arrived at a «*clever*» solution?

The transport network in plasmodial slime mold is a useful system to address these issues. The plasmodium Physarum polycephalum is an aggregate of protoplasm with a network of tubular elements and nutrients through which chemical signals travel, whose geometry is related to internal communication. Moreover, the tubes act as «channels», allowing the body to navigate their environment and can be disassembled and reassembled in a few hours in response to environmental changes. When presented in different positions many small sources of food rolled oats to a starved plasmodium, it strives to reach all of them, as a result, only a few tubes are in contact with each source of food. The body tries to optimize the shape of the network to facilitate the absorption of available nutrients. However, this may be difficult to achieve when multiple power sources are limited due to body mass in organism.

The effects of two power sources have been previously reported and minimization of total network length was found to have an important role. This network shaped body allows certain physiological needs that must be met: 1st. the absorption of nutrients from the food source for the most efficient way possible, because almost all body mass is in the power supplies to allow for absorption, 2nd. the maintenance of intracellular communication and connectivity throughout the organism, and 3rd. the meeting of the limited resources of body mass. The network formed is considered as a solution to the problems of survival of organism.

Contrary to this, if food is abundant, organism finally split into two parts for two power supplies. Even this case, however, just before the split, organism draws only the shortest distance. Therefore, the shortest connection appears once as a transitional and finally is disconnected, and then the result of the disengagement is the separation of the body. The key points of «intelligent behavior» in Physarum polycephalum is, first, that achieving the oat bits decided to make the shortest possible route to obtain food from each source, and second, that for the path has to predict its path as it does not route to a trial and error, but does everything the first time. To generate such a movement is necessary to control system information of Umwelt – Jakob von Uexküll's thesis about the meaningful environment of agencies (Uexküll, 1909) – and a command system to make decisions.

To study the mechanisms of learning from Physarum polycephalum, they were exposed to adverse conditions presented with three consecutive pulses at constant intervals. Thereby plasmodium reduced their walking speed in response to each episode. When the plasmodia were subsequently subjected to favorable conditions, they spontaneously reduced their locomotive speed in time for the next episode might have occurred unfavorable. This implied the anticipation of impending environmental changes. Thus, Nakagaki and his colleagues have explored the mechanisms underlying anticipatory behavior from the perspective of nonlinear dynamic systems (Nakagaki, Kobayashi, Nishiura and Ueda, 2004).

However, the conclusion reached is that organism is able to remember the periodic changes that have not experienced before. This indicates that the body has a general capacity for learning, memory and anticipation, independently details of frequency.

Although the results described in the study were obtained through real slime molds – or slime – prokaryotic organisms like bacteria, can show an «intelligent behavior» with a simple mechanism of learning and memory in terms of nonlinear dynamics. The perspective of nonlinear dynamics might be the key to unlocking the secret of how biological systems to overcome the challenges to their survival (Takamatsu, Takaba and Takizawa, 2009).

Interestingly, studies of nonlinear dynamics Nakagaki, introduced in this work include multirythmics oscillator behavior in the motility study (Kobayashi, Tero and Nakagaki, 2006). May be considered Physarum polycephalum plasmodia act as a system of coupled oscillators, based on Hopf bifurcation theory and solves some of the symmetry properties defined in the dynamic oscillatory concentration of ATP or Ca^{2+} thickness of the plasmodium and protoplasmic flow [2].

As Jakob von Uexküll – father of biosemiotics – said concerning the plan of significance of the myxomycetes: «Every living being is constituted, as we all know, but we forget easily, as opposed to all mechanisms, not parts but organs. An organ is always a product formed by living cells, each of whom possess a unique sound. The body as a whole has its organic sound, which is the sound of significance» (Uexküll, 1940). This «meaningful sound» or «ego qualities» (ich-ton) – as Uexküll called – would be understood as the semantic aspects of the multirythmics oscillations patterns system itself (organ and whole organism) in its displacement (Kishimoto 1957a, 1957b; Miyake *et al.*, 1993) and its development (Takamatsu, Takaba and Takizawa, 2009), from a «enactive» and «*subjectual*» [3] of the interaction between your Innenwelt – or phenomenological world of the body – and his Umwelt – or «multi-sensory perceptual field of the environment» [4]. Therefore, there would be a description of oscillation biosemiotics characterizing autopoietic agent status, and thus proprioceptive (thanks to contractile proteins such as actin, myosin and tubulin, etc.), interoceptive (thanks to signals and intracellular cAMP WGCP, Ca^{2+}, PIP3, etc.) and exteroceptive (through chemotaxis, haptotaxis, or thermotaxis, etc.).

