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Patterns of Life: Intertwining Identity and Cognition

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1. CONTEXT

Artificial Life's (AL) vocation is to contribute to a better scientific theory of life and of living organisms. I take AL to be guided by two principal motivations.

1. Building artificial living beings/objects as a proof for competing claims about different aspects of life and different levels of the living organization. This is the same motivation of artificial intelligence in regards to cognitive science. It is indeed an innovation in science, since physics relied principally on prediction for proof and validation. In these cases we also have validation by construction, quite a different matter.

2. Using the results of AL for practical and technological concerns. I think that the circulation between research and technological innovation is to a large extent what made this new wave of AL attractive. There is, again, a parallel to the AI of the early 60s, where the technological loop was first established with expert systems and such. In the case of AL, applications to nanotechnology and robotics play a similar role, at least in the public and the funder's eyes.

It is clear that AL has long historical roots and that it has fed to and from many parallel endeavors, of which it is a recent reincarnation, so to speak. These roots comprise most patently the cybernetics movement in the 50s, and the cognitive science and AI in the 80s, but it surely it is complex and multiple-branched tree. This is not to deny that AL has a specificity today which is amplified significantly by the convergence of previous results and

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new research tools. However, in so far as it is important in science to see where one comes from, among many other reasons to avoid repeating mistakes, the historical roots of AL should be investigated in a serious manner.

It is also clear that there are a number of epistemological options for diverse research programs in AL. We need to be clear about them. For this special issue, my purpose here is to sketch the options that I have been cultivating for some 20 years and why.

2. THE AUTONOMY VIEWPOINT

I want to start by declaring that I think that understanding of organisms and the living *is* possible, that defining these terms in a satisfactory manner is not a utopian dream, and that we even have a good deal of the road already charted. However, this is under a fundamental condition: that the autonomy of the living is highlighted instead of forgotten, as it has been (Varela, 1979; Varela & Bourgine, 1991).

To highlight autonomy means essentially to put at center of the stage two interlinked propositions.

Proposition 1: Organisms are fundamentally a process of constitution of an identity.

(a) By identity I intend here a unitary quality, a coherence of some kind. It is not meant as a static structural description (it is a process), nor as carrying a mentalistic or psychological connotations (it is identity in a generalized not a personalistic sense).

(b) The nature of this process is always one of a operational closure (Varela, 1979), that is, a circular reflexive interlinking process, whose primary effect is its own production.

(c) It is this operational closure which gives rise to an emergent or global coherence, without the need of a ‘‘central controller,’’ hence the identity I have in mind here is nonsubstantially localized, and yet perfectly able to generate interactions.

(d) An essential key here is, of course, what we have recently learned about ‘‘emergent’’ properties in various complex systems.

(e) Different organisms differ in the kinds of multifarious identity mechanisms they have, due to their unique evolutionary pathways.

Proposition 2: The organism’s emergent identity gives, logically and mechanistically, the point of reference for a domain of interactions.

(a) The living identities are produced by some manner of closure, but what is produced is an emerging interactive level. The interactions have relevance and consequences for the unitary identity, although mechanistically all interactions occur both at component level and unity’s level.

(b) The configurations of a level of interaction for the entire unit creates

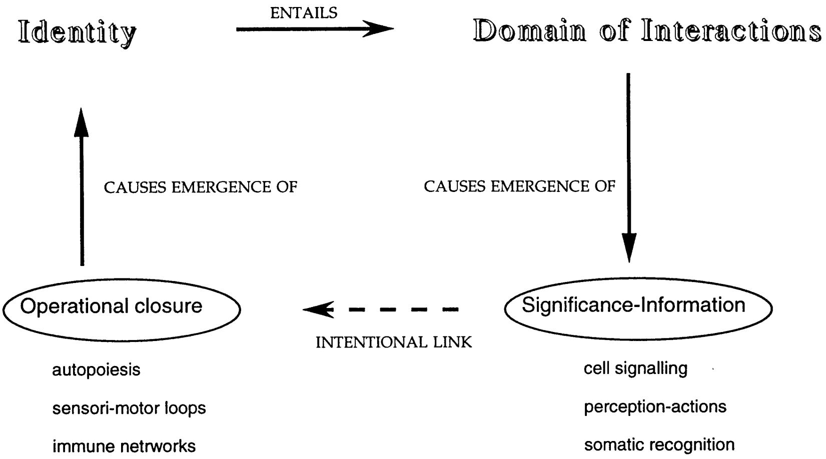

FIG. 1. The two key intertwined concepts to account for the autonomy of the living.

a perspective from which an interaction can occur. In other words, this is the source for informational, intentional, or semantic values to all living organisms.

