Neural Synchrony and the Unity of Mind:
A Neurophenomenological Perspective[1]

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To appear in:
Axel Cleeremans (ed.),
The Unity of Consciousness: Binding, Integration and Dissociation
(New York: Oxford University Press, in press)

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[1] FV passed away May 28, 2001. This paper is based on an invited lecture he gave at the ASSC Meeting at Brussels in June 2000, and on subsequent extensive revisions in collaboration with ET during the period of December 2000 to March 2002. It was then presented by ET at the conference "Beyond the Hard Problem: Consequences of Neurophenomenology," at Boulder, Colorado, in May 2001. ET is supported by the Social Sciences and Humanities Research Council of Canada, the McDonnell Program in Philosophy and the Neurosciences, and the Fetzer Institute through a grant to the Center for Consciousness Studies, University of Arizona, Tucson.

1. PREAMBLE

In this paper, we wish to present a fresh approach to research on neural synchrony and the unity of mind and consciousness through a consideration of the *place of mind in the network of natural causality.* In particular, beyond the mechanisms of neural synchrony, we wish to consider the issue of the causal efficacy of consciousness—that aspect of consciousness in virtue of which we human beings (and other animals) qualify as conscious *agents*. Our approach will be to reconsider neural synchrony and consciousness within the context of two key concepts—*emergence* (or emergent processes) and *embodiment.*

In a certain basic sense, “mental causation” (as philosophers call it) is not a problem, but a *prima facie* given of everyday experience: I decide to raise my hand and I feel it move as a result of my own effort;[2] I say a harsh word, and the person before me shows signs of being hurt. Mental causation becomes a problem only within the current theoretical problem-space of dualism versus materialism (see Kim 1998). Yet given this problem-space, the only alternatives, it seems, are all dead-ends—substance dualist interactionism (the immaterial mind has an essentially mysterious two-way causal commerce with the material world); causal overdetermination (the mental and the physical are mutually independent sufficient causes of the same physical events); causal preemption or irrelevance (the mental has only those intrinsic causal powers that the physical already has); or epiphenomenalism (the mental is causally or explanatorily inert).

Instead of engaging these positions on their own terms, we intend to shift the discussion in this paper to a different theoretical context, one inspired by the tradition of phenomenology (see Petitot et al. 1999). The importance of phenomenology is that it anchors theoretical investigations of consciousness (whether scientific or philosophical) on “the things themselves,” that is, on experience as it is lived and verbally articulated in the first person, rather than simply on the third-person, experimental correlates of experience (e.g., neural correlates), or on the abstract representations of experience (“mental property *M*” and “physical property *P*”) algebraically manipulated by philosophers in the pre-given problem-space of dualism versus materialism (see Kim 1998).

The particular context of our discussion here is the research program known as “neurophenomenology” (Varela 1996). The working hypothesis of neurophenomenology is that phenomenological data and cognitive scientific data can function as reciprocal constraints in the science of consciousness. Accordingly, neurophenomenological explanations proceed in two complementary directions, from the phenomenology of first-person experience to the biology of consciousness, and back again, with formal dynamical models mediating each way. Thus neurophenomenology comprises three main domains of investigation: (1) phenomenological data and *a priori* invariants of experience; (2) somatic and neural substrates; and (3) formal dynamical models.[3]

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[2] Contrary to Hume, who thought we experience only the regular succession or constant conjunction of (e.g.) one’s decision to raise one’s hand and the hand’s going up, whereas what we experience includes also the force and effort of our own bodies in action (see Jonas 1966, pp. 26-33). As the nineteenth century philosopher Johann Jakob Engel said of Hume: “He ought to use his muscles, but instead he uses his eyes; he ought to grasp and struggle, and instead he is content to watch” (quoted in Sheets-Johnstone 1999, p. 461).

[3] With regard to metaphysics, neurophenomenology suggests replacing materialism or physicalism with a form of non-reductive naturalism. The kind of non-reductive naturalism we favor is a new and radically biological version of the dual aspect theory, according to which mental properties and physical properties are two mutually

It is within this context that the two key concepts of *emergence* and *embodiment* come to the fore. The concept of emergence provides the means for extending and enriching the notion of natural causation, without violating the supposed causal closure of physics. The concept of embodiment provides the means for criss-crossing the so-called "explanatory gap" between first-person phenomenology and third-person neuroscience.[4]

Accordingly, this paper proceeds in three stages. (1) We first take up the issue of how the current work on neural synchrony can help to provide an understanding of the unity of mind at the level of a *unified moment* of conscious experience. Accordingly, the emphasis here will be on *large-scale* transient brain integration, in contrast to the traditional issue of local "binding." (2) Next, we take up the question of causality in the context of complex dynamical systems, neural assemblies in particular. Here we explore neural synchrony as exemplifying the "upwards" (local-to-global) sense of emergence in complex (nonlinear) systems. We then turn the matter around to its logical and empirical flip-side, namely, the modulation of local processes by so-called global order parameters. This aspect exemplifies the "downwards" (global-to-local) sense of emergence. It is within this overall context of *double causation* that the causal efficacy of consciousness needs to be considered. (3) Finally, having spelled out this extended form of causality, we turn to the issue of how such double causation stands in relation to the phenomenological side of mental life. Here the key step is to remind ourselves that the neural and mental processes under discussion are necessarily embodied in the whole organism and situated or embedded in the environment. It is only when these dimensions of embodiment and embeddedness are brought to the fore that a productive criss-crossing of the explanatory gap becomes possible.