«We must not overlook the fact that we ascribe to the amoeba of a myxomycete Umwelt, as yet limited, typical of all amoebae, in which bacteria are noted as having meaning in its Umwelt, and also are perceived and created» (Uexküll, 1940). These bacteria are part of the Umwelt of the myxomicete as carriers of food meaning for chemotaxis, also exhibit intelligent behaviors of communication and cooperation in the aggregation and displacement.

2. The social intelligence of bacteria

As we have seen with the myxomicetes organizational development and coordinated behavior of organisms depends on communication with its environment both abiotic (environmental factors and substances from the immediate environment) and biotic (between organisms of the same species or species or different kingdoms). In the case of bacteria, the communicative processes that have been studied are of three types: intra, inter and meta-organismic (Witzany, 2008a). Bacteria can distinguish between species-specific signals and signals that can modulate interspecific behavior, thus allowing coordinate specific behaviors of the species, as different species.

---

[2] «*All that means life is bound to protoplasm*» (Uexküll, 1930-1944). Uexküll, J. von (1930), *Die Lebenslehre,* Potsdam: Verlag Kiepenheuer und Müller, und Zürich: Orell Füssli Verlag.

[3] Thus establishing a relationship between «autopoietic enaction», while the representation or performance of the agency and turn the emergency of the world from a background of understanding through «functional circles» cognitive feedback and «*conformity to plan*» (Uexküll, 1940), and «*subjectness*» by Jesper Hoffmeyer (1998) in which the action which the subject creates his own world while allowing their self-creation. This will avoid the connotation that it solipsistic subjectivity, and legitimizes the phenomenological foundation of life of the agent.

[4] Transdisciplinar definition of Umwelt term of Jakob von Uexküll, produced by the sum of all circles of the subject functional activity in the present tense, as morphological structures (Baupläne) of each subject, formed according to the plan (Planmäßigkeit) constructive self-organization.

On standard states growth, the bacteria live in complex hierarchical communities. To build such communities or colonies, they must carry cooperative behavior in which some cells altruistically give their life for food from others in the formation of fruiting bodies, as for example with the Myxococcus xanthus. The complex patterns of forming a colony emerge through communication-based interactions between individual bacteria colony (Ben-Jacob, 2009). Individual cells cogenerated take on new features and abilities that are not pre-stored in the genetic information of cells, i.e., that not all information required to effectively respond to all environmental conditions are stored genetically. This responds to a statement by Gregory Bateson that the environment has a direct impact on the genetic background of the population, but it is certain that the environmental impact to bear on the genes of each individual's genetic form [5].

When a cell receives a signal through a receptor, initiates a series of steps in an internal network of interpretation which can carry a transcription factor to activate an area in its genome. This in turn can activate a whole-genome network. Thus, the meaning of a complex signal depends on the interpretations made by the host cell. The information content of the signal is reinforced by a mapping of interpretation. But not all the information content required to respond effectively to all the conditions of Umwelt is stored or preset in the genetic code.

To solve the incompleteness of information, evaluated the problem bacteria through collective detection (collective sensing), recalling the information stored from past experience (epigenetic memory) [6], and then execute the distribution of information processing of a group between 10^9 and 10^{12} bacteria grouped in the colony: the transformation of the collective settlement in a supra-organism is what Ben-Jacob calls a «super-brain» (Ben-Jacob, 2009). A super-brain composed between 10^9 and 10^{12} «nanobrains» of the morphology of a hair. It is a form of fiber – helical coils bacterial chemotaxis receptor on the cytoplasmic domains conserved. Each signal unit (which forms the super-brain) appear to be a field of several billion (according to Ben-Jacob) of helical receiving elements, packed in a package of 100 nm diameter, whose dynamics follows a logical architecture determined by the rules of association between TSCT (Stock *et al.*, 2000) as CheW, the CheA and CheY (the receiver signals, the donor phosphoryl – histidine kinase – and response regulator – a aspartic acid messenger protein –) and the scaffolding of receiving – helical fibers.