(c) This entails that living systems bring forth significance: organisms are autonomous, not heteronomously directed.

These two key notions—how identity comes about and what this identity permits as generating life's proper domain of existence expressed in Propositions 1 and 2—are complementary, the flip side of each other. This is illustrated in Fig. 1.

I warn the reader that my position is an explicit one which has the advantage that it can be open for discussion. A second advantage is that we can point to two basic falsifiable consequences of this theory of the organism.

1. No adequate understanding of a level of life will be feasible unless and until the appropriate identity mechanism is identified. In particular this predicts that all functionalist approaches will fail. (This is already quite apparent in the current study of the origin of life).

2. The role of historical coupling and contingency is not secondary but inseparable from organismic existence, since identity is not ''substantial'' or ''abstract.'' In particular, there cannot be a disembodied theory of life, and the work of simulations can only be a help, not a reconstitution.

3. CELLULAR IDENTITY

In this section take the general scaffolding present in Section 2 and put it to work on a fundamental aspect of living systems: the cellular unity. This is, of course, not the only one we need to understand, but it will illustrate in some detail all of the key notions covered in Section 2 in a general level.

3.1. Autopoiesis: The Process of Cellular Unity

The bacterial cell is the simplest of living systems because it possesses the capacity to produce, through a network of chemical processes, all the chemical components which lead to the constitution of a distinct, bounded unit. To avoid being trivial, the attribute ‘‘living’’ in the foregoing description must address the process that allows such constitution, not the materialities that go into it, or an enumeration of properties.

But what is this basic process? Its description must be situated at a very specific level: it must be sufficiently universal to allow us to recognize living systems as a class, without essential reference to the material components. Yet at the same time it must not be too abstract; that is, it must be explicit enough to allow us to see such dynamical patterns in action in the actual living system we know on earth, those potentially to be found in other solar systems, and eventually those created artificially by man.

Contemporary cell biology makes it possible to put forth the characterization of this basic living organization—a bio-logic—as that of an autopoietic system (from Greek: self-producing) (Maturana & Varela, 1973, 1980). An autopoietic system—the minimal living organization—is one that continuously produces the components that specify it, while at the same time realizing it (the system) as a concrete unity in space and time, which makes the network of production of components possible. More precisely defined: An autopoietic system is organized (defined as unity) as a network of processes of production (synthesis and destruction) of components such that these components:

(i) continuously regenerate and realize the network that produces them, and

(ii) constitute the system as a distinguishable unity in the domain in which they exist.

This is illustrated in Fig. 2.

Thus, autopoiesis attempts to capture the mechanism or process that gener-

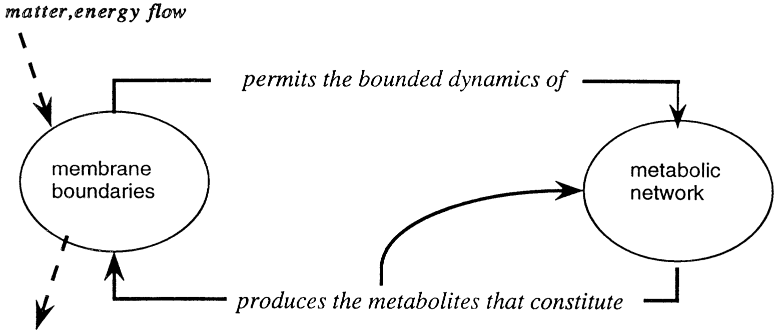

FIG. 2. Outline of the autopoietic closure of the minimal living organization.

ates the identity of the living and thus to serve as a categorical distinction of living from nonliving, not more not less. This identity amounts to self-produced coherence: the autopoietic mechanism will maintain itself as a distinct unity as long as its basic concatenation of processes is kept intact in the face of perturbations and will disappear when confronted with perturbations that go beyond a certain viable range which depends on the specific system considered. Obviously, all of the biochemical pathways and membrane formation in cells can be immediately mapped onto this definition of autopoiesis.