2. FIRST STAGE:
RESONANT NEURAL ASSEMBLIES AND LARGE-SCALE BRAIN INTEGRATION

There is now little doubt in cognitive neuroscience that specific cognitive acts require the transient integration of numerous, widely distributed, and constantly interacting functional areas of the brain. For this reason, any hypothesis about the neural correlates of a moment of consciousness must account for the *integrated* or *coherent* operation of large-scale brain activity. A central theme of this volume (and earlier discussions) is that it is plausible to link such integration to the *unity* of consciousness, that is, to the basic phenomenological fact that we do not experience the different facets of our experience (sensing, moving, remembering, feeling, and so on) in fragmented patches, but in coherent wholes.

So stated, this notion of "mental unity" remains intuitive, and accordingly needs careful conceptual and phenomenological analysis and elaboration. Such a task is beyond the scope of this paper. In general, we assume that the unity of consciousness cannot be accounted for in either phenomenological (subjective, personal-level) or neural (objective, subpersonal level) terms alone, but requires the integration of both. As Susan Hurley (1998) has recently

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irreducible aspects of one single underlying neutral individual, the living animal. For elaboration of this view, see Hanna and Thompson (forthcoming).

[4] *Criss-crossing* the gap should be contrasted with *closing* the gap, that is, with explanatory and ontological reduction. Neurophenomenology is offered not as a way to close the gap, but rather as a way to move productively from one domain to the other by way of a third mediating domain, which in itself is neither physical nor mental, but formal or "eidetic" (in Husserlian parlance), the mathematical domain of dynamical systems theory. (We owe the phrase "criss-crossing the gap" to Robert Hanna.)

discussed: “Unity seems to have both personal and subpersonal aspects, which suggests that a normative personal-level account of unity might be supplemented with a functional subpersonal-level account… But such a functional account would have to be at the right level…” (p. 52). We submit that the right level corresponds precisely to that of large-scale brain integration, a view quite resonant with Hurley’s position that the right level is one at which “[p]eople and other animals can be seen… as dynamic singularities: structural singularities in the field of causal flows characterized through time by a tangle of multiple feedback loops of varying orbits” (p. 2). (We also share with Hurley the view that this tangle loops through the body and the environment: see Section 4.) Our working assumption is that the integrated or coherent dynamics of large-scale brain activity is the vehicle of the unified and transitory character of what Husserl called “the living present” in the temporal flow of conscious experience (Husserl 1991/1893-1917; see also Varela 1999).

Given this assumption, the issue that arises is how this large-scale dynamic integration is actually accomplished in the brain so as to produce a flow of unified cognitive moments. Elsewhere Varela et al. (2001) have extensively reviewed and discussed this issue of large-scale integration from the perspective of current neuroscience. Here we present only a brief summary of the main ideas.

Let us begin with a point discussed by several contributors to this volume, the fact that neuronal groups exhibit a wide range of oscillations (theta to gamma ranges, 6-80 Hz) and can enter into precise *synchrony* over a limited period of time (a fraction of a second). How is this fact to be understood? Where we differ from other researchers in addressing this question is in the emphasis we place, first, on synchrony as precise *phase-locking*, and second on *long-range synchronization.* Thus by “synchrony” in this paper we mean the precise phase-locking of widely distributed neuronal sub-populations or regions as directly quantified by novel statistical methods (Lachaux et al. 1999). (Phase synchrony determined in this manner is not equivalent to indirect measures of synchrony as spectral coherence or local energy emission, which do not separate phase and amplitude components.)

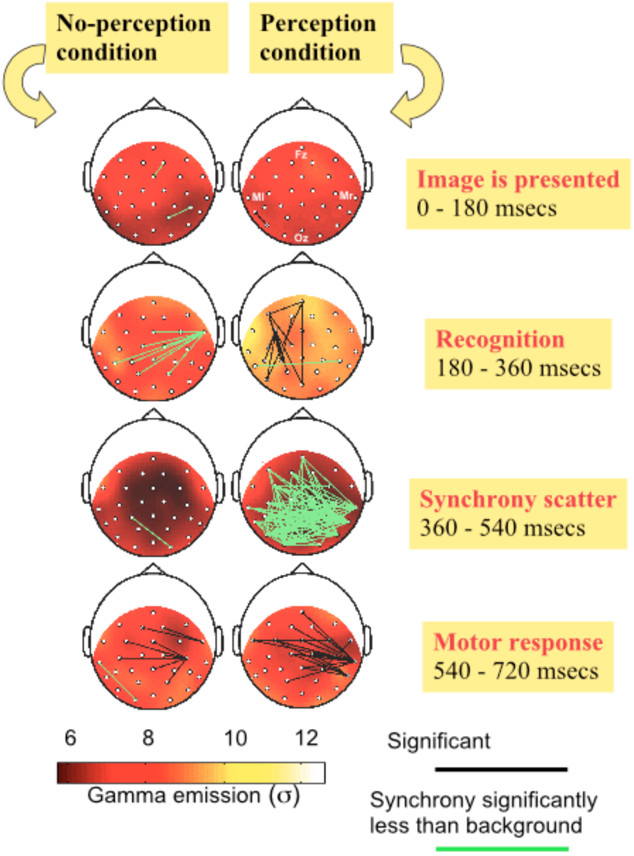
The role played by the synchronization of neuronal discharges, although not a new idea to neuroscience, has been greatly highlighted by recent results from microelectrodes in animals (see Roskies 1999). Two scales of phase synchrony can be distinguished—short-range and long-range. Most animal studies based on microelectrode recordings have dealt with short-range synchronies (e.g., Gray et al. 1999), or synchronies between adjacent areas corresponding to a single sensory modality (e.g., Koenig et al. 1995). These local synchronies have typically been interpreted as subserving “perceptual binding.” Detailed evidence for long-range synchronizations between widely separated brain regions, however, has also been found (Bressler et al. 1993; Roelfsema et al. 1997; Rodriguez et al., 1999; von Stein et al. 2000). This evidence supports the more general notion that phase-synchrony should subserve not simply the binding of sensory attributes, but *the overall integration of all dimensions of a cognitive act*, including associative memory, emotional tone, and motor planning (Damasio 1990; Varela 1995; Varela et al. 2001).