The intelligent behavior of bacteria attracts attention to current biosemiotics studies (Witzany, 2008a, 2008b). Bacteria have developed complex communication capabilities (eg quorum-sensing, chemotactic signaling and plasmid exchange) to cooperatively self-organize into highly structured colonies with elevated adaptability of the environment. Eshel Ben Jacob and colleagues (2006) propose that the bacteria use their intracellular flexibility, participating in signal transduction networks and genomic plasticity, to collectively maintain linguistic communication: the self and collective interpretation of chemical signals (syntax) the exchange of chemical messages (semantic) and dialogues (pragmatic). The sense of community-based education permits colonial identity, intentional

[5] Bateson, G. (1979), *Spirit and Nature,* Amorrortu Publishers, 2006, 2nd ed., 3rd repr., Buenos Aires, pp. 55-56, 132 and 144.

[6] Recently has been suggested that bacteria also have epigenetic memory of the past, which allows you to track how they handled previous encounters with antibiotics. To learn from experiences of the bacteria so they can better cope with a second meeting with the same antibiotic as reflected by the fact that the colony is expanding rapidly and acquires a more complex pattern. This effect can be erased by the growth in neutral conditions. One possibility is to this effect is related to a genetic change of the population. Another possibility involves epigenetic inheritance at the level of the genome (Ben-Jacob, Shapira and Tauber, 2006).

determination (e.g., from autoinducers or pheromones for mating courtship), the deliberate alteration of colony structure (e.g., formation of fruiting bodies) decision making (e.g., spores), recognition and identification of other colonies, are functions that could begin to be associated with bacterial social intelligence. This social intelligence, if any, would be necessary to go beyond communication to encompass unknown process to generate additional intracellular memory of colonial heritage and a common context of the genome.

The criterion of cell-cell communication, in this case in bacteria, involves the transduction processes and decoding of their signals – a type of semiochemical vocabulary – through components such as homoserine lactones LuxI and LuxR – in Vibrio fischeri – for autoinduction or quorum sensing, or serine-threonine kinase and intracellular receptors capable of transforming growth factor (in the formation of genes that regulate and control the mitotic and meiotic) and pressure regulator with the environment For Bacillus subtilis (Kang *et al.,* 1996), apart from collaborating in neurological and immunological processes (García Martínez, 2007)[7]. Professor Klaas J. Hellingwerf argues that by studying the characteristics of signal transfer in bacteria, these functional characteristics *supervene* in higher organisms, such as memory, learning and intelligence and a rudimentary but distinct reportable (Hellingwerf, 2005) and can not only imitate typical neural network, but that certain proteins involved both in bacterial communication for growth or stagnation as in the detection of light (Barends *et al.,* 2009), are also active in neuronal processes, such as neuroplasticity, and as enhancers cognitive in the case of phosphodiesterase inhibitors such as vinpocetine (Medina *et al.,* 2006)[8]. In the latter case[9] this is a two component signal transduction (TCST), in which certain molecules convert a chemical stimulus mechanism in a specific cellular response signal, providing a change in cellular function. It is a sensory mechanism, which also acts as a molecular form of memory required for chemotaxis. Is mediated by a pair of proteins that consist of a sensor (S) or recipient and a response regulator (RR) adaptive. Perception and adaptation are two lines of action of signs, through which Uexküll called «functional circuit» or feedback on bacterial receptors. Interestingly, some involved in the E. TCST coli (and therefore in prokaryotes), are also covered in some eukaryotes – as in the slime – also acts on neural networks as a mechanism for coupling of stimulus-response basis to enable agencies to detect and respond to changes the Umwelt, i.e. the surrounding environment which is «carrier of meaning» (Uexküll, 1940). This is the case of the histidine protein kinase, acting as a transmitter in the E. coli, is also involved as a response regulator of the myxomycetes osmosis (Shuster *et al.,* 1996; Stock *et al.,* 2000)[10].

---

[7] The beneficial effects of serine-threonine kinase are the regulation of cell survival by phosphorylating pro-apoptotic proteins inhibiting its activity. Phenomena are also involved in neuroprotection by trophic factors against the degeneration of intraneurons and striatal projection neurons and neuronal differentiation. Serine-threonine kinase AKT, known as protein kinase C (PKC) contributes to cellular functions, including nutrient metabolism and regulation of transcription, apart from being regarded as the key regulator of cell proliferation and survival. Their dysfunction or mutation contributes to neuronal apoptosis and cell Huntington's disease and Alzheimer's.

