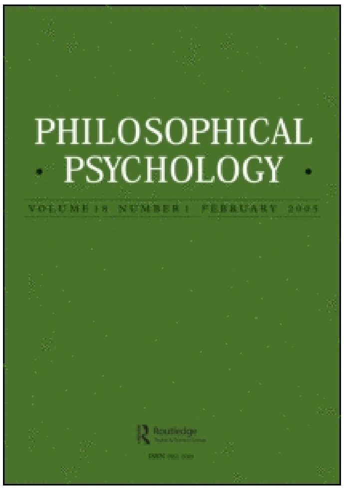

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A patterned process approach to brain, consciousness, and behavior

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A patterned process approach to brain, consciousness, and behavior

JOSÉ-LUIS DÍAZ

ABSTRACT *The architecture of brain, consciousness, and behavioral processes is shown to be formally similar in that all three may be conceived and depicted as Petri net patterned processes structured by a series of elements occurring or becoming active in stochastic succession, in parallel, with different rhythms of temporal iteration, and with a distinct qualitative manifestation in the spatiotemporal domain. A patterned process theory is derived from the isomorphic features of the models and contrasted with connectionist, dynamic system notions. This empirically derived formulation is considered to be optimally compatible with the dual aspect theory in that the foundation of the diverse aspects would be a highly structured and dynamic process, the psychophysical neutral "ground" of mind and matter posed (but not properly determined) by dual aspect and neutral monist theories. It is methodologically sound to approach each one of these processes with specific tools and to establish* concurrences *in real time between them at the organismic level of analysis. Such intra-level and inter-perspective correlations could eventually constitute psychophysical bridge-laws. A mature psychology of consciousness is necessary to situate and verify the bridges required by a genuine mind–body science.*

1. The mind–body problem: an interdisciplinary domain among brain, cognitive, and behavioral sciences

At the present state of development of knowledge and understanding it seems that a "transparent" theory about the nature or even about the gross neural correlates of consciousness is a long way ahead. This is not only due to strenuous problems with the concept and recording of consciousness, with all the ontological mind–body theses, or with the still elementary knowledge about higher brain functions. Thus, despite the advent of cognitive science and other integrative attempts, philosophy of mind endeavors and scientific modeling or theorizing still belong to two different cultures. Fortunately, some philosophers (e.g. Churchland, 1995; Dennett, 1991; Flanagan, 1992; Hardcastle, 1994) have become acutely sensitive to the philosophical implications of important discoveries in cognitive neuroscience (perception,

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blindsight, memory, dream research), in behavioral science (meaningful vocal signals, tactic deception in non-human primates), or in neural computation (neural network models of cognitive capacities associated with consciousness). Their efforts point to the interdisciplinary direction sorely needed on the way towards deciphering the difficult puzzle concerning the nature of consciousness.

Time seems ripe for "robust" theories about the connection between brain, consciousness and behavior to take shape. In order to be considered robust, such psychophysical or psychobiological theories should derive from two complementary sources: a well-grounded mind–body ontology and the elaboration of pertinent empirical models from current science (Díaz, 1995). This dual enterprise is difficult enough, but not harder than the resulting task of relating both sets of concepts in a meaningful way. There are rhetorical, methodological, and epistemological bridges to be constructed before "deep" psychophysical correlates and laws can be conceived. Nevertheless, this conceptual effort is necessary if we are to advance in the enterprise of naturalizing consciousness in a manner that goes beyond the gross (or "superficial") correlations provided by psychobiology. Indeed, despite their considerable conceptual and applied interest, these correlations (such as REM phase and dream report or decreased monoaminergic transmission and depressed affect) are ontologically indeterminate in the sense that they are compatible with most of the major psychophysical theories and are not decisive in upholding or eliminating any one of them.

Elsewhere (Díaz, submitted), I have summarized the main difficulties facing some of the prevalent mind–body theories in philosophy of mind. In this context I suggested that dual aspect and neutral monism, two closely related ideas which have not been in the front line of the discussion for some time, offer some advantages in terms of mental emergence and causality, but noted that their main difficulty remains unsolved. This obstacle is the formulation of the nature of the neutral ground from which consciousness and matter emerge, and the mechanisms involved in these "aspectual" manifestations. This obstacle has not been overcome even after the attempted application of Niels Bohr's complementarity principle, several quantum mechanical properties, and other suggestive but psychophysically opaque concepts like "holomovement", "information", and "energy". Finally, I submitted that a patterned process theory could meet some elements of this challenge by posing that a dynamic and highly structured process of whole living organisms could manifest itself in several distinct facets (higher brain activity, phenomenological experience, organized behavior) and, therefore, that it could be observed and theorized about from different perspectives. In order to defend the proposal, the patterned process formulation needs to be developed in terms of both the sciences involved and philosophy of mind. The purpose of the present paper is to develop the prolegomena of such an exercise.

2. Dynamic cognitive systems and patterned processes

A set of cognitive theories closely related to the complexity and dynamic system paradigms in science have fostered a connectionist and distributed notion of informational systems. Some of these theories, such as microgenetic, holonomic, and dynamic pattern theories of cognition, not only appear to imply a neutral or multiple aspect ontology, but to hold promise of the formulation of a psychophysical approach to consciousness.

Microgenetic theories are conceptually based on the process philosophy of Bergson and Whitehead. They advanced in Germany and Sweden as a branch of the Wurzburg and Gestalt schools of psychology which emphasized *Aktualgenese*, the developmental progressions or "actual genesis" of cognitive processes. In its present manifestation, cognitive microgenesis (see Brown, 1991; Hanlon, 1991) constitutes a process model of cognitive formation in which the development of mental phenomena is considered to evolve in micro time through an unfolding of premature and preconscious stages, ultimately emerging as consciousness and behavioral processes. Processes are in this way conceived as transitions of structural units eventually generating novel forms. One general assumption of this program is that microgeny recapitulates phylogeny and ontogeny, and another (consonant with connectionism) is that the neural states underlying cognitive functions consist of fields rather than centers of activation. More neurophysiological in its rooting, the holonomic theory of Pribram (1986) considers the brain landscape of dendrite activation and consciousness to be two realizations or embodiments of an enfolded, basically energetic matrix of the world. In a related vein, the process theory of Sabelli and Carlson-Sabelli (1990) uses concepts from thermodynamics and chaos theory to propose a monistic view of mind, evolution, and history as expressions of "energy". On the other hand, inspired by concepts of synergetics (Haken, 1977) and complexity sciences, the dynamic pattern theory (Kelso, 1995; Kelso *et al.*, 1988) has fostered unitary models of pattern formation and self-organization in non-linear dynamic processes as varied as behavioral actions, pattern perception, and memory.