The evidence for long-range interaction is naturally studied from recordings at a mesoscopic scale, from local field potentials (LFPs) in animals and humans, or from surface EEG/MEG recordings. The phenomenon of long-range interaction is well illustrated by a series of studies by Roelfsema et al. (1997; see also Munk 2000, and von Stein 2000), who recorded LFPs from several electrodes implanted in the cortex of cats. Cats were presented with a grating that signaled the onset of a trial; when the orientation of this grating changed (2-4 secs later) the animal had to press a response key to obtain a food reward. The dynamic changes in the correlation between the electrodes placed in visual, association, somatosensory, and motor areas were then analyzed over time. During the execution of the task there was a selective increase in the correlation between the respective LFPs. As soon as the animal focused its attention on the stimulus, a coherent pattern appeared; this pattern was further increased until the task was completed, particularly between areas of the visual and parietal cortex, and areas of the parietal and motor cortex. Interestingly, during the reward period this coherent pattern disappeared, and neural activity shifted to low frequencies with no correlation between areas. This is direct evidence that large-scale synchrony (at least as inferred through correlation) emerges as the underlying basis for an active, attentive behavior.

We have presented further evidence in a study using the recognition of high-contrast black and white patterns ("Mooney figures") as faces as a paradigmatic example of a moment of consciousness (Rodriguez et al. 1999) (see Figure 1). This study showed for the first time that the conscious perception of meaningful complex forms is accompanied by synchronous activities in distinct brain regions at the scalp level. In this study, the EEG was recorded by electrodes at the scalp surface. Subjects were shown upright and upside-down Mooney figures, which are easily perceived as faces when presented upright, despite the necessary perceptual binding and contour reconstruction, but usually perceived as meaningless back and white forms when upside-down. Subjects had to decide as rapidly as possible whether or not they perceived a face at first glance and then report accordingly by pressing on a two-choice button. When the pattern of phase synchrony between pairs of electrodes in the gamma band was directly measured, it showed marked quantitative *and* qualitative differences between the "perception" and "no perception" conditions. Between 200-260 msec, a first period of significant synchronization was observed. It involved left parieto-occipital and fronto-temporal regions, and is related to the perception process itself. It was followed by a massive period of *loss* of synchronization well below the reference level and peaking around 500 msec ("phase-scattering"). Phase-scattering is observed between parietal and occipito-temporal regions bilaterally. Finally, a second synchrony increase appears around 700 msec. This final period coincided with the subject's button-pressing, and hence may be related to the motor response elaboration under both conditions. This is the only period of time in which some similarity between the phase synchrony patterns under the two conditions was noted.

It is worth emphasizing that the stage of active phase-scattering appears as a massive effect in the results of this experiment. In agreement with previous proposals (Varela 1995), this finding suggests that an active uncoupling or phase-scattering procedure may be necessary for the transition between different synchronous neuronal assemblies. Large-scale integration must implicate not only the establishment of dynamic links, but also their active uncoupling to give way to the next cognitive moment. Indeed, this active disruption of synchrony seems to punctuate the two other phases of the cognitive task in this experiment—perception proper, and decision and response afterwards. The disassembly of synchronous assemblies may be the neural basis for the temporal parsing of cognitive acts into the moment-to-moment unity of the "living present" of conscious experience (Varela 1999). The actual mechanism of phase-scattering, the role of various concurrent frequencies in long-range synchronization, and the role of several rhythms (from theta to gamma) are some of important research topics in this line of research (see Varela et al. 2001, p. 236).

Figure 1. The shadow of a perception: average scalp distribution of gamma activity and phase synchrony (modified from Rodriguez et al. 1999). EEG was recorded from electrodes at the scalp surface. Subjects were shown upright and upside-down Mooney figures (high contrast faces), which are easily perceived as faces when presented upright, but usually perceived as meaningless black-and-white forms when upside-down. Subjects had to decide as rapidly as possible whether or not they perceived a face at first glance and then report accordingly pressing a two-choice button. Color coding indicates gamma power (averaged in a 34-40 Hz frequency range) over an electrode and during a 180 msec time window, from stimulation onset (0 msec) to motor response (720 msec). Gamma activity is spatially homogenous and similar between conditions over time. In contrast, phase synchrony is markedly regional and differs between conditions. Synchrony between electrode pairs is indicated by lines, which are drawn only if the synchrony value is beyond the distribution of shuffled data sets ($P < 0.01$; see Rodriguez et al. 1999, Methods). Black and green lines correspond to a significant increase or decrease in synchrony, respectively. Marked quantitative and qualitative differences are observed between the ‘perception’ and ‘no perception’ conditions. Between 200-260 msec, a first period of significant synchronization was observed in the perception condition, involving left parieto-occipital and fronto-temporal regions. It was followed by a massive period of loss of synchronization well below the reference level, peaking around 500 msec (‘phase scattering’), and involving parietal and occipto-temporal regions bilaterally. (Synchrony scatter may reflect a process of active desynchronization necessary for the transition between different synchronous neural assemblies: see Varela 1995; Rodriguez et al. 1999; Varela et al. 2001). A second synchrony increase appears around 700 msec. It coincides with the subject’s button-pressing, and hence may be related to the motor response elaboration under both conditions. This is the only period of time in which some similarity between the phase synchrony patterns under the two conditions was noted.