[8] The phosphodiesterase inhibitor type 1 (PDE1) has been proven effective in facilitating long-term potentiation, improve the structural dynamics of dendritic spines, improve memory recall, and improve performance on cognitive tests in humans. Although these studies demonstrated the efficacy of vinpocetine in the improvement of plasticity in normal subjects, little is known about the effectiveness of PDE inhibitors to improve the plasticity in cases of severe cognitive impairment.

[9] In the case of phosphodiesterase inhibitors, have the HAMP domain (histidine kinases, guanylate cyclase, methyl binding proteins, phosphatases) and DHKA as models of two-component system of signal transduction inhibitors of phosphodiesterase.

[10] The slime mold Dictyostelium discoideum contains at least 11 histidine kinase «HK» (Doka, DHKA-D and ESTs) involved in a series of activities including osmotic response and development. One of them

3. Information transfer and irritability cell: The minimal cognitive process and the law of Weber-Fechner

We have seen that both slime molds and bacteria exist in the cognitive processes that unravel intelligent behaviors in both the memory and pattern recognition (myxomycetes) and the social environment (bacteria). In fact there are more studies that look at what Pier Luigi Luisi, and B. S. Mueller called «minimum cognitive» (Müller, Di Primo and Lengeler, 2001) allowing differential settlement between living as non-living systems (such as vacuoles or micelles), as the co-emergence of autopoietic unity with cognitive activity (Luisi, 2006). One important thing to bear in mind is no focus or core intelligent, but it is an emergency in the system itself. Emergency that might arise from teleonomic biochemical activities (Kováč, 2006) characteristic of autopoietic systems as «molecular recognition». These considerations allow us to dive to 1th level perspective biosemiotics (Matsuno, 2008) where the transduction of biochemical signals into information they become recognizable, and macromolecular level of awareness of the environment, and rheological transitions of the cytoplasmic sol-gel (Sato, Wong and Allen, 1983).

Now, we consider a key issue in these activities for the recognition of information, and it is the semantic concept of information. The semantics of the signals (and, in general, the language) is governed by the enrichment (Werner and Vedral, 2010). The meaning enriches the information content of a signal. But as Bateson says the information is differences that make a difference [11].

According to Vlatko Vedral says in the addition of information, it allows very sophisticated responses by simple signals. As *information contained in an intercellular message is not contained in the signal,* the probability of the signal to be sent or shock value to the recipient. Therefore, Shannon's theory is almost irrelevant to information and communication in understanding the development process. Vedral argues that the meaning of a message is determined by how information affects the agent's intentional state. The agents coordinate their actions through the use of communication to adjust their strategies in order to draw it together and accomplish their goals interlock. But this has little to do with the probability of a signal. Therefore, Shannon's theory says nothing about the meaning and understanding of language.

This brings us back to Bateson's idea that, being information of relative nature, the difference is not located in time or space (not contained in the signal). This brings us to an issue that is related to quantification of cognition. Is to mean that there is a limit on the recognition of difference abiotic or biotic stimulus of Umwelt where no processing. There must, necessarily, a gradient threshold below which the gradient can not be perceived, and therefore there must be a law governing the minimum threshold of perception that allows the three conditions necessary to define an agent: their individuality, the asymmetry interactive and regulations (Barandiaran, Di Paolo and Rohde, 2009). A law «supervening» or homeomorphic equivalent of *Weber-Fechner law* (Cope, 1976; Copellia, 2002), in which the smallest discernible change in the magnitude of a stimulus must be proportional to the magnitude of the stimulus: $s = k\ Ln\ (A/A_0)$ that relates the sensory experience *(s)* with sensory activation *(A),* where k is a constant and A_0 is the minimum level of sensory activation in which no-show experience. In the progress of the

is a hybrid HK DHKA important factor in osmoregulation, phosphorylating the response regulator REGA, causing inhibition of cAMP phosphodiesterase activity-dependent Rega, and increasing levels of cAMP, which in turn regulate the activity of protein kinase A.