These models follow several assumptions of the "complexity" sciences (Mainzer, 1994; Yates, 1987), three of which refer to the required cerebral correlates of consciousness: (1) a *holarchic (holistic-hierarchic) morphology* of multiple ensemble levels, each composed of multiple parts; (2) a *coordinated interaction* of parts and levels resulting in non-linear stochastic behavior, and (3) an *emergence of dynamic patterns* from the coordinated interaction of the parts, so that the "bottom-up" information of a lower level converges in the upper level with the "top-down" information from higher levels resulting in the characteristic complexity features of difficult predictability, rich patterning, and semi-ordained behavior. In accordance with this view, it is important to acknowledge that important developments in representation theory (Freyd, 1987), sensory-motor coordination (Kelso *et al.*, 1988), cognitive microgenesis (Hanlon, 1991), and brain sciences (Aertsen, 1993) have emphasized the aspects of spatiotemporal coordination whereby dynamic phenomena acquire meaning.

These approaches constitute substantial progress toward an integrated theory concerning the structure of the neuropsychobehavioral processes that meet the challenge of studying and modeling them in real time. Nevertheless, dynamic systems theory and related models entail a distributed view of information which is difficult to reconcile with the modularity of mind, brain, and behavior which is the dominant working paradigm in biobehavioral and neurocognitive sciences (Fodor, 1983; Baars, 1988; Shallice, 1988). In order to advance in the direction of attuning system dynamics and modularity, it seems propitious to apply the principles of the pattern-and-process approach of long-term, large-scale evolutionary systems to the microgenetic level, and to do that it is pertinent to formulate a concept which unites pattern and process.

Pattern and *process* are two words that appear together in the titles of books and articles of several very different disciplines when their aim is to identify and analyze the dynamic evolution of items as complex and diverse as cultural objects, ecosystems, geological sediments, and biological species (Grande & Rieppel, 1994; Hamilton, 1967). Thus, the two words are generally associated with the long-term dynamics of large-scale structures; however it would be profitable to use the same approach to deal with small-scale and observed-duration events. Fisher (1994) comes very near to formulating a unitary patterned process concept when he recognizes that certain hierarchically structured events, such as walking, muscle contraction, and so on into the minutiae of physiology, can be independently described both as patterns and processes. Thus, it can be proposed that patterned processes are cinematic spatiotemporal transitions of certain states that can be defined by particular forms, shapes, or configurations. Moreover, there is a group of processes occurring in living systems that can be recognized as stochastic transitions between particular configurations, and such processes include intermodular brain activity patterns, the processing of consciousness contents, and the changes of bodily shapes that define and organize expressive behavior. Thus, as it will be shown below, brain, consciousness, and behavior processes could be collectively identified as *spatiotemporal patterns of activity* integrating *patterned processes* and the common features of the neural, mental, and behavioral processes constitute the fundamental empirical basis to formulate a patterned process theory. Moreover, cross-domain isomorphisms may constitute heuristic criteria in the search of correlations and, eventually, psychophysical laws.

3. Patterned processes, Petri nets, and connectionism

In accord with microgenetic, holonomic, dynamic pattern, and related connectionist ideas, patterned process theory would conceive the systems involved in meaningful information transmission as dynamic systems. Moreover, this stance would also presuppose that the cognitive and phenomenological aspects of neural activity are not carried out by individual neurons but by the cooperative activities of vast groups of neurons organized in networks. Also in agreement with connectionism, complex information is not supposed to be coded by the spike frequency of individual cells, but by the timely and coherent activities of massive neuron assemblies which are spatially separated but functionally bound. Now, in contrast with connectionism, patterned process theory is not a fully distributed, vastly parallel, and spatially neutral architecture. Thus, in accord with current brain theory (Kuffler & Nicholls, 1976), the specification of modules and of the origin and destiny of the connections among the modules is required in order to determine the content of the information.

Moreover, neural network activity is not considered to be the counterpart of higher cognitive functions unless the nets are organized in modules, and modules in the dynamic society of the brain. Perhaps a graphic example would illustrate the difference. Dynamic systems theory would say that a meaningful understanding of a fluid would include not only a snapshot of the molecules of water in a container forming a complex pattern fixed in time, but a motion picture of the trajectories of the molecules over time. Pattern process theory would specify that a biodynamic system behaves in the form of transitional states, so that the information about its dynamics should include the identification of particular states and their sequence patterns.

Neural networks and dynamic system connectionist models are certainly useful to simulate some observable features associated to consciousness, such as short-term memory, attention, interpretation and polymodal cognitive ability (Churchland, 1995; Pribram, 1993) and are conceptually compatible with higher mental properties insofar as cognitive processing is construed as a dynamic system evolution along an "activation landscape" where the evolving states have representational content (Horgan & Tienson, 1991). Nevertheless, masses of neurons used as processing elements have strong advantages over neuron networks to depict actual neural dynamics (Freeman & Jakubith, 1993; Hardcastle, 1994) and there is still a need to develop empirically derived theoretical and computational models of modular and intermodular activity in order to further approach the neural correlates of awareness and organized behavior. Patterned process models of the qualitative dynamic behavior of four-dimensional systems would offer new possibilities in the analysis of neuropsychobehavioral processes. The most appropriate analogies and models of patterned processes seem to be continuous Petri net formal systems and diagrams.