This evidence suggests that the best level for understanding the neural basis of the unity of consciousness is likely to be that of transient and emergent "dynamical brain signatures" (Lutz et al., in press) rather than the structural level of specific circuits or classes of neurons (Crick & Koch 1998). Nevertheless, the evidence so far regarding synchronization in the human brain is only correlative, not causal: there is still no direct proof that alterations in synchrony lead to changes in either behavior or consciousness. Future studies in this direction are a priority.

The neural processes just discussed fall into the broad category of networks of nonlinear oscillators, a paradigmatic example of self-organization (see, e.g., Kopell 2000). A key concept in this context is that of *emergence* or *emergent processes*. Emergent processes correspond to the collective behaviors of large ensembles, in which positive and negative feedback interactions give rise to non-proportional (or nonlinear) consequences. This is the central topic of the next stage of our paper.

3. SECOND STAGE
EMERGENCE: UPWARDS AND DOWNWARDS CAUSATION

Although emergence has been much discussed in science and philosophy, going back to the nineteenth century (Beckerman et al. 1992; McLaughlin 1992; Emmeche et al. 1997), and figures prominently in the sciences of nonlinear complexity (e.g., Kelso 1995; Holland 1999), there is still no commonly accepted understanding of this notion. In contemporary philosophy, two main currents of discussion can be discerned, one in the philosophy of mind, the other in the philosophy of science. The impetus of the first is the classic mind-body problem of determining the ontological status of mental properties in relation to physical properties (see Kim 1998). To say that mental properties are emergent is to say that they are realized in and determined by physical-biological properties, but not reducible to physical-biological properties. The impetus of the second is to clarify notions of emergence that arise within fields of natural science, such as quantum mechanics (Teller 1986; Silberstein and McGeever 1999) and nonlinear dynamical systems theory (Newman 1996; Bedau 1997; Silberstein and McGeever 1999; Rueger 2000). Our treatment of emergence derives primarily from this second current, in particular from dynamical systems theory, but has implications for the first current, as we discuss below.

3.1 Emergence and Upwards Causation

According to standard usage in cognitive science, an emergent process is one that belongs to a network of subunits, results from the locally defined interactions of those subunits, and does not belong to any single subunit. The idea is that purely local interactions can give rise to new patterns of behavior, which appear at higher (global) levels of description. Thus neurons acting as coupled nonlinear oscillators give rise to new patterns of behavior at the level of neural assemblies formed through phase synchrony. This aspect of emergence can be called *local-to-global determination* or *upwards causation*. As a result of upwards causation, novel processes emerge having their own features, lifetimes, and domains of interaction.

3.2 Emergence and Downwards Causation

There is another side to emergence through self-organization, however, that of *global-to-local determination,* often called "downwards causation" (Campbell 1974), whereby global characteristics of the system govern or constrain local interactions. This aspect of emergence is less frequently discussed, but has long been noted by researchers in synergetics and dynamical systems theory (Kruse and Stadler 1990; Stadler and Kruse 1994; Kelso 1995; Port and Van Gelder 1995); is central to some views about consciousness and the brain (Sperry 1991; Freeman 1999); and plays a key role in a recent important study that uses dynamical systems theory to understand intentional action (Juarrero 1999). Global-to-local effects do not take the same form as local-to-global ones: they typically manifest through changes in control parameters and boundary conditions, rather than through the interacting dynamical variables. Coherent and collective behaviors, called *collective variables* or *order parameters* in the language of synergetics (Haken and Stadler 1990; Kelso 1995; Bressler and Kelso 2001), constrain or prescribe the behavior of the individual elements of the system, "enslaving" them, as it were, so that they no longer have the same behavioral alternatives open to them were they not interdependently linked in the system. On the other hand, the behavior of the individual elements generates and sustains the order parameters. Although typically described as "circular causality," this reciprocal (but not symmetrical) relationship between local and global levels in self-organizing systems seems better described as *reciprocal causality*.

3.3 Characteristics of Emergence

Given the importance of emergence to this discussion, we think it worthwhile to attempt a more precise analysis of this notion. Our aim here is to explicate the notion of emergence presupposed in the science of complex systems, not to engage in *a priori* conceptual analysis. Philosophers and scientists have considered many different kinds of natural phenomena to be emergent in one sense or another (e.g., water in relation to hydrogen and oxygen; a tornado in relation to its constituent air and water molecules; the living cell in relation to its chemical constituents; an insect colony in relation to its members; intentionality and consciousness in relation to the nervous system; etc.), and they have emphasized different criteria of emergence (e.g., novel form of identity, nondeducibility, or downwards causation) that do not classify these phenomena with respect to emergence in the same way (Shröder 1998). Therefore, there seems to be no good reason to search for any single, neatly analyzable concept of emergence independent of particular explanatory contexts.

We offer the following, provisional, working definition of emergence in the case of complex dynamical systems:

> *Definition*: A network N of interrelated components exhibits an emergent process E with emergent properties P if and only if:
>
> (1) E is a global process that instantiates P and arises from the nonlinear dynamics D of the local interactions of N*'s* components.
> (2) E and P have a global-to-local ("downwards") determinative influence on the dynamics D of the components of N.
>
> And possibly:
>
> (3) E and P are not exhaustively determined by the intrinsic properties of the components of N, i.e., they exhibit "relational holism."