[11] Bateson, G., *op. cit.,* p. 111.

study of Weber-Fechner law, Stanley Smith Stevens (1906-1973) proposed an extension of the law referred to Stevens (Stevens, 1957), a power law that relates the magnitude «subjectual» [12] of the stimulus (,) with the intensity (,) and the nature of stimulation (, ,) described two kinds of sensory continuum: a continuum involving metathetic or qualitative variations in the quality or sensory location, and prosthetic or quantitative continuum involve changes in sensory magnitude.

Interestingly, these psychophysical laws studied since its inception [13] for the objective quantification of a subjective sensation in the human psyche, and in 1884 was extrapolated to the irritability of both single-celled organisms (bacteria and slime) and plants by Wilhelm Pfeffer (1888).

Pfeffer noted that if a bacterium moves toward the attractant gradient, the more energy available to the bacteria to continue to reach the attractant. Pfeffer made various measurements between the concentrations of malic acid as an attractant on the amount of ammonia to neutralize the bacterial pulling pressure in the capillaries. Left tables found in concentrations that, in seeking the solution to find the minimum threshold of irritation, and varying environmental conditions temperature to 5 °C, the variation in malic acid concentration on the threshold of irritation response to attractant hair always followed the Weber-Fechner law – both in thermo bacteria (Pfeffer, 1888; Keller and Segel, 1971) [14], as in sperm of ferns, and myxomycetes (Pfeffer, 1888; Hillen and Painter, 2009).

The irritability of a cell is part of the cognitive process that allows describing the perception of a stimulus, responding in a nonlinear shape. Is primarily a homeostatic capacity that allows organisms to survive and adapt to environmental changes. But with these adjustments combine a number of inter-sensitive «subjectual» Innenwelt agency that responding to the Weber-Fechner law before the tropism or taxis in front of his Umwelt. As Rodolfo R. Llinás (2003) says a «subjective feeling» or «*protoqualia*» [15] that provide an electrical signal or chemical potential as a function of stimulus at the time that blunts the perception threshold, triggering a cellular action consistent. This may be the origin of qualia – Rodolfo Llinas comment – if there is a geometric amplification of irritability of millions of bacteria to establish the fruiting body, or billions of neurons to establish coherent feature synchronous movements of one arm to offer the hand of a hominid of his species. This amplification geometric fulfills the law of Weber-Fechner.

---

[12] In the definition offered by Stanley Smith Stevens (Stevens, 1957) is the magnitude of subjective sensation caused by a stimulus. I believe should replace the subjectivity for Hoffmeyer's «subjectness» criterion discussed above.

[13] Gustav Theodor Fechner (1801-1887) stated in 1860 in his «Elemente der Psychophysik» ideas connectives between matter and psyche, developed in his mind since 1850. Understood to be measured (existentialist obsession Lord Kelvin) through a relative increase body energy, and the corresponding increase in mental intensity. As the work was verification of the theories made in 1825 and 1834 by Ernst Heinrich Weber (1795-1878) for the study of measurements of conductive hearing loss and also about touching, published in «Die Lehre vom und Tastsinn Gemeingefühl» in 1946, Fechner wanted to keep the name of «Weber's law» even though Weber himself never formulated, extending also to the weighs detection.

[14] Pfeffer's work on the Weber-Fecher law in bacterial chemotaxis is verified by C. Weibul in his work «In Bacteria». Vol. 1. I. C. Gunsalus & R. Y. Stanier (eds.), p. 153. But where is really shown is in Keller and Segel (1971).

[15] «The human 'qualia' are the geometric amplification of a single cell irritability still not well understood (…) On-cell origin is little that can be said today, but this ignorance is not a definitive reason to believe that scientifically unexplained phenomena because we have strong evidence that qualia are tied to the electromagnetic activity of the brain and which are 'soluble in Anaesthesia'». Llinas, R. R. (2001), *I of the Vortex, From Neurons to Self,* MIT Press.

«Amplification is offered through the organization of specialized circuits in sensory functions» (Llinás, 2003). Such circuits are precisely the Uexküll's *Funktionkreises* sensory or functional circuits (Uexküll, 1920) that allow multi-complex structured so depending on the signal transduction specializations, and autoinduction of signals for transfer information (Castro, 2009). One things set out in structure of Weber-Fechner formula is the geometric progression, based on the number e, base of natural logarithms, as we have seen previously in studies of Pfeffer implies that qualia are distributed as harmonics.