It important to point out two aspects of the living phenomenology that this autopoietic characterization does not address in detail. First, how this basic autopoietic organization, present at the origin of terrestrial life, becomes progressively complexified though reproductive mechanisms, compartmentalization, sexual dimorphism, modes of nutrition, symbiosis, and so on, giving rise to the variety of pro- and eukaryotic life on Earth today. Second, I take here the view that reproduction is not intrinsic to the minimal logic of the living. Reproduction must be considered as an added complexification superimposed on a more basic identity, that of an autopoietic unity, a complexification which is necessary due to the constraints of the early conditions on a turbulent planet. It is here where particular molecular classes play a key role, such as nucleic acids. Reproduction is essential for the long-term viability of the living, but only when there is an identity can a unit reproduce. In this sense, identity has logical and ontological priority over reproduction, although not historical precedence.

The typical AL question to ask in this context is then: Can a molecular structure simpler than the already intricate bacterial cell, satisfy the criteria of autopoietic organization? This question can be answered by simulation and analysis of a minimal autopoietic system. Studies of minimal systems converge to the assumption of an enzyme-mediated polymerization reaction basis. Consider for example (Varela, Maturana, & Uribe, 1974) a two-dimensional grid where two kinds of elements can move randomly: substrates (S) and a few catalysts (*). A first transformation (‘‘composition’’) produces new elements as monomers (M), which can link up in chains (‘‘bonding’’), until they decay, with a different kinetics than composition. Simulations show the spontaneous emergence of a polymer chain that loops onto itself. In this simulation we allow differential permeability through the polymer chain (i.e., null for the catalyst, very low for the monomers, high for the substrate) and an approximation to Brownian motion. Interestingly, not only do such self-distinguishing units arise through these very simple rules, but their loopiness is endowed with a degree of self-regulation, as when decay has occurred on a membrane segment. Given the ranges of differential diffusion and decay, the very boundary of the unity permits its own repair back into a unity, again distinct from its background.

Thus simulation illustrates the emergence of a bounded unity, involving the parallel, distributed nature of the chemical-like processes. I wish to add here that we used this cellular automata a decade before they become popular as ideal cases to study emergent properties. The simulation above is an explicit attempt to produce a minimal autopoietic system, and in this sense is quite different from the purpose of other cellular automata, which look for properties other than self-distinction, such as reproduction (in the case of Conway's game of life) or spatiotemporal patterns (in the case of Wolfram's classifications).

What about such minimal autopoietic systems in actual chemical media and as relevant for the origin of life? In fact, the encapsulation of macromolecules by lipid vesicles has been actively investigated as a promising candidate for an early cell (see Deamer, 1985). Luisi and Varela (1989) make the case that a reverse micellar system can come close to the mark for being a minimal autopoietic system. Recently Luisi's group has succeeded in producing micellar systems hosting in its aqueous core a reaction which leads to the production of a surfactant, which is a boundary for the reverse micellar reaction (Bachman, Luisi, & Lang, 1992; Luisi, 1993). The interest of this case is that much is known about these chemical systems making it possible to actually put into a operation a minimal autopoietic system.

So far, I have addressed the issue of organism as a minimal living system by characterizing its basic mode of identity. This is in keeping with Proposition 1 above, which is, properly speaking, to address the issue at an ontological level: the accent is on the manner in which a living system becomes a distinguishable entity and not on its specific molecular composition and contingent historical configurations. For as long as it exists, the autopoietic organization remains invariant. In other words, one way to spotlight the specificity of autopoiesis is to think of it self-referentially as that organization which maintains the very organization itself as an invariant. The entire physicochemical constitution is in constant flux; the pattern remains, and only through the organizational invariance can the flux of realizing components be ascertained. In particular, although autopoietic systems are most certainly dissipative chemical systems, a purely matter–energy characterization misses entirely the specific architecture or material circuitry (e.g. Fig. 2) of these very specific chemical systems, which inaugurate the domain of autonomous individuals, and thus of life altogether.

To repeat: I have addressed here only the minimal organization of cells that gives rise to living autonomy. As I have said, my purpose is to highlight the basic bio-logic which serves as the foundation from which the diversity visible in current organisms can be considered: only when there is a identity can elaborations be seen as family variations of a common class of living unities. Every class of entities has an identity which is peculiar to them; the uniqueness of the living resides in the kind of organization it has.