Petri nets are computational tools used to represent dynamic and parallel information processing systems in which concurrent and causal dependence transitions are explicitly represented in bidimensional graphs (David, 1994; Peterson, 1981). The traditional Petri net architecture includes the representation of "places" (nodes), "transitions" (contacts), and "arcs" (arrows) that connect places and transitions. The active elements in the net are "tokens" residing in the places, and the firing of the net is depicted by the removing of a token from one place and locating it in another one, the recipient of an identified transition. Thus, in a relatively simple way, Petri nets represent and analyze the qualitative behavior of certain complex systems understood as a process and processes as series of occurrences or activations of elements.

It is essential to note that Petri nets represent a special variety of dynamic system. In contrast with classic dynamic systems like turbulence, a patterned process, Petri net system assumes and requires the definition of a set of elements (places or nodes) and the dynamics of the system is established by the activation of a particular route of the possible transitions (contacts and arcs) among them. The definition of the elements of the net is ontologically indifferent or, one could say, *heuristically* arbitrary. For example, in the case of patterned process theory, an element in a brain net could be an active neural (morpho-functional) module, an element in a stream of phenomenological consciousness could be an identifiable content, like a single sensation, and in the case of behavior, an operationally defined behavioral unit. Moreover, in the case of patterned process theory, the elements of the net are assumed to be sets of malleable, context-dependent components and not autonomous, fixed building blocks. Indeed, once defined, recorded, and depicted as places in the net, the elements interact and produce a temporally open dynamic flow of activity. In this sense, and in contrast with classic dynamic systems, patterned processes depicted in Petri nets have something like a script structure that could be described as "cinematic" not only because of their sustained movement, but also because of their episodic composition, and plot-like architecture or structure of causally interrelated actions.

The particular relevance of Petri nets to cognitive science has sporadically been shown with their application to model (1) propositional logic and knowledge processing systems (Chaudhury *et al.*, 1993), (2) neural networks (Vankatesh & Masory, 1993) or nervous system behaviors (Seong *et al.*, 1993), and (3) music scores and compositions (Haus & Sametti, 1991, 1994). Clearly, these characteristics and applications make Petri nets promising tools in the modeling of patterned processes both at the conceptual and analytic levels. Nevertheless, in order to become more relevant to the modeling of living patterned processes, Petri nets need to be developed in order to accommodate not only closed recursive systems, but ongoing events and processes in real time. The traditional model needs to be extended so that it may reflect the *topological ordering* of nodes and their dynamic behavior in terms of the *order of firing events* (Lu, 1992) in "continuous" Petri nets. There are recent developments in Petri net theory and algorithms which make this objective quite feasible. Thus, there are Petri net models for formally analyzing the properties of real-time ("embedded") systems (Barthomieu & Díaz, 1991; Felder *et al.*, 1994; Yao, 1994), and for on-line validation in distributed systems (Díaz *et al.*, 1994).

4. Petri net models of brain, consciousness, and behavior

It is surely possible to generate many different types of models of brain, mental, and behavioral activities depending upon, for example, the initial set of assumptions and constraints employed. In the Petri net models outlined below, I follow a common strategy of trying to identify basic or elementary units, to construe diagrams in accord with their dynamic character, and to be able to depict them in flowcharts.

What is to be defined as an "elementary unit" of brain function? A standard assumption in psychobiology is that morphological and functional units of brain activity correlate with specific mental or behavioral processes such as memory engrams, particular sensations, basic emotions, hallucinations, mental depression, or the so-called "mechanisms of action" of psychoactive drugs. Neural hypotheses and explanations of these types of mental processes have ranged and evolved from the molecular, to the cellular, intercellullar, and modular levels of explanation. Indeed, within the living hierarchy of systems within systems (Miller, 1978), or "holarchy" (Koestler & Smythies, 1969), the brain can be conceived as a complex hierarchical system of successive layers or levels (Churchland & Sejnowski, 1993). Information

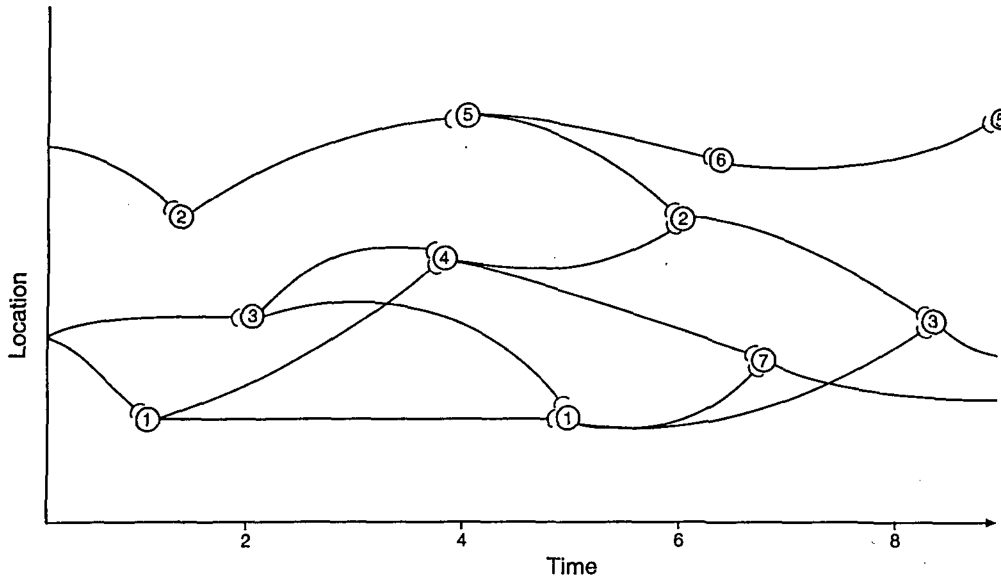

FIG 1. Spatiotemporal patterns of inter-module brain activity.The Petri-net-like (Peterson, 1981) flux of activation among seven (1–7) hypothetical brain modules is charted (ordinates) as a function of real time (abscissa). Thus, intermodule activation (-( ), feedback systems (e.g. 2-5-2; 3-4-2-3), and higher brain information-transmission events are modeled in an open-ended continuum allowing for the analysis of concurrent, parallel, and topologically specified activities.

is transformed and progressively converges at each one of the levels of brain organization in accord with specific mechanisms emerging from the coordinated functions of the sub-system. It can be proposed that on the top layer of the brain compositional systems spatiotemporal patterns of brain inter-module activity emerge and evolve, and that these dynamic patterns constitute the highest emergent properties fully capable of top-down effects. Thus, even though a particular mental or behavioral process should be properly understood as an integrated multi-layered or holarchic (holistic-hierarchic) phenomenon ranging from the organismic or behavioral to the molecular levels of organization, specific patterns of intermodule activity would be considered the brain units correlating with particular mental and behavioral processes. The proposed dynamics of brain intermodular activities could be modeled in Petri nets (Figure 1) with the specification of (1) the localization of brain modules (places or nodes), (2) their established conductivity (afferent and efferent contacts or established and recorded transitions), and (3) the patterns of activation among them (arcs).