This is the nexus between the phenomenological perception of the intensity gradients of a stimulus and the sensation produced by it. Not only would proof that you can measure or quantify the cognitive processes and the degree of perception of the stimulus. Epistemological aspect also would set a nexus between an experimental biological study of a phenomenon whose description is based on physical-chemical processes in which they are based, and the phenomenological description of emergent process by identifying their acting parts or components «material» interacting, requiring collateral energy – consumption of negative entropy and latent information (Ben-Jacob, Shapira and Tauber, 2006) – as well as functional circuits for determining the effects of which encoding of the events that preceded them (by normative shape) thereby revealing a hierarchy of logical types characteristic of the phenomenon underlying the truth of their existence.

Conclusions

My proposal is that we can develop a speech not only philosophical but also biosemiotics – and therefore transdisciplinary – existing contributions to support a minimum cognitive organisms lacking nervous system to develop. There are five conditions for the possibility of determining a minimal cognitive principle that we have studied both in the myxomycetes (Physarum policephalum and Dictyostelium discoideum) and gram-negative proteobacteria (mixobacterias and E. Coli):

1. The ability of agencies to discern a hostile environment suitable for survival (Cognitive criteria [16] selectivity, control, interaction and valence).
2. The ability of cell-cell communication. This communication is not only transmit information from the environmental conditions to phagocytose or flee, or accession to form fruiting body, but also the ability to communicate about communication on the communicative norms, and therefore the ability to establish a «meta-communication» or as Bateson refers to a «hierarchy of logical prototypes» that provides the ability to learn about the context (normative criteria, continuity, memory, control, interaction, selectivity and interdependence).
3. The ability of autonomous motility and its integration into a cooperative collective mobilization through coupled oscillatory movements (cognitive criteria of interaction, interdependence, reduce randomness, control and continuity).
4. Anticipatory reaction to photoluminescence periodic signals (cognitive criteria of control, interaction, anticipation, memory, valence and reduction of randomness).
5. The determination of population density thresholds through the tensegrity structure of the cytoplasm and haptic perception (haptotaxis, elasticotaxis) between contiguous or adjacent cells (cognitive criteria of valence, interdependence, control, memory, selectivity, regulation and continuity).

[16] Cognitive criteria of Pamela Lyon.

They are all part of self-regulation and self-organization of the agencies in the face of «enaction autopoietic» which gives the meaning of cognition as it is «functional circles» minimal, as described Uexküll as a basis for a theory of significance in living organisms, but also as Bateson determined in one of the fundamental criteria for the cognitive process – specifically the fourth criterion.

We have seen that the determination of a quorum, or autoinduction, is responsible for coordinated social behavior, and together with the synchronization of oscillatory pulses allow the control of population densities as well as conferring a memory is called short-range chemical.

Both in the slime and bacteria, as primitive organisms still standing in the history of the origin and biological evolution, have remained both the morphology and physiology almost intact (Baluška and Mancuso, 2009). From them we learned that while the slime bacteria are eukaryotes and prokaryotes, both maintain principles of autopoietic self-organization and development alike. If Maturana was right in identifying between autopoiesis and cognition (Maturana, 1970)[17] – although this identification is not tautological as noted Luisi – then the biochemical and biophysical basis underlying the vital dynamics of their development, causing a conception «teleomechanism» or «vital materialism» – as the successful conception of Timothy Lenoir (1989) – of cognition.

As we can see minimal cognitive foundations of an intelligent systems is not exclusive of higher organisms. Rather share these fundamentals all unicellular animal and not animal, such as slime molds, bacteria, plants and even the endothelial cells of blood vessels, neurons and glia cells. Through these grounds we can establish attempt between the Umwelt and Innenwelt that Uexküll spoke to us a century ago as «tonus»[18] (Uexküll, 1909) and combines as a «minimal cognitive» when tones are recognized among peers, besides being a fundamental condition for a possible biosemiotic biological phenomenology or «bio-phenomenology» in the coming years.

References

Baluška, S., and Mancuso, S. (2009), *Deep evolutionary origins of neurobiology*, Communicative & Integrative Biology 2:1, 60-65.