Now, the history of biology is, of course, marred by the traditional opposition between the mechanist/reductionists on the one hand and holist/vitalists on the other, a heritage from the biological problem-space of the 19th century. One of the specific contributions of the study of self-organizing mechanisms—of which autopoiesis is a specific instance—is that the traditional opposition between the component elements and the global properties disappears. In the simple example of the cellular automaton illustrated above, it is precisely the reciprocal causality between the local rules of interactions (i.e., the components rules, which are akin to chemical interactions) and the global properties of the entity (i.e., its topological demarcation affecting diffusion and creating local conditions for reaction) which is in evidence. It appears to me that this reciprocal causality does much to evacuate the mechanist/vitalist opposition and allows us to move into a more productive phase of identifying various modes of self-organization where the local and the global are braided together explicitly through this reciprocal causality. Autopoiesis is a prime example of such dialectics between the local component levels and the global whole, linked together in reciprocal relation through the requirement of constitution of an entity that self-separates from its background. In this sense, autopoiesis as the characterization of the basic pattern of the living does not fall into the traditional extremes of either vitalism or reductionism.

3.2. Identity of the Living and Its World

The second, complementary dimension of basic bio-logic that is central to focus our discussion is the nature of the relationship between autopoietic autonomous unities and their environment, in keeping with Proposition 2. It is ex-hypothesis evident that an autopoietic system depends on its physicochemical mileu for its conservation as a separate entity, otherwise it would dissolve back into it. Whence the intriguing paradox proper to an autonomous identity: the living system must distinguish itself from its environment, while at the same time maintaining its coupling; this linkage cannot be detached since it is against this very environment from which the organism arises, comes forth.

Now, in this dialogic coupling between the living unity and the physicochemical environment, there is a key difference on the side of the living since it has the active role in this reciprocal coupling. In defining what it is as unity, in the very same movement it defines what remains exterior to it, that is to say, its surrounding environment. A closer examination also makes it evident that this exteriorization can only be understood, so to speak, from the ‘‘inside’’: the autopoietic unity creates a perspective from which the exterior is one, which cannot be confused with the physical surroundings as they appear to us as observers, the land of physical and chemical laws *simpliciter,* devoid of such perspectivism.

In our practice as biologists we switch between these two domains all the time. We use and manipulate physicochemical principles and properties, while swiftly shifting to the use of interpretation and significance as seen from the point of view of the living system. Thus a bacteria swimming in a sucrose gradient is conveniently analyzed in terms of the local effects of sucrose on membrane permeability, medium viscosity, hydromechanics of flagellar beat, and so on. However, on the other hand the sucrose gradient and flagellar beat are interesting to analyze only because the entire bacteria points to such items as relevant: their specific significance as components of feeding behavior is only possible by the presence and perspective of the bacteria as a totality. Remove the bacteria as a unit, and all correlations between gradients and hydrodynamic properties become environmental chemical laws, evident to us as observers but devoid of any special significance.

I believe that this truly dialectical relationship is a key point. In fact, it might appear as so obvious that we do not appreciate its deep ramifications. I mean the important distinction between the environment of the living system as it appears to an observer and without reference to the autonomous unity—which we shall call hereafter simply the environment—and the environment for the system, which is defined in the same movement that gave rise to its identity and that only exists in that mutual definition—hereinafter the system’s world.

The difference between environment and world is the surplus of signification which haunts the understanding of the living and of cognition, and which is at the root of how a self becomes one. It is quite difficult in practice to keep in view the dialectics of this mutual definition: neither rigid isolation nor simple continuity with physical chemistry. In contrast, it is easy to conflate the unit’s world with its environment since it is so obvious that we are studying this or that molecular interaction in the context of an autonomous cellular unit and hence to miss completely the surplus added by the organism’s perspective. There is no food significance in sucrose except when a bacteria swims upgradient and its metabolism uses the molecule in a way that allows its identity to continue. This surplus is obviously not indifferent to the regularities and texture (i.e., the ‘‘physical laws’’) that operate in the environment, that sucrose can create a gradient and traverse a cell membrane, and so on. On the contrary, the system’s world is built on these regularities, which is what assures that it can maintain its coupling at all times.

What the autopoietic system does—due to its very mode of identity—is to constantly confront the encounters (perturbations, shocks, coupling) with its environment and treat them from a perspective which is not intrinsic to the encounters themselves. Surely rocks or crystal beads do not beckon sugars gradients out of all the infinite possibilities of physicochemical interactions as particularly meaningful—for this to happen a perspective from an actively constituted identity is essential. It is tempting, at this point, to slide into some vaporous clouds about ‘‘meaning’’ reminiscent of the worst kind of vitalism of the past or informational jargon of the present. What I emphasize here is that what is meaningful for an organism is precisely given by its constitution as a distributed process, with an unbreakable link between local processes where an interaction occurs (i.e., physicochemical forces acting on the cell), and the coordinated entity which is the autopoietic unity, giving rise to the handling of its environment without the need to resort to a central agent that turns the handle from the outside, like an *élan vital,* or a pre-existing order at a particular localization, like a genetic program waiting to be expressed.

