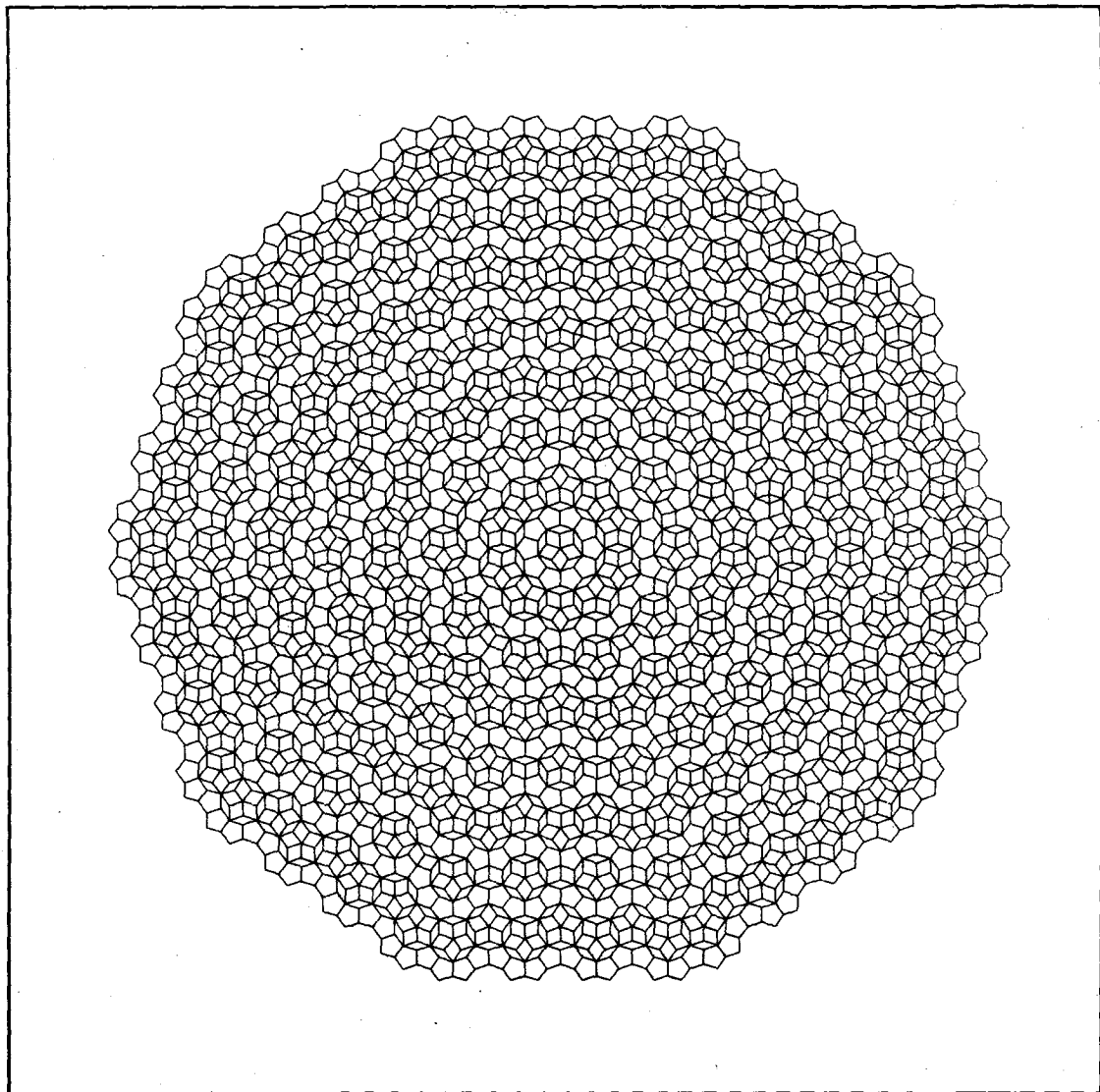


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INFORMATION AND SYMMETRY IN THE BIOLOGICAL AND SOCIAL REALM: NEW AVENUES OF INQUIRY

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1. INTRODUCTION: NEW VIEWS ON TWO CLASSICAL CONCEPTS

Information and symmetry — symmetry and information — constitute overarching concepts within numerous scientific disciplines. Symmetry, from its artistic and geometric origins, has played a guiding role in formulating our present view of matter, forces, fields, chemical bonds, crystal structures, etc. However, it is not an easy concept:

P.W. Anderson, "*by symmetry we mean the existence of different viewpoints from which the system appears the same.*" (Anderson, 1972, p. 394).