Barandiaran, X.; Di Paolo, E., and Rohde, M. (2009), *Defining Agency. Individuality, normativity, asymmetry and spatio-temporality in action*, Journal of Adaptive Behavior, in press [Rohde, M., and Ikegami, T. (eds.), Special Issue on Agency].

Barends, T. R., *et al.* (2009), *Structure and mechanism of a bacterial light-regulated cyclic nucleotide phosphodiesterase*, Nature, 459 (7249), pp. 1015-8.

Bateson, G. (1979), *Espíritu y Naturaleza,* Amorrortu Editores, 2006, 2.ª ed., 3.ª reimp., Buenos Aires.

Ben-Jacob, E. (2009), «Learning from Bacteria about Natural Information Processing». In: *Natural Genetic Engineering and Natural Genome Editing,* Edited by G. Witzany, Annual New York Academy of Sciences, 1178, pp. 78-90.

Ben-Jacob, E.; Shapira, Y., and Tauber, A. I. (2006), *Seeking the Foundations of Cognition in Bacteria. From Schrödinger's Negative Entropy to Latent Information*, Physica A, 359, pp. 495-524.

[17] «Living systems are cognitive systems and living as a process is a process of cognition. This statement is valid for all organisms, with or without a nervous system». This would be the assertion that Francisco Varela join with Humberto Maturana to the concept of Autopoiesis, also called Santiago theory (Maturana and Varela, 1980, p. 13).

[18] Uexküll used the term «tonus» to stimulation that is sent to target organs (effectors) from Innenwelt. «Tonusthaltheorem» explains that time and interactive capability of the operator that associates to each living system your Umwelt is like-flows.

CASTRO, O. (2009), *Jakob von Uexküll: El concepto de Umwelt y el origen de la biosemiótica*. Trabajo de investigación para la obtención del DEA, Departament de Filosofia, Universitat Autònoma de Barcelona.

COPE, F. W. (1976), *Derivation of the Weber-Fechner law and the Loewenstein equation as the steady-state response of an Elovich solid state biological system*, Bulletin of Mathematical Biology, 38(2), pp. 111-118.

COPELLI, M. (2002), *Physics of psychophysics. Stevens and Weber-Fechner laws are transfer functions of excitable media,* Physics Review E, 65, 060901-1-4.

GARCÍA MARTÍNEZ, J. M. (2007), *Mecanismos intracelulares de supervivencia y muerte neuronal en modelos excitóxicos y transgénicos de la enfermedad de Huntington*. Tesis doctoral, Universidad de Barcelona, Departamento de Biología Celular y Anatomía Patológica.

HELLINGWERF, K. J. (2005), *Bacterial observations: a rudimentary form of intelligence?,* Trends in Microbiology 13(4), pp. 152-158.

HILLEN, T., and PAINTER, K. J. (2009), *A user's guide to PDE models for chemotaxis*, Journal of Mathematical Biology, 58, pp. 183-217.

HOFFMEYER, J. (1998), *Surfaces inside surfaces. On the origin of agency and life*, Cybernetics and Human Knowing, 5(1), pp. 33-42.

KANG, CH. M., *et al.* (1996), *Homologous Pairs of Regulatory Proteins Control Activity of Bacillus subtilis Transcription Factor B in Response to Environmental Stress*, Journal of Bacteriology, 178(13), pp. 3846-3853.

KELLER, E. F., and SEGEL, L. A. (1971), *Traveling Bands of Chemotactic Bacteria: A Theoretical Analysis*. Journal of Theoretical Biology, 30, pp. 235-248.

KISHIMOTO, U. (1958a), *Rhythmicity in the protoplasmic streaming of a slime mold, Physarum polycephalum I*, The Journal of General Physiology, 41(6), pp. 1205-1222.

— (1958b), *Rhythmicity in the protoplasmic streaming of a slime mold, Physarum polycephalum II*, The Journal of General Physiology, 41(6), pp. 1223-1244.

KOVÁČ, L. (2006), *Life, chemistry and cognition. Conceiving life as knowledge embodied in sentient chemical systems might provide new insights into the nature of cognition*, European Molecular Biology Organization, Vol. 7, No. 6, pp. 562-566.

LENOIR, T. (1989), *The Strategy of Life: Teleology and Mechanics in Nineteenth-Century German Biology*, University of Chicago Press.

LLINÁS, R. R. (2001), *I of the Vortex, From Neurons to Self*, MIT Press.