In Figure 1, the elements do not represent individual neurons but topologically organized and neurophysiologically defined brain modules. Similarly, the points of contact between modules do not represent individual synapses but multisynaptic global effects of one module upon the next. In general neurobiologists consider that a single neurotransmitter is largely responsible for specific intermodule communication, such as the nigro-striatal dopaminergic system or the septum-hippocampus cholinergic system. In this case, the elements in the net could be codified in

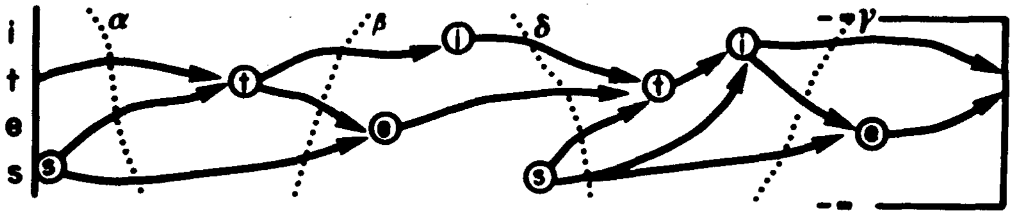

FIG 2. Spatiotemporal patterns of conscious mental activity. The Petri net model of observable features associated to phenomenological consciousness (Díaz, 1996) represents mental contents (s, sensations; e, emotions; t, thoughts; and i mental images) as elements, their processing as vectors, and their effects as arrow tips. States of consciousness (zones delimited by dotted lines) arise from a coordination or binding of concurrent elements.

higher-order color Petri nets (Peterson, 1981) allowing for distinctive features of the information to be modeled, beginning with its excitatory or inhibitory effect. It is important to emphasize that neurophysiologically defined brain modules are not closed, informationally encapsulated systems, but regional maps of neuronal aggregates sharing a predominant function (Shallice, 1988). Let us now turn to consciousness and phenomenological experience.

Despite the considerable semantic and conceptual difficulties concerning the analysis and definition of consciousness, it has been possible to assess first-person verbal reports that fulfill reasonable (but not stringent) requirements for operational definitions, sampling procedures, standardized reports, inter-evaluator agreements and so forth (Howe, 1991; Place, 1993). Reliable and often exciting data from perception, attention, dream, memory, or neuropsychological research offer a few examples of the viability and vitality of consciousness research (Flanagan, 1992; Hardcastle, 1993). Nevertheless there is a need for the design of heuristic models that incorporate the main phenomenological features of consciousness.

Recently, I proposed a preliminary model of observable traits associated with phenomenological consciousness (Díaz, 1996) which includes five features of reportable streams of consciousness plotted in a Petri-net-like flux of transitions. The five features are: temporality, processing activity, content, qualia, and unity (Figure 2). The resulting model can be readily associated with the "surface" of James's (1890) enduring "stream of consciousness" metaphor.

The nodes or elements of the stream of Figure 2 correspond to specific mental contents, which in this case are four classes of mental objects: sensations, emotions, thoughts, and mental images. Qualia could be represented in higher-order Petri nets as further specifications of the nodes, such as colors, and the flux of processing activity among contents corresponds to transitions and arcs.

The program of modeling observables associated with subjective streams requires an extension of the *protocol analysis* approach of Ericsson and Simon (1984) or the empirical phenomenology methods (Klein & Westcott, 1994) into a realistic *heterophenomenology* (*pace* Dennett, 1991). In fact, some renditions of reliable first-person accounts have been amenable for analysis and transcription into occurrence transition diagrams of the type shown in Figure 2 and other "narrative" methods (Abell, 1993; Wildgen, 1994).

It is interesting to acknowledge that the idea that behavior is integrated by "units" is common to Pavlov's reflexology, Skinners' behaviorism and classical ethology (Thompson & Lubinski, 1986). As it occurs with brain modules and contents of experience, behavioral units are conceptual abstractions of certain observational data which, in order to be operationally defined, need to be specified in terms of localization, orientation, topography, intrinsic properties, and physical effects. Moreover, a normal lapse of organized and expressive behavior is composed of a sequence of formant units unfolding in an intricate "quasi-linguistic" transitional order (Bateson & Klopfer, 1981). Such streams of behavior develop in specific amalgams or combinations of simultaneous units, in certain temporal iterations, and are endowed with different qualities of expression (Díaz, 1989). In accord with this conclusion, behavioral sequences and actions can be modeled with dynamic Petri nets as has been done by Anathol Holt and others since the 1970s (Adorni & Poggi, 1991; Bateson, 1991; Rautberg, 1993).

Even though the main feature of each one of these processes is distinctly unique (neural mental, muscular) there is a striking similarity in the architecture and formal features of the three processes, so that they can be collectively identified as spatiotemporal patterns of activity integrating patterned processes. Based on the common features of the neural, mental, and behavioral psychophysical processes described above, I will now expand on the central premises and some applications of a patterned process theory.