K. Mainzer, "*symmetry means the invariance of a theory with respect to a transformation of its coordinates by a mathematical transformation group.*" (Mainzer, 1988, p. 162).

The term information was originally coined by Scholastic philosophers and later taken over by biologists and communication engineers. It has played a guiding role in computer sciences, telecommunications, genetics, molecular biology, neurosciences, and so on. It is not an easy concept either:

G. Bateson "*What we mean by information — the elementary unit of information — is a difference which makes a difference.*" (quoted by Qvortrup, 1993, p.13).

C. F. von Weizsäcker, "*information is only that which produces information.*" (in Küppers, 1990).

Both concepts would have in common: an observer, an object or a system in an environment, epistemic operations (actions) by the observer or by the environment upon the system, and subsequent identification of the changes in the system's components or properties by following the impact of those very changes in the structure of the observer himself/herself or in his/her measurement apparatuses. Symmetry, as the "science of form", focuses on the processes and transformation rules which grant the permanence of structures, while information represents, following its Latin etymology *informare*,

the impinging factors that change the form of these structures (i.e., the breaking of symmetries). Even in this simplified view, an endless regression takes place between both concepts: when looking for symmetries one has to use a previous set of informational exchanges, and when looking for information one has to deal with a previous set of forms and symmetries in the underlying structures. This recursive character is explicit in some of the above definitions — perhaps a more suitable definition could be built by simultaneously embracing both concepts in their recursivity. In part, it is the limited “observational window” of any real observer that implies the appearance of this *ad hoc* interconvertibility between information and symmetry, depending on the time and space scales used for the observation. And of course, the *measurement problem* has to be involved in these elemental considerations too: not only at the quantum level, but also in the spatial, temporal and structural networking of occurrences that necessarily accompany the real-world manifestations of these two concepts (Matsuno, 1992; Gunji et al., 1995).

Both symmetry and information have developed a nucleus with rather crisp conceptualizations — group theory and mathematical information theory — and a large aureole of fuzzy interrelationships, particularly concerning the multiple “meanings” that information actually conveys. In fact, the scope that these “grey” acceptations of information and symmetry may cover is extremely broad: not only in the well-trodden paths of the scientific disciplines above the level of chemistry (particularly biology and the neurosciences), but also in the multifarious dimensions of daily life, in most of the behavioral and socioeconomic interactions, and even in the arena of law, politics, and international conflict.

An initial exploration in the underlying coherence behind these “fuzzy” or “grey” acceptations of symmetry and information in the biomolecular, neuronal, behavioral, and social realms will be the goal of this article. For reasons that will become manifest in the next section, “wet” symmetries will be the term initially chosen.

It is unclear whether the distinction between information and symmetry can be neatly kept in the “fluid” sociobiological realms. It is in the classical paradigm of the sciences (originally for the study of closed systems) where these terms have been divorced and assigned separated roles: the very notions of *state* and *laws of nature* are not alien to that. We might argue that in the biological and social quarters both terms appear as subsumed within a peculiar type of organization based on intertwined *infosymmetrical* processes which together allow for the permanence of the cellular, organismic or social entities. A genuine “social way of existence” takes place which is based on collective problem-solving by the networks of constituent *active* elements (“internal observers”). The culmination of the corresponding *life-cycles* becomes the fundamental referent for the whole processes and problem-solving operations.

Contemporary science has developed an impressive conceptual edifice which allows a learned observer to ascend from the quantum world up to a particular molecule — the “Quantum Staircase” as described by Froggat and Nielsen (1991): Fundamental Symmetries, Lorentz invariant (quantum theory), superstrings, quantum gravity, GUT, Standard model, relativistic hadron physics, nuclear physics, atomic physics, and chemistry. This “edifice” is also described by Mainzer (1988) for the process of emergence of observable chemical structures: Lorentz-invariant quantum systems (EPR-correlations), Galilei-invariant quantum systems, Born-Oppenheimer procedure (molecular quantum mechanics), Hartree-Fock approximation (molecular chemistry). However, there is only a trivial parallel if the observer’s goal is to truly ascend, let us say, from the set of mole-

cules and cells of an individual, up to his/her daily behavior, and to the whole activities of an institution or a company, or even of a nation. And there is little doubt that these organizational instances are mutually interconnected by dense "information flows" — whatever meaning we assign to that term. The classical concept of information, like classical logic, becomes a hindrance in order to comprehend the successive layers of collective problem-solving (and problem-generation) within such information-driven entities: "society of enzymes", "society of cells", "society of individuals".