If we invert our perspective, this constant bringing forth of signification is what we may describe as a permanent lack in the living: it is constantly bringing forth a signification that is missing, not pregiven or pre-existent. Relevance must be provided *ex nihilo:* distinguish relevant from irrelevant molecular species, follow a gradient uphill and not downhill, increase the permeability to this ion and not to that one, and so on. There is an inevitable *contretemps* between an autonomous system and its environment: there is always something which the system must furnish from its perspective as a functioning whole. In fact, a molecular encounter acquires a significance in the context of the entire operating system and of many simultaneous interactions.

The source for this world-making is always the breakdowns in autopoiesis, be they minor, like changes in concentration of some metabolite, or major, like disruption of the boundary. Due to the nature of autopoiesis itself—illustrated in the membrane repair of the minimal simulated example above—every breakdown can be seen as the initiation of an action on what is missing on the part of the system so that identity might be maintained. I repeat: no teleology is implied in this ‘‘so that’’: that’s what the self-referential logic of autopoiesis entails in the first place. The action taken will be visible as an attempt to modify its world—change from place of different nutrients, increase in the flow of a metabolite for metabolic synthesis, and so on.

In brief, this permanent, relentless action on what is lacking becomes, from the observer side, the ongoing cognitive activity of the system, which is the basis for the incommensurable difference between the environment within which the system is observed and the world within which the system operates. This cognitive activity is paradoxical at its very root. On the one hand the action that brings forth a world is an attempt to reestablish a coupling with an environment which defies the internal coherence through encounters and perturbations. However, such actions, at the same time, demarcate and separate the system from that environment, giving rise to a distinct world.

The reader may balk at my use of the term cognitive for cellular systems. But from what I have said it should be clear that the constitution of a cognitive domain links organisms and their worlds in a way that is the very essence of intentionality as used in modern cognitive science, and as it was originally introduced in phenomenology. My proposal makes explicit the process through which intentionality arises: it amounts to an explicit hypothesis about how to transform this philosophical notion of intentionality into a principle for natural science. The use of the term cognitive here is thus justified because it is at the very base of how intentionality arises in nature.

In brief, the term cognitive has two constitutive dimensions: first its coupling dimension, that is, a link with its environment allowing for its continuity as individual entity; second its interpretative dimension, that is, the surplus of significance a physical interaction acquires due to the perspective provided by the global action of the organism.

4. NEUROCOGNITIVE IDENTITY

4.1. Perception–Action as Basic Neuro-logic

In the previous section, I have presented the fundamental interlock between identity and cognition, Propositions 1 and 2, as they work in the case of a minimal organism. In this section I want to show how the more traditional level of cognitive properties, involving the brains of multicellular animals, is in some important sense the continuation of the very same basic process.

The shift from minimal cellularity to organism with nervous system is swift and skips the complexity of the various manners in which multicellular organisms arise and evolve. This is a transition in units of selection, and one that implicates the somatic balance of differentiated populations of cells in an adult organism as well as crafty development pathways to establish a bodily structure. As Buss has stated recently, ‘‘The evolution of development is the generation of a ‘somatic ecology’ that mediates potential conflicts between cell and the individual, while the organism is simultaneously interacting effectively with the extrasomatic environment’’ (Buss, 1987, p. 12). For my purposes here I will expeditiously assume the identity of a multicellular organism, distinctly different from an autopoietic minimal entity in its mode of identity, but similar in that it demarcates an autonomous entity from its environment (Varela & Frenk, 1987).

Now, what’s the specific place of the nervous system in the bodily operation of a multicellular? This is, I believe, the key observation: Whenever motion is an integral part of the lifestyle of a multicellular, there is a corresponding development of a nervous system linking effector (muscles, secretion) and sensory surfaces (sense organs, nerve endings). The fundamental logic of the nervous system is that of coupling movements with a stream of sensory modulations in a circular fashion. The net result are perception–action correlations arising from and modulated by an ensemble of intervening neurons, the interneuron network. Correspondingly, neurons are unique among the cells of a multicellular organism in their axonal and dendritic ramifications permitting multiple contacts and extending for large distances (relative to cellular soma sizes) providing the essential medium for this intra-organismic sensor–effector correlation.