5. General properties of the models and the implications of their isomorphism

I have been referring to certain types of processes, namely to some defined by change and transition of living patterns. Such patterned processes are kinetic and particularly cinematic spatiotemporal transitions of states defined by particular forms, shapes or configurations unfolding in an orderly fashion. In turn, a state is constituted by a peculiar form in action, such as a combination of forms. Notice that, in contrast to Piagetian, morphogenetic, phylogenetic, microgenetic, and dynamic pattern theories, patterned processes are defined by the transition between *states* and not between *stages* and that, therefore, the theory is not concerned in principle with a teleological function, objective or trend of a process, but with its internal microstructure. It can be foreseen that the goal or outcome of the process could be inferred by the analysis of its units in sequence, roughly as the meaning of a sentence can be dissected and deduced by generative grammar procedures. In this way the word *process* refers to an integrated series of connected events unfolding in conjoint coordination and integrating a recognizable course or program (Rescher, 1996), while the adjective *patterned* constrains the type of process in several ways related to the theory of form.

These processes are said to be patterned for two critical reasons. They are patterned in the sense that they are primarily defined by dynamic forms and configurations. Repeatable and recognizable configurations, in turn, can be defined at different levels of analysis, from very elementary formants, to several levels of form integration (Harrison, 1993). This constraint situates patterned processes in the conceptual and methodological domains of the morphological and behavioral disciplines which make more use of object observation, description, and pattern recognition than sciences dealing with system composition (Díaz, 1985; Kuhn, 1977). Moreover, since forms and patterns acquire a given energetic configuration depending upon the substantial composition and mechanical features of their physical support (Harrison, 1993; Thompson, 1917), they cannot be conceived to be fully realizable or reproduced in different ways. For example, in contrast to strong functionalism claims, higher brain activities, with their awareness and movement correlates, can take place precisely because they arise as the result of the coordinated activities of the biological sub-systems involved and such activities cannot be accurately simulated by computer hardware or software.

On the other hand, patterned processes are said to be patterned not only because they are constituted by dynamic spatial configurations, but also because an essential feature of such dynamic forms or units is to unfold in a peculiar time-dependent behavior. This *spatiotemporal texture of activity* is an essential feature of all patterned processes and it can be defined by the amalgam of a spatial feature (combination), two temporal features (sequence and periodicity) and a spatiotemporal feature (quality). *Combination* designates the possible simultaneity of units in a state defined by a given cluster of relations which make them either synchronous (co-existing in time), physiologically bound, or fused in meaning (like musical harmonies or word–gesture mergers). *Sequence* refers to the serial flux of configurations, units, or states. In patterned processes the succession is typically defined by a probability of transition which is neither completely random (spectral density 1/f2) nor strictly predictable (power l/f0) but exhibit an intermediate 1/f spectral density found in DNA, music, speech and human cognition sequences (Gilden *et al.*, 1995; Voss & Clarke, 1975). Such semi-ordained transition probabilities define patterned processes as self-organized, contingent, and stochastic processes. *Periodicity* refers to the wave-pattern fluctuation of patterned processes where intervals or rhythms between given units or cycles of sequences can be recognized, ranging from simple iterations (e.g. gate) or ultradian and circadian rhythms to the more complex iterations and intervals of music and linguistic prosody. Finally, the global property and attribute called *quality* refers to the mode or manner in which the event takes place, usually defined and analyzed by the use of adjectives. Some examples of the qualitative feature in patterned processes are the qualia of consciousness, the qualitative character of motor behavior which embodies emotion and integrates individuality, musical timbre or color, and linguistic connotation. In the complexity concept of Goodwin (1994), organisms express their nature and acquire their meaning through the peculiar qualities of their form.

In more inclusive and final terms, patterned processes could be said to be spatiotemporal in the general relativity sense of a unity between space and time in a tetra-dimensional model that compels both the theorist and the researcher to focus more on morpho-functional processes than on static objects. From such a perspective, it would not be possible to fully understand or model a brain activity, a conscious occasion, or a behavioral sequel without having recourse to both discrete states and their continuous unfolding in time. Feedforward and feedback mechanisms should be realistically simulated by identification of their substrates based on experimental data. Patterned processes need to be based on a description of the elements involved in a state of present activation, but would also depict the dynamics of activity by the input/output characteristics of the defined elements and their synchronization operations. In this way, patterned process theory seems to be a suitable language to describe both structure and activity, and thereby reconcile system modularity and dynamics.

Patterned processes can be said to be essentially dynamic or *active* in the sense that they consist of movement and change requiring kinetic energy to develop and manifest. Thus, patterned processes exhibit different forms of kinetic energy including electric, chemical, heat, and mechanical. In this sense, there is an implicit emphasis on the displacement of the Newtonian and Cartesian notion of a static stuff by the notion of fluid energy which, according to Whitehead (1929, p. 309), is inconceivable apart from any structure in action. In this manner, patterned process theory could be considered a kinetic theory involving change, movement, and operation and thereby explicitly conforming to the "kinetic preconception" of modern science (Harrison, 1993). But more than just movement and change, we have seen that patterned processes have a script or cinematic structure entailing the successive activation or enaction structure of operationally defined elements. As a consequence of all of these attributes, patterned processes can be conceived of as higher-level *informational processes* that, due to their very complex underlying structure and the resulting cinematic or narrative architecture, exhibit not only informational but also semantic properties. To paraphrase Dretske (1981), the flow of information thus acquires meaning and content.

How far can we take the isomorphism among these processes? For example, even though a general isomorphism seems to clarify, specify, and strengthen the concept and theory of patterned processes, is it possible to claim a more complete identity among neural, mental, and behavioral processes? Not for the moment. There are methodological and conceptual problems in the identification of the elements and components across the three domains. Thus, despite the widely held belief among cognitive neuroscientists that brain modules assume specific psychological functions, in the present theory the activation of a specific brain module is not necessarily supposed to correspond to particular mental contents or behavior units on a one-to-one basis. Indeed, after revealing the tautologies involved in the modularity assumption, Shallice (1988) replaces the inference of independent functions with that of a functional specialization of a part of a system. Thus, given the evidence that anatomical modules or behavioral units may subserve several functions, and that reliable measurements of each one of the three processes in real time and in active individuals is at present not only technically impossible but hard to envisage, cross-domain isomporhism remains for the moment a heuristic program with some limited, but significant implications. For example, it could be said that such isomorphism is a scientifically heuristic form of holism allowing for the search and verification of bridge-laws linking cognitive phenomena, particularly consciousness and purposeful behavior, to higher-level processes of neural function. Nevertheless, since Van Leeuwen (1990) has claimed that, unless semi-permanent structural components are assumed, the isomorphism heuristics is actually indeterminate, it is possible to see the case of Petri net models and patterned processes as precisely such a case. In other words, these models which utilize time-scale relatively permanent structures may fill the lacuna between operationally defined arbitrary structures and natural, non-arbitrary, foundations. The apparent paradox of treating them in any of these contractory modes is related to the fact that there are no linguistic categories for objects conflating the properties of nouns (permanence) and verbs (change, action).