Part of the reason is the unilateral (mechanistic) emphasis on the positive or *constructive* or side of the informational processes, "presences"— while most of the biological and social phenomena equally rely on spontaneous or provoked *degradative* processes, "absences" (e.g., protein degradation, cell death, obsolescence). The way living beings fabricate, feel and respond to "absences" within their overall problem-solving organization may constitute one of the key factors to enlarge the present understanding of information and symmetry (Marijuán, 1995). In other words, how irrelevant infinities are systematically discarded from the behavioral search-space of these informational entities.

As the last section of this article briefly discusses, it appears that in the *era of information* the present system of the sciences has not yet developed a coherent way of giving meaningful responses, and not just pragmatic ones, for the subtle net of informational processes and exchanges which grant the permanence of the socioinformational entities — our own societies included. This may well be, paraphrasing the philosopher Ortega y Gasset, *the paradox of our time*.

2. "WET" SYMMETRIES AND THE NEW BIOLOGY OF THE CELL

From the energetical point of view, life is a modest phenomenon. All biological reactions are crowded into a very narrow range just above the ionization potential of water, implying very small energy changes (below 1.5 eV). Electrons in such reactions are deprived, step by step, of their bond energy and excreted very often coupled to oxygen, in the form of water. As Szent-Györgyi (1968, pp. 8, 9) eloquently put it: "water is in any case the most central substance of living nature. It is the cradle of life, the mother of life, and its medium. It is our *mother and matrix*."

The wondrous solvent, dielectric, electromagnetic, and crystalline properties of water (just how water structures interact with macromolecules, solute ions, and colloidal particles largely remains an unanswered question — Israelachvii and Wennerström, 1996) represent a world of constructive possibilities, biochemically and biophysically. Grasping the laws which govern the behavior of chemical substances within the "wet" world was incomparably more difficult than for the "solid" one. The classical *law of mass action*, formulated in 1844 by C.M. Guldberg and P. Waage, after Lavoisier's law and Le Chatelier's principle, has been considered the Newtonian law of chemistry: it took 168 years after the appearance of the *Principia* (Hellemans and Bunch, 1988).

Curiously, what this law states is a *mirror symmetry* for chemical reactions. When displaced from equilibrium, when the symmetry of reactions is broken by adding more substrates or products, they "react" with a velocity (reaction rate) that depends on a specific constant times the corresponding concentrations of substrates/products. At

equilibrium the velocity is the same in both directions. In the process of restoring the broken symmetry, a real *chemical work* can be produced by the system, as measured by the change in the entropic and enthalpic components of the Gibb's free energy. This work can be effectively converted, by appropriate molecular devices, to other forms: mechanical, electrical, thermal, light, etc. During recent decades bioenergetics has made big strides towards understanding the fundamentals of such energy interconversion processes (Harold, 1986)

2.1. The Biological Networking of Reactions: Enzymes

The living cell, the "society of enzymes", has become a consummated player in coordinating the symmetry breakings, symmetry restorations, and interconversion processes within massive ensembles of chemical reactions. More than 500 different metabolic reactions, and several hundred specific non-metabolic reactions (performed by DNA-, RNA-, and membrane dedicated enzymes and proteins, plus proteases, protein-kinases, chaperons, etc.) take place within the cellular volume. Every enzyme is in itself an extraordinary "ecological machine" capable of negotiating complex energy exchanges within its internal and external environment, so that the substrate transformation in its active site is performed at an uncanny velocity, in average $10^6 - 10^9$ times above the value mandated by the law of mass action. How this is possible goes well beyond the scope of this brief paper: a host of quantum properties are involved, particularly weak forces and coherent modes of oscillation (Conrad and Liberman, 1982; Fersh, 1985; Conrad, 1990; Welch, 1992; Igamberdiev, 1993). As Liberman (1974) has meaningfully put it, the working of enzymes does not abide to the principle of "minimal action" but to the principle of "minimal *prize* of action". Even the biological flow of time may be related with the irreversible quantum transitions that enzymes perform. The effective decoupling between the two sides of the individual reaction, and the independent commitment of each side to the advancement of the overall life cycle, ends up with the Newtonian "time indifference" that the law of mass action implies. A new arrow of time, the biological one, emerges.