In contrast to the usual mode of description for neural architectures, I wish to emphasize from the start the situatedness of this neuro-logic: the state of activity of sensors is brought about most typically by the organism's motions. To an important extent, behavior is the regulation of perception. This does not exclude, of course, independent modulations from the environment. However, what is typically described as a ''stimulus'' in the laboratory, a perturbation which is deliberately independent of the animal's ongoing activity, is less pertinent (outside the laboratory) for understanding the biology of cognition.

Let me backtrack a moment and reframe our discussion on cognitive self alongside that of a minimal molecular self. I am claiming that contemporary neurosciences—like cell biology for the case of the living organization—give enough elements to conceive of the basic organization for a cognitive self in terms of the operational (not interactional!) closure of the nervous system (Maturana & Varela, 1980; Varela, 1979). I speak of closure to highlight the self-referential quality of the interneurons networks and of the perceptuomotor surfaces whose correlations it subserves. The qualification operational emphasizes that closure is used in its mathematical sense of recursivity, and not in the sense of closedness or isolation from interaction, which would be, of course, nonsense. More specifically, the nervous system is organized by the operational closure of a network of reciprocally related modular subnetworks giving rise to ensembles of coherent activity such that:

(i) they continuously mediate invariant patterns of sensory–motor correlation of the sensory and effector surfaces; and

(ii) they give rise to a behavior for the total organism as a mobile unit in space. This is illustrated in Fig. 3.

The operational closure of the nervous system then brings forth a specific

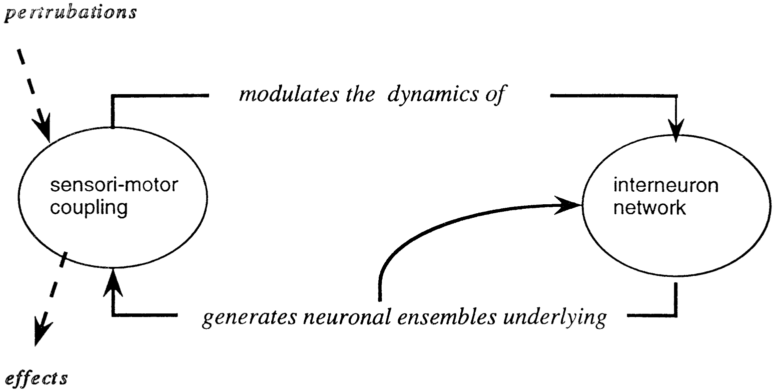

FIG. 3. Outline of the operational closure of the nervous system.

mode of coherence, which is embedded in the organism. This coherence is a cognitive identity: a unit of perception/motion in space, sensory–motor invariances mediated through the interneuron network. The passage to cognition happens at the level of a behavioral entity and not, as in the basic cellular self, as a spatially bounded entity. The key in this cognitive process is the nervous system through its neuro-logic. In other words the cognitive self is the manner in which the organism, through its own self-produced activity, becomes a distinct entity in space, but always coupled to its corresponding environment from which it remains nevertheless distinct. A distinct coherent self which, by the very same process of constituting itself, configures an external world of perception and action.

4.2. Cognitive Self and Perceptual World

The nature of the neurocognitive identity just discussed is, like that of the basic cellular self, one of emergence through a distributed process. What I wish to insist upon here is the relatively recent (and stunning!) conclusion that lots of simple agents having simple properties may be brought together, even in a haphazard way, to give rise to what appears to an observer a purposeful and integrated whole, without the need for a central supervision. We have already touched on this theme when discussing the nature of the autopoietic process and cellular automata modelling and later when discussing the constant arising and subsiding of neuronal ensemble underlying behavior. This issue is crucial for my whole argument: I base my conclusions on contemporary studies from various biology-inspired complex systems which cover a good deal of the ground common to AL researchers in general. It introduces an explicit alternative to the dominant computationalist tradition in the study of cognitive properties for which the central idea is that of processing an external information successively elaborated to reconstitute a centralized representation. This fundamental paradigm of the digital computer program will not do for biology, nor for AI.