6. The empirical model in philosophical context: patterned processes and the mind–body problem

Most mind–body philosophical theses favor either a strong or a weak reduction of concepts of consciousness to neural concepts. Even the emergence and supervenience theses share such a requirement that many analysts, not only dualists, have argued do not readily apply to the problem of consciousness in view of the radical and puzzling heterogeneity of physical and mental objects. The only alternative to psychophysical reduction is the rather vague notion of psychophysical correlation, and this would pertain only to the case of two mind–body stances, namely dual aspect and psychophysical parallelism. Even though the latter was quite popular among neuroscientists in the first half of the century, the idea did not consolidate because mind–body dualism came to be considered disreputable and because psychophysical correlation remained a fuzzy notion.

Patterned process theory is a multiperspective formulation where the relationships among neural, mental, and behavioral processes would be those of a correlation and not of "classical" reduction. This is the case because higher neural activities and consciousness are considered to occur at the same level of organization in the hierarchy of organic systems; consciousness or behavior do not comprise a level or layer by themselves, but are considered to be cognitive or motor aspects of the highest form of brain organization emerging at the level of the organ situated in the context of an alive organism coping in a changing environment.

The "correlation" proposed here is not of the traditional statistical kind, but a real-time signal concurrence in multiple and simultaneous data generating systems, similar in principle to those appearing from sound, volumetric, and electrical recordings of the heartbeat and that lead to meaningful physiological concepts and deep insights into cardiac function. Strong item-to-item or event-to-event cross-correlations describing the interdependence of the data in phenomenologically diverse but physiologically integrated processing systems can be drawn at discrete times. Real-time system computational models (Rajkumar, 1991; Soucek, 1989) and multiple time-series analyses can provide formal leads in this direction. Once a nomological intra-level and inter-perspective concurrence is obtained, partially successful reductions (explanations in terms of the sub-systems) and amplifications (explanations in terms of the supra-systems) may take place, and thereby the concurrences may be said to constitute bridge laws. This formulation offers the considerable advantage over classical reduction in that, instead of eliminating or minimizing folk and/or scientific psychology, it fosters (and indeed requires) the development of a mature psychology of consciousness in order to be able to find empirical concurrences and formulate correlation bridges sorely needed in the development of a genuine psychophysical or mind–body science.

Patterned process theory is a program that is both phenomenologically realist and methodologically naturalist; that is to say, phenomenological properties are considered real and causally efficacious. States of consciousness are said to be real insofar as they are supposed to be aspects of certain high-level brain operations and, therefore, the dynamics of consciousness should be reflected in the corresponding dynamics of the bodily systems instantiating and expressing consciousness. Moreover, the psychophysical process emerging bottom-up from inter-network activity as an aspect of the cooperative action of neural modules can easily be considered capable of coordinating the activities of the brain, and thereby of behavior, neuroendocrine or neuroimmunological systems, in a top-down fashion.

Since pattern process theory does not entail a *form–substance* duality where different "forms" (e.g. mind, consciousness) could be realized or embodied in different "substances" (e.g. bodies, brains, machines), property dualism can be accepted only insofar as each one of the processes, although dynamically isomorphic and physiologically integrated with the others, appears in very different phenomenological facets, each one amenable to (and indeed calling for) independent observation, analysis, and theorization. In this light, it becomes clear why the property dualism of strong functionalism is an inadequate frame of reference for the mind–body problem. The mistake here is taking the brain or the body as static support objects analogous to computer hardware and the mind or consciousness as similar to an algorithm that can be realized or instantiated in any given machine (see Edelman, 1992 for a more extensive discussion of this issue). These parallelisms are based on an Aristotelian matter–form dichotomy and its related distinctions, both of which are far removed from the integrative morpho-functional notions of present-day biology and related dynamic processes concepts such as patterned process theory.

As already envisaged in process philosophy since Bergson and Whitehead (see Ford, 1987 and Griffin, 1989), the ontology of becoming sheds a very different light on the mind–body problem than traditional theses, because the relationship of consciousness and brain is not comparable to that existing between form and substance, process and matter, information and structure, or function and organ, but between fundamentally unique but phenomenologically diverse dynamic processes. Patterned process theory offers essentially the same answer to the main ontological question of whether the ultimate reality is matter or mind as a process-oriented dual aspect and neutral monism theory; that is *the fundamental reality is motion, and complex motion is mind–matter*. This concept does not deny the reality of things, such as bodies, brain modules or behavioral actions, but considers them manifolds of process. Physical objects are what they are not because of a continuity of their material components but because of their processual unity and an involvement in a matrix of processes is inherent in the very concept of any particular thing

(Rescher, 1996). Of course, this formula is not a complete and final solution to the mind–body problem by itself, but it is a key concept from which philosophical and scientific concepts can arise or be reconciled. For example, all the general notions of "information", "energy", and "movement" that have been invoked as the fundamental ground of mind and matter by several contemporary authors favoring a dual-aspect solution (Bohm, 1986; Chalmers, 1996; MacDonald, 1994; Pribram, 1986) converge in patterned process theory. As it has been shown now, Petri net models of higher neural activity, phenomenological consciousness, and organized motor behavior show that very different events have similar formal features and suggest that such isomorphism and the verification of ensuing correlations may constitute arguments in favor of a neutral monist, multiple aspect mind–body theory. In such a theory the nature of the fundamental reality can be said to have the dynamic, energetic, and informational features of a patterned process.