A toy model, based on stochastic automata with binary variables, which captures some of the macroscopic (switching) properties of enzymes and their collective sharing of substrates, effectors, and products has been developed by Marijuán and Westley (1992). This simple model is interesting because it allows a direct comparison between enzymes and similar electronic circuits made out of logical gates and flip-flop elements (Marijuán, 1994). Two aspects become clear. First, the enormous gap in underlying processing power between both types of elements — basically derived from the non-picturable nature of the enzyme function at the quantum level (Conrad, 1985, 1992; Igamberdiev, 1993). And second, the interconnecting role that water and the associated Brownian motion play — the enzymatic, intracellular, and intercellular exchange of signals through the water channel represents an elegant biological solution to the awesome *wiring problem* that plagues the design of VLSI circuits. Again, water provides *de gratis* a fundamental functional aspect. In this regard, when discussing the "functionalist thesis" endorsed by artificial intelligence and artificial life researchers about the separability between "material substrate" and "logical form" in biological systems (Langton, 1988), one cannot help but wonder how the water matrix and the enzyme non-picturable function might be included into that separable "logical form".

2.2. High-Order Cellular Symmetries

What matters for our analysis is that around 10^6 enzymes and proteins of 2,000 different types are simultaneously at work within a standard prokaryotic cell (the figures would be around $10 - 10^3$ higher for the eukaryotic type). These enzymes simultaneously behave as "watchdogs" regarding the detection of potential symmetry breakings, and as "workhorses" for the subsequent symmetry restoration and energy interconversion processes (Matsuno, 1993; Marijuán, 1995). The stringent controlling demands that a such vast enzyme system implies have been tackled by a series of organizational (enzymic) inventions: ordered design of the metabolic net, molecular depots and accumulation of strategic metabolic intermediaries, alternating work/futile cycles, generalized coupling of unfavoured reactions via kinases and phosphatases with the ATP-ADP-AMP system (extremely displaced out of equilibrium) and other nucleotide systems, intracellular compartments, membrane and microtrabecular systems, "metabolons", channeling phenomena, etc. (Srere, 1988; Welch, 1992; Igamberdiev, 1994).

But perhaps the most important controlling device is the network of effectors (activators and inhibitors) acting upon numerous regulated enzymes, proteins, receptors, and channels situated in strategic junctures of the overall net. For instance, classical enzymologists dubbed animal phosphofructokinase (PFK — the most important enzyme in the glycolysis pathway) an "all-hysteric" enzyme, after 7 effectors were authenticated and it was found that a fantastic number of 23 different substances could be impinging in its functioning (Sols, 1981). This generalized "intermolecular sharing" of effectors, substrates, and products appears as the basic evolutionary tool to create functional blocks which can be easily adjusted to meet systemic demands.

In other words, it seems clear that "high order symmetries" (*curvilinear* symmetries for Igamberdiev, 1994) have been evolved by the cell for the only purpose of regulating and controlling many other low order symmetries. This is particularly true for the ATP-ADP-AMP system which acts as a energetic "currency", and also for the especial substances known as second messengers: Ca, cAMP, cGMP, Diacylglycerol, InsP_3 , etc., which are synthesized only for informational purposes. An elegant interpretation based on a putative metabolic field and its corresponding gauge symmetry has been proposed by Welch (1992); also Alves and Marijuán (1995) have made gauge symmetry suggestions based on the stochastic equations that control the behavior of every molecular automata. However, the discussion on second messengers will lead us to the origins and organization of "signaling systems", i.e., to the emergence of the cellular devices responsible for the intercellular exchange of signals loaded with *meaning*; it will be retaken in the next section.

2.3. Enzyme Degradation: New Instances of "Balance"

Until now we have considered enzymes and proteins as stable building blocks. It is time to complete the picture by paying attention to a couple of new experimental fields in the molecular biology of the cell: *protein degradation* and *apoptosis* (cell death). Unexpectedly, these two "negative" topics, previously related to the category of mere cellular waste-disposal systems, have become central topics to explain intracellular and multicellular organization. The balance between synthesis and degradation, construction and destruction, ("presences" and "absences") nowadays appears as crucial for the problem-solving dynamics of the living cell. Could a cell made up of everlasting enzymes and proteins adapt to a changing environment?

The molecular life-cycle of the enzyme involves six basic stages (or seven, for eukaryotes): DNA transduction, RNA maturation, RNA translation at the ribosome, protein folding (with the help of chaperons), native enzyme or period of functional activity, spontaneous degradation, and forced degradation to the constituent amino acids. In relation with the last stage, the cell has evolved a number of *adaptive* mechanisms exploiting this phenomenon of provoked "absences" in its general order of processes: the families of specialized proteases, the proteasome, the ubiquitin system, the N-Rule, the 'destruction box', the *ad hoc* expression of genes, etc. (Driscoll, 1994; Hershko, 1991; Bradshaw, 1989; Bachmair et al, 1986; Neurath, 1989). The list of unicellular and multicellular processes depending on total (or partial) protein degradation by proteases is almost endless, including the control of the cell cycle itself.