Although the term "emergent property" is widespread, we prefer "emergent process." Strictly speaking, a property *per se* does not emerge, but rather comes to be instantiated or realized in a process or entity that emerges in time. (Properties as such are timeless, but emergence is a temporal process: see Hattiangadi, in press.) For example, the property of being alive does not emerge, but is instantiated or realized in the emergent process of autopoiesis that constitutes living cells (Maturana and Varela 1980). The emergent processes of concern to us here arise in the case of large ensembles that form "non-decomposable" systems (Wimsatt 1986; Bechtel and Richardson 1993), in which the nonlinear interactions of the components result in whole-system processes that have a global-to-local ("downwards") determinative influence on those components. Nonlinearity is due to presence of positive and negative feedback relations. These relations account for the determination of patterns of behavior, seen as constrained alternatives in the space of all possible global states of the system (i.e., as attractors in phase space). The emergent whole-system processes are *morphodynamical* (Petitot 1995), in the sense that they determine the system's identity through time as a unity having its own proper domain of interactions and whose properties and behaviors can be physically realized in multiple ways. The paradigm of such an *emergent identity* (Varela 1997) is the autopoiesis (self-production) of the living cell (Maturana and Varela 1980), but emergent identities also include neural assemblies (Bressler and Kelso 2001; Varela et al. 2001) and immune networks (Varela and Coutinho 1991).

Some philosophers reject the notion of downward causation because they find it irreconcilable with the causal closure of the physical domain (Kim 1993, 1998). Yet the notion of emergent processes as collective variables or order parameters does not seem vulnerable to this problem. Indeed, the whole issue of supervenience and downwards causation in current philosophy of mind seems strangely out of touch with contemporary science (Humphreys 1997), because no account is taken of the novel concepts introduced from nonlinear dynamical systems theory (and quantum mechanics), which provide an explicit causal backbone for notions of supervenience, emergence, and reciprocal upwards-downwards causation.

One might object that although we need to appeal to global order parameters for *explanatory* purposes, they are not genuinely *causal*, because all causation is local, efficient causation, and therefore "downwards causation" is really a misnomer. This objection begs the question, however, of whether "cause" can also legitimately mean "standing" or "structuring" causes in the form of order parameters operating as "context-sensitive constraints" that modify a system's phase space or the probability distribution of events in that space (Juarrero 1999).

An open question about emergence in complex systems is whether they involve "relational holism," i.e., relations that are not reducible to the intrinsic features of the components (Silberstein and McGeever 1999). The paradigm case of relational holism is quantum entanglement (Teller 1986), but it has been suggested that the phenomena studied in nonlinear dynamical systems theory might also qualify (Silberstein and McGeever 1999). The thought here is that although nonlinear dynamical *models* operate in a purely "classical" domain, nevertheless the nonlinear relations in the *phenomena* being modeled may exhibit some form of relational holism (though presumably one weaker than the so-called "fused" states found at the quantum level). The reason for entertaining this thought, according to Silberstein and McGeever (1999), is that it may go some way toward giving a naturalistic explanation of the radical form of multiple realizability found in nonlinear dynamical systems, namely their "dynamical autonomy" (Wimsatt 1986), which occurs when changes at the microlevel do not make a causal difference at the global dynamical level of attractors and order parameters. If this line of thought is correct, then emergence and downward causation in complex systems would violate not simply the methodological doctrine of microphysical reduction—already overturned by the sciences of complexity (Kellert 1986)—but the ontological doctrine of "mereological supervenience" (that a whole supervenes entirely on the intrinsic properties of its parts). Clearly, these are open questions that require careful conceptual and empirical study.

3.4 Emergence and the Efficacy of Mental Acts

Given that the coupled dynamics of brain, body, and environment exhibit self-organization and emergent properties at multiple levels (see Kelso 1995; Port and Van Gelder 1995), and that emergence involves both upwards and downwards causation, it seems legitimate to infer that downwards causation may occur at multiple levels in these systems, including that of conscious cognitive acts in relation to local neural activity.

Indeed, this point has been noticed by several authors concerned with the dynamical approach to cognition (Kruse and Stadler 1990; Stadler and Kruse 1994; Kelso 1995; Freeman 1999; Juarrero 1999). J.A.S. Kelso expresses the general idea when he writes: “Mind itself is a spatiotemporal pattern that molds the metastable dynamic patterns of the brain” (Kelso 1995, p. 288). Similarly, Walter Freeman describes consciousness as an order parameter and “state variable-operator” in the brain that “mediates relations among neurons” (1999, p. 132). “Far from being an epiphenomenon,” he continues, “it must play a role crucial role in intentional behavior. It is the task of the neurodynamicist to define and measure what that role is” (ibid.). The philosopher Alicia Juarrero has devoted an entire book to unfolding the implications of this idea for the philosophy of action. Let us quote at length from her introduction, for it states the idea especially clearly:

> Since the global level of all complex adaptive systems contextually constrains the behavior of the components that make it up, I postulate that behavior constitutes action (a wink, as opposed to a blink) when the brain’s self-organized dynamics, as characterized by consciousness and meaning, originate, regulate, and constrain skeleto-muscular processes such that the resulting behavior “satisfies the meaningful content” embodied in the complex dynamics from which it issued.
>
> Thinking of agents and their actions in this manner provides a previously unavailable way of conceptualizing the difference in etiology and trajectory of winks and blinks. Bottom-up, formulating a prior intention to wink would be the felt counterpart of a neurological phase change, the dynamical self-organization of a more complex level of coherent brain activity that integrates neuronal patterns embodying wants, desires, meaning, and the like. Unlike Newtonian causes, however, this higher level of neurological organization would not be simply a triggering device. The global dynamics of self-organizing complex adaptive processes constrain top-down their components (motor processes in the case of behavior). As contextual constraints, however, a system’s dynamics are not occurrent events like Newtonian forces. An intention’s constraints would be embodied in the meta-stable dynamics that characterize the intention’s neurophysiological organization, and as such would not immediately disengage. Rather, by serving as the brain’s operator or order parameter, these contextual constraints that embody an intention (acting top-down) would provide the behavior with continuous, ongoing control and direction by modifying in real time the probability distribution of lower-level neurological processes and, as a consequence, the behavioral alternatives available to and implemented by the agent (Juarrero 1999, pp. 7-8).