The ontology favored by patterned process theory would be a neutral stance. It asserts that there is a process that is psychophysical in nature so that consciousness and higher brain activities are aspects of this process in a sense similar to P.A.M. Dirac's assertion that electric and magnetic charge are aspects of a single electromagnetic force, a duality originally proposed in the 1930s and that is still a basic tenet of modern string notions which many analysts trust will unify gravity and quantum theories in a single "Theory of everything" (Taubes, 1996). To continue with the analogies with physics, intermodular brain activities are thought to be dual to consciousness in the same form that we understand that magnetic monopoles are dual to electrons, that is to say, only in the four-dimensional spatiotemporal domain. This analogy from modern physical theory seems adequate in terms of the spatiotemporal constraint of the psychophysical process, but it does not suggest the complexity requirement. The dynamic nature of a system is conceived to include the mental properties of awareness only when a massively interactive, self-organizing, multi-layered living system gives rise to subsequent emergent properties of converging information, culminating in a psychophysical process. In other words, and in contrast with the panpsychist implications of Whitehead's "actual occasions" and other process philosophy concepts (Griffin, 1989; Rescher, 1996), it is only at a higher and dynamic modular level of description that a truly psychophysical process can be conceived to arise so that meaningful concurrences between conscious and physiological states may be found only at that level. Such correlations will be feasible when a single vocabulary is adopted for all domains involved. Patterned process theory could become one such vocabulary.

I may conclude by saying that patterned process theory promises to provide a coherent notion of a psychophysical ground. Such a neutral foundation would accommodate the isomorphism of brain, consciousness, and behavior processes and foster the search of psychophysical correlations in the form of psychophysical concurrences. Despite the need for further analysis and empirical evidence, these concepts may prove useful in the conceptual establishment and methodological development of an integrated mind–body science.

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References

ABELL, P. (1993). Some aspects of the narrative method. *Journal of Mathematical Sociology, 18*, 93–134.

ADORNI, G. & POGGI, A. (1991). Actions representation in a 4-D space. *International Journal of Man–Machine Studies, 35*, 825–841.

AERTSEN, A. (Ed.) (1993). *Brain theory. Spatio-temporal aspects of brain function.* Amsterdam: Elsevier.

BAARS, B. (1988). *A cognitive theory of consciousness.* Cambridge, UK: Cambridge University Press.

BARTHOMIEU, B. & DÍAZ, M. (1991). Modeling and verification of time dependent systems using time Petri nets. *Transactions on Software Engineering, 17*, 259–274.

BATESON, M.C. (1991). *Our own metaphor.* Washington, DC: Smithsonian Institution Press.

BATESON, P.P.G. & KLOPFER, P.H. (1981). *Perspectives in ethology.* New York: Plenum Press.

BOHM, D.J. (1986). A new theory of the relationship of mind and matter. *Journal of the American Society for Psychical Research, 80*, 113–135.

BROWN, J.W. (1991). *Self and process. Brain states and the conscious present.* New York: Springer Verlag.

CHALMERS, D.J. (1996). *The conscious mind.* Oxford, UK: Oxford University Press.

CHAUDHURY, A., MARINESCU, D.C. & WHINSTON, A. (1993). Net-based computational models of knowledge-processing systems. *Expert, 8*, 79–87.

CHURCHLAND, P.M. (1995). *The engine of reason, the seat of the soul.* Cambridge, MA: MIT Press.

CHURCHLAND, P.S. & SEJNOWSKI, T.J. (1993). *The computational brain.* Cambridge, MA: MIT Press.

DAVID, R. (1994). Petri nets for modeling of dynamic systems—a survey. *Automatica, 30*, 175–202.

DENNETT, D. (1991). *Consciousness explained.* Boston, MA: Little Brown.

DÍAZ, J.L. (1985). *Análisis estructural de la conducta.* Mexico City: Universidad Nacional Autónoma de México.

DÍAZ, J.L. (1989). *Psicobiología y conducta. Rutas de una indagación.* Mexico City: Fondo de Cultura Económica.

DÍAZ, J.L. (1995). Hunting for consciousness in the brain: what is (the name of) the game? *Behavioral and Brain Sciences, 18*, 679–680.

DÍAZ, J.L. (1996). The stream revisited: a process model of phenomenological consciousness. In S. HAMEROFF, A. KASZNIAK & A. SCOTT (Eds) *Toward a scientific basis of consciousness.* Cambridge, MA: MIT Press.

DÍAZ, M., JUANOLE, G. & COURTIAT, J.-P. (1994). Observer—a concept for formal on-line validation of distributed systems. *Transactions on Software Engineering, 20*, 900–913.

DRETSKE, F.I. (1981). *Knowledge and the flow of information.* Cambridge, MA: MIT Press.

EDELMAN, G.M. (1992). *Bright air, brilliant fire.* New York: Basic Books.

ERICSSON, K.A. & SIMON, H.A. (1984). *Protocol analysis. Verbal reports as data.* Cambridge, MA: MIT Press.

FELDER, M., MANDRIOLI, D. & MORZENTI, A. (1994). Proving properties of real-time systems through logical specifications and Petri net models. *Transactions on Software Engineering, 20*, 127–142.

FISHER, D.C. (1994). Stratocladistics: morphological and temporal patterns and their relation to phylogenetic process. In L. GRANDE & O. RIEPPEL (Eds) *Interpreting the hierarchy of nature*. New York: Academic Press.

FLANAGAN, O. (1992). *Consciousness reconsidered*. Cambridge, MA: MIT Press.

FODOR, J.A. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.

FORD, M.P. (1987). *A process theory of medicine*. Lewinson, NY: Edwin Mellen Press.

FREEMAN, W.J. & JAKUBITH, S. (1993). Bifurcation analysis of continuous time dynamics of oscillatory neural networks. In A. AERTSEN (Ed.) *Brain theory. Spatio-temporal aspects of brain function* (pp. 183–207). Amsterdam: Elsevier.

FREYD, J.J. (1987). Dynamic mental representations.*Psychological Review*, *94*, 427–438.