The balance between synthesis and degradation is subject to a careful regulation. The fabrication of new enzymes and proteins is the cell's basic concern: about 40 % of the dry weight of the cell is devoted to the ribosomal machinery and auxiliary molecules, which means a prodigious allotment of resources (Goodsell, 1991). Every second, several thousand peptide bonds are formed in the prokaryote (in the hundred thousands for the eukaryotic cell); in a few minutes, a large fraction will be degraded, either spontaneously or forcedly, following what is called the "N-rule". This inevitable destruction implies that by different ways, the "absences" (or *functional voids*) of the enzymes and proteins which should be present have to be felt, and measured, and this information fed into the productive machinery. Then the necessary presences will materialize accordingly. The complex measurement problem that this implies—in time, space, and networking interconnections—is in accordance with the highly sophisticated protein machinery that recently has been found governs gene expression (scores of individual proteins contribute to organize logical "machines" that decide about the expression of numerous genes — Tjian, 1995).

2.4. The Cell as a Problem-Solving "Engine"

In the cellular balance of processes, construction has to dominate, for entropic reasons, upon destruction (which ultimately represents a previous energy investment in the synthesis, not always recoverable, plus the degradation work itself). Accordingly it makes sense saying that the existential problems of the living cell become solved *productively*: by the synthesis of adequate active elements "filling-in" the occurring "functional voids" within the life-cycle of the entity as detected and measured by the active elements themselves. Functional voids represent transient "calls" to the productive (and/or destructive) cellular machinery. Once solved, they may be equated to the amount of chemical work that both the enzymic "work horses" and the synthetic machinery have performed in order to restore the "wet symmetries" inherent to the advancement of the life-cycle trajectory (Marijuán, 1995); *a posteriori* every functional void implies a rather definite energetic countervalue (or at least, a rough estimate seems attainable).

Let us realize that it is the gradients of dynamic information generated at the multiple symmetry-breakings within the overall network of "wet symmetries" that triggers and orientates the use of the structural information accumulated in the DNA and related productive machinery — without this dynamic information produced by the network of active elements, the DNA becomes a useless molecule, an inert chemical structure. But the converse is also true: without the DNA memory, there is no steering capacity for the metabolic net and associated productive machinery. The overall picture is that "voids" or avalanches caused by new metabolites, and/or changes of state in synthesized en-

zyme-proteins, and/or in the expression of genes are systematically solved by the concurrent action of the high-order organization of these very elements: the metabolic net, the signaling system, and — let us put it at the top — the DNA and related synthesizing machinery.

Actually, the overall capacity to *produce* and self-modify the population of active elements according to the problems or needs of the system within a life-cycle trajectory carefully regulated, is what distinguishes the living organization from any other self-organizing process found in nature. Only the “vacuum”, multicellular organisms, and economic systems would share with the cell such an intertwining of infosymmetrical processes underlying the productive (generative) capacity. The parallel between the generative power of the vacuum and biological systems has been elegantly drawn by Conrad (1989, 1996).

3. BUILDING A MULTICELLULAR ORGANISM

The interpretation of the cell as a problem-solving “engine” provides interesting insights into the construction and functioning of multicellular organisms, symmetries included.

The existence of bilateral symmetries in animal species is very often regarded as a Darwinian adaptation to environmental demands, in particular to motion; at the same time translational — e.g., segments — and radial symmetries are disregarded because they do not easily fit into that framework. However, coherent with the heretofore ideas, we are going to argue that symmetries, far from being an adaptive invention, are a necessary feature of complex organisms both in constructive and functional aspects.

The way organisms are built from within, by *intususpection*, is unique to the living. All other constructive macroscopic processes, either in nature or in the artificial world, are made from without, by *accretion*. Only highly sophisticated elemental units (cells) having an internalized description of themselves and carefully controlling their own reproduction and the interaction with the surrounding medium could develop such a peculiar constructive process. The demands posed by the communication with the surroundings have to be emphasized. Prokaryotic cells, for instance, although capable of developing elemental morphogenetic processes, could not materialize the whole “abstract” molecular tools necessary to control a complex multicellular development. Their relatively poor DNA organization and, above all, their too simple “mini-signaling-system” (e.g. what is called the two component pathway — Stock et al., 1990) only allowed for the development of microbial colonies.