I have raised this point to caution the reader against the force of many years of dominance of computationalism and the consequent tendency to identify the cognitive self with some computer program or high level computational description. This will not do. The cognitive self is its own implementation: its history and its action are of one piece. Now this demands that we clarify the second aspect of the neurocognitive identity to be addressed: its mode in relation with the environment.

Ordinary life is necessarily one of situated, embodied agents, continually coming up with what to do faced with ongoing parallel activities in their various perceptuomotor systems. This continual redefinition of what to do is not at all like a plan, stored in a repertoire of potential alternatives, but enormously dependent on contingency, improvisation, and more flexible than planning. Situatedness means that a cognitive entity has—by definition—a perspective. This means that it is not related to its environment ‘‘objectively,’’ that is independently of the system’s location, heading, attitudes, and history. Instead, it relates to it in relation to the perspective established by the constantly emerging properties of the agent itself and in terms of the role such running redefinition plays in the system’s entire coherence.

Again, as we did for the minimal cellular self, we must sharply differentiate between environment and world. Again the mode of coupling is double. On the one hand, such body-in-space clearly happens through the interactions with the environment on which it depends. These interactions are of the nature of macrophysical encounters—sensory transduction, muscle force and performance, light and radiations, and so on—nothing surprising about them. However, this coupling is possible only if the encounters are embraced from the perspective of the system itself. This amounts, quite specifically, to elaborating an interpretation relative to this perspective. Whatever is encountered must be valued one way or another—like, dislike, ignore—and acted on some way or another—attraction, rejection, neutrality. This basic assessment is inseparable from the way in which the coupling event encounters a functioning precept–motor unit, and it gives rise to an intention that unique quality of living cognition.

Phrased in other terms, the nature of the environment for a cognitive self acquires a curious status: it is that which lends itself to a surplus of significance. Like jazz improvisation, environment provides the ‘‘excuse’’ for the neural ‘‘music’’ from the perspective of the cognitive system involved. At the same time, the organism cannot live without this constant coupling and the constantly emerging regularities; without the possibility of coupled activity the system would become a mere solipsistic ghost.

For instance, light and reflectance (among many other macrophysical parameters such as edges and textures, but let us simplify for the argument’s sake), lend themselves to a wide variety color spaces, depending on the nervous system involved in that encounter. During their respective evolutionary paths, teleost fishes, birds, mammals, and insects have brought forth various different color spaces not only with quite distinct behavioral significance, but with different dimensionalities so that it is not a matter of more or less resolution of colors (Thompson, Palacios, & Varela, 1992). Another dramatic example of this surplus significance and the dazzling performance of the brain as the generator of neural ‘‘narratives’’ is provided by the technology of the virtual realities. What is most significant for me here is the veracity of the world which rapidly springs forth: we inhabit a body within this new world after a short time of trying this new situation (i.e., 15 min or so), and the experience is of truly flying through walls or of delving into fractal universes. This is so in spite of the poor quality of the image, the low sensitivity of the sensors, and the limited amount of interlinking between sensory and image surfaces through a program that runs in a personal computer. Through its closure of the nervous system is such gifted synthesizer of regularities, that any basic material suffices as an environment to bring forth a compelling world.

This very same strategy of the situatedness of an agent which is progressively endowed with richer internal self-organizing modules is becoming a productive research program even for the very pragmatically oriented field of robotics, as well illustrated in the work of R. Brooks or L. Steels. It is interesting to note that Brooks also traces the origin of what he describes as the ‘‘deception of AI’’ to the tendency in AI (and in the rest of cognitive science as well) to abstraction, i.e., for factoring out situated perception and motor skills. As I have argued here (and as Brooks argues for his own reasons), such abstraction misses the essence of cognitive intelligence, which resides only in its embodiment. It is as if one could separate cognitive problems in two parts: that which can be solved through abstraction and that which cannot be. The second is typically perception–action and motor skills of agents in unspecified environments. When approached from this self-situated perspective there is no place where perception could deliver a representation of the world in the traditional sense. The world shows up through the enactment of the perceptuomotor regularities. ‘‘Just as there is no central representation there is no central system. Each activity layer connects perception to action directly. It is only the observer of the Creature who imputes a central representation or central control. The creature itself has none: it is a collection of competing behaviors. Out of the local chaos of their interactions there emerges, in the eye of the observer, a coherent pattern of behavior’’ (Brooks, 1987, p. 11).