GILDEN, D.L., THORNTON, T. & MALLON, M.W. (1995). 1/f noise in human cognition. *Science*, *267*, 1837–1839.

GOODWIN, B. (1994). *How the leopard changed his spots. The evolution of complexity*. New York: Charles Scribner.

GRANDE, L. & RIEPPEL, O. (1994). *Interpreting the hierarchy of nature. From systematic patterns to evolutionary process theories*. New York: Academic Press.

GRIFFIN, D.R. (1989). *Archetypal process*. Evanston, IL: Northwestern University Press.

HAKEN, H. (1977). *Synergetics—an introduction*. Springer Series on Synergetics, vol 1. Berlin: Springer.

HAMILTON, T.H. (1967). *Process and pattern in evolution*. New York: MacMillan.

HANLON, R.E. (Ed.) (1991). *Cognitive microgenesis. A neuropsychological perspective*. New York: Springer Verlag.

HARDCASTLE, V.G. (1993). The naturalists versus the skeptics: the debate over a scientific understanding of consciousness. *Journal of Mind and Behavior*, *14*, 27–50.

HARDCASTLE, V.G. (1994). Psychology's "binding problem" and possible neurobiological solutions. *Journal of Consciousness Studies*, *1*, 66–90.

HARRISON, L.G. (1993). *Kinetic theory of living pattern*. Cambridge, UK: Cambridge University Press.

HAUS, G. & SAMETTI, A. (1991). Scoresynth: a system for the synthesis of music scores based on Petri nets and a music algebra. *Computer*, *24*, 56–61.

HAUS, G. & SAMETTI, A. (1994). Modelling and generating musical scores by Petri nets. *Languages of Design*, *2*, 39–57.

HORGAN, T. & TIENSON, J. (1991). *Connectionism and the philosophy of mind*. Boston, MA: Kluwer.

HOWE, R.B.K. (1991). Introspection: a reassessment. *New Ideas in Psychology*, *9*, 25–44.

JAMES, W. (1890/1950). *Principles of psychology*. New York: Dover.

KELSO, J.A.S. (1995). *Dynamic patterns. The self organization of brain and behavior*. Cambridge, MA: MIT Press.

KELSO, J.A.S., MANDELL, A.J. & SCHLESINGER, M.F. (1988). *Dynamic patterns in complex systems*. Singapore: World Scientific.

KLEIN, P. & WESTCOTT, M.R. (1994). The changing character of phenomenological psychology. *Canadian Psychology*, *35*, 133–157.

KOESTLER, A. & SMYTHIES, J.R. (1969). *Beyond reductionism*. London: Hutchinson.

KUFFLER, S.W. & NICHOLLS, J.G. (1976). *From neuron to brain*. Sunderland, MA: Sinauer Associates.

KUHN, A. (1977). Dualism reconstructed. *General Systems*, *22*, 91–97.

LU, RQ. (1992). P/r nets and process concepts. 1 and 2. *Science in China, Series A*, *35*, 21–31 and 148–157.

MACDONALD, C. (1994). An energy/awareness/information interpretation of physical and mental reality. *Zygon*, *29*, 135–152.

MAINZER, K. (1994). *Thinking in complexity. The complex dynamics of matter, mind, and mankind*. New York: Springer-Verlag.

MILLER, J.G. (1978). *Living systems*. New York: McGraw-Hill.

PETERSON, J.L. (1981). *Petri net theory and the modelling of systems*. Englewood Cliffs, NJ: Prentice-Hall.

PLACE, U.T. (1993). A radical behavioristic methodology for the empirical investigation of private events. *Behavior and Philosophy*, *20*, 25–36.

PRIBRAM, K.H. (1986). The cognitive revolution and mind/brain issues. *American Psychologist, 41,* 507–520.

PRIBRAM, K.H. (1993). *Rethinking neural networks: quantum fields and biological data.* Hillsdale, NY: Lawrence Erlbaum.

RAJKUMAR, R. (1991). *Synchronization in real-time systems.* Boston, MA: Kluwer.

RAUTBERG, M. (1993). Amme—an automatic mental model evaluation to analyze user behavior traced in a finite, discrete state-space. *Ergonomics, 36,* 1369–1380.

RESCHER, N. (1996). *Process metaphysics.* New York: State University of New York Press.

SABELLI, H.C. & CARLSON-SABELLI, L. (1990). Process theory as a framework for comprehensive psychodynamic formulations. *Genetic, Social, and General Psychology Monographs, 117,* 5–27.

SEONG, R.K., WON, G.K., SANG, H.L. & CHUL, H.L. (1993). Representation of nervous system behaviors using fuzzy Petri nets. *Journal of the Korea Information Society, 20,* 644–655.

SHALLICE, T. (1988). *From neuropsychology to mental structure.* Cambridge, UK: Cambridge University Press.

SOUCEK, B. (1989). *Neural and concurrent real-time systems.* New York: John Wiley.

TAUBES, G. (1996). A theory of everything takes shape. *Science, 269,* 1511–1513.

THOMPSON, D.W. (1917/1942). *On growth and form.* Cambridge: Cambridge University Press.

THOMPSON, T. & LUBINSKI, D. (1986). Units of analysis and kinetic structure of behavioral repertoires. *Journal of the Experimental Analysis of Behavior, 46* 219–242.

VANKATESH, K. & MASORY, O. (1993). A high level Petri net model of olfatory bulb. *IEEE International Conference on Neural Networks* (pp. 766–771). New York: IEEE.

VAN LEEUWEN, C. (1990). Indeterminacy of the isomorphism heuristic. *Psychological Research, 52,* 1–4.

VOSS, R.F. & CLARKE, J. (1975). *Nature, 258,* 317.

WILDGEN, W. (1994). *Process, image, and meaning.* New York: John Benjamins.

WHITEHEAD, A.N. (1929/1978). *Process and reality.* London: The Free Press, Macmillan.

YAO, YL. (1994). A Petri net model for temporal knowledge representation and reasoning. *Transactions on Systems, Man, and Cybernetics, 24,* 1374–1382.

YATES, F.E. (Ed.) (1987). *Self-organizing systems: the emergence of order.* New York: Plenum Press.