The evolution of complex multicellular organisms necessitated two additional features: the development of a global coordinate system, and a very efficient way for cellular individuals to navigate through the differentiated positional and functional spaces. Roughly speaking, the working coordinate system (anterior-posterior, dorsal-ventral, and left-right axes) was provided by batteries of *homeogenes* defining the regional identities, and the navigational intelligence and differentiating capability was provided by the *signaling system*. Once robust batteries of homeogenes and efficient signaling systems were in place within eukaryotic cells, all the bilateral, segmental, and radial symmetries of complex morphologies, and the variety of cell types and differentiated organs appeared explosively. Actually, an extremely fast process of evolutionary com-

plexification took place in the branches of life endowed with such a kind of organization (Wills, 1989; Ghering, 1992; McGinnis and Kuziora, 1994; Carroll, 1995).

The cell-cycle control was a necessarily previous multicellular achievement. Taming the molecular processes involved in the reproduction of cells made them amenable both to a complex intuspection process and to the development of specialized functions for the whole organism. It implied a coherent integration among the above cellular subsystems, the reproductive machinery, and a new, sophisticated cell-death machinery (apoptosis). The process of apoptosis has been recently recognized as a normal developmental event that is critical for organogenesis in a wide variety of contexts. The inhibition of apoptosis is lethal for even the simplest multicellular organisms (e.g., *C. elegans*); its partial malfunctioning causes severe illnesses (Thompson, 1995). Like the protein degradation case, it adds a new instance of balance, of "flux", to cells themselves and to multicellular organization.

In the process of multicellular development, the capacity to "set aside" groups of dormant cells that will follow a differentiated developmental path — or e.g., will suffer apoptosis — becomes a fundamental aspect (Davidson et al., 1995). It implies a delicate fine-tuning between the signaling system and the cell-cycle machinery (the instances known as "checkpoints" constitute the specialized interface between both subsystems — Murray, 1992; Kirschner, 1992). How additional regional and positional identities are superimposed upon such "set aside" cell groups is the next question. As it has been recently discovered, the individual identities are achieved after a series of repeated "infosymmetrical processes" which parcel out the masses of cells. For decades, two rival developmental schools had argued about the dominant role played either by "genetic addresses" (García Bellido et al., 1979), or by diffusion gradients of morphogenetic factors à la Turing (1952). The new developmental findings have now established that both mechanisms are elegantly ("symmetrically") interlinked: activated master-genes provoke the appearance of morphogenetic gradients, which in their turn provoke the differential activation of new genes, which subsequently provoke the formation of new, finer morphogenetic gradients, and so on (Basler and Struhl, 1994; O'Farrell, 1994). This hierarchy of successive levels of interlinked information-gradients and modification of cellular high-order symmetries, involving batteries of homeogenes, seem to have governed morphology and differentiation both for vertebrates and invertebrates along the whole evolutionary process (surprisingly, even the development of an organ as diversified as the eye has been consistently conserved — Ghering, 1995).

3.1. Multicellular Problem-Solving: "Informational Physiology"

During the developmental path that totipotent cells follow towards specialization, the net of receptors and channels (in the thousands), converter enzymes (in the hundreds -mostly protein kinases and phosphatases), and second messengers (less than ten) which are integrated into the signaling system, have to be specifically tailored in order for the cell to be able to "understand" the incoming informations, and to appropriately respond to them (Bray, 1990; Egan and Weinberg, 1993). Within the especial processing space of the signaling system, informational operations of compression and decompression are performed which discard scores of irrelevant phenomena and allow establishing a precise correspondence between specific microscopic events (incoming or outgoing signals) and avalanches of internal symmetry-breakings (functional voids). Subsequently, cells may exchange signals loaded with *meaning*, or information content, about their own internal states (Marijuán, 1996).

The incoming signals imply a “call to action”, the mobilization of specialized enzymic pools of the target cell in order to contribute to solve the problems — functional voids — of the cells who have send the signal. In this regard, the limited rate of protein synthesis and the limited available intracellular space and water (solvation rate) have been powerful motive forces for cells to differentiate and specialize their individual enzymic pools, increasing their conjoint metabolic efficiency. (And the related necessity to bridge the gap between the microscopic dimension of the received signal and the mesoscopic or macroscopic dimension of the targeted metabolic network is one of the basic reasons for the existence of long chains of amplifying protein-kinases within the signaling system — see Conrad, 1984, 1990).