Clearly, the issue here is not only philosophical, but also empirical and experimental. If conscious cognitive acts are emergent phenomena, then we can accordingly hypothesize that they are causally efficacious with respect to local neuronal activity, and therefore that it should be possible to observe the effects of a moment of consciousness and its substrate large-scale neural assemblies at the level of local properties of neuronal activity. Let us mention two cases that can be used to address this point.

Human epileptic activity

It stands to reason that epileptic activity modifies the subject's mental competencies. The converse, although less documented, also seems to be the case: the subject can voluntarily affect his or her electrical condition leading to the arising and course of a seizure. Penfield and Jasper already in 1954 described a parietal seizure blocked by the initiation of a complex mathematical calculation (Penfield and Jasper 1954), and recently more extensive observations have confirmed such cognitive influences (Schmid-Schonbein 1998). One can assume that such intervention is possible because the epileptogenic zones are embedded in a complex network of other brain regions that actively participate in mental life. Such network interactions are multiple and distributed over a large scale (Varela et al. 2001). It follows that the global level of integration (the result of upwards causation) may produce downwards effects, acting eventually on the local level of epileptogenic zones, whose activity can be taken as an indicator of the downwards influence. More precisely, the question is whether a particular cognitive task or state can manifest as a specific effect in the local activity given by an epileptic discharge, when seen at a sufficient level of detail. Recent studies by Varela and colleagues have shown that there are deterministic temporal patterns within the apparent random fluctuations of human epileptic activity, and that these patterns can be modulated during cognitive tasks (Le Van Quyen et al. 1997a, 1997b). Analysis of the sequence of intervals between spike discharges from the epileptic focus of a particular patient has shown that the spikes display a distinct periodic activity for a short time before they move away to a different temporal pattern; that this periodic activity is differentially modulated during perceptual tasks engaged in by the patient; and that the modulation is carried by frequencies in the gamma range (30-70 Hz) (for details see the original studies, and Thompson and Varela 2001). These findings suggest that the act of perception on the part of the patient contributes in a highly specific manner, via the phase synchrony of its associated neural assembly (i.e., the perceptual order parameter), to "pulling" the epileptic activities towards particular unstable periodic orbits. Thus downwards causation need be no metaphysical will-o'-the-wisp, but can be an empirically tangible issue. Whether such cognitive "control" can be harnessed in a therapeutic direction is an open question, but these studies may point to the possible physiological basis of such interventions.

Voluntary perceptual reversals

Another case worth exploration, especially in light of recent studies of binocular rivalry (Leopold and Logothetis 1999; Wilson et al. 2001), is the visual experience of multistability, in particular the well known Necker cube reversal. During continuous observation of the same Necker cube figure, a subject's perception will switch back and forth between the two alternative views, and one can record the switching times by asking a subject to push a button every time his or her percept switches. Kelso and colleagues asked subjects to view a Necker cube in one of eight randomly presented spatial orientations, thus using the orientation as a control parameter. As expected, for each orientation, no consistent pattern was found in the switching time series data. What Kelso and colleagues were interested in, however, was whether and how the distribution of switching times might change as the orientation of the cube approached that of a flat figure (which would not be expected to be perceptually ambiguous). They found that the switching time distribution for each orientation was unimodal and asymmetric, with the histograms showing a single hump of varying height and a long tail (a well known finding for multistable perception: see Leopold and Logothetis 1999, p. 258), but that as the appearance of the figure approached that of a two-dimensional hexagon (40 deg.) or a square (80 deg.), the frequency distribution was considerably flattened, with the histograms showing an "extended tail," indicating that occasionally a given orientation is perceived for a long time without switching. Hence the switching-time distribution is parameter dependent. Kelso and colleagues model these results in terms of the dynamics of a wide array of nonlinear oscillators coupled together by a phase relation (the order parameter). By introducing variant orientations and thus changing the subject's experience, one can detect the traces of the changes in phase space, and new dynamical modes appear, in this case revealing a saddle node instability. What we wish to suggest is that, given these results, it seems reasonable to infer that different "cognitive" interpretations of the Necker cube display initiated by the subject will shift slightly the neuronal bias that defines the cube reversal. This inference could eventually be tested by studying human clinical subjects with implanted electrodes (like the epileptic patient in the studies mentioned above) as they perform *voluntary* perceptual reversals of the Necker cube or other ambiguous figures.

3.4 From Emergence to Embodiment

On the basis of the discussion so far, we submit that no modern attempt to study consciousness can avoid such reciprocal or bi-directional causation, without falling into the barren extremes of neuroreductionism, or epiphenomenalism, or substance dualism. What emergence as reciprocal causation provides is a perspective from which to begin to relate the lived experience of conscious, intentional action to its neural and somatic basis by way of formal dynamical models (phase space geometries), which in themselves are neutral with respect to the distinction between the mental and the physical. For this reason, emergence as reciprocal causation is a central conceptual tool of neurophenomenology.

Yet in order to criss-criss the explanatory gap between phenomenology and neuroscience, still another step needs to be taken: the *embodied* and *embedded* context of emergence as reciprocal causation needs to be recovered. In other words, mental unity and neural dynamics as discussed above need to be understood in the context of the whole living organism as a sentient being acting in its environment. This point brings us to the third stage of our paper.