LUISI, P. L. (2006), *The Emergence of Life: from Chemical Origin to Synthetic Biology*, Cambridge University Press.

MATURANA, H. R. (1970), *Biology of Cognition*. Reimpreso en MATURANA, H. R., and VARELA, F. J. (1980), *Autopoiesis: The Organitation of the Living*, Reidel Publishing Company, Doldrecht, Holland.

MEDINA, A. E., *et al.* (2006), *Restoration of Neuronal Plasticity by a Phosphodiesterase Type 1 Inhibitor in a Model of Fetal Alcohol Exposure*, The Journal of Neuroscience, January 18, 2006, 26(3) pp. 1057-1060.

MIYAKE, Y., *et al.* (1993), *Environment-dependent self organization of positional information field in coupled nonlinear oscillator system*, The IEICE Transactions Fundamentals, E76-A (5), pp. 780-785.

MÜLLER, B. S.; DI PRIMIO, F., and LENGELER, J. W. (2001), «Contributions of Minimal Cognition to Flexibility». In: N. CALLAOS, W. BADAWY & S. BOZINOVSKI (eds.), *SCI 2001 Proceedings of the 5th World Multi-Conference on Systemics, Cybernetics and Informatics,* Vol. XV, Industrial Systems: Part II, by the International Institute of Informatics and Systemics, 93-98.

NAKAGAKI, T. (2001), *Smart behavior of true slime mold in a labyrinth*, Research in Microbiology, 152, pp. 767-770.

NAKAGAKI, T.; YAMADA, H., and TOTH, A. (2000), *Maze-solving by an amoeboid-organism*, Nature, 407, p. 470.

PFEFFER, W. (1888), «Über chemotaktische Bewegungen von Bacterien, Flagellaten u. Volvocineen». In: *Untersuchungen Botanischen aus dem Institut zu Tubingen,* Vol. 2, Verlag von Wilhelm Engelmann, Leipzig, pp. 582-661.

SATO, M.; WONG, T. Z., and ALLEN, R. (1983), *Rheological Properties of Living Cytoplasm. Endoplasm of Physarum Plasmodium*, The Journal of Cell Biology, 97, pp. 1089-1097.

SHUSTER, S. C., *et al.* (1996), *The hybrid histidine kinase DokA is part of the osmotic response system of Dictyostelium*, The EMBO Journal, 15, No. 15, pp. 3880-3889.

STEVENS, S. S. (1957), *On the psychophysical law*, Psychological Review, 64(3), pp. 153-181.

STOCK, A. M., *et al.* (2000), *Two-Component Signal Transduction*, Annual Review of Biochemical, 69, pp. 183-215.

TAKAMATSU, A.; TAKABA, E., and TAKIZAWA, G. (2009), *Environment-dependent morphology in plasmodium of true slime mold Physarum polycephalum and a network grow model*, Journal od Theoretical Biology, 256, pp. 29-44.

UEXKÜLL, J. VON (1909), *Umwelt und Innenwelt der Tiere*, Berlin: J. Springer, 261.

— (1930), *Die Lebenslehre*, Potsdam: Müller und Kiepenheuer Verlag, und Zürich: Orell Füssli Verlag.

— (1940), *Bedeutungslehre*, Leipzig: Verlag von J. A. Barth.

VEDRAL, V. (2010), *Decoding Reality the Universe as Quantum Information*, Oxford University Press, Oxford. In: WERNER, E. (2010), *Meaning in a Quantum Universe,* Science, Vol. 329, No. 5992, pp. 629-630.

WERNER, E. (1996), *Applications of Multi-Agent Systems*, J. W. PERRAM and J.-P. MÜLLER (eds.) (Springer Verlag, Berlin), pp. 19-39.

WITZANY, G. (2008a), *Biocommunication of Unicellular and Multicellular Organisms*, Triple C, 6(1), pp. 24-53.

— (2008b), *Biocommunication of Bacteria and its Evolutionary Interrelations to Natural Genome Editing Competences of Viruses*, Nature Precedings, 1738.2

ÓSCAR CASTRO GARCÍA

Department of Philosophy
Universitat Autònoma of Barcelona
OAS-BioAstronomy Group
Segurilla Astronomical Observatory (OAS)
oscarcastrogarcia@yahoo.es