The multiplicity of systems within the multicellular organization (digestive, circulatory, respiratory, muscle-skeletal, hormonal, neuro-endocrine, immune system, nervous system...) may be understood as evolutionary inventions to distribute global problems of the organism —functional voids at the organismic level— among specialized populations of cells. These inventions maximize the local problem solving capabilities and minimize the related bulk processes of transportation, energy expenditure, waste, entropy production, etc. As a result, a coherent organismic life is made possible (Marijuán, 1996). The global problems of the organism may be broken down among populations of specialized cells working in differentiated subsystems. The exchanged signals convey the meaning of performing specialized cellular functions; obviously the recipient cells need the appropriate apparatus (signaling system) in order to decode and build the “meaning” (or its abstract equivalent), and be able to internally solve it, and export the solution. But it is a process which has to occur in both directions: local needs of cells have to be integrated into global organismic signals (cells as problem-generators), and global organismic needs have to be decomposed into microscopic signals generating functional voids in local cells (cells as problem-solving engines). As we have already pointed out, most of these signaling processes make use of the massive interconnecting properties of the water-channel.

For instance, how the blood glucose concentration in mammals is kept constant (perhaps, with the oxygen and water intake, the most important organismic “void” to be regularly filled-in) constitutes a extremely robust and sophisticated process which implies the water-mediated activities of scores of specialized cells and organs: liver, pancreas, intestine, heart, skeletal muscles, brain (hunger and satiation behavior), etc. An intricate interplay between circulating hormones (e.g., insulin) and a multitude of intracellular proteins (particularly the plasma-membrane glucose transporters) and metabolic depots (glycogen, lipids) takes place at the molecular level (Mueckler and Holman, 1995). Traditionally it is only at the neuronal tissue of the brain where “information processing” is looked upon. However, whatever aggregate we may observe at the level of multicellular organization, it can be interpreted as an information processing and productive device which functions to detect, measure, amplify, solve, exchange, export, etc., the occurring problems — functional voids, as we say here — of the cellular individuals and the whole organism in the advancement of the life-cycle (Marijuán, 1995, 1996).

3.2. On the Nervous System

The nervous system, the “society of neurons”, is an internal specialized subsystem which, from initial trophic functions (Horridge, 1968), has evolved to lead the whole organism in its problem-solving interaction with the external environment. The most sophisticated “social” outcome of neurons is the production of adaptive behavior and

learning. For an individual neuron, depolarizations and production of spikes may be understood as instances of functional voids generation and solution: the production of spikes, with the associated synaptic, cytoplasmic and nuclear events, restores the symmetry-breaking of depolarization.

Duality Theory, as developed by Collins (1991), see also Collins and Marijuán (1996), contemplates the vertebrate brain as an abstract problem-solving playground where topologically distributed variables ("tuning precision voids") occurring at the neuronal columns of cerebral maps are processed as an overall entropy that different brain sub-structures tend to minimize. Because of the evolutionary design of nervous systems (e.g., the vertebrate phenomenon of *decussation*) internal and external organismic "problems" locally increase that entropy value. The subsequent blind (abstract) minimization by the nervous system's topological mechanisms produces as a byproduct the adequate behavioral and learning outputs. A problem-solving behavior well adapted to the advancement of the individual's life cycle emerges from all these distributed processes and minimization operations.

The above theory integrates neurophysiological and neurocomputational phenomena (e.g., "decussation", "tuning precision voids") with cognitive and emotional processes (e.g., "memory-addressing", "prejudice towards the familiar"), providing a sensible explanation about the emergence of biologically adaptive behavior. But perhaps its most interesting aspect regards the use of symmetry transformations in the projections of sensory maps towards secondary and tertiary association areas. "Canonical representations" are formed which provide a unique signature to the perceptual phenomena, agglutinating the neuronal dialects of the different sensory modalities and allowing an economic information-storage into the cortical memory.

If the basic postulates of this theory are correct, we find again a dramatic intertwining of infosymmetrical processes at the highest cognitive level. Symmetry and Information, as distinctive categories of human consciousness, would correspond to two separated, but interlinked modes of mental operation: metasensory-dominance and metamotor-dominance. They respectively correspond to the shifting relationships established in between the frontal cortex and the sensory and the motor areas, which are mediated by the convergence in the basal ganglia. Quite a few dual categories, e.g.: listening versus speech, perception versus action, synthesis versus analysis, symmetry versus information, would emerge from this unending oscillation underlying the highest cognitive function.

Perhaps the present formalizations on information and symmetry might be fruitfully enlarged in order to discount — integrate — the distinctively *human factors* that are derived from the evolutionary nature of our system of perception/action.