4. THIRD STAGE: EMBODIMENT

Having suggested that one should expect reciprocal causal-explanatory relations between neural events and conscious events when the latter are conceived of as order parameters of large-scale brain dynamics, we now go one step further and suggest that the processes crucial for consciousness may cut across the brain-body-world divisions, rather than being limited to neural events in the head.

Although it is often assumed that consciousness must "supervene" entirely on internal neural states, it is far from clear how one is supposed to distinguish between "internal" and "external" states. Despite the philosophical fiction of a brain-in-a-vat, it is doubtful (even as a mere thought experiment) that one can "peel away" the body and the environment as "external" to the brain processes crucial for consciousness. The nervous system, the body, and the environment are highly structured dynamical systems, coupled to each other on multiple levels (Chiel and Beer 1997). Because they are so thoroughly enmeshed—biologically, ecologically, and socially—brain, body, and environment seem better conceived of as mutually embedding systems than as externally and internally located with respect to one another. Neural, somatic, and environmental elements may interact to produce (via emergence as upwards causation) global organism-environment processes, which in turn may affect (via downwards causation) their constituent elements. Although speculative, these points gain plausibility from considering the dimensions of embodiment.

4.1 Dimensions of Embodiment

The relation between neural dynamics and conscious situated agents can be described in terms of the participation of neural processes in the *cycles of operation* constitutive of the agent's life. At least three kinds of cycles need to be distinguished for higher primates:

(i) cycles of *organismic regulation* of the entire body;
(ii) cycles of *sensorimotor coupling* between organism and environment;
(iii) cycles of *intersubjective interaction,* involving the recognition of the intentional meaning of actions and linguistic communication (in humans).

Organismic regulation

The participation of the brain in organismic regulation is diffuse and multifaceted. Its main basis is the autonomic nervous system, in which sensors and effectors to and from the body link neural processes to basic homeostatic, or homeodynamic (Rose 1998), processes of the internal milieu and viscera. Emotional states—reflecting the links between the autonomic nervous system and the limbic system via the hypothalamus—are part and parcel of homeodynamic regulation (Panskepp 1998; Damasio 1999). In the brain-stem, nuclei that regulate homeostasis are interconnected with nuclei that regulate sleep, wakefulness, and arousal. In addition, there are numerous mutual interactions between brain and body at biochemical levels, visible especially in the molecular components of the endocrine, immune, and nervous systems. The integrity of the entire organism depends on such regulatory cycles involving brain and body at multiple levels.

Organismic regulation, because of its linkage to basic emotional operating systems in the mammalian brain, has a pervasive affective dimension that manifests in the range of affective behaviors and feelings typical of mammalian life (Panskepp 1998). We propose to call this affective dimension of organismic regulation *sentience.* Sentience is the feeling of being alive, the inescapable affective backdrop of every conscious state (Watt 1998), inescapable because of the need for every conscious state to be grounded on the regulatory and emotional states of the whole organism.

Consciousness, from this perspective, does not seem to be adequately understood by being broken down into the forms of qualitative awareness particular to each sensory system. Sentience—also called "primal consciousness" (Panskepp 1998) and "core consciousness" (Damasio 1999)—does not seem to be organized according to sensory modality, but rather according to the regulatory, emotional, and affective processes that constitute the organism's *feeling of self* (Damasio 1999). For this reason, the scientific search for neural representational correlates of conscious experience in a particular sensory modality such as vision (Crick and Koch 1998) misses the biologically and phenomenologically more fundamental phenomenon of sentience, whose affective character, we would argue (see Thompson and Varela, forthcoming), pervades visual (and indeed all sensory) experience. Nor would we equate sentience simply with "qualia," at least as this notion is typically used by philosophers to mean the purely "phenomenal" properties of internal mental states. Rather, sentience is the capacity of the whole organism to feel its own activity, a capacity based on its neural and bodily constitution, and exercised in its comportment toward the world.

Sensorimotor coupling

Situated activity on the part of the organism takes the form of cycles of sensorimotor coupling with the environment. What the organism senses is a function of how it moves, and how it moves a function of what it senses (Maturana and Varela 1987; Hurley 1998; O'Regan and Noë, in press). The substrates of these cycles are the sensorimotor pathways of the body mediated in the brain by multiple neocortical regions and subcortical structures. Transient neural assemblies mediate the coordination of sensory and motor surfaces, and sensorimotor coupling with the environment constrains and modulates the neural dynamics (Chiel and Beer 1997). It is this cycle that gives rise to the comportment of the organism as a situated agent (Maturana and Varela 1987; Varela et al. 1991; Varela 1997).

Intersubjective interaction

In primates, especially apes and humans, affective comportment and sensorimotor coupling play a huge role in social cognition. Higher primates excel at interpreting others as psychological subjects on the basis of their bodily presence (facial expressions, posture, vocalizations, etc.) (Povinelli and Preus 1995). Just as the experiential dimension of organismic regulation is sentience, and that of sensorimotor coupling is perceptuo-kinaesthetic experience, so that of social cognition is empathy, in the broad sense of affectively mediated experience of self and other (Thompson 2001).

Intersubjectivity, including the neural substrates of social cognition and empathy, is less well understood than organismic regulation and sensorimotor coupling. Nevertheless, neural structures that are known to be important to social cognition (e.g., amygdala, ventromedial frontal cortices, and right somatosensory-related cortices) are also important to emotion (Adolphs 1999). The common ingredient may well be "feeling," in the sense of affective experiences resulting from the neural mapping of one's own emotional body states or those of another (Damasio 1999; Adolphs 1999).