To conclude, the two main points that I have been trying to bring into full view in this section devoted to the cognitive identity are as follows. First, I have tried to spell out the nature of its identity as a body in motion-and-space through the operational closure of the interneuron network. This activity is observable as multiple subnetworks, acting in parallel and interwoven in complex *bricolages,* giving rise again and again to coherent patterns which manifest themselves as behaviors. Second, I have tried to clarify how this emergent, parallel, and distributed dynamics is inseparable from the constitution of a world, which is none other than the surplus of meaning and intentions carried by situated behavior. If the links to the physical environment are inevitable, the uniqueness of the cognitive identity is this constant genesis of meaning. Or, again to invert the description, the uniqueness of the cognitive agent is this constitutive lack of signification which must be supplied faced with the permanent perturbations and breakdowns of the ongoing perceptuomotor life. Cognition is action about what is missing, filling the fault from the perspective of a cognitive agent.

5. THE CLOSURE GALAXY

The last two sections illustrate the strategy outlined in Section 2 for research program in AL that center its attention to the autonomy of the living.

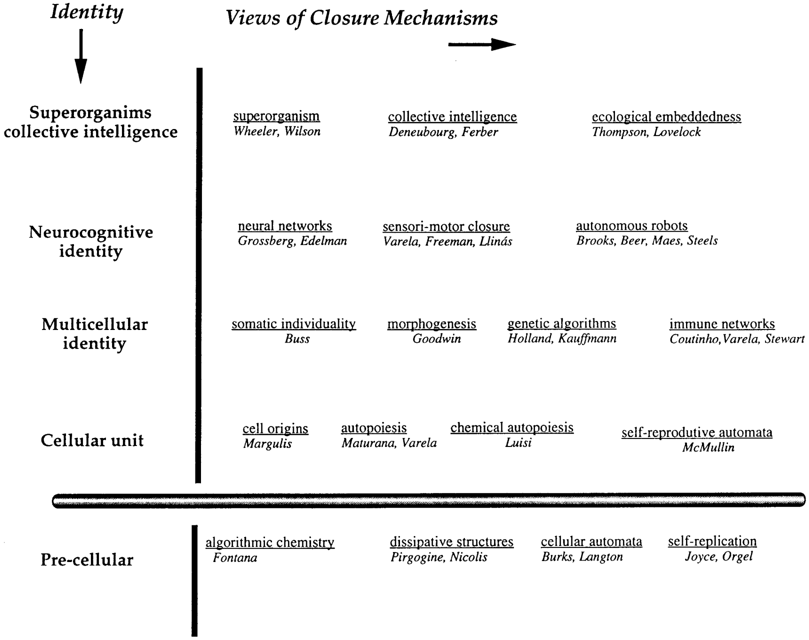

FIG. 4. A view of the "closure galaxy," with authors whose work touch various levels of identity and specific closure mechanisms.

Needless to say, I believe that there is whole constellation of related work that follows broadly, if not explicitly into this framework. This is illustrated in Fig. 4 where the "closure galaxy" is peppered with different contributions to various identity levels and various modes of analysis from empirical to simulations.

It is also very evident by now that I put a very strong emphasis in the explicit analysis of the epistemological grounds onto which one is based for a research direction in AL. It is useful to end, then, by contrasting my brand of AL based on autonomy and other very distinguishable trends in current AL. I distinguish at least three main contrasting paradigms.

1. *Functionalism.* The main strategy here is based on a duplication of function or property as an indicator of adequacy. Briefly stated: as long as we see a property reappear in an artificial system we are getting somewhere, hence greater reliance on simulations. This is quite popular in researchers like C. Langton in AL or D. Dennett in cognitive science, or even more blatantly in popular writers like S. Levy.

2. *Physicalism.* The main point is the reliance on some physical–molecular description, in contrast to some explicit emergent property. Recently, R. Penrose has become an extreme advocate of this position by using quantum mechanics to explain consciousness.

3. *Anti-naturalists.* The main point is to argue that the entire enterprise of defining life, the organism and cognition scientifically is doomed to fail. The most traditional representatives are vitalists of various ilk, but support is less common today. More common are strict dualists like J. Eccles, or more interestingly, neomysterianists like T. Nagel.

A detailed discussion of the various competing paradigms would require another article. I am merely offering this sketch to make it as clear as I can where my own position stands in this diverse ecology of AL schools as they continue to evolve. The future will say who grasped the most fruitful trail. In any case it seem to me that we are onto something and that we already have the beginnings of a good theory of life and the organism.

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