4. PROBLEM-SOLVING IN THE "SOCIETY OF INDIVIDUALS"

There is little doubt that human societies are organized around the life-cycle of individuals, the satisfaction of their vital needs. It is a fact that underlies the social invention of multiple specialized systems (e.g., economic, legal, political, cultural systems; technologies, arts, communications, etc.). These systems, again, can be understood as tools to allow the distribution of global problems among specialized populations of problem-solver agents, and vice versa (Marijuán, 1996).

In the economic process, problem-solving interactions are particularly rich both in information and symmetries. Basic economic tools such as *money* and the system of *prices* imply a continuous intertwining of infosymmetrical processes by the participant agents –not unlike the use of ATP and second messengers by the cell, or the use of morphogenetic factors in multicellular development: somehow the measurement of economic “absences” within markets parallels the molecular measurements by signaling systems. For reasons not far away from the ones impelling cell differentiation, the adaptive behavior of individuals trying to fill in the necessities of their life cycles has led to specialized trades and professions. In this context of specialization, the system of market/prices works as an abstract, distributed information-processing device which detects, measures, communicates, amplifies, solves, etc., the needs of the specialized individuals within the social ensemble (Marijuán, 1996). Prices within the market constitute the signals that convey the information related to the unfulfilled needs of individuals with respect to the productive structures. Money becomes both a measuring instrument and an abstract problem-solving device to spatially and temporally play with (react to) the gradients created by such unfulfilled symmetries: the spatio-temporal price gradients perceived by the productive (and consumer) agents generate changes in the productive structures, which modify the price gradients themselves, which in their turn generate new productive structures, etc.

The permanence of the economic agents is granted through a careful measurement process of their internal state. The whole internal production and consumption changes in every productive agent are regularly compressed, through the accounting system (curiously, comprising a “balance” and a double or “symmetric” accounting process), into a few symbolic signals: *price*, *cost*, *benefit*. It is these highly abstract signals, and their spatio-temporal gradients, that are used by the other agents in their own economic games, discarding the infinite complexities of the ongoing life-stories. In the overall picture that emerges, what should count, at least from the perspective of natural science, is not only how “selfish agents” maximizing their own benefit could produce overall optima (Kauffman, 1993), but how the amazing informational choreography that underlies the economic process might take place. Later it can be discussed whether most of that choreography is competitive, or predominantly cooperative.

Symmetry may find another profound meaning in political science. In democratic societies, there is a continuous legal and political struggle to guarantee “equal opportunities” — if conflicts and excesses of “social entropy” are to be avoided. It is to say, the legal system and the political system have to restore basic symmetries in the relationships between individuals, lost during the economic process. A complicated system of balances between both symmetry and symmetry-breaking seems the only way for societies to maximize the vital problem-solving dynamics of their own members (well-being, “happiness”). A scientific underpinning for human rights and democratic systems may be envisioned. Indeed symmetry and symmetry-breaking (and information compression) are ubiquitous in many other facets of social life: culture, art, religion, sports, games... As a matter of fact, symmetry becomes a necessary component of any non-coercive, durable interrelationships between individuals or institutions. The oft-cited “tit for tat” rule, which derives from the prisoner dilemma, and which has been deemed the best strategy to promote collaboration and prevent conflict (Axelrod, 1984), is a symmetry rule after all.

As was suggested in the Madrid 1994 conference on *Foundations of Information Science* (Marijuán, 1996b), the “society of enzymes”, the “society of neurons”, and the

“society of individuals”, at last may well be following similar information-symmetry based, existential strategies.

A brief, final comment on “information science” is inescapable. As we have mentioned at the Introduction, it looks at least paradoxical that while contemporary society is entering into the *information era*, the informational phenomena have been discounted as mere epiphenomena unrelated to the discussion of any disciplinary foundation. The possibility of a genuine information science does not mean envisaging a pandemonium where finally everything resolves into information, imitating the reductionist stance of classical physics; but seriously considering the construction of a new scientific perspective, the fragments of which are presently scattered away in other disciplines (philosophy, mathematics, physics, computer sciences, biology), to be devoted to the study of the vast field of informational phenomena in nature and society. This new science could indeed contribute in an equal footing with other disciplines to the “interdisciplinary exploration” that the system of sciences performs (Marijuán, 1996b). In this sense, an array of information based subdisciplines such as information physics, informational chemistry, bioinformation, and socioinformation could represent a valuable complement to chemical physics, biophysics, biochemistry, psychobiology, and sociopsychology (or for that matter, neurophysics, neurochemistry, sociophysics, sociochemistry, and sociobiology), and of course, to economy and political science.

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