Intersubjectivity involves not only emotional and affective components, but also distinct forms of sensorimotor coupling, as seen in the so-called "mirror neurons" uncovered in area F5 of the premotor cortex in monkeys (Gallese and Goldman 1999). These neurons display the same pattern of activity, both when the animal accomplishes certain goal-directed hand movements, and when the animal observes the experimenter performing the same actions. The recognition of the intentional meaning of actions apparently depends on patterns of neural activity in premotor areas that are similar to those internally generated to produce the same type of action. There is evidence for a mirror neuron system for gesture recognition in humans (Gallese and Goldman 1999), and it has been proposed that this system may be part of the neural basis for the development of language (Rizzolatti and Arbib 1998). These findings and hypotheses support earlier phenomenological analyses of empathy (e.g., Stein 1964/1917), according to which empathy is based on the passive (non-voluntary) association or "pairing" of the living bodies (*Leib*) of self and other, and the internal mimicking of another's movement (Petit 1999; Thompson 2001).

4.2 Radical Embodiment and the Neural Correlates of Consciousness

The foregoing overview of the dimensions of embodiment supports the following fundamental point: no neural process *per se* can be "the place where consciousness happens," because conscious experience occurs only at the level of the whole embodied and situated agent.

Neurons and neural assemblies are not conscious subjects; persons and animals are. No doubt the tendency to speak of neural correlates of consciousness (NCCs) as localized pieces of brain circuitry or as special classes of neurons comes from the neuroscientific practice of describing the functional properties of neurons with regard to capacities of the organism, such as color vision and motor planning. But clearly such bits of tissue are not by themselves *sufficient* for those capacities, but rather are *necessary enabling conditions* that must be properly incorporated into the organismic cycles of operation just discussed.

It has become commonplace to think that one of the first steps to a scientific theory of consciousness is to discover the neural correlates of consciousness. The term "correlate" is potentially misleading, however, for the goal is to discover not mere correlates, but rather neural events that are necessary and/or sufficient for the contents of consciousness (Kanwisher 2001), as can be seen from this useful definition of the NCC notion:

> An NCC (for content) is a minimal neural representational system N such that representation of a content in N is sufficient, under conditions C, for representation of that content in consciousness (Chalmers 2000, p. 31).

Notice that the causal-explanatory relation in this definition is one-way, from internal neural events to conscious experience. In this paper, we have proposed a more expansive, two-way account. Using the tools of dynamical neuroscience and "embodied" or "enactive" cognitive science (Varela et al., 1991), we have suggested (1) that as a result of the generic feature of emergence in complex systems, one can expect there to be two-way or reciprocal relations between neural events and conscious activity; and (2) that the processes crucial for consciousness may cut across the brain-body-world divisions, rather than being skull-bound neural events. Based on the foregoing overview of the dimensions of embodiment, we suspect that consciousness depends crucially on the manner in which brain dynamics are embedded in the somatic and environmental context of the animal's life, and therefore that there may be no such thing as a *minimal internal neural correlate* whose *intrinsic properties* are sufficient to produce conscious experience (see also Noë and Thompson, forthcoming).

Another way to put this last point would be to say that the identification of conscious contents with neural contents suffers from the "localizationist bias" (Wimsatt 1976, 1980; Bechtel and Richardson 1993) of regarding within-system processes (in this case, neural ones) as more fundamental to the explanation of system-level properties (conscious experience) than between-system processes (brain-body-environment coupling). This bias derives, we believe, from the Cartesian heritage of seeing consciousness as an "inner" property of the "mind-brain," rather than a capacity (or complex set of capacities) of embodied, situated, and intersubjective organisms (Thompson and Varela, forthcoming). In more phenomenological terms, the subject of consciousness is the living body (*Leib*) in the world, not the skull-bound brain.[5]

4.3 Criss-Crossing the Gap

What we have said concerning embodiment is both too little and more than enough. It is too little because each dimension of embodiment needs to be considered in more detail and linked to the phenomenology of first-person experience. This task is beyond the scope of this paper, but is the main subject of forthcoming work (Thompson and Varela, forthcoming). Yet what we have said here is more than enough to indicate the main idea, which is to go beyond the notion of a skull-centered correlate of consciousness to consider the multifarious ways in

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[5] More precisely: the subject of sentience, or primal or core consciousness, is the living body in the world, whereas the subject of self-consciousness is the *person*.

which brain processes are part of organismic cycles that generate the somatic, environmental, and social dimensions of our experience. Only within such a context, we submit, will a productive criss-crossing of the explanatory gap between phenomenology and neuroscience become possible.

5. CONCLUSION

In this paper, we have presented a new approach to research on neural synchrony and the unity of consciousness, one growing out of neurophenomenology. This approach strives to criss-cross the explanatory gap by using the conceptual tools of (1) large-scale perspectives on the synchronization of brain processes in transient global patterns; (2) dynamical systems theory for understanding emergence as reciprocal causation in the context of self-organization; and (3) enactive cognitive science for understanding the embodied and embedded nature of the brain dynamics underlying the unity of consciousness. A distinctive feature of this neurophenomenological approach is that allows conscious activity to be a causally efficacious participant in the cycles of operation constitutive of the subject's life. By making the non-dualistic notion of the living body (*Leib*) its conceptual fulcrum, and by explicating the dynamics of the living body in terms of emergence as reciprocal causation, neurophenomenology presents a clear methodological alternative to neuroreductionism (e.g., Churchland 1994; Crick 1994), epiphenomenalism (e.g., Jackendoff 1987), and substance dualism (e.g., Eccles 1994), all of which presuppose the unworkable conceptual dualism of mind versus